## C44 Forensic Investigation of an Underground Gas Main Explosion

*Chin-Chin Lim, MSc, MBA*, Poh Ling Chia, BSc, and Ming Kiong Michael Tay, PhD, MBA*, Centre for Forensic Science, Health Sciences Authority, 11 Outram Road, Singapore 169078, Singapore*

The goal of this presentation is to present a case study of a forensic investigation into the explosion of a buried section of a town gas distribution system.

This presentation will impact the forensic community and/or humanity by illustrating how forensic scientists can complement structural design and civil engineers, as well as gas safety experts, in determining the cause of engineering failures.

Background

The explosion occurred in a single-story seafood restaurant erected on a 35-cm thick reinforced concrete (RC) floor slab on land reclaimed from the sea 30 years ago. This concrete base had two layers of reinforcement bars (re-bars) and was supported by large pilings driven into the ground. As a result of soil settlement, there was a void of 30-50 cm under the monolithic concrete slab, apparently extending throughout the entire space under the restaurant. The rear area of the restaurant was a fairly open concrete structure with corrugated iron roofing, false ceiling and thin-walled partitions.

The underground town gas main entered the restaurant at the rear area. The piping consisted of two levels of 4-inch gas pipes joined together by an inclined spigot. At the upper level, the inclined spigot was connected by a spigot-and-hub joint to a horizontal pipe, both of which were embedded in a concrete channel in the RC slab. The town gas in the main contained hydrogen (62%), carbon dioxide (18%), carbon monoxide (6%), methane (5%), pentane (5%) and traces of nitrogen, oxygen and a malodorous mercaptan. Although this pipeline was still charged, it had been capped for three years. The restaurant had converted to using LPG cylinders in a manifold in the kitchen and dining area.

In response to a major leak in the underground water main, located in the open dining area, two workmen opened the water valve pit, ventilated it for an hour and began working around the leaking water valve. About 30 minutes later, as they were hacking tiles in the pit with an iron spike and an electrical drill, a series of explosions occurred, The first explosion occurred in the valve pit, followed by a series of directional explosions moving underground towards the rear of the restaurant where the town gas main was located. The explosions covered the premises with debris, smoke and dust but no fire resulted. The injured workman recalled smelling cooking gas immediately after the first explosion.

The explosions damaged the ceiling, roofing and walls, popped floor tiles, and dislodged furnishings. The rear area where the underground town gas main entered the premises sustained the most severe damage. The explosion broke the concrete channel in which the gas pipe was embedded, exposing the 45$^{o}$ elbow (bend) attached to a horizontal pipe, and a void underneath with a disconnected inclined spigot partially buried in subsided soil. The horizontal pipe attached to the elbow was partially resting on the lower layer of re-bars. The upper layer of re-bars had been cut and removed to create space for embedding the horizontal section of pipe during installation.

The explosion also dislodged the LPG cylinders which were all intact and clearly not the cause of the explosion. Except for two blown out sewage inspection chamber (IC) manhole covers in the open eating area, all of the manhole covers were intact, and waste-water in these ICs was found to be free-flowing. Property management personnel indicated there was no foul smell coming from the underground sewage system before the explosion.

The town gas company promptly shut off the gas supply to the area after the explosion. Two structural engineering consultants hired by the gas company to investigate the incident independently concluded that the separation of the 45$^{o}$ elbow joint was sudden, was unlikely to have been caused by natural soil settlement, and was a result rather than the cause of the explosion. One consultant dismissed the possibility that the explosion was due to leakage of town gas.

Key issues

- Our lab was tasked to verify the consultants' findings and examine the following issues:
- Was the dislodged joint caused gradually and progressively by the settlement of soil? Or was the joint failure sudden and catastrophic?
- Was the explosion caused by methane produced either by the reclamation soil in-fill or underground sewage system?
- Was the explosion caused by town gas leaking from the gas pipeline?

Analysis of residual gases

Holes were drilled at 5 locations through concrete floor and the void underneath these holes was analyzed for hydrogen and methane but none was detected. Less than 50 ppm methane (well below the 50,000 ppm LEL for methane) was found in the IC manholes. Soil samples collected from around the damaged gas pipe, and from the water valve pit, were examined for methane, ethane, propane and butane, but none was detected.

 ** Presenting Author*

Examination of the dislodged joint

The inclined spigot and the 45º elbow attached to the horizontal pipe were cut and brought to the lab for further examination. The cut-out spigot was not deformed or dented. However, its inner surface and end (circular ring) were rusty.

The 45º elbow (bend) had two hubs, one of which was attached to the horizontal pipe. A flexible optical fibre scope revealed rust spots and patches on the interior surfaces of both the hub and the pipe, indicating the presence of moisture and oxygen within the piping system for some time. In addition to rust spots, the interior walls of the hub had a circular arc of rust corresponding to the end of the spigot. This arc of rust, evidently formed by prolonged contact with the end of the spigot, was not concentric, indicating that the spigot was not aligned axially to the hub.

The joint was mechanical with a seal effected by compressing a wedge-shaped annular gasket of elastomeric material, partially lined with lead sheath, onto the jointing surface in the pipe hub and the outside of the pipe spigot, by means of a pressure gland and a series of bolts and nuts. This joint was carefully dismantled and examined. Rust and fine soil particles were found on the tapered inner surface of the hub where the gasket had been in close contact with the iron surface. The gasket had suffered extensive wear and tear. The elastomeric material was permanently deformed and flattened. The lead sheath was torn and severely thinned out on one side, and stained with rust or brownish soil stains. The lead layer had buckled furrows with dirt and fine soil between the lead and elastomeric layers, indicating that the seal was not gas-tight. The furrows evidently resulted from the spigot end pressing against the top part of the hub, creating a disproportionate amount of pressure along the top of the annular gasket, which thinned and extended out the lead along its circumference, creating folds in the wider available space. The inner surface of the gasket indicated uneven contact with the spigot end and the gasket was not evenly seated around the entire joint.

Findings

The most probable cause for the explosion was a damaged gasket resulting from a badly aligned and severely stressed joint. This faulty gasket was not gas-tight; the leak led to a diffusion and accumulation of town gas in the connecting spaces between the monolithic concrete slab and the subsided soil. The electric drill ignited the flammable gas and triggered the explosion, which generated a significant expanding force in the underground space, lifting up and breaking the weak concrete floor channel bearing the horizontal pipe. The uplifting raised the horizontal pipe and attached elbow, and created a sudden longitudinal pullout force, which caused a sudden axial withdrawal and separation of the 45º elbow joint.

The misalignment of the joint was probably due to the settlement of soil under the buried inclined spigot, which drastically reduced support for this underground segment. Severe stress was created at the elbow joint because the embedded horizontal pipe and the elbow were firmly supported by the lower layer of re-bars in the concrete channel, whereas the inclined spigot pipe being inadequately supported, was sinking. The weight of this partially buried spigot in subsiding soil created a concentration of stress on the joint.

Conclusion

Our investigations revealed departures from industry practices concerning installation of the joint and support of the piping system. Failure to account for soil settlement and provide adequate long-term support for the inclined spigot and lower level of pipes resulted in misalignment and sagging. Although gas pipelines are commonly designed for 50 years of service, the forced dislocation (deflection) of the piping and fittings eventually took the joint to its limit, creating leakage paths between the spigot pipe and the gasket. A continuous outflow of town gas ensued as the pipe was pressurized.

Detailed examination of the joint was crucial in this case, over and above general observations about damages and speculations over different possible contributing factors. This case illustrates how forensic scientists can complement structural design and civil engineers, as well as gas safety experts, in determining the cause of engineering failures.

**Gas Pipe, Stressed Joint, Gasket Failure**

 ** Presenting Author*