ICL PLASTICS INVESTIGATION, GLASGOW, MAY 2004†

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At approximately twelve noon, on 11th May 2004 an explosion occurred at the Grovepark Mills premises of ICL Plastics Ltd, in the Maryhill district of Glasgow. This explosion was caused by leakage of LPG into the building basement, which then ignited causing an explosion subsequent collapse of the building, resulting in a number of deaths and serious injuries.

This paper describes the technical aspects of the on-site and off-site investigation of this incident carried out by HSL, who worked closely with HSE and the Strathclyde Police to uncover the cause of the explosion and subsequent collapse of the building.

The paper describes some of the issues associated with this investigation relating to the nature of the building's construction and its subsequent collapse. It describes how the expertise from a broad range of disciplines from across HSL, HSE and outside combined to work through the thousands of tons of rubble at the site and gather the evidence required to understand the cause of the incident. In addition, the additional complexity of the investigation associated with the broad range of potentially hazardous plastic processing and coating techniques carried out by ICL at the premises (which led to considerable speculation in the press as to the cause of the explosion) is also discussed.

INTRODUCTION

The ICL Plastics Ltd incident occurred at approximately twelve noon on 11th May 2004. The activities carried out at the site were based around the plastic coating of a range of items, which was carried out a Victorian four-storey mill building (known as Grovepark Mills) in the Maryhill area of Glasgow. The incident involved an explosion of a Liquefied Petroleum Gas (LPG)/air mixture in the basement of the building, resulting in the collapse of the building. This explosion and collapse resulted in nine deaths and 33 serious injuries. The nature and severity of this incident resulted in a Public Inquiry (1) addressing, safety and related issues arising, and to make recommendations in the light of the lessons identified from the causation and circumstances leading up to the incident.

Clearly this was a significant incident that resulted in a lengthy and complex investigation. This paper aims to a give an overview of the incident investigation to give an outline of the process and most significant findings. It is not intended to cover every detail of the investigation.

BACKGROUND TO THE INVESTIGATION

The HSL investigation of the ICL incident began in earnest on the 17th May 2004 following the completion of the rescue and recovery phase, which had taken almost all of the six previous days. HSL's Visual and Presentation Services were on site from 12th May 2004, working with HSE to record aspects of the rescue and recovery, and the changes to the site resulting from that work that may have impacted on the investigation.

Once started, the on-site investigation was obviously extensive and lasted from 17th May to 6th July 2004. Subsequent to this, further work was carried out at HSL Buxton, in addition to other relevant sub contracted work. The investigation was carried out in close liaison with HSE and under the control of the Strathclyde Police. At the outset of the investigation an approach was agreed with Strathclyde Police, to allow HSE and HSL staff to work with them and the demolition team (contracted by Strathclyde Police), employing a two-stage approach to removal of the rubble and recovery of evidence. The first stage was for teams to systematically sift through the debris on site and withdraw items of evidence for examination where possible, working to a zoning plan agreed with Strathclyde Police. The demolition contractor would then remove the remaining debris (in excess of 5,000 tons), that had undergone this primary sift, and transfer it to a secure police site at Brand Street in Glasgow. A second sifting of evidence then took place using a conveyer system, along which all of the material removed from the site was passed and sifted by a team of briefed Scene of Crimes Officers to identify other items that may have been of interest to the investigation, but were missed by the initial on-site sift.

Based on witness and other early evidence, it was fairly certain that there had been an explosion prior to the building collapse. With this in mind, a number of initial lines of enquiry were drawn up that could have caused an explosion within the building, which included:

- The bulk LPG supply or other sources of LPG (propane or butane cylinders).
- The mains natural gas supply.
- Process materials such as plastic dusts, paints and solvents.
- Ground borne methane.
- Explosives.

THE INCIDENT SITE

The Grovepark Mills building was of a brick construction, with the timber floors above ground level supported by cast iron columns – a single line running down the centre of the building with a spacing of approximately 3 m.

Because of the nature of the incident, a key aspect of the investigation was understanding the layout and use of the Grovepark Mills building prior to the collapse. Based on witness evidence from ICL workers and management, the understanding was as follows:

- Basement – Confined to one end of the building (beneath an area known as dispatch) and was notionally unused other than for minor storage. It could only be accessed via the stair tower at the southwest corner of the building.
- Ground Floor – Dispatch area and plastic coating operations (Coating Shop) involving the use of granulated and powdered plastics, paint spraying, and a number of different ovens, powered by natural gas, LPG and electricity.
- First Floor – Canteen, locker room and maintenance workshop and storage.
- Second Floor – Offices.
- Third Floor – Storage plus natural gas central heating boilers/water heaters.

Figure 1 shows a Strathclyde Police aerial photograph of the Grovepark Mill site shortly after the incident (within 1 hour). At this time the recovery and rescue operation was in its early stages and so the site was more or less undisturbed following the collapse. As already described, witness accounts indicated that the building collapse was preceded by a loud noise suggesting an explosion. At this early stage, it was also clear that one of the deceased found in the basement of the building had burn injuries and damage to his clothing consistent with engulfment in a flash fire.

In terms of the collapse, general observations were:

- The building collapsed more or less within its own footprint, although a few items were found a more considerable distance from the building.
- The collapse was more severe at the basement end of the building, progressively reducing to the other end of the building, which was still standing, although unstable.
- A striking feature noted was the elevated steel and concrete floor section protruding from the rubble to the right of the rescue workers in the photograph in Figure 2 taken on 13 May. Although its origin was not obvious in these early stages, it became clear later that this steelwork formed part of the ground floor/basement ceiling as indicated by the light and electrical fittings found

Figure 1. Aerial view of the site shortly after the incident

Figure 2. Elevated steel and concrete floor section

attached to the underside. The position of this floor section shown in this photograph clearly suggests that it had lifted.

– Items of significance that were found outside the area of collapse were several pieces of concrete (with one surface characteristically painted blue) weighing up to 25 kg found some distance from the building (up to approximately 60 m). Later investigation drawing on witness evidence indicated that this concrete came from the floor in the dispatch area and was probably projected out of the open roller shutter door in this area. This is significant as it is consistent with these pieces of concrete being ejected out of the door prior to the building collapse.

THE SOURCE OF THE EXPLOSION

Given the nature of the work carried by ICL Plastics Ltd, there were clearly a number of possibilities for the source of explosive atmosphere, including various items of gas powered equipment such as ovens etc. One particular oven that received considerable attention in the press at the time as the likely source of the explosions, was based on a recycled refuge truck container, and was referred to as the "Cleny oven". This oven is shown in position in Figure 3 after the rubble had been removed. As already described, the approach to the investigation on site was to systematically work through the site, using the main lines of enquiry to assess and recover possible evidence as it was found. As a result of the approach and other practical constraints of the investigation, the "Cleny oven" wasn't uncovered and examined until three weeks or so into the investigation. There were also other ovens on the site, the most significant of which was a large oven powered by LPG, having at some point been converted from an electric oven. On recovering these ovens, we were able to effectively eliminate them as the source of the explosion based on their

Figure 3. The "Cleny oven"

condition, the operation of the control systems, and the wider evidence that by that this stage was clearly indicating that there had been a gas explosion in the basement of the building. It is now well known that the explosion was as a result of a LPG leak, which is discussed further below. However, as part of the investigation other sources of explosive atmosphere were investigated and eliminated as briefly discussed below. One of the most significant other potential sources under investigation was a natural gas leak from the extensive natural gas system within the building.

This was, however, eliminated as a potential source based on the physical lay-out of the system in relation to the basement: no natural gas pipe work entered the basement area, the supply entering the building from the opposite end and in fact did reach as far as the space above the basement area, stopping just short. In addition, the pipe ran at ceiling level on the ground the floor and so there was some considerable distance from the basement. Because of the buoyancy of natural gas, there is no realistic scenario in which natural gas from the pipe work would be able to enter the basement.

Another possibility investigated was ground borne methane; based on the fact that there were known to be old coal mine workings in this area of Glasgow. This was investigated extensively by P Metcalfe et al., 2006 (2) working with HSL (3) to sample and analyse a number of bore holes at the site over a period of several weeks. This work provided no evidence that methane was present or could have been the source of explosive atmosphere. Their work did, however, confirm the presence of propane in the ground over an extensive area.

The possibility of a dust explosion was also dismissed as there were no materials or processes carried out in the basement that could have produced a credible explosive

atmosphere, or provide a credible ignition source for example a dust cloud.

As already indicated, there were a number of pieces of evidence that indicating something unusual with regard to LPG. Significantly, the investigation identified a leak in the buried LPG pipe, which connected the external LPG pipe to pipe-work inside the building. This leak was just outside the basement area. Figure 4 shows the route of the excavated pipe from the external tank to the basement wall. Figure 5 shows the corroded elbow where the leak occurred. Figure 6 shows the LPG pipe where it entered the basement on the inside.

All of the evidence indicated that this leak was the source of the explosive atmosphere. Tracer gas testing (SF6) carried out by HSL demonstrated a path from the leak through the wall to the inside of the basement wall. While this was clearly a significant finding, because of the major disturbance of the building collapse, the original gas path may have been disturbed or obstructed, but this finding demonstrated the viability of such a path. The leak rate from the damaged pipe was measured, using compressed air and was found to be equivalent to a leak of 57 m^3/hour of propane.

A key property of LPG is that it is heavier than air and on finding its way into the basement it accumulated. The direction of collapse of the basement partition walls also supported the presence of an explosive atmosphere and ignition in the area where the pipe/leak entered the building. Further supporting evidence were severe burns already noted to the deceased individual found in this area of the basement and the high propane concentration found in blood samples taken from him.

The metallurgical aspects of the leak were investigated in detail, by my colleague Dr Parrott, 2006 (4), which showed that the leak in the pipe was due to a combination of corrosion and mechanical load on the pipe associated with large pieces of concrete resting against it. It was not caused by the building collapse. In his report he describes the opening/leak in the pipe developing in three stages: initially just corrosion, then a combination of mechanical loading and corrosion accelerating the failure, followed finally by the opening of the crack due to its weakened state. He suggests that the rate of LPG release

Figure 4. Excavated LPG pipe coming down from LPG torch (was bottom right but removed by this stage) to the basement wall visible centre left.

Figure 5. Photograph showing corrosion/crack in pipe elbow

Figure 6. Shows the location of where the LPG pipe entered the basement. Note sheared off by building collapse

increased during the final period when the pipe was in its most weakened state.

THE EXPLOSION

At around the same time as the excavation of the LPG pipe, other significant evidence indicating that an explosion occurred in the basement area was beginning to appear. This was most clearly evident from damage observed to the steel sections of the dispatch floor. This was a retrofitted steel floor in this area of the building which effectively created the basement from the large pit in this end of the building, which we understand was originally associated with its use as a paper mill. The floor was an approximately rectangular shaped table structure constructed from an of steel I-beam frame, covered with checker plate and supported by 12 box section steel legs. One section of this structure is shown lifted back into place in Figure 7.

The damage to this floor structure indicated very large forces, characteristic of those associated with the overpressure generated by a gas-air explosion and not that of a simple building collapse. In addition, the evidence found clearly indicated that these large forces were acting in an upward direction from within the basement area. Key evidence found on the steel floor sections was:

i. Floor section lifted into the air, already note in Figure 2.
ii. Broken welds, bolts and distorted fixing plates where supporting legs were joined to the steel floor section (see Figures 8 a & b). This was found on both floor sections.

Figure 7. Showing floor section lifted back into place

iii. Distortion of main 'I-section' members that make up the steel floor (White G, (5)).
iv. Large forces acting to break welds between checker plate and 'I-section' support beams.
v. Destroyed concrete floor section. (elevated position of floor sections and unique projection of pieces of the concrete ground floor adjacent to steel floor some distance outside the building) that are consistent with the explosion preceding the building collapse and not the reverse.

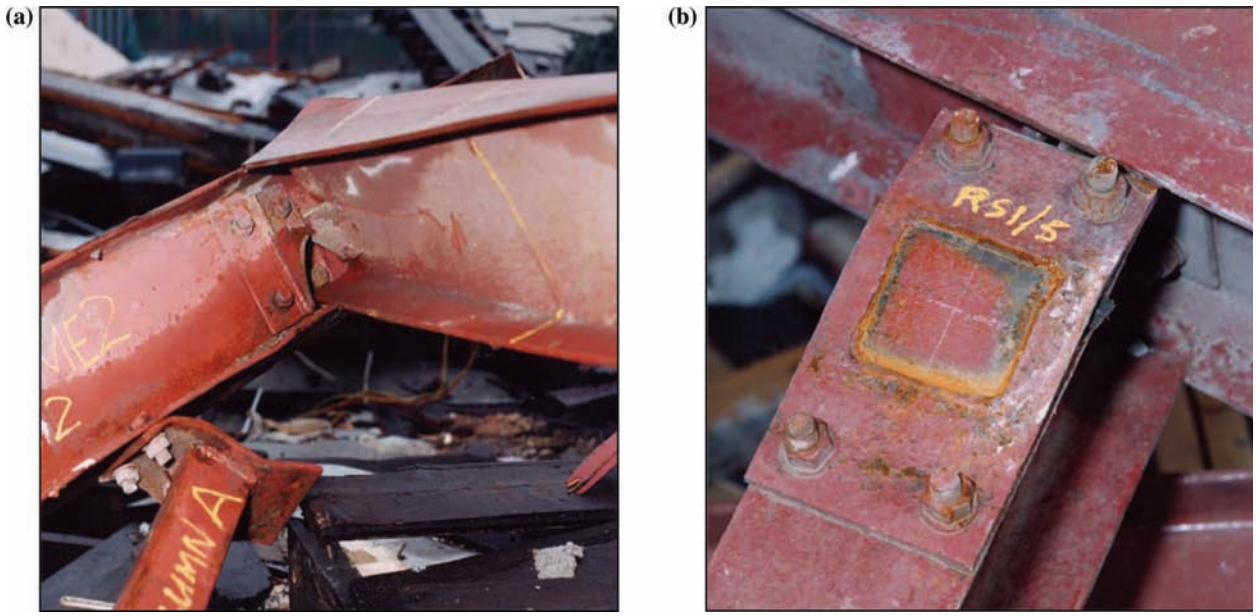

Figure 8. (a,b) Showing the damaged steel I section structure with characteristic detachment of supporting leg, bottom right

ASSESSMENT

The exact sequence of events during the explosion is difficult to establish, but from this and other evidence the best understanding is:

i. The ignition most likely occurred in the basement area that was directly accessed from the stair tower (between the gable-end and first Party wall), based on the direction of fall of the basement partition walls. This is also the area where the deceased individual with burn injuries was found, who presumably had just entered the basement. The ignition source could have been the operation of the light switch.

ii. The explosive atmosphere in the basement is unlikely to have been well mixed, and so the duration of the explosion overpressure pulse is likely to have been several seconds. There would have been an initial period of relatively slow pressure rise corresponding to low speed laminar flame propagation. The latter stages of the explosion would have involved interaction between the flame and piers, walls etc leading to flame acceleration and very rapid rates of increase in pressure.

iii. The explosion produced in the basement would have started to vent through the doorway to the stair well. However, this would have had only a small effect on limiting the explosion overpressure, as it is relatively small opening in comparison to the volume of the basement.

iv. At the same time, the explosion overpressure would be exerting large forces on the basement walls and ceiling. The weakest parts of the basement would fail initially, for example the basement party walls. This would have effectively created a single space partially obstructed by the stone piers. Any explosive atmosphere in these spaces could then become directly involved in the explosion, if not already. Equally, any excess of explosive atmosphere present in the initial space could then mix with the air from these spaces to increase the size of the explosion.

v. The dispatch floor started to lift and break apart, venting the explosion into the ground floor space as gaps began to appear around the edge of floor. The indications are that the steel sections lifted at an angle, the gable end lifting the highest, pivoting about the other end that was connected to the adjacent concrete floor by Rawl bolts. This would have tended to direct the outflow of high-pressure gas from the basement onto the walls at the gable end of the building.

vi. Notwithstanding the venting of the explosion from the basement, the overpressure could have continued to increase and start removing the checker plates and by this stage the explosion/overpressures produced would have expanded into the ground floor space above.

Analysis of the structural damage to the steel floor sections indicates an overpressure of approximately 0.7 bar in the basement, possibly higher (White, G (5)) indicating a powerful explosion.

Using this overpressure it was possible to make a simple estimate of the minimum volume of explosive atmosphere required based on a number of basic assumptions:

- The explosion process was adiabatic, i.e. there are no heat losses to the surroundings.
- Ignition of a stoichiometric propane/air mixture (4.0% v/v from Kuchta, (6)) in a confined volume will generate an overpressure of 8 bar abs.
- The net internal volume of the basement of approximately 330 m^3 and there was minimal ventilation.

Using this simple method we were able to estimate that as an absolute minimum, the volume of LPG vapour required to produce the overpressure estimated is of the order 1.31 m^3. At the leak rate measured on site (57 m^3/hour) and assuming 100% transfer from the leak to the cellar, it in theory would only have taken a few minutes to produce the explosive cloud required. Even at a much-reduced rate (e.g. 100 to 200 litres per hour) it seems credible that a quantity of LPG required could still have formed within the basement over a period of the order of 10 hours.

Evidence from the site indicates that there had been a leak of LPG for sometime (extensive migration of LPG through the ground at the site). LPG may therefore having been leaking into the cellar for sometime, or there may have been a critical change in the leak that resulted it finding its way into the cellar only a few hours before. There is a broad spectrum of combinations of leak size and duration that could be considered, and it is clear that given a leak much smaller than that measured post incident, the cloud would still have formed.

This does raise a number of difficult questions; such as why wasn't the leak in the LPG pipe detected just prior to the incident from the stenching agent or the impact on the ovens performance? There was only one piece of equipment using LPG (the oven already referred to) and tests carried out at HSL indicate that a large leak (up to 22 m^3/hour) would not have had any discernable effect on the performance of the oven burners, and so in this respect would have also gone unnoticed.

SUMMARY

This was clearly a very unfortunate incident where a corroded pipe leaked a commonly used explosive gas into the basement of a building. This led to powerful explosion in the basement and the subsequent collapse of the building.

The investigation of the incident was extensive and time consuming, working with a number of authorities and drawing on a broad range of skills from HSL and outside.

REFERENCES

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