



Health and Safety Executive

The Putney Explosion

A report of the investigation by the Health
and Safety Executive into the explosion on
10 January 1985 at Newnham House,
Manor Fields, Putney





Rescue services search for survivors

Health and Safety Executive

A report by HM Factory Inspectorate

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A report of the investigation by the Health and Safety Executive into the explosion on 10 January 1985 at Newnham House, Manor Fields, Putney.

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General views of damage

Summary

On 10 January 1985 an explosion destroyed the central section of a three-storey block of luxury flats in South London, killing eight of the residents. Preliminary investigations indicated a gas leak as a probable cause.

On the afternoon of 10 January the Health and Safety Commission (HSC) directed the Health and Safety Executive (HSE) to investigate and make a special report in accordance with Section 14(2)(a) of the Health and Safety at Work etc Act 1974 (HSW Act). The Secretary of State for Employment asked in Parliament that a copy of the report be sent to him.

The investigation was carried out under the direction of the Area Director by inspectors from the South London Area of the Factory Inspectorate assisted by specialist inspectors from Factory Inspectorate headquarters, and London and Home Counties South Field Consultant Group, together with scientists from HSE's Research and Laboratory Services Division (RLSD). They worked closely with investigation teams from the South Eastern Gas (Segas), Midland Research Station (MRS) and the Engineering Research Station (ERS) of the British Gas Corporation (BGC) and with the police, fire authority and departments of the London Borough of Wandsworth.

It was found that the explosion was caused by gas leaking into the building from a crack in the gas main, a 150mm (6 inch) diameter cast iron pipe buried at the rear of the building, which carried gas at low pressure. The crack was primarily due to loading on the pipe caused by differential settlement. The loading could not be evenly distributed along the pipe, as it was held rigidly near the point of failure by the concrete encasement of a drain, which acted as a fulcrum.

The report recommends that certain remedial action should be taken at Manor Fields, and that the British Gas Corporation (of which Segas is an operating division) should, in consultation with HSE and other authorities, develop programmes to deal with the wider implications of the incident.

Incident

1 Early on the morning of 10 January 1985, an occupant of Flat 12, one of the top floor flats in Newnham House, Manor Fields, Putney, noticed a faint smell of gas. He opened the door to his front landing and found the smell was much stronger. At 7.02 am his wife reported a suspected gas leak to Segas while he alerted the residents in the flats beneath him. The assistant porter, delivering a parcel to one of the flats, also noticed a strong smell of gas in the front stairway to Flats 7 to 12. When the occupants of Flat 9 told him that Segas had been informed, he opened the stairway windows before returning to his office. At about 7.15 am, only minutes before the arrival of the Segas emergency engineer, the explosion occurred, demolishing the six central flats and breaking windows in most homes in a quarter mile radius (see Figures 2 and 18 for extent of damage).

2 The emergency services arrived promptly and for two days, in sub-zero temperatures, cleared the demolished structure and searched the rubble for survivors. Only one occupant of the six central flats was rescued alive; the remaining eight were found dead.

3 During this time Segas ensured that the gas supply

to all flats on the estate was safe. The gas main at the rear of the premises was cut and capped to isolate the section of the main adjacent to the damaged part of Newnham House. The service riser to Flats 1 to 6 Newnham House was cut between the main and the service valve. Before gas was restored to the neighbouring block of flats, the main and services were subjected to pressure soundness tests. When the gas supply was restored each flat was visited to check the supply from the meter to each appliance and that the installations were sound. During the next four days all flats on the estate were visited by Segas personnel to check the supply integrity of pipework and appliances.

The site

Manor Fields

4 Figure 1 shows the layout of Manor Fields, a large private residential estate built in the early 1930s. The thirteen blocks of flats on the estate are located in extensive grounds and although varying in size and layout are built to a similar architectural style. The roadways on the estate were constructed at the same time, with narrow service roadways at the rear of the blocks. Figure 1 also shows the route of the 150mm

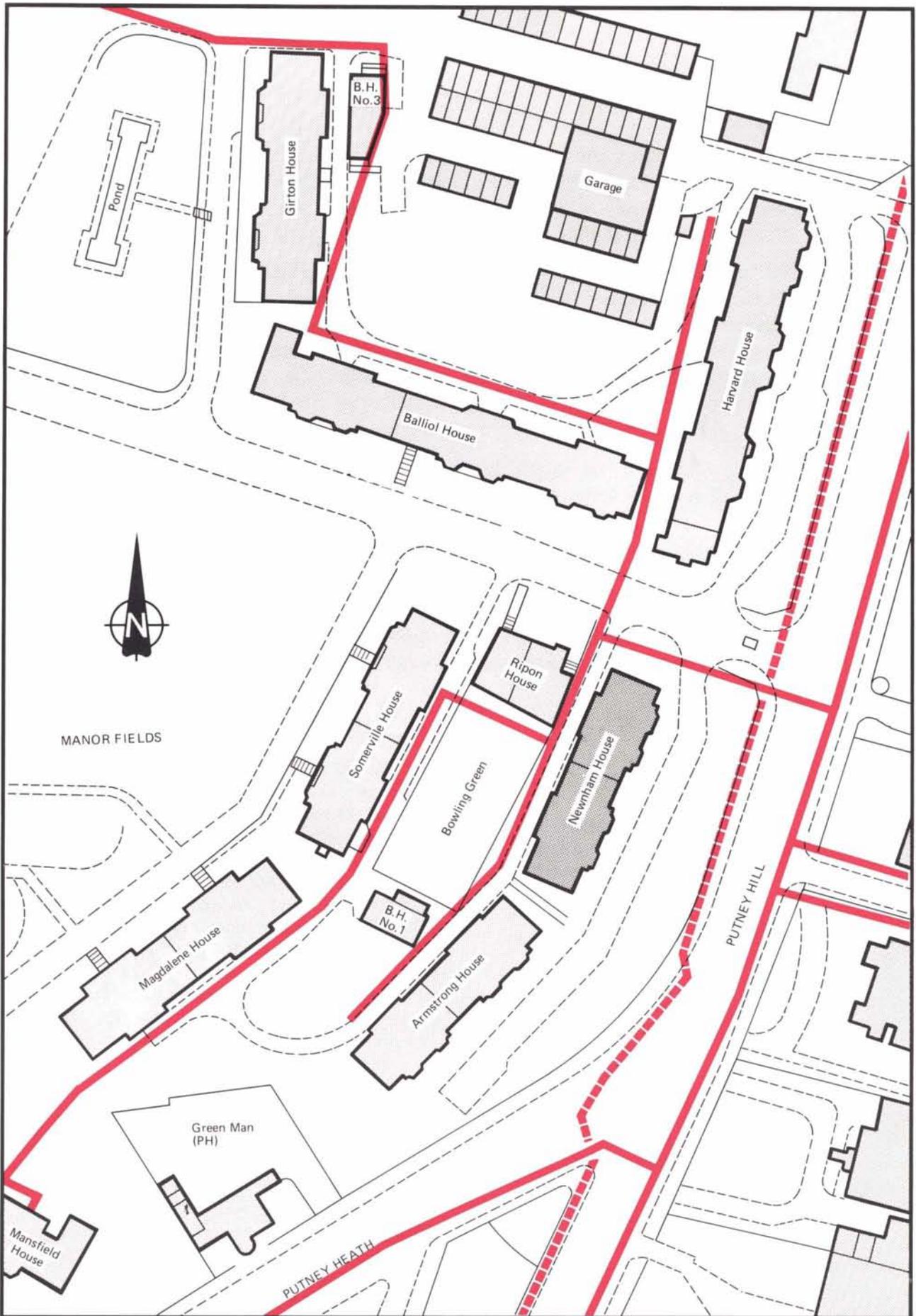


Fig 1 Plan of estate showing gas mains



Fig 2 Area of Newnham House destroyed by explosion

diameter cast iron low pressure gas main, installed in 1933, in relation to these roadways. During 1982 service supplies to each block of flats were replaced with new 50mm diameter steel pipes, when the communal oil fired heating system was replaced by individual gas fired central heating boilers. Conversion from town to natural gas was carried out in 1972.

Management of the estate

5 The freehold is owned by Swallow Securities, who employ a firm of managing agents, Gross Fine & Krieger Chalfen, to deal with all matters concerned with the running of the estate and to collect the service charges from residents. A residents' association negotiates with the managing agents on matters of general concern. Most of the residents are leaseholders, but some are tenants.

Newnham House

6 Newnham House, one of the smaller blocks on the estate, stands back from Putney Hill and is separated from this main road by a private access road to the two main entrances at the front of the building. The narrow service road behind the block is used by tradesmen and refuse collection vehicles. Beyond this is an area of grass known as the 'Bowling Green'. The three storey block comprises a total of twelve self-contained flats. Each floor has a similar layout: two triple bed roomed flats towards the south end and two double bed roomed flats towards the north end of the building (see Figure 3).

7 The building is of substantial construction, typical

throughout the estate. The external walls are 450mm thick at lower levels with spread footings supported on concrete strip foundations generally about 1.3m below ground level. The wall thickness reduces to 330mm from ground floor window level for the remaining height of the building. The conventional suspended ground floor and other details are shown in the cross section in Figure 4. A longitudinal duct, some 760mm wide and 900mm deep runs below ground floor and centrally for the full length of the building. The duct holds disused hot water pipes from the obsolete oil fired district heating boilerhouse. Brickwork to the duct walls is built up to the underside of the floor joints.

8 First and second floor slabs together with the roof slab are of reinforced concrete placed *in situ* and hollow pot construction spanning the width of the building. End support is by means of a reinforced concrete edge beam placed *in situ* built into the external brickwork. Intermediate support is by a similar beam supported in the central brick-built load bearing partition walls.

9 Ventilation is provided to the under floor space through air bricks, placed in the external brick walls. A cross flow of air is maintained by the intermediate honeycombed dwarf wall construction and holes left in the duct brickwork.

10 Outside soil and rainwater downpipes at the back of the building discharge into gullies connected to the main drainage system by pipes running under the service road to manholes alongside the Bowling Green edge of the road.

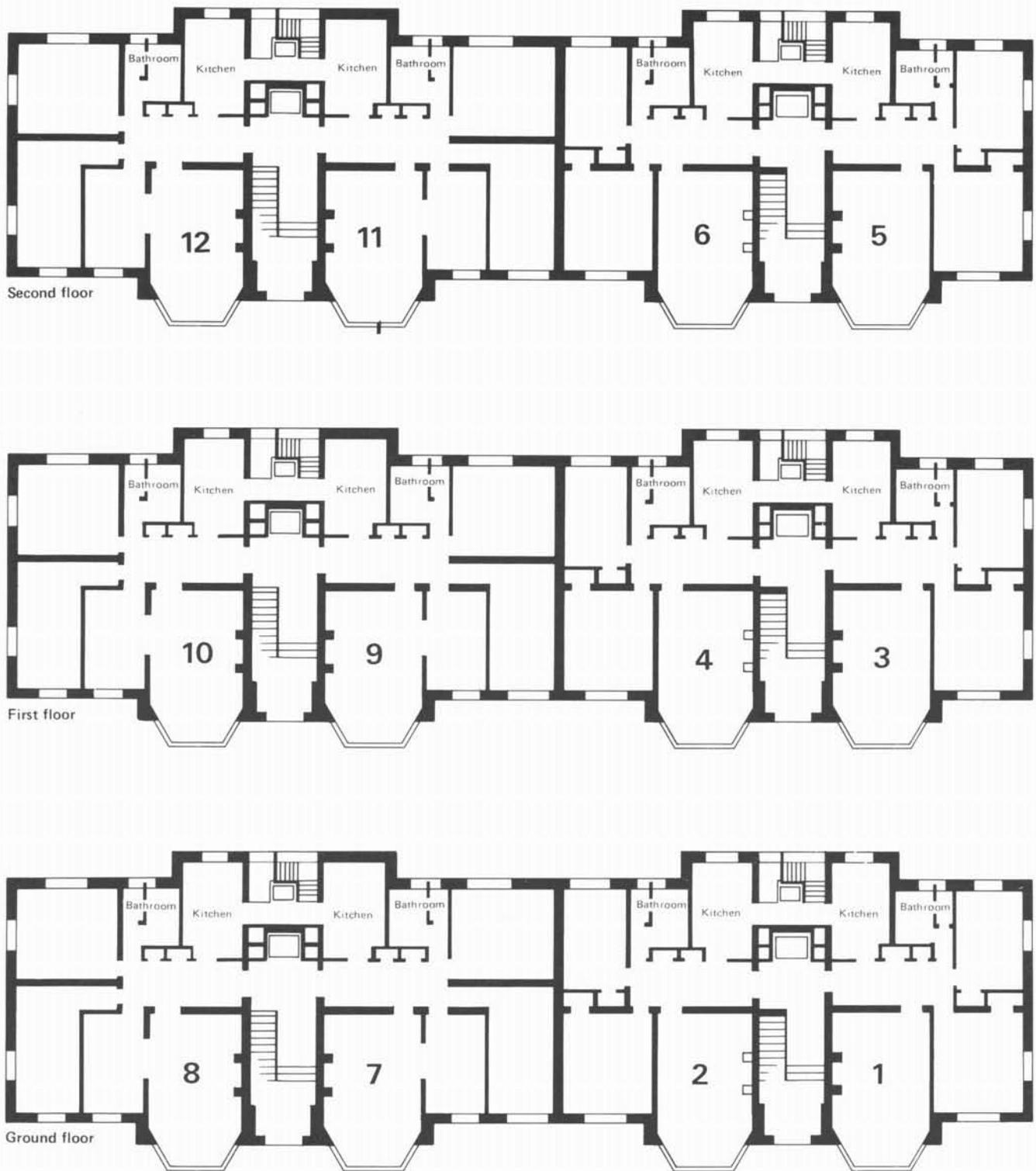


Fig 3 Floor plans of Newnham House

11 The two front entrances to the house each open onto a hall with a stairway. A passenger lift shaft with a small service duct either side is at the back of each hall (shown in Figure 5). The staircase at each rear entrance is built around a goods lift shaft and is well ventilated by large openings in the back wall. The kitchen door of each flat opens onto this back staircase and on the outside landing, beside this door, is a cupboard where individual gas meters are installed.

12 The gas main runs parallel to Newnham House under the far edge of the service road, approximately 2.5m to 3.5m from the rear wall (see Figure 6) and approximately 700mm deep. It supplies the block through two 50mm (2") service risers running up the outside of the block to one side of each rear stairwell (Figure 7). These pass through the outside wall at each floor level and are connected to the individual gas meters.

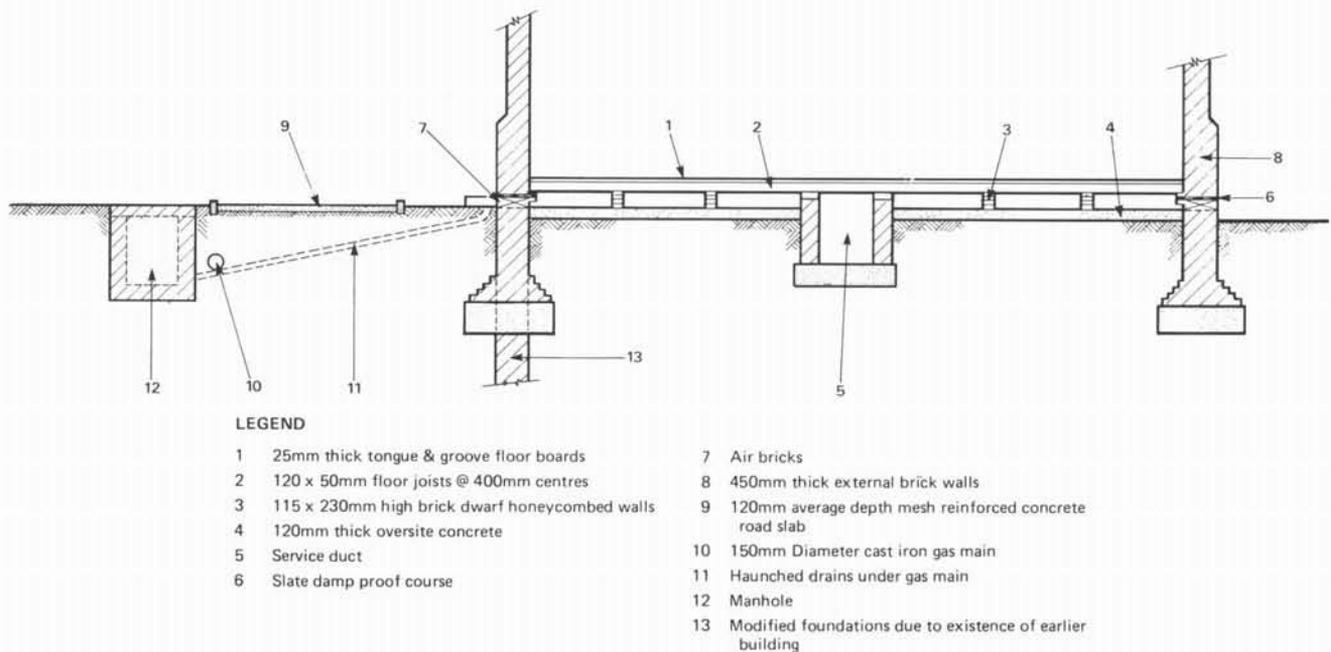


Fig 4 Section through ground floor

Investigation

13 The Newnham House site was handed over to HSE on the morning of 12 January 1985, when the London Fire Brigade had completed their rescue work and the police had eliminated foul play as a cause of the explosion. During the next seven days, while the investigation was carried out, the site was under HSE's control. In addition to directing the investigation HSE was responsible for the property, much of it valuable, in the remaining flats and arranging for residents and relatives to retrieve items, when it was safe for them to do so. This was made easier by the early erection of security fencing around the site with the gates permanently manned during the day and locked at night.

14 The explosion left parts of the remaining building in a dangerous condition. Under the direction of HSE improvements in structural safety were effected by use of a mobile access platform and a crane to enable the investigation to proceed (see Figure 8).

15 Much of the site investigation was carried out by teams from Segas, MRS and ERS supervised by HSE. Subsequent laboratory work was done by RLSD.

Aims

16 Early accounts of the explosion clearly indicated that gas was involved and the major thrust of the investigation concentrated on this aspect. The main aim was to find the source of gas. This involved examining, and where appropriate eliminating, the possibility of

- (a) appliance defects;
- (b) installation pipework failures;
- (c) meter and service pipe failures;
- (d) gas main failure.

17 After eliminating the first three as possible sources of gas, attention was focussed on the likelihood of a failure in the distribution gas main. To determine the nature of this failure and assess the various contributing factors the on-site examination then considered the following:

- (a) locating site of failure;
- (b) measurement of pipe slope;
- (c) assessment of soil to determine compaction and corrosivity;
- (d) the pipe bed;
- (e) the condition of the road.

The pipe itself was then subjected to metallurgical examination in the laboratory.

18 A further aim of the investigation was to trace the path of the gas into the building.

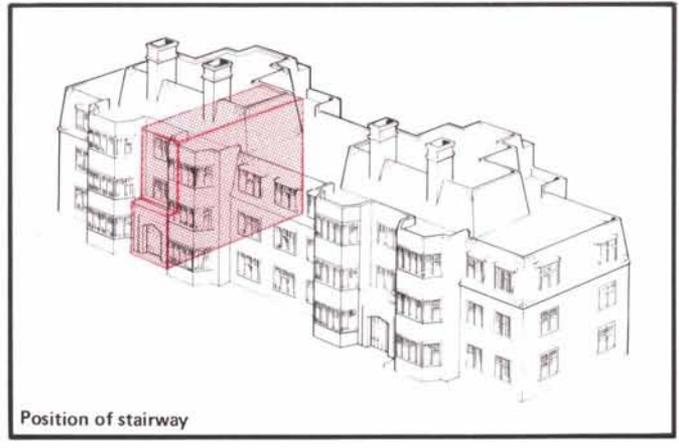
19 Background information, such as Meteorological Office reports, was obtained, to enable the investigation team to assess various influencing factors which may have contributed to the pipe failure and the resultant gas escape.

20 Other aspects of the investigation included an examination of the damage caused by the explosion, to identify its possible seat. A portable liquefied petroleum gas fired heater found in the debris was removed for detailed examination.

Examination of internal installations

Meter installation

21 The meters at each flat had been installed using similar techniques. All were of standard domestic design



Position of stairway

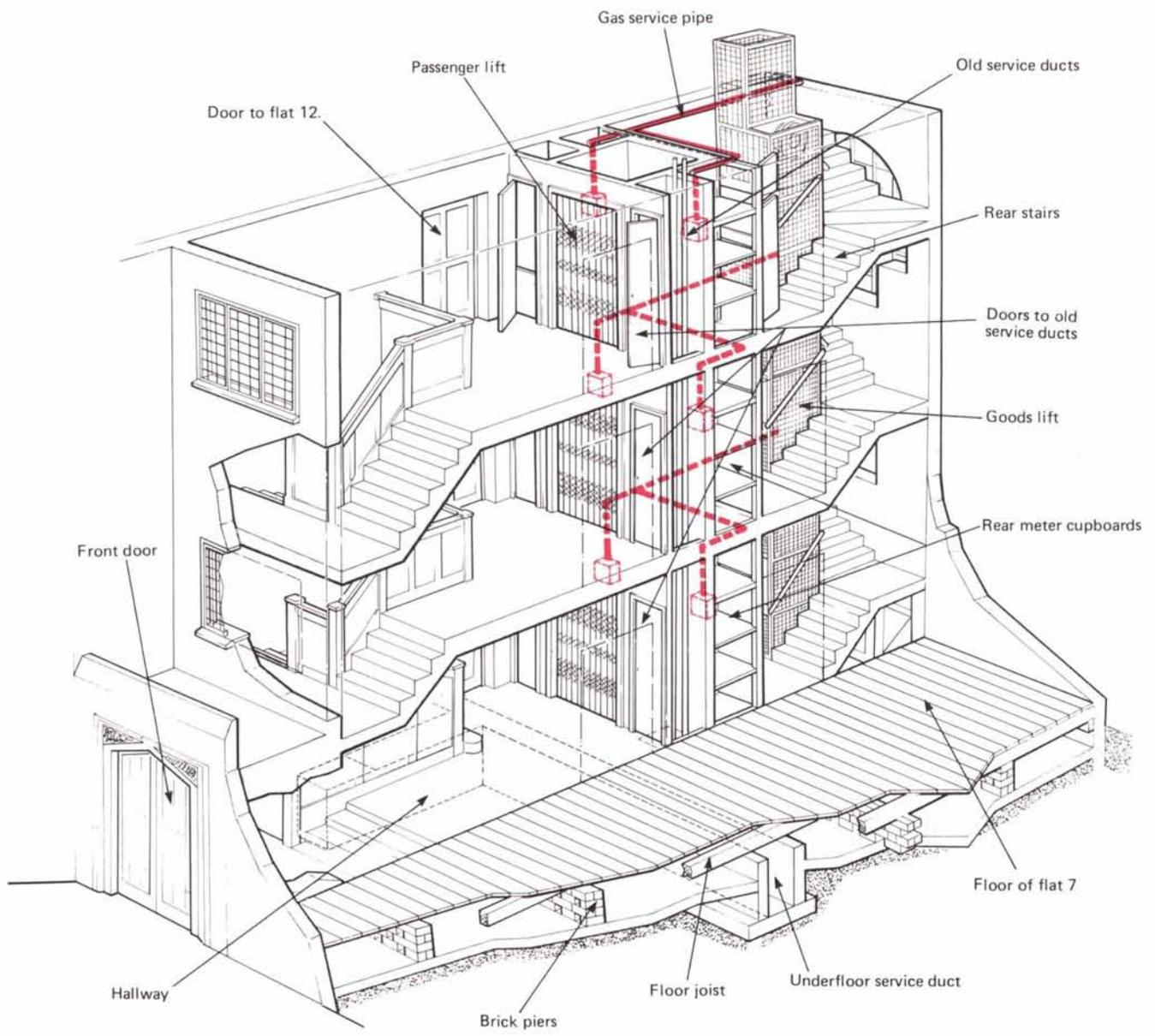


Fig 5 Section of Newnham House through stairway

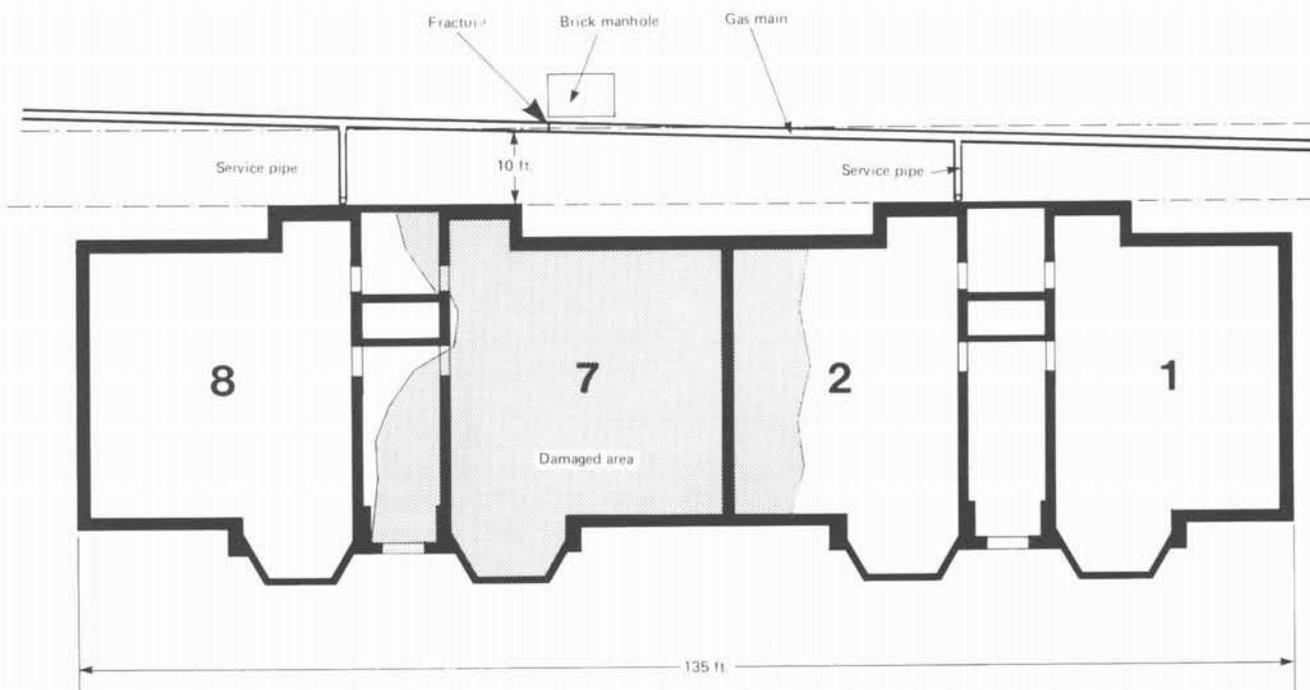


Fig 6 Plan of ground floor of Newnham House



Fig 7 Rear view of Newnham House

and of steel construction except the older style meters installed in Flats 3 and 6. They were all fitted with meter controls and pressure governors. The type of fittings used for inlet connections were of, either flexible or rigid steel pipework, and for the outlet connections, flexible or rigid pipes fitted to either mild steel or copper installation pipework.

Testing

22 Where possible, tests were carried out on the soundness of the meter and internal installation pipework. The test method was based on that described in British Standard CP 331: Part 2: 1974. This determined the gas-tightness of the meter installation

and associated internal pipework supplying any gas appliance.

23 It was not possible to carry out soundness tests at Flats 7, 9 and 11 because of the damage sustained by the internal supply pipework. Soundness tests carried out for the remaining flats showed that the meters and installation pipework were gas-tight. There was no evidence to indicate a source of gas from the internal installation.

Appliances

24 The most recent major installation work was carried out during 1982 and coincided with the abandonment of the communal oil-fired central heating



Fig 8 Mobile access platform

system, and the installation of new gas services to the premises. At that time individual, balanced-flue, central heating boilers were installed in each flat. Occupiers selected one of two models, either Vaillant Combi or Potterton Netaheat 11F boilers. In addition gas cookers were installed in Flats 6, 7, 9 and 11, gas hobs in Flats 8 and 12, and a gas fire in Flat 12.

25 Those appliances from the demolished flats were removed for further examination by RLSD. The details of this examination are given in Appendix 1. There was no evidence to suggest they had contributed in any way to the incident.

Pressure tests

26 A series of pressure tests was carried out on the service pipes and main at Newnham House to identify any possible sources of gas escape.

Service pipes

27 The gas supplies to Flats 1 to 6 and 7 to 12 were from two separate service pipes, each fitted with a service valve under the road. The pipes were 63mm medium density polyethylene from the main to the service valve and 50mm coated steel from the service

valve up to the outside of the block to the customers' meters. The service pipe to Flats 1 to 6 proved sound when pressure tested. Testing on the service pipe to Flats 7 to 12 registered a small drop in pressure on the manometer, but of insufficient size to contribute to the incident in any way.

28 The four older gas service risers, which had been disconnected and abandoned in 1982, were also pressure tested. Although one riser showed a very slight leak and one riser failed to hold pressure due to damage at the time of the incident it is thought unlikely that any significant quantity of escaping gas could have entered the building by way of any of the abandoned risers.

Main

29 The isolated section of main was pressure tested with the service connections sealed off (Figure 9). The initial test using a hand pump showed a significant leak as pressure sufficient to register on the manometer could not be achieved; compressed nitrogen from a cylinder, introduced at a flow rate of about $4\text{m}^3\text{hr}^{-1}$, also failed to register any increase in pressure in the main. A compressed air line was then connected to the main and this test showed a flow rate of about $55\text{m}^3\text{hr}^{-1}$ was required to maintain a pressure of 25-30 mbar, (ie its normal operating pressure). A flow rate of $55\text{m}^3\text{hr}^{-1}$ of air is equivalent to a leakage rate of about $70\text{m}^3\text{hr}^{-1}$ of natural gas at the normal operating pressure. It is not possible, however, to estimate from these tests what proportion of the gas actually entered Newnham House.

Tracing the gas path

30 To try and identify

- (a) the probable location of the leak; and
- (b) the preferred path for escaping gas,

a series of tests using sulphur hexafluoride (SF_6) as the tracer gas were carried out (Figure 10). With a bar, holes were made along each side of the service road and along the branch main behind Ripon House. Nitrogen was used as carrier gas and was introduced into the main from the south end at about $1.4\text{m}^3\text{hr}^{-1}$. The tracer gas (SF_6) in nitrogen was injected through a long capillary tube into the nitrogen stream near to the carrier gas inlet. Initially the SF_6 was detected qualitatively using an electron capture detector with a Ni 63 source. Once the SF_6 presence was detected at the various bar holes a semiquantitative chromatographic detector was used to establish whether high or low concentrations were present. The flow of carrier gas was deliberately kept low to prevent the whole area becoming saturated with tracer gas before it could be detected at the various points along the route of the main. A further test was then carried out by turning off the nitrogen and SF_6 supplies and purging the main with compressed air. The chromatographic detector clearly showed high concentrations of SF_6

Fig 9 Investigators conduct pressure tests



Fig 10 Tracing the gas path

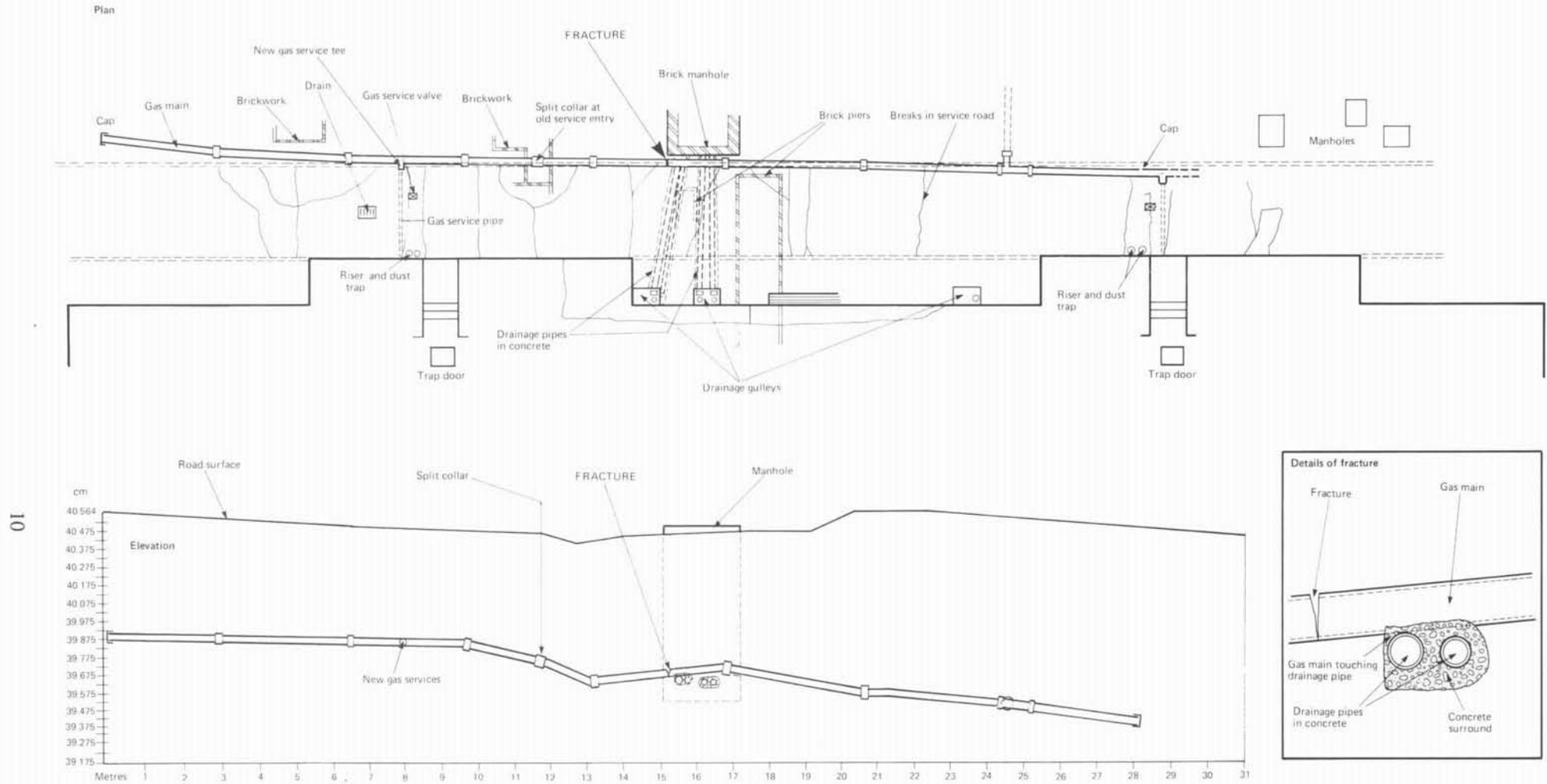


Fig 11 Detailed plan of pipe profile

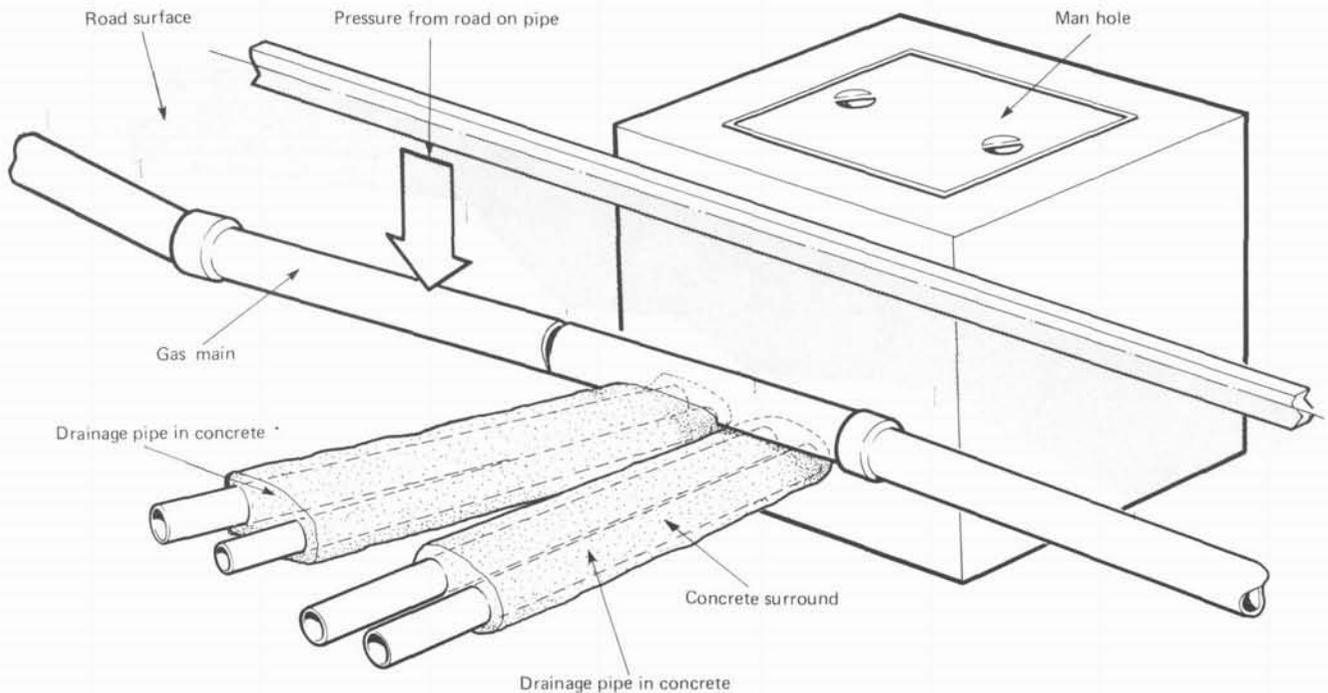


Fig 12 Concrete surround of pipes

along the rear of the building, between the outer load bearing wall and the underfloor concrete raft and where the concrete raft joined the service duct.

Excavation of main

31 An excavation about 1.5m long and about 0.6m deep was carried out over the main behind Flat 7 which was shown by the SF₆ test to be the most likely location of the leak. However, the exposed part of the main was found to be intact (Figure 13). The main was repressurised with compressed air and on wetting the walls of the excavation with soap solution, bubbles formed on the southern end wall. A second excavation was carried out about 1m south of the first excavation leaving a 'bridge' over the main. This excavation also showed the main to be sound and a further air test with soap solution showed bubbles coming from the north end of this excavation. Subsequently the 'bridge' between the two excavations was carefully removed. At about 5cm above the main, pale, dry backfill could be seen, indicating that gas had escaped in this area, causing it to dry out. Further excavation to the 'crown' of the main revealed a partial circumferential fracture which was slightly open at the top and extended along about 75% around the circumference of the pipe. Dry ground was observed for about 30cm to the east of the main in the direction of the property, and underneath the main. About 20cm north of the fracture the main was firmly embedded in the concrete surround of four earthenware drains. The gas main was directly on top and in contact with one of the drains. These drains ran from gullies on the east side of the service road to a manhole on the west side (see Figures 11 and 12).

32 Considerable voids were found underneath the concrete encasement. These were generally about 75mm

in depth along the whole distance from the outlet manhole up to Newnham House footings. There were also large voids under the gullies in places reaching about 300mm in depth.

33 In order to keep the fracture faces dry until the next day, when the fractured pipe could be removed, it was wrapped with Denso tape.

34 The following morning, and with the fracture still encased with Denso tape, a further pressure test was carried out to locate the source of an SF₆ reading to the north of the fracture. There was a slight leakage from one of the lead yarn joints on the 150mm diameter branch behind Ripon House. After carrying out this test it was necessary to complete the fracture of the pipe before attempting removal in order to prevent the fracture faces rubbing together. A 0.4m length of pipe was first removed, approximately 2.5m south of the fracture. Under the direction of RLSD, the main was cut about 1.5m north and 2.2m south of the fracture and the pipe removed from the trench. After preliminary examination and photography both sections of pipe were taken to RLSD for detailed metallurgical examination. When the section of main to the north of the crack was removed from the trench the red brown colour of an earthenware pipe could be seen where it had been in contact with the gas main in the pipe bed.

35 After exposing the full length of main a split-collar was found approximately 5m to the south of the fracture described above (Figure 14). When the split-collar was removed a 44mm diameter tapped hole was revealed in the top of the main, with a partial circumferential fracture running from it in either direction. It is not unusual for fractures to occur at

Figs 13 and 14 Views of the fractured pipe



Fig 15 Fracture faces of all pipes



such 'tapping' points where the pipe would be normally weakened. Segas confirmed that this fracture had been the source of a gas leak in 1982 and had been repaired by fitting the split collar. The fracture was extended to full circumference by longitudinal loading and lengths of pipe measuring 1.5m and 1.9m north and south respectively were retrieved for examination by RLSD.

Examination of the pipe bed

36 Once the pipe had been removed, the bed was examined. The pipe profile is shown in Figure 11. Variations in the support provided by the soil in the pipe bed may lead to increased stress in the pipe material if external loads such as heavy vehicles are applied. To assess these variations penetrometer readings were taken at intervals along the pipe bed on either side of the fracture. The variations in support are clearly shown in the test results given in Appendix 2.

Metallurgical examination of fractured pipes

37 The detailed report of the examination is given in Appendix 3 and the chemical analysis in Appendix 4. The conclusion of the examination of the 1985 fracture was that the probable origin of the failure was on the outer surface of the pipe between 0 degrees and 30 degrees clockwise from top dead centre, viewed on the south face of the fracture. At this point the original thickness of the pipe was at the lower limit of specification and the strength of the pipe had been

reduced by porosity in the casting and progressive graphitic corrosion in service. The effective wall thickness in this region was 6mm compared with an original nominal thickness of 10.9mm. It is considered however that the pipe was in relatively good condition for its age and would have withstood the internal gas pressure.

38 The appearance of the fracture and the proposed origin of failure are consistent with the pipe having been subjected to cantilever bending at a point close to the fracture position. There was also evidence that the length of pipe immediately south of the fracture had been poorly supported.

39 Examination of the 1982 fracture indicated that the origin was probably at the threaded hole. Stressing of the pipe in this area could have been caused by a downward bending moment at the pipe (ie loading) or possibly by the overtightening of an insert in the threaded hole, or by a combination of both. Generally there was less graphitic corrosion at the site of the 1987 fracture (Figure 16) than at the 1985 one (Figure 17).

Condition of service road to Newnham House

40 The road is about 2.5m wide and laid originally in concrete panels of various lengths. The roadway concrete varies in thickness between 100mm and 155mm and contains a central layer of 150 x 150mm (6 x 6in) welded steel mesh. Where excavation had been made across the road, this layer of welded mesh



Fig 16 South face of 1982 fracture

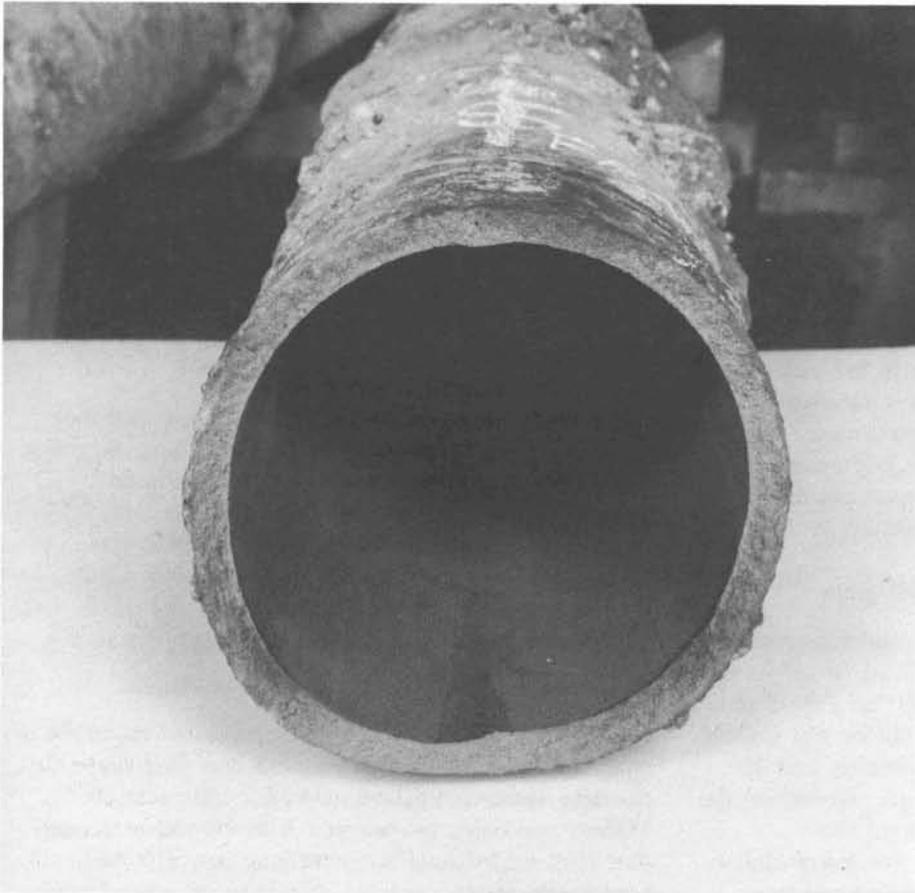


Fig 17 South face of 1985 fracture

was removed and had not been replaced when the road surface was reinstated. There were cracks extending the width of the road and these, together with earlier repairs, has formed the concrete into small panels with discontinuous reinforcement. Kerbs of 80mm to 130mm high bound the road surface, although a kerbstone just south of the gas main fracture had been removed to let water drain from the road towards the Bowling Green.

41 Figure 11 shows levels of the roadway and indicates a local settlement of the surface of up to 180mm immediately south of the fracture. This dip was outside the kitchen window to Flat 7 and evidence from residents and porters indicated it had been there about two years. It frequently filled with water after heavy rain and one resident had complained to the estate office some 12 months previously because of the difficulties he had when taking his dog for its morning walk. Tests established that there were no substantial leaks in the outlet drainage to Newnham House, but there were indications that the gullies had been blocked and had been overflowing causing local flooding.

Causes of settlement

42 Prior to 1930 there had been a large house on the site. Excavations revealed substantial foundations and indications of cellars and other underground structures remaining from the building. The road to the north of the fracture was positively supported by old brickwork and foundations, which effectively prevented any road settlement in that immediate area.

43 To the south of the fracture the soil formation gave very poor support to the road. Adverse conditions included:

- (a) a poorly graded matrix of soft clay, pebbles and stones which was probably backfilled soil from Newnham House footing excavations;
- (b) a wet soil formation with no natural or installed drainage;
- (c) the containment of water in the area by the transverse brick walls;
- (d) the flooding of the area;
- (e) cracking and reinstatement repairs to the concrete resulting in increased ground bearing pressures being imposed by traffic, whose present day axle loads would not have been anticipated in the early 1930s when the road was built;
- (f) the ageing of the roadway, 50 years being a good life for a concrete road, especially when poorly laid.

44 These conditions have resulted in road settlement developing from nothing immediately north of the gas main fracture to between 100 and 200mm some 3 to 5m to the south.

Route of gas into Newnham House

45 The SF₆ test showed the likely route the gas may have taken. Soil settlement beneath the drains left a

clear passage some 75mm deep and 300mm or more wide for the gas to pass through from the main fracture to the outside of the building.

46 The foundations to the west wall of Newnham House had been constructed over the footings and cellar walls of the original building, leaving transverse gaps between the new and old wall. Poorly mortared joints in the same area may have allowed passage from the outside to the inside. Excavations on the inside through the oversite concrete revealed loose brick, rubble and gravel on the inside of the wall and gaps between the oversite concrete and wall allowing easy passage for the gas.

47 It is likely therefore that the gas travelled under the road beneath the Newnham House outlet drains, through the gap between the original building footings and the overlaying new walls or alternatively through the poorly mortared joints in the same area, then up the inside of the wall through loose hardcore and through the gap at the edge of the oversite concrete and into the underfloor void.

48 From this point the gas could have followed many routes into the central ducts, and into the flats through gaps around the skirting boards, between floorboards and through carpets. Surviving occupants smelt gas strongly in the front stairway to Flats 7 to 12 immediately before the explosion but, apart from Flat 12, not inside the flats. It is not known whether gas was smelt in the ground floor flats (see Figure 5).

49 It is considered that the gas main fracture was of recent origin. The dry backfill near the break indicated that gas was leaking at least for several hours before the incident but it is unlikely to have been for much longer. If gas had been leaking for, say, a whole day, either the explosion would have occurred earlier, because there would have been many sources of ignition in the building, or the presence of such quantities of gas would have been noticed and preventative action taken.

Weather

50 The relevant meteorological records have been obtained and are detailed in Appendix 5. They show that for the previous four days at Kew, the nearest weather station, the surface temperature varied between -7°C and -15°C and at 10cm depth the soil temperature varied between 0.5°C and -0.2°C. If similar conditions had occurred near Newnham House these could have affected the route of the gas as the ground surface of the Bowling Green, which in warmer weather could have provided an alternative route, was sealed by frost so that the gas took the path of least resistance which lead into Newnham House.

51 Soil temperature at 1m depth (approx that of the pipe) showed a drop from 7.1°C to 5.5°C over the first ten days in January. Even a small temperature change of this sort would increase stress in an already stressed pipe, and might therefore contribute to the failure even if only marginally.

52 Segas have repair gangs on standby for emergency work when temperatures are forecast to drop quickly, but they have no way of predicting where failures will occur.

Site of explosion

53 It is a common practice in the investigation of major explosions to plot regions of common damage. The damage profile (Figure 18) shows the major structural damage to Newnham House as centering on the middle of the building with little favour to the back or front. The extent of the off site damage indicates that the explosion had involved a large volume of a flammable gas-air mixture.

54 Close study of the remaining structure and debris points to the area of the explosion as centering around the ground floor Flat 7. The underfloor void to Flat 7 is bounded by the load bearing walls to Flats 2 and 8, restricting the flow of gas out of Flat 7 at this level. However the underfloor duct would permit cross flow of air between the back and front of the buildings. This arrangement would encourage a build up of gas throughout Flat 7. Normal ventilation and the underfloor duct would account for the escape of gas from Flat 7 into the hallway where it was smelled strongly.

55 Pressure damage from the explosion was more evident in the adjacent ground floor flats than at first and second floor level with the greater venting of the explosion taking place in the direction of Flat 8. For example, the partition wall between the kitchen and bathroom in Flat 8 had been blown into the bathroom and that between the dining room and the front bedroom had collapsed into the front bedroom. In Flats 10 and 12 similar damage was limited to cracking of internal walls. There was little evidence of scorching or after-burning of materials of the building construction. Flame, in propagating through a flammable gas-air mixture, usually has sufficient heat to scorch paintwork and soften or melt plastic etc particularly at edges. Charring of wood for example would be a sign of prolonged burning which might have resulted from the burning of residual gas. The only evidence of scorching which could be definitely attributed to identifiable parts of the building, as distinct from timber and plastic items found in the general debris, was noted on the wooden door frame to the back door of Flat 7 and the woodwork to the lift area between Flats 7 and 8. After-burning was limited to a mattress and a section of skirting board believed to have come from Flat 2.

56 It is only possible to guess the size and extent of the flammable gas atmosphere within Newnham House. Because natural gas is considerably lighter than air its presence should be easily detectable by smell quite widely within the building. However, for a gas air mixture to burn, a concentration between certain specific limits is needed and it is unlikely that these concentrations existed throughout the whole building.

The explosion damage within the building, the nature of the building collapse, the extent of window damage around Newnham House and the physical conditions needed in diluting natural gas to a flammable gas-air mixture strongly indicate that the explosion was centred on Flat 7.

57 Ignition of such a flammable gas air mixture at any point in the flat would lead to the explosion travelling from room to room with most of the pressure being vented through the weaker elements (windows) of the flats. An explosion occurring in this way would be capable of deflecting the external walls outwards and damaging the internal walls to such an extent that the reinforced concrete floors and upper structure would collapse to the ground.

LPG cabinet heater

58 A liquefied petroleum gas (LPG) fired heater removed from the debris at Newnham House was eliminated by RLSD as a possible source of fuel for the explosion. Their investigation showed that the LPG cylinder was intact and not leaking and that the flame failure device was probably functioning correctly before the explosion and would have prevented unlit gas escaping through the burner.

History of gas leaks on the estate

59 During 1982 and 1983, when the new gas service pipes and central heating systems were being installed, there were a number of reported leaks. Segas records show four escapes were caused by leaking service pipes, five by leaking joints and two by mains cracked at 'tappings'. None of these escapes was caused by a fracture in the main similar to that involved in the incident.

60 Following normal Segas procedure, in October 1983 and September 1984 leakage surveys were carried out on the site and showed no indications of leakage. A vehicle-mounted flame ionisation detector was used. It was driven over a predetermined route at up to 20 mph. In addition walking surveys were carried out in December 1983 and 1984 over parts of Manor Fields, which showed no leakage of gas. These did not, however, cover that part of the gas main to the rear of Newnham House.

61 Although there had been several escapes of gas from the main at Manor Fields, most were from joints etc rather than cracks, the circumstances leading to the escapes could be explained and the flow rates involved were sufficiently small not to have caused concern.

Condition of service roads on the estate

62 The construction of these roads is similar to that at Newnham House. They are generally in poor condition from excessive settlement and because they have been disturbed or broken for various reasons. Over the years

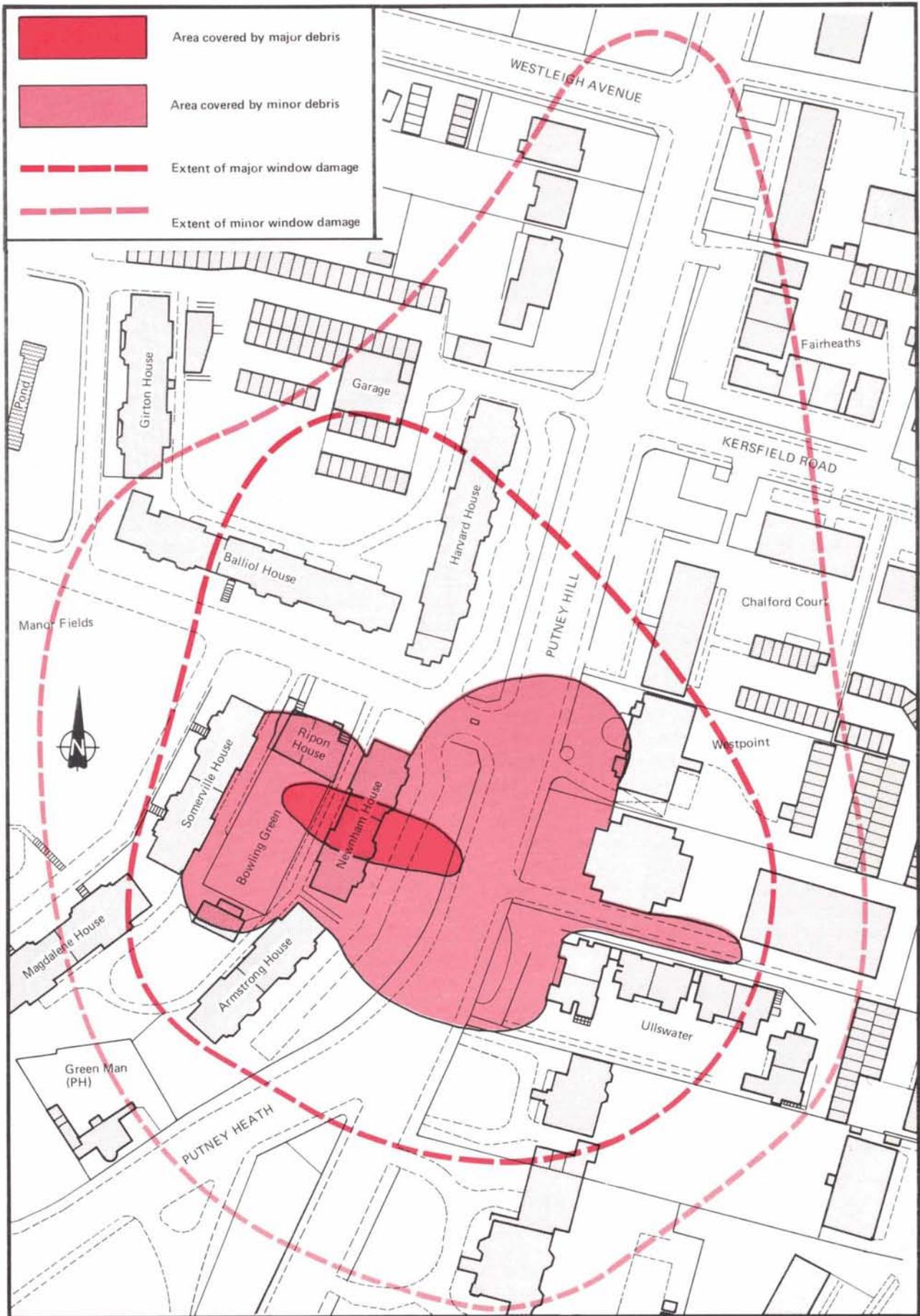


Fig 18 Extent of blast damage

different types of vehicle have used them, in particular refuse trucks and, in certain places, oil tankers. The only surface and land drainage on the estate are a few gullies in low lying large areas of the main roadways. None of the narrow service roads are drained.

Depending on the location this has resulted in very wet formations with poor load bearing capacity. This condition has been further exacerbated by the storm water and bath water gullies to the houses being blocked and 'flooding' the road area, causing further weakening of the formation.

63 The gas mains were laid about 750mm to 900mm below road level with the service connections between 450mm and 600mm deep. The mains, so far as can be seen, lie in general towards the edge of the service roads, farthest from the buildings.

64 The roads are generally at the end of their useful life, as would be expected after 50 years, and would originally have been laid to carry only the lightest traffic. In the 1930s it would not have been anticipated that vehicles of the axle loads of today would be used.

65 Even when all these road conditions are taken into account it could not be anticipated that a gas main beneath the road would fracture unless there were other major contributory factors.

Action by Segas following the King Report (1977)

66 The King Inquiry was set up in 1977 by the then Government to examine the circumstances of a range of serious gas explosions and to consider any improvements to procedural systems or any new measures which might reasonably be implemented.

67 One of the report's recommendations was that BGC should replace all higher risk priority mains by 1984 at the latest, and should step up this programme as and when resources permitted. Clause 92 of the report indicated those factors which should be considered in assessing this risk. These are:

- (a) steel mains without corrosion protection;
- (b) small diameter grey cast iron mains (particularly when operating at medium pressure or where such mains are close to premises with cellars or basements);
- (c) mains which have a history of fractures;

- (d) a high incidence of joint leakage which does not respond to gas conditioning, or where the pipe material is suspect;
- (e) mains which are in areas of local subsidence or in corrosive soils.

68 BGC reviewed their mains replacement policy so that it was in line with these recommendations, and the policy has been implemented by Segas as follows:

- (a) all 75mm diameter and below cast iron and spun iron mains in the locations causing the greatest risk to the public have been replaced except for 6km which will be dealt with by July 1985;
- (b) all medium pressure (ie 75 mbar to 2 bar) cast iron and spun iron mains up to 150m diameter in similar locations have been replaced;
- (c) all unprotected steel mains (ie not having cathodic protection) up to 175mm diameter in these locations have been replaced.

The replacement of 100mm diameter, low-pressure, cast and spun iron mains in the most hazardous locations was subsequently included in this programme. The total length of mains set for abandoning in all these categories was 225km per annum, a target that has been met.

69 The mains on the Manor Fields Estate were not included in this replacement programme as they were over 75mm diameter (150mm) and operating at low pressure (25 to 30 mbars).

70 Having completed their programme by 1984, Segas are now dealing with those mains regarded as of lesser risk. These are classified on a priority basis using a BGC system for points allocation for replacement of cast iron/spun iron mains. This incorporates the operating pressure, the risk to the public, the history of breaks in the main and the size of pipe.

Gas incidents since 1977

71 Statistics were contained in the King Report of the number of incidents involving gas mains which occurred from 1972 to 1977. These are shown in Table 1 which also shows incidents which have occurred since 1977, based on national figures supplied by BGC.

72 The table shows that the total numbers are generally lower than prior to 1977. In addition, the number of incidents resulting in fatalities is small, and has remained fairly constant from year to year.

Table 1 Gas explosions involving mains

	1972/3	1973/4	1974/5	1975/6	1976/7	1977/8	1978/9	1979/80	1980/1	1981/2	1982/3	1983/4	1984/5
Total explosions	25	23	28	23	26	26	15	12	11	9	6	10	16
Explosions resulting in severe damage	6	9	10	8	10	17	9	6	6	4	5	4	8
Explosions resulting in fatalities	0	4	3	4	3	0	2	1	1	2	1	0	3
Number of fatalities	0	5	5	5	5	0	2	1	1	3	2	0	10

Notes

1 Figures up to 1976/7 were published in the King Report.

2 The category "explosions causing severe damage" includes those incidents where the premises were partially or totally demolished.

3 The two categories of severe damage and fatal incidents are not exclusive and a single incident may be included in both.

Conclusions

73 The explosion was caused by the ignition of a flammable mixture of natural gas and air. The gas escaped from a fracture in the 150mm gas main near Newnham House, and then found its way into the building.

74 The break in the mains resulted from stresses induced by vertical loading, probably due to heavy vehicles servicing the flats on the mains below, and perhaps to the gradual deterioration or sinking of the service area beneath which the mains were situated. In ordinary conditions, factors of this kind might not give rise to the fracture of a large pipe; in the case of Manor Fields, it so happened that the main was located at the top of the concrete encasement of earthenware drains, which provided a fulcrum and resultant stress concentration in the pipe. Work by Segas subsequent to the accident on other parts of the estate has revealed that the concrete around several of the drains was laid after the gas mains; and this may also have been the case at Newnham House.

75 Localised road subsidence was another factor. Road maintenance is the responsibility of road owners, which in the case of Manor Fields would rest with the freeholder, although the costs are defrayed from the leaseholders according to the terms of their leases. There is little published advice available indicating the risks associated with road subsidence around the buried gas mains and it is not reasonable to have expected Swallow Securities or their agents to have been aware of the significance of this factor.

76 The condition of the road behind Newnham House had deteriorated over the two years before the incident. Using their current monitoring procedures for detecting leaks, it is not considered reasonable that Segas would have been aware of this. However, consideration should be given to the inclusion of an evaluation of the state of roads in both routine surveys and appropriate call-outs. Information obtained should be fed into the policy for the replacement of mains, and the road owner should be advised where appropriate.

77 Additional factors are probably:

- (a) Road loading. Although studies have shown that heavy vehicles have little effect on pipes properly laid under adequately constructed roads, these conditions did not exist at Manor Fields. It is thought that the traffic over a period of time coupled with settlement and changing ground conditions caused uneven loading of the pipe.
- (b) Condition of pipe. The 1982 fracture was chiefly the result of the pipe being weakened by a tapped hole. There would therefore have been no reason for Segas to investigate this matter in more detail, as that failure would not have indicated to them that there were either patent defects in the pipe or that there were adverse conditions surrounding it. The

metallurgical tests revealed that the thickness of the pipe at the 1985 fracture was at the lower limit of specification and the pipe was further weakened by porosity in the casting and progressive graphitic corrosion in service. It is not possible to trace where, if anywhere, similar pipes are installed but it is not unreasonable to assume that such pipes are laid throughout Manor Fields.

- (c) Weather. The change in temperatures could have contributed to the failure of the pipe and the frosting of the ground near Newnham House could have increased the likelihood of the preferred route for the escaping gas to be into the building. The contingency plans set up by Segas for dealing with the effects of low temperatures are considered adequate.

78 The gas is thought to have entered the building through cracks in the foundations. The underfloor construction of the building allowed the dispersal of gas within the building as did the underground central service duct. There are no practicable measures which could have been taken to prevent escaping gas entering and being dispersed through this building.

79 The question arises whether similar conditions may exist in other urban areas, giving rise to the risk of similar accidents. Clearly the possibility cannot be ruled out. The layout of Newnham House is by no means untypical of that of many urban blocks of flats; and the increasing size and weight of service vehicles of all kinds and the decay of service areas, with the ageing of major blocks built in the earlier part of the century, render it in fact quite likely that similar conditions are to be found elsewhere than in Putney.

80 Given the lack of published advice available to the construction industry about the precautions necessary when installing services near to gas mains, it is possible that the co-existence of these with mains could be a factor in similar conditions elsewhere; but drains and other services are not the only subterranean "hard spots" which could give rise to the same difficulty where vertical pressure is applied to a pipe laid across them.

81 Excavation is currently the only reliable method of validating the bed of pipes to establish their vulnerability. It is not reasonably practicable to excavate as part of routine maintenance programmes; and Segas are neither to be blamed for assuming, in the absence of evidence to the contrary, that the pipe at Manor Fields was in an acceptable condition, nor could they, as part of their ordinary maintenance, be expected to uncover other such situations if they exist.

82 The King Report recommended that the higher-risk priority cast iron gas mains should be replaced at an accelerated rate. The cast iron mains most at risk were identified as those of less than 75mm diameter and operating at medium pressure, ie 75 mbar to 2 bar. The mains at Manor Fields Estate did not merit replacement under these criteria.

83 The programme of replacement of cast iron pipes already undertaken since the King recommendations, and to be undertaken under current plans over the next five years, will reduce the overall risk, through the abandonment of 13 000 km of grey cast iron mains. The mains at Manor Fields Estate however, being of 150mm diameter, fall outside the current replacement programme and would not, in the ordinary course of events, have been replaced for about 20 years, assuming continuation of the present BGC programme beyond the next five years.

84 The number of gas mains explosions resulting in fatalities is currently small. Nevertheless, in the light of the possibilities revealed at Putney, it would seem right for BGC to review their current priorities for replacement; in particular, to identify on a national basis cases where mains pipes near to substantial inhabited blocks (or traffic arteries) could in principle be subject to heavy and increasing stresses, to consider what weighting should be given to these factors, and to develop programmes for mains replacement in such conditions.

85 BGC consider that they have successfully achieved the objectives set by the King Report for abandonment, and replacement of higher risk mains and associated services by 1984, at a cost of about £1.2bn. Out of this total, £700m was spent on mains replacement and about £500m on associated services. BGC have a 5 year rolling programme for dealing with replacement and abandonment of mains regarded as of lesser risk, and plan to spend £800m on replacement of mains including associated services between 1984 and 1989. The programme is expected to roll forward at least until the end of the century on the basis of priorities selected by BGC, as described at para 70. Thus the programme for the current 5 years, though very extensive, represents some slowing down in real expenditure terms as compared with the earlier effort on mains identified by BGS as having the highest priority. BGC justify this on the basis that a gradually reducing programme is risk efficient; ie corresponds to the decreasing likelihood of incidents as the programme increasingly covers the higher risk areas.

Recommendations

General

86 As demonstrated elsewhere in the report, the Putney explosion affected mains which would not have been replaced under existing programmes for some 20 years, in a situation which can by no means be regarded as unlikely to occur elsewhere. We take the view that this calls for a re-examination by BGC of their priorities in the light of our findings, and for a long-term commitment binding on BGC's successors, to

an adequate level of expenditure. In our view the starting point for a consideration of what is adequate should be the levels of real expenditure maintained up to the present time, and any real reduction needs to be publicly justified. We so recommend.

87 With regard to the need for steps to be taken to safeguard the integrity of mains, BGC should

- (a) investigate on a national basis the possible incidence of cases in urban areas where factors such as loading through differential settlement and by vehicles may apply; and in the light of that submit to HSE their intentions for re-ordering of current priorities or for further expenditure.
- (b) review the need for further studies on the movement of gas through soil or into buildings and consider what detection measures may be practicable.
- (c) review their above ground techniques for detecting problems with pipes and pipe beds and make recommendations where appropriate to improve the procedure.
- (d) in consultation with the Government Departments responsible and Local Authorities
 - (i) review the standards available for the reinstatement of concrete roads following excavations for services etc and where appropriate make recommendations to ensure their continued serviceability.
 - (ii) consider the adequacy of guidance and publicity associated with poorly maintained roads under which gas mains are buried, and where appropriate take action to improve this.
- (e) in consultation with the other public utilities consider the adequacy of guidance on work in the vicinity of gas mains by these bodies.

88 The HSE should draw up guidance to the construction industry on the safeguards required when working near cast iron gas mains. (This work has commenced).

Specific

89 We recommend that Segas replaces all gas mains on the Manor Fields Estate. (This work is now in hand.)

90 We recommend that in view of the contribution made by road subsidence in the service road at Newnham House, exacerbated by the use of refuse collection vehicles etc, Swallow Securities take steps to ensure that this road and others on the estate where similar conditions occur should be reconstructed to an adequate load-bearing standard.

Appendix 1 Report on examination of gas appliances from explosion at Newnham House, Putney

Seven gas appliances recovered from Newnham House following the explosion have been examined with the conclusions set out below. The appliances are:

- 1 several fragments apparently from a single cooker (possibly a NEW WORLD);
 - 2 Flavel Diana Mk 3 cooker;
 - 3 Leisure 74 Universal cooker;
 - 4 Spectrum Marketing built-in hob (model SP24/A/MB/03);
 - 5 Potterton Netaheat central heating boiler;
- 6&7 two Vailiant combined water heater/central heating boilers.

Appliance 1

A number of severely damaged cooker fragments were received which are presumed to be pieces of a single appliance because of

- (a) matching enamel colour;
- (b) similar metal castings;
- (c) matching fragments of governor casting;
- (d) identical gas control valves for oven and hob.

The gas supply tube for this appliance was of a flexible rubber sheathed type and had been severed close to the cooker. All valves required to be pushed inwards before being able to turn and were in the off position. There was, however, a fairly large gas leak (between 0.8 and 9 litres per minute of air at 30mm water gauge) from the spindle of one hob valve, presumably as a result of a damaged seal. In view of the damage evident elsewhere, the leak might well be a result of damage sustained during or after the explosion. No grill assembly belonging to this appliance was present.

Appliance 2

This appliance was relatively lightly damaged, and still connected to an intact flexible supply tube with bayonet connector. All valves were in the 'off' position, and there was no significant leakage of gas.

Appliance 3

Although substantially intact, this appliance was more distorted than appliance 2, and the internal plumbing leaked slightly in a number of places. The total leakage of air at 30mm water gauge was about 100ml per minute. One hob valve was apparently turned slightly from the 'off' position but there was hardly any flow from the corresponding jet. The flexible supply tube was severed about 40cm from the cooker and had been twisted to break the reinforced metal spirals within.

Appliance 4

All the valves on this appliance were in the 'off' position, and there was no significant leakage internally. Being 'built-in', the appliance had been connected directly to a copper feed pipe with a compression union which had been strained and was no longer gas-tight. The tube was severed about 70cm from the appliance.

Appliance 5

The gas pipework for this appliance was fragmentary, and could not be tested. The regulator and solenoid valve assembly was however intact, with both pilot and main valves in the 'off' (ie inactivated position). The two control valves were arranged in series so that both would have to be open for gas to reach the burner. A flame failure device consisting of a flame sensor and switch was fitted to the pilot jet and was in working order. This device could not be tested further however, as the electrical connections to the valve had been severed and the logic circuitry was damaged and incomplete.

Appliances 6 and 7

The internal gas connections were apparently intact and gas-tight. A more detailed examination of the many sensors and switches was not carried out.

Appendix 2 Penetrometer readings

Depth Inches	Location south of service riser			Joint North of Collar			Joint immediately south of collar					2nd Joint South of collar				Fracture		
	Under Main	Adj to Main	*															
Cone	0.75	0.75	0.00	0.75	1.0	0.75	1.20	0.5	0.5	0.0	0.0	0.5	0.25	1.0	2.0	0.0	0.0	0.0
3	1.25	0.75	1.50	3.00	2.7	2.00	0.90	1.2	3.0	2.7	1.3	3.0	stone	5.5	4.5	0.5	0.5	0.8
6	5.75	1.25	stone	0.00	1.5	1.00	1.00	1.5	1.5	9.5	2.2	2.0		stone	2.0	stone	1.8	1.3
9	6.75	1.25		stone	2.7	2.00	1.20	1.7	1.0	stone	5.5	3.5			3.0		3.1	1.3
12	7.25	1.25		4.50	9.0	11.04	4.00	stone	stone	stone		stone			3.0		1.8	1.3
15	stone	1;25		4.50	stone	stone	7.50								stone		1.8	1.3
18		1.25		4.50			3.50										1.8	3.3
21		3.5		4.50			12.00										1.8	2.8
24		stone		4.50			10.50										1.8	2.8

* Half way to service isolation valve

Readings taken from area of soil exposed by removed section of pipe

Location Depth inches	1.2	2.0	2.29	3.0	4.0	6.0	7.0	8.0	11.0	12.0
Cone	0.05	1.45	0.15	0.5	0.05	0.05	0.05	1.45	0.05	0.05
3	0.50	1.15	—	3.25	1.25	0.75	2.75	2.75	1.15	1.75
6	1.00	stone	1.75	2.25	1.75	1.15	2.40	stone	1.75	2.75
9	1.00	1.75	stone	—	stone	1.45	2.75		stone	3.75
12	1.15	1.45		2.75		—	—			stone
15	1.25	stone		1.75		5.75	4.25			
18	1.50			1.75		5.75	3.25			
21	1.50			1.75		5.75	3.25			
24	4.75			1.25		5.75	3.25			

Appendix 3 Metallurgical report

On 17 January 1985 five lengths of pipe and the two halves of a split collar were removed from the site and sent to HSE's laboratories in Sheffield. The collected items are listed below.

(1) A 1.85m length of pipe of 150mm (6") nominal internal diameter, marked 'COLLAR' with a painted arrow pointing south at the position marked 'TDC' (top dead centre). These markings and those on item (2) were present before the pipe was removed from the trench. This pipe had a fracture at the end nearer the markings and the other end had been cut.

(2) A 1.46m length of pipe of 150mm nominal internal diameter, marked 'COLLAR' with an arrow pointing north at the position marked 'TDC'. There was a fracture at the marked end and the other end had been cut.

(3) A split collar, with four nuts and bolts, capable of enclosing a pipe with a diameter approximately 150mm.

(4) A 2.21m length of pipe of 150mm nominal internal diameter, marked 'FRAC' (fracture) with an arrow pointing south at the position marked 'TDC'. There was a fracture at the marked end and the other end had been cut.

(5) A 1.52m length of pipe of 150mm nominal internal diameter, marked 'FRAC' with an arrow pointed north at the position marked 'TDC'. There was a fracture at the marked end and the other end had been cut. This length of pipe contained a joint at approximately 1.2m from the marked end.

(6) A 0.39m length of pipe of 150mm nominal internal diameter, with painted dashes that indicated where 'TDC' had been when the pipe was in the trench. This pipe contained a joint and both ends had been cut. In service this length of pipe lay between items (2) and (4).

The pipes were laid in 1933 and had probably therefore been manufactured in accordance with the then current BS78:1917 *Cast Iron Pipes and Special Castings for Water, Gas and Sewage*. This specification was therefore used as a basis for dimensional measurements and mechanical property determination.

The external surfaces of items (1) and (2) were covered largely with adherent soil except over a length of 9cm either side of the fracture. It was apparent that a collar, such as item 3, had been fitted over this fracture, presumably as a method of repair.

The fracture faces on items (1) and (2) matched, indicating that they had been originally part of the same separately cast pipe. At this fracture location there had evidently been a 44mm diameter, threaded hole at top dead centre. Approximately 75% of the fracture area was corroded and the remainder, located between 110° and 190° clockwise from TDC on the southern face of the fracture, had a bright appearance. Despite the corrosion

it was apparent that the probable brittle fracture of this length of pipe had been initiated at the threaded hole some time ago and the original fracture had propagated around 75% of the circumference. The remainder of the fracture was of very recent origin and occurred when the pipe was removed from the ground. Metallographic examination indicated that items (1) and (2) were made from pearlitic grey cast iron which had been statically cast. The thickness, although variable around the circumference, was within the specified limit. Chemical analysis of a sample from item (1) was carried out at HSE's Cricklewood laboratories, and the results are given in Appendix 4. The results were typical of this type of material.

Radiography of the pipe around and including the fractures on items (1) and (2) showed that some graphitic corrosion, in the form of discrete 'plugs', had occurred on the external surface of the pipe. This was confirmed by examination of longitudinal microsections through the fracture face on item (1) at several positions around the circumference. These microsections showed that the typical depth of corrosion was 1mm with a maximum local depth of 2mm. In addition slight intermittent graphitic corrosion was observed on the fracture face itself. The latter had occurred after fracture and it indicates that the fracture had occurred some time previously, probably measurable in years rather than months. The extent of surface corrosion is unlikely to have influenced the initiation of the fracture at the threaded hole. Stressing of the pipe in this area could have been caused by a downward bending moment on the pipe or possibly by the overtightening of an insert in the threaded hole, or by a combination of both.

The undersides of items (4) and (5) were free from adherent soil throughout distances of 1.21m north and 1.60m south of the fracture. Within this region there was a longitudinal array of small, discrete protrusions, accompanied by circumferential rust stains around the lower half of the pipe. These stains and protrusions were probably formed by the corrosive action of water which had flowed around the pipe and had collected at the lowest point leaving a deposit. This indicates that the soil had not been fully compacted around the underside of the pipe and that the pipe had not been fully supported underneath in these areas. In addition several small areas of off-white material were observed adhering to the underside of item (5) at a distance of 10-40cm north of the fracture. The location of these deposits corresponded with an area of concrete across the base of the trench underneath the pipe.

The fracture faces on items (4) and (5) also matched, indicating that item (4) and the portion of item (5) extending from the fracture northwards to the joint had been originally part of the same separately cast pipe. This fracture was entirely brittle and of recent origin.

However, a region of the fracture, extending from 150° to 230° clockwise on the southern face, was noticeably cleaner and brighter than the rest. This part of the fracture had been generated some time after the rest of the fracture had occurred eg during pipe removal. The origin of the older portion of this fracture appeared to be on the outer surface of the pipe between 0° and 30° clockwise from TDC when viewed on the southern face of the fracture. The original thickness of this pipe varied around the circumference at the fracture, and at 0° to 30° position it was on the lower limit of the specification. There was also some visible casting porosity in this region and evidence, from radiographs and microsections, of graphitic corrosion extending to a maximum depth of 4mm. The effective thickness of metal at the origin was 6mm, compared with an original nominal thickness of 10.9mm. Using simple bending theory this reduction thickness corresponded to a local reduction in maximum allowable bending moment of approximately 45%. This pipe had been made from grey pearlitic cast iron and had been statically cast. Radiography showed that graphitic corrosion was present, in the form of discrete 'plugs', throughout the length of item (4). Tensile test pieces were manufactured from the pipe wall adjacent to the southern face of the fracture and the tensile strength, measured in the longitudinal direction, was in the range 131-138 MPa. This measured strength was slightly

below specification but it was not practicable to use the specified method and the discrepancy is not therefore necessarily significant. Chemical analysis of a sample from item (4) was carried out at the Cricklewood laboratories, and the results are given in Appendix 4. The results were typical of this type of material. Observations on items (4) and (5) are consistent only with the fracture having been produced by downward bending of the pipe about a fulcrum, such as the area of concrete in the trench, close to the fracture position so that the upper surface of the pipe in this region was in tension.

Summary

Graphitic corrosion of buried cast iron pipes is a localised phenomenon which is strongly dependent on soil conditions and climate. Graphitic corrosion was present intermittently in the form of discrete 'plugs' of varying depth throughout all regions of the pipes examined. However, the extent of corrosion is neither unusual nor inconsistent with the pipes which have been buried for 50 years. Furthermore the corrosion and the metallurgical deficiencies would not, in the absence of external loading, have caused the pipes to either leak or fracture, but the load bearing capacity of the pipes, in a bending mode, would have been reduced significantly with respect to the original strength by these deficiencies.

Appendix 4 Chemical analysis of pipe samples

Drillings of metal taken from the pipes bearing the two fractures were degreased and analysed. The results of three replicate analyses are reported for each sample, together with the mean result. An error figure of ± 1 standard deviation (calculated to include the imprecision in calibration and in sample measurement) is reported, and all results are rounded to two decimal places and to three significant figures as appropriate. Note that the results for Titanium (quoted in brackets) are tentative because the analytical procedures used are not particularly reliable for this element.

Samples from pipe length south of 1982 fracture

Analyte	Results (% W/W)			Mean
	1	2	3	
Al	<0.01	<0.01	<0.01	<0.01
As	0.04	0.04	0.04	0.04 \pm 0.01
Total C	2.73	2.77	2.73	2.74 \pm 0.01
Graph. C	1.95x	2.17	2.18	2.17 \pm 0.02
Co	0.02	0.02	0.02	0.02 \pm 0.01
Cr	0.08	0.08	0.08	0.08 \pm 0.01
Cu	0.04	0.05	0.05	0.05 \pm 0.01
Fe	92.0	92.6	92.2	92.3 \pm 1.6
Mg	0.01	0.01	0.01	0.01 \pm 0.01
Mn	0.52	0.53	0.52	0.52 \pm 0.01
Mo	<0.01	<0.01	<0.01	<0.01
Ni	0.05	0.05	0.05	0.05 \pm 0.01
P	1.44	1.45	1.45	1.45 \pm 0.10
S	0.061	0.062	0.059	0.061 \pm 0.002
Si	2.70	2.69	2.60	2.69 \pm 0.10
Sn	<0.01	<0.01	<0.01	<0.01
Ti	(0.11)	(0.11)	(0.11)	(0.11)
V	0.12	0.12	0.12	0.12 \pm 0.01

Note that the graphic carbon result marked with a cross is considered to be in error, and has not been used in calculation of the mean.

Samples from pipe length south of 1985 fracture

Analyte	Results (% W/W)			Mean
	1	2	3	
Al	<0.01	<0.01	<0.01	<0.01
As	0.05	0.05	0.95	0.05 \pm 0.01
Total C	2.84	2.88	2.84	2.85 \pm 0.01
Graph. C	2.15	2.16	2.13	2.15 \pm 0.02
Co	0.02	0.02	0.02	0.02 \pm 0.01
Cr	0.08	0.08	0.08	0.08 \pm 0.01
Cu	0.07	0.07	0.06	0.07 \pm 0.01
Fe	91.4	91.6	91.1	91.4 \pm 1.5
Mg	0.01	0.01	0.01	0.01 \pm 0.01
Mn	0.49	0.48	0.48	0.48 \pm 0.01
Mo	<0.01	<0.01	<0.01	<0.01
Ni	0.05	0.05	0.05	0.05 \pm 0.01
P	1.38	1.37	1.37	1.37 \pm 1.09
S	0.086	0.087	0.089	0.087 \pm 0.003
Si	2.45	2.44	2.45	2.45 \pm 0.09
Sn	0.01	0.01	0.01	0.01 \pm 0.01
Ti	(0.09)	(0.10)	(0.10)	(0.10)
V	0.12	0.12	0.12	0.12 \pm 0.01

Appendix 5 Report supplied by Meteorological Office

Meteorological data – R B G Kew – January 1985

<i>Date</i>	<i>Maximum temperature degrees (C)</i>	<i>Minimum temperature degrees (C)</i>	<i>Grass minimum temperature degrees (C)</i>	<i>Concrete minimum temperature degrees (C)</i>	<i>Rainfall amount</i>
1	5.6	3.0	– 0.2	– 0.1	Trace
2	4.2	1.1	– 3.8	– 2.0	Nil
3	4.9	1.0	– 2.6	– 1.5	Nil
4	3.4	– 0.5	– 5.5	– 2.9	0.9
5	3.4	– 2.5	– 6.0	– 4.5	NIL
6	3.9	– 4.0	– 9.5	– 8.1	4.4
7	– 1.8	– 4.3	– 7.3	– 6.5	Nil
8	– 0.6	– 8.5	– 15.1	– 10.7	Trace
9	2.2	– 4.9	– 8.8	– 5.9	Nil
10	3.6	– 4.4	– 11.0	– 5.6	Nil
11	2.1	– 2.1	– 7.3	– 5.4	Nil
12	4.1	– 1.8	– 3.3	– 3.5	0.8

Soil temperatures degrees Celcius (°C) at 0900 GTM

<i>Date</i>	<i>Depth (10 cm)</i>	<i>Depth (20 cm)</i>	<i>Depth (30 cm)</i>	<i>Depth (100 cm)</i>
1	2.6	4.0	6.1	7.1
2	2.4	3.6	4.8	7.0
3	2.5	3.5	4.9	7.0
4	2.4	3.4	4.7	6.9
5	1.0	2.5	4.1	6.7
6	0.5	1.8	3.5	6.5
7	0.2	1.5	3.0	6.1
8	– 0.2	1.0	2.8	6.0
9	– 0.1	1.0	2.6	5.7
10	0.0	1.0	2.5	5.5
11	– 0.1	0.9	2.5	5.3
12	0.0	0.9	2.5	5.2

Notes

Air temperatures are recorded by thermometers exposed in a louvred screen 4ft above short grass and values are noted in degrees Celsius (°C).

Maximum temperature is for the 24 hour period beginning at 0900 GMT on the date of entry.

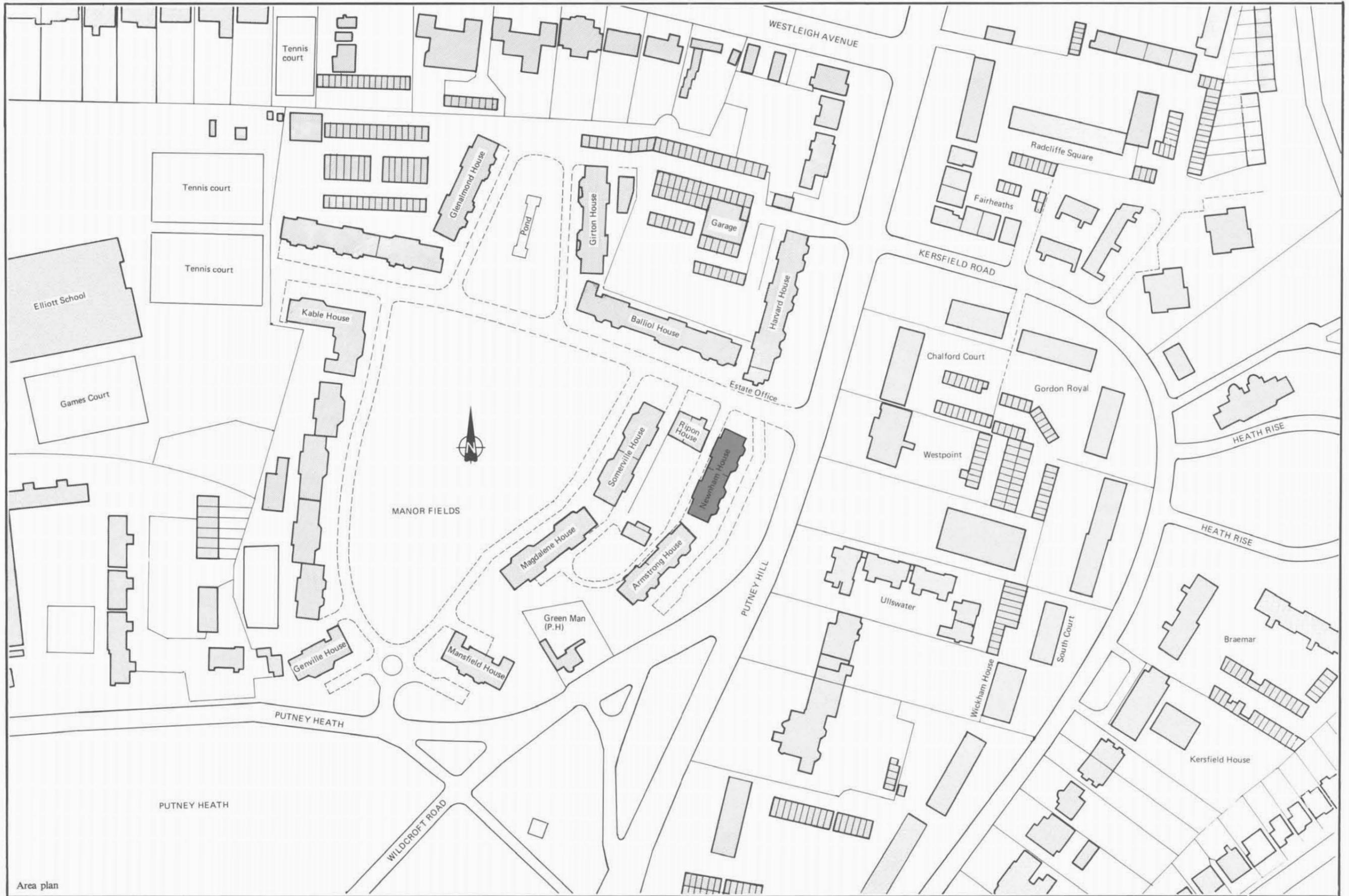
Minimum temperature is for the 24 hour period ending at 0900 Greenwich Mean Time (GMT).

Grass minimum temperature is recorded by a thermometer exposed to the air one or two inches above the ground, the bulb being in contact with the

tips of the grass blades and refers to the 24 hour period ending at 0900 GMT on the date of entry.

Concrete minimum temperature is recorded by a thermometer exposed with its bulb in the centre of, and in contact with, the surface of a concrete slab which is about 3ft by 2ft and 2in thick and is set flush with the ground and refer to the 24 hour period ending at 0900 GMT on the date of entry.

Soil temperatures are temperatures at the depth indicated and read at 0900 GMT on the date of entry.



Area plan



General views of damage

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