Conclusions drawn from the Toulouse accident: application to loss estimation for explosions

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INTRODUCTION

On September 21, 2001, at 10:15 AM there was an explosion in an ammonium nitrate storage silo in the AZF chemical plant to the south of Toulouse (France).

The factory and its surroundings were devastated; there were 31 deaths and property damage up to a distance of 3 km.

The tragic consequences of this accident make it clear that this risk had been underestimated, both from the point of view of the measures foreseen in safety management - which were shown to be insufficient or inadequate - and those deriving from urban planning, with the establishment of numerous activities characterised by their vulnerability to events of this type.

In addition to this, the unusualness of these types of accidents causes loss estimates to be made to on the basis of tests and suppositions, with a high degree of uncertainty with respect to real conditions.

With the aim of advancing knowledge of the effects of explosions, ITSEMAP personnel travelled to the area of the accident in order to collect data on the consequences of the accident so as to validate or correct certain parameters that are used in the estimation of the consequences of events of this type.

This article presents the principal conclusions of a study on the analysis of the consequences of the accident and gives parameters which form an advance in the technical knowledge used for the estimation of probable maximum losses (PML) for similar situations.

AMMONIUM NITRATE

Ammonium nitrate is widely used as the basis for nitrogenous fertilisers. Under normal pressure and temperature conditions it is a colourless or white solid crystalline material without odour. Its melting point is 169.6°C and its boiling point is 210°C, although it breaks down at lower temperatures.

It is not a combustible substance, but it does favour combustion, so it can contribute to beginning of fire or intensifying it in the presence of combustible materials, giving the mixture of materials "explosive" properties.

The violent breakdown of ammonia nitrate without organic impurities is also possible, although locally elevated pressure and temperature conditions are necessary for this to occur.

LOSS PRECEDENTS

The most serious explosion of ammonium nitrate took place in Opau (Germany) in 1921. The accident was caused by negligence and ignorance as to the danger inherent in this compound. It is believed that the cause of the accident was the use of explosives in order to break-up mounds of caked ammonium nitrate.

This procedure had previously been routinely used. It was not to be used again: the explosives which had been placed acted to detonate the entire mass and the consequences of the explosion were devastating. The effects were felt at more than 25 km distance and 562 people were killed. It was estimated that more than 4,500 tonnes of ammonium nitrate were involved.

General view of the factory before the explosion.

THE FACTORY

The AZF factory, belonging to the company Grande-Poiroisse, subsidiary of TotalFinaElf, occupies an area of approximately 62 hectares on an industrial estate to the south of the city of Toulouse. Access to the installations is provided by the N-20 highway (known as the road of Spain).

The factory is dedicated to the production of nitrogenous fertilisers and intermediary chemical products (320,000 t/year of urea and 280,000 t/year of ammonia nitrate are its most significant products).

The factory started operating in the 1920s and has undergone various modifications. The storage of ammonium nitrate however was done in hangers dating back to the first stages of activity.

The hangers in which the accident occurred contained approximately 200-300 tonnes of ammonium nitrate which were bulk stored, it seems because the product was outside commercial specifications (with respect to size and appearance).

THE ACCIDENT

The explosion occurred in hangar number 221, used for the storage of ammonium nitrate, and caused a crater with a diameter of 50 m and depth of 10 m. Buildings and processing equipment in a radius of some 150 m were destroyed, and the explosion registered the equivalent of an earthquake measuring 3.5 on the Richter scale.

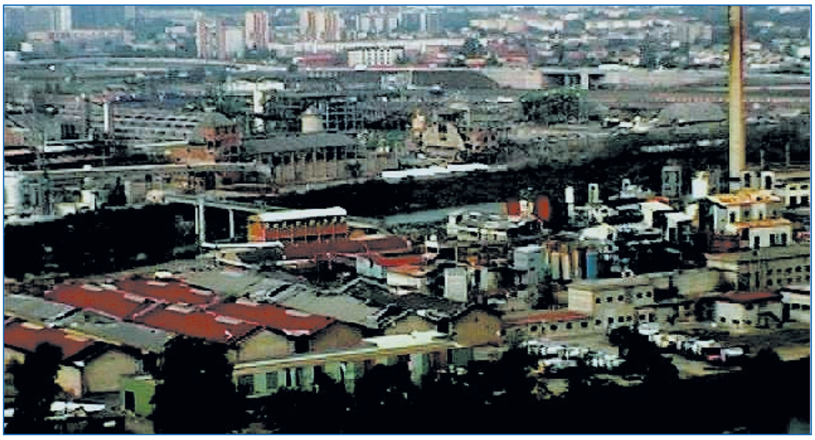
It is thought that the most probable cause of the accident was an error in the management of residues from a chlorine compound with a similar appearance to ammonium nitrate. It has been proved that these two compound react.

In addition to this, the pressure produced - and therefore its effects - could have been increased due to the degree of confinement in the storage (the dimensions of hangar 221 were 25 m long, 8 wide and from 2 to 4 high).

THE DAMAGE

With regard to personal injury, the effects of the explosion caused the death of 31 people - thirty of them in the AZF factory itself and the surrounding area - and more than 2,400 injuries.

The explosion was found to have caused property damage



General view of the factory after the explosion.

up to a distance of more than 3 km from the explosion, with the following breakdown:

- 25,000 homes damaged.
- 11,000 homes with serious damage.
- 300 companies affected.
- 1,400 rooms damaged in three university residences.
- Three university centres.
- Seventy schools and kindergartens were affected.
- One hospital seriously damaged.
- A football stadium seriously damaged.
- A leisure centre seriously damaged.
- In total, damage with a value in the order of EUR 2 billion is estimated.

ESTIMATION OF DAMAGE AS A CONSEQUENCE OF EXPLOSIONS

Traditionally, the estimation of the consequences of explosions is carried out through the model of an equivalent mass of TNT whose simplicity allows the extent of consequences to be predicted using simple tools, this circumstance is very important from the insurance point of view in that it reduces underwriting costs.

To do this, the mass of potentially explosive material is corrected in accordance with its characteristic breakdown energy and an efficiency factor which is determined by the reactivity of the substance, and the confinement in which the explosion takes place, etc.

The following expression is used:

$$m_{eq\,TNT} = \eta\; m\; H_d \,/\, H_{TNT}$$

Where:

- $m_{eq\,TNT}$ equivalent mass of TNT (kg)
- η efficiency of the explosion
- m mass of substance which caused the explosion (kg)
- H_d specific breakdown energy of the considered material (J/kg)
- H_{TNT} specific breakdown energy of TNT ($4{,}76.10^6$ J/kg)

The efficiency of the explosion *h* is dependent both on the reactivity of the substance under study and on the conditions under which the explosion takes place, principally confinement.

According to studies published in the publication *Ammonium Nitrate Guide of the FMA* (Fertiliser Manufacturers Association), the maximum considered efficiency for ammonium nitrate is 25%.

Additionally, the effects, both qualitative (crater, pressure, noise) and quantitative (values of the explosion's variables) are strongly dependent on a parameter known as "scaled distance" which is analogous to the relationship between the distance to the explosion and the size (characteristic length) of the explosive mass.

This "scaled distance" follows the following expression:

$$\bar{r} = \frac{r}{\sqrt[3]{m_{eq\,TNT}}}$$

where,

- $\bar{r}$ scaled distance.
- r distance to the centre of the explosion
- m_{eqTNT} equivalent mass of TNT explosive

In this way it can be inferred that, starting from a certain explosion, in order to obtain for example a crater with double the diameter, it would be necessary to have a quantity of explosive 8 times greater then the original one.

Using this "scaled distance" different authors have estimated the *pressure peak* produced in the explosion, this variable is of greater importance in the estimation of damage.

The property damage arising as a consequence of an explosion from a particular pressure level may be assessed in accordance with the data given in the following table.

Pressure peak ΔP_{max} (bar)	Damage
0,01	Some glass breakage.
0,02	Damage to house roofs. 10% of windows broken.
0,03	Homes habitable after simple repairs. Minor structural damage.
0,03-0,07	Glass breakage. Damage to house frames.
0,07	Breakage of all glass in windows
0,07-0,15	Habitable after major repairs. Roofs damaged, 25% of all walls have failed. Damage to frames and doors. Breakage of fibre-cement panels. Loosening of aluminium or steel panels.
0,16-0,20	Partial collapse of cement structures, total destruction of ordinary homes.
0,20-0,27	Industrial heavy machinery suffers slight damage. Breakage of liquid storage tanks, collapse of metal structures in buildings with ordinary construction.
0,35	Damage is not repairable. 50 to 75 percent of exterior walls are damaged.
0,47	Wagons are overturned.
0,50	Breakage of brick walls. Homes need to be demolished.
0,70	Demolition of 75% of houses.
1-2	100% destruction.

CONSIDERATIONS ON THE APPLICABILITY OF THE MODELS TO THE TOULOUSE ACCIDENT

In order to collect reliable and objective data with respect to the consequences of the AZF explosion, an on the spot inspection was carried out to validate or, if necessary, correct the calculation parameters of the aforementioned models.

In general terms results were obtained in line with the calculated effects according to the models, with the following exceptions:

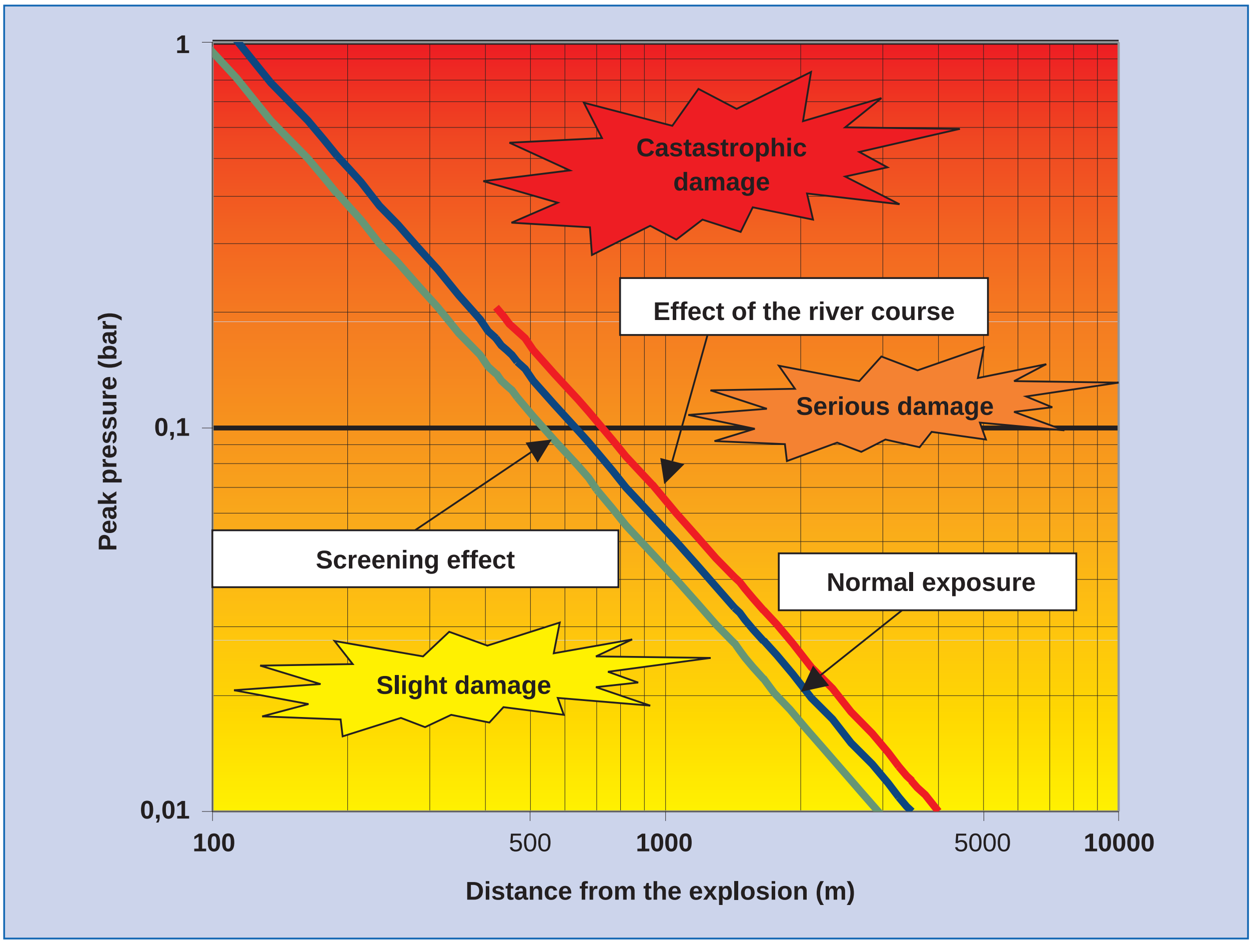
- The estimated efficiency for the ammonium nitrate explosion would be in the order of 60 percent - notably higher than that given by the Fertiliser Manufacturers Association, which states a value of 25%.
- There was a significant attenuation effect of the pressure peak due to the existence of structures (two or more buildings) that had a screening affect around the area where the explosion took place.
- The unique nature of the river course with respect to the "channeling" of the pressure wave, this caused the effects on structures on either side of the channel to be notably higher than those that would have been expected according to the previous models.

The diagram of this page shows the influence of the two last factors on the pressure levels obtained with respect to those forecast, together with an evaluation of the associated damage.

CONCLUSIONS

The following conclusions are obtained from the consequences of this accident and their analysis:

- The Toulouse accident has again brought to the forefront the devastating consequences of explosions in ammonium nitrate storage; the sector had thought that this risk was "under control".
- In consequence, safety management systems should be revised in companies operating in this type of activity in order to ensure the control of this risk, both with regard to preventative measures (incompatibilities, activities, etc.), and with regard to those aiming to reduce consequences (maximum quantities, separation, etc.)
- The findings with regard to the degree of reactivity of ammonium nitrate as an explosive mean that estimates of losses brought about by activities of these types should be revised. ■



Estimated pressure levels and damage in the Toulouse explosion as a function of distance and orographic factors.