Fire Research Note No 1054

ESTIMATION OF MAXIMUM EXPLOSION PRESSURE FROM DAMAGE TO SURROUNDING BUILDINGS

EXPLOSION AT MERSEY HOUSE, BOOTLE - 28 AUGUST 1975

by

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SUMMARY

An explosion in the ground floor flat of a 16-storey block caused severe damage to the flat, some other parts of the 16-storey block and resulted in the failure of many windows in surrounding property.

Calculations based on the decay of pressure with distance, and the dimensions and thickness of glazing broken in nearby buildings, indicate that the peak explosion pressure within the flat was between 46 and 81 kN/m^2 (6.5 and 11.5 lbf/in^2). These pressures are substantially greater than those that would be expected from measurements made from explosions in single, empty, compartments, and are also greater than that calculated from an equation making some allowance for turbulence, and indicate that a high degree of turbulence was generated by the complexity of the compartmentation and the contents of the flat.

These findings emphasise the importance of tests to be carried out by the Fire Research Station in a complex array of compartments and corridors and the development of appropriate mathematical expressions for the relationship between vent area and explosion pressure for a given set of conditions.

Department of the Environment and Fire Offices' Committee
Joint Fire Research Organization

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INTRODUCTION

An explosion occurred in the ground floor flat of Mersey House, a 16-storey block of flats, St James Drive, Bootle, Merseyside, at approximately 0245 hours on Thursday, 28 August 1975. The explosion, which caused extensive damage to the ground floor and some of the higher levels in Mersey House and severely injured the caretaker, the occupant of the flat in which the explosion occurred, appeared to be due to the escape of gas from the domestic supply to the flat. The west face of Mersey House is illustrated in Fig 1 and the damage sustained at ground and first floor level on the west and north faces is illustrated in Figs 2 and 3.

The opportunity was taken by the Fire Research Station to examine the damage to surrounding properties with a view to assessing the maximum explosion pressures developed within the flat in Mersey House, (and hence to estimate the quantity of natural gas involved in the explosion). In this regard, the assistance given by officers of Sefton District Council and of Merseyside Fire Brigade was most valuable and is gratefully acknowledged. The content of the present note will be confined to the estimation of pressures in the flat from damage to surrounding properties. A full report including estimates of the explosion pressures within the flats from damage sustained by Mersey House is published elsewhere.

DAMAGE TO PROPERTY ADJACENT TO MERSEY HOUSE

A plan showing property in the vicinity of Mersey House is given in Fig 4.

Blocks of flats and other dwellings in the vicinity suffered damage, as well as Mersey House, resulting from the blast produced by the gas explosion. Chestnut House, an 11-storey block of flats, 60 m to the west of Mersey House, lost the glazing in half of the large windows and about 1/7th of the small windows on its eastern face. Four or five windows were broken on the north side and a few more on the western and southern sides. Salisbury House, an 11-storey block of flats, 50 m to the south-west of Mersey House (with respect to flat No 1) lost 4/5th of the large windows and 1/5th of the small windows on its eastern face, together with 2/3 of the large windows and half of the small windows on the northern side. A few windows were broken on the western side and some were noted broken on the southern face. No damage occurred to Stanley House to the north-west of Mersey House. Windows were also cracked or broken in dwellings in St James Drive to the east (up to 115 m away from Mersey House) in Bradshaw Walk (160 m north-west of Mersey House) and in Clifton Walk, up to 115 m north-west of Mersey House. The extent and distribution of blast damage indicated that the blast originated from the west face of Mersey House.

Assessment of pressures generated in explosion by calculation from known window damage to surrounding block of flats

The pressure wave or waves resulting from the gas explosion in Mersey House would have been attenuated in amplitude as they moved away and expanded. It is possible to estimate the maximum pressure generated by the explosion from the damage caused by the expanding wave. Butlin and Tonkin[2] have established that the pressure generated by a vented gas explosion (normal to the face of the compartment containing the vent) decays outside the confining structure, after a certain threshold distance, by a simple inverse linear law, ie $P \propto {}^1/d$ or in simple terms when the distance from the explosion is doubled the pressure is halved, which is in accord with the known laws of decay of blast waves at a considerable distance from a solid-state explosion[3]. Further, it has also been shown that if a fixed distance of 9 m is used as the threshold distance referred to above, then the maximum pressure generated inside a 28 m^3 compartment of wall length about 3 m is approximately three times that at 9 metres.[2] Mainstone[4] has shown how the window damage can be used to estimate pressures at a point so that the combination of the three factors can be used to give an estimate of the maximum pressure in the explosion.

As the effect of blast waves from all explosions is directional, the window damage to the east face of Chestnut House will be considered as it is in effect in a line normal to the vented explosion. The larger window panes broken were very nearly 1 m x 1 m square and of 4 mm thick glass. The minimum breaking pressure for such a window from Mainstone's nomographs is 4 kN/m^2, ie the pressure at 60 m for the explosion would have been approximately of this value. This would indicate a pressure of 27 kN/m^2 at 9 m and hence 81 kN/m^2 at the origin, if the threshold distance were not scale dependent.

The figure of 81 kN/m^2 is based on the results from a compartment of 28 m^3 value whereas the value of the flat in Mersey House was approximately 140 m^3. Scaling the results fro 28 m^3 for use with the flat with respect to a characteristic dimension, (ie the cube root of the volume), the distance at which the pressure outside the flat is equal to one third that for the maximum internal pressure could be 16 m for the flat. This gives a maximum internal pressure of 46 kN/m^2.

Estimation of pressures generated inside the flat in Mersey House

Many empirical formulae and equations are available for use in predicting the maximum pressures generated in vented gas explosions. Perhaps the most comprehensive theoretical derivation of the pressures developed is that of Yao[5] which takes into account the effects of turbulence on a vented gas explosion and is also capable of predicting the appearance of different pressure peaks with respect to time as well as amplitude. The theory has been found to agree satisfactorily with a wide range of results from experiments on gas explosion venting. The complete solution of Yao's differential equation necessitates machine computation but for this note a simplified version of the formulae will be used to predict the maximum pressure generated in the flat at Mersey House.

$$\Delta P_2 = \frac{38 \chi^{1.35}}{\alpha^2} \qquad (1)$$

where ΔP_2 is the maximum pressure (gauge), χ = turbulence factor with the limitation $2 < \chi < 4$ (for the above simplified solution) α = venting coefficient defined by

$$\alpha = \frac{C}{\sqrt{2}} \; \frac{Av}{A} \; \frac{1}{Su} \; \left(\frac{g P_o}{\rho_o}\right)^{\frac{1}{2}} \left[\frac{1}{\nu^{\frac{1}{8}}}\right]^{7/6} \qquad (2)$$

where
- C = discharge coefficient
- Av = area of vent ft^2
- A = minimum cross sectional area of wall containing the vent, ft^2
- Su = burning velocity ft/s
- P_o = initial pressure (abs, lbf/ft^2)
- ρ_o = density of unburned gas (lb/ft^3)
- ν = dimensionless density ratio, unburned: burned gas

The lounge in the ground floor flat of Mersey House was the main compartment from which explosion pressures affected buildings in the vicinity.

The venting ratio for this compartment, $Av/A = 0.28$.

Taking $\rho o = 0.71$ lb/ft^3 (for 10 per cent natural gas/air mixture)

$po = 14.7 \text{lbf/in}^2 = 2117 \text{ lbf/ft}^2$

$g = 32 \text{ ft/s}^2$

and

$$V = \frac{M_u T_b}{M_b T_u} = 8$$

where M_u = molecular weight, unburnt gas

M_b = molecular weight, burnt gas

T_u = temperature of unburnt gas ^oR

T_b = temperature of burnt gas ^oR

and $C = 0.6$.

Substitution in equation 2 gives

$$\chi = 8.95$$

and $$\Delta P_2 = 3.2\,\chi^{1.35} \text{kN/m}^2 = 0.46\,\chi^{1.35} \quad \text{lbf/in}^2 \qquad (3)$$

Using the upper limiting value, 4, of χ for which (1) has been established $\Delta P_2 = 21$ kN/m^2. This value is a factor of about 2 or 3 less than that predicted from external damage. It should be noted that a value of 4 for χ has been found to correlate with experiments with bursting vent covers under conditions where there was no initial turbulence from obstacles present. In circumstances where intial turvulence is present Yao suggests that higher values of χ should be used. It can be seen that for values of χ up to 6 or 7 much higher values of ΔP_2 would be obtained, and equation 3 gives values of ΔP_2 of 35 and 45 kN/m^2. Confirmation of this would necessitate checking the extension of the range of (1) by full computation.

The pressures predicted by Yao's formulae are obviously affected by the values of χ and $^{Av}/A$ chosen. Further information is required concerning the quantitative effects of various factors on the turbulence generated before precise values of χ can be chosen. In the case of a gas explosion with multiple vents, the value of $^{Av}/A$ will be governed by the net venting provided at any given time during an explosion. It can be seen, for example, that if the kitchen window in the flat at Mersey House was for any time the only vent then the predicted peak pressure would be considerably higher. A further point is that under turbulent conditions the value of S_u (the laminar burning velocity) used in the above equations should be modified accordingly. Yao's theory is furthermore not developed to consider the pressures resulting from circumstances where restricted venting results in damage to the confining structure, and hence increased venting.

It is clear therefore that accurate predictions of the pressures generated in turbulent gas explosions like that in Mersey House are not possible without further experimental evidence of the quantitative effects of different modes of turbulence generation together with some refinement of Yao's equation and its complete solution.

The estimates of pressure developed in the flat range from the theoretical value of 21 kN/m^2 through the scaled value of 46 kN/m^2 based on external damage to other property to 81 kN/m^2 for the unscaled value based on external damage.

Nature and route of the explosion

It is evident that the gas explosion in flat No 1 Mersey House resulted from a leak of natural gas in the kitchen of the flat. There was sufficient time before ignition for a gas/air layer to build up under the ceiling, the only indications of limitations on the depth of the layer were firstly the existence of a ventilation brick in the kitchen and secondly the fact that the occupant was presumably able to move around (ie the oxygen content of the atmosphere was sufficient to prevent distress). For the maximum pressure to be developed, the concentration of gas would need to be about 10% in air (leaving an oxygen concentration of about 19%). The source of ignition could have been a match, a pilot light or sparking electrical contacts, and ignition probably occurred in the kitchen. The gas layer would probably have extended throughout the kitchen and lounge and thence through the whole of the flat. With ignition taking place in the kitchen, the explosion would have spread from the kitchen into the lounge via the (open) door way. The kitchen window would have provided some 'back relief', if it blew out before the explosion had progressed from the kitchen. This seems unlikely. The movement of flame through the door to the lounge could have increased the speed of propagation of flame.

Estimates of the time-scale and nature of the pressure pulse

Although Yao's theory (used above to assess the pressures generated in the explosion) in principle can predict the time scale as well as the amplitude of pressure pulses, the venting of the Mersey House explosion is too complex to attempt such a solution. Estimates of time-scale, therefore can only be obtained by reference to experimental results. Recent experiments at FRS with vented natural gas/air explosion using glass windows as vents in a 28 m^3 enclosure indicate a smooth rise to a maximum pressure of 11 kN/m^2 just above the bursting pressure of the glass, 350 ms after ignition. This event is followed by a rarefaction and the other pressure peaks. The tests were made using a set of three windows of similar size to those in the lounge at Mersey House but with slightly thicker glass (5 mm instead of 4 mm) with no obstacles present which could increase turbulence. Earlier experiments in a compartment of 35 m^3 volume, using natural gas/air mixtures under conditions designed to give rise to turbulence, and low bursting pressure vent material over the whole of one face, resulted in a maximum pressure of 21 kN/m^2, with the peak pressure occurring 200 m s after ignition[6]. Other experiments in the same compartment using natural gas and very high bursting pressure vent materials (9 in brick wall)[7] showed that the time to maximum pressure increased with 'bursting strength' of vent cover. The time to attain maximum pressure, 42 kN/m^2, were approximately 500 m sec after ignition. The larger volume of the flat, approximately 1420 m^3, would tend to extend the time scale of the pressure pulses compared with the experiments referred to above.

It would appear, therefore, that in the early stages of an explosion such as that at Mersey House, a smooth rise in pressure would occur up to the bursting of the first vent at about 300 m sec (assuming no turbulence in this stage) followed possibly by rarefaction and then another series of pressure peaks until about 500 m after ignition, depending on the complexity of the explosion within the flat.

CONCLUSIONS

The maximum pressure produced by the explosion in the ground floor flat of Mersey House - estimated (a) from the pressure required to break windows in neighbouring buildings (between 46 and 81 kN/m^2) and (b) by calculation from a semi-empirical equation (21 kN/m^2), exemplified the imprecision of available methods of calculation. Greater precision would be expected from calculations using data from damaged parts of the structure of the flat itself but such evidence may not always be available. For example, the total destruction of a building in which an explosion occurred would only allow an estimate of the minimum disruptive pressure.

There is therefore a need for a refinement of relationships for the calculation of explosion pressures. This in turn requires adequate methods for assessing the contribution of turbulence to the pressure generated in an explosion.

The importance of turbulence can be seen from a comparison of the maximum explosion pressure expected from an empty single compartment (10-20 kN/m^2) and that obtaining in the reported incident for which the values 46-81 kN/m^2 are considered to embrace the actual maximum pressure.

An explosion test rig of modular design comprising communicating rooms and corridors into which obstacles and restrictions can be inserted, is being commissioned by the Fire Research Station. Explosion data obtained from experiments in this test rig will allow the contribution of turbulence to be ascertained. Mathematical expressions of the relationship between explosion controlling parameters, including turbulence, and explosion pressure can then be verified by application to the conditions of test in the explosion test rig and the resultant explosion pressures.

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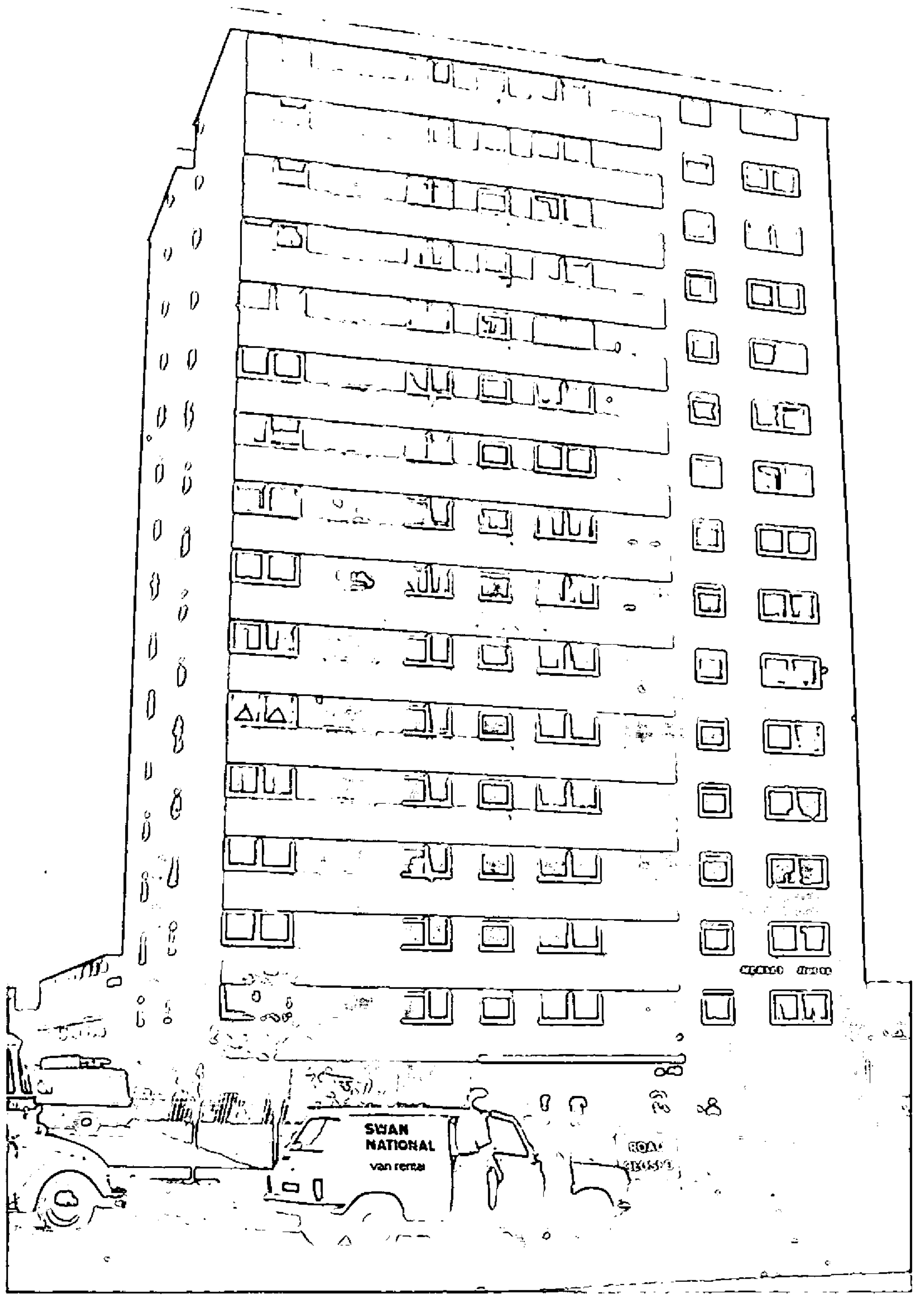

FIG.1 MERSEY HOUSE BOOTLE WEST FACE

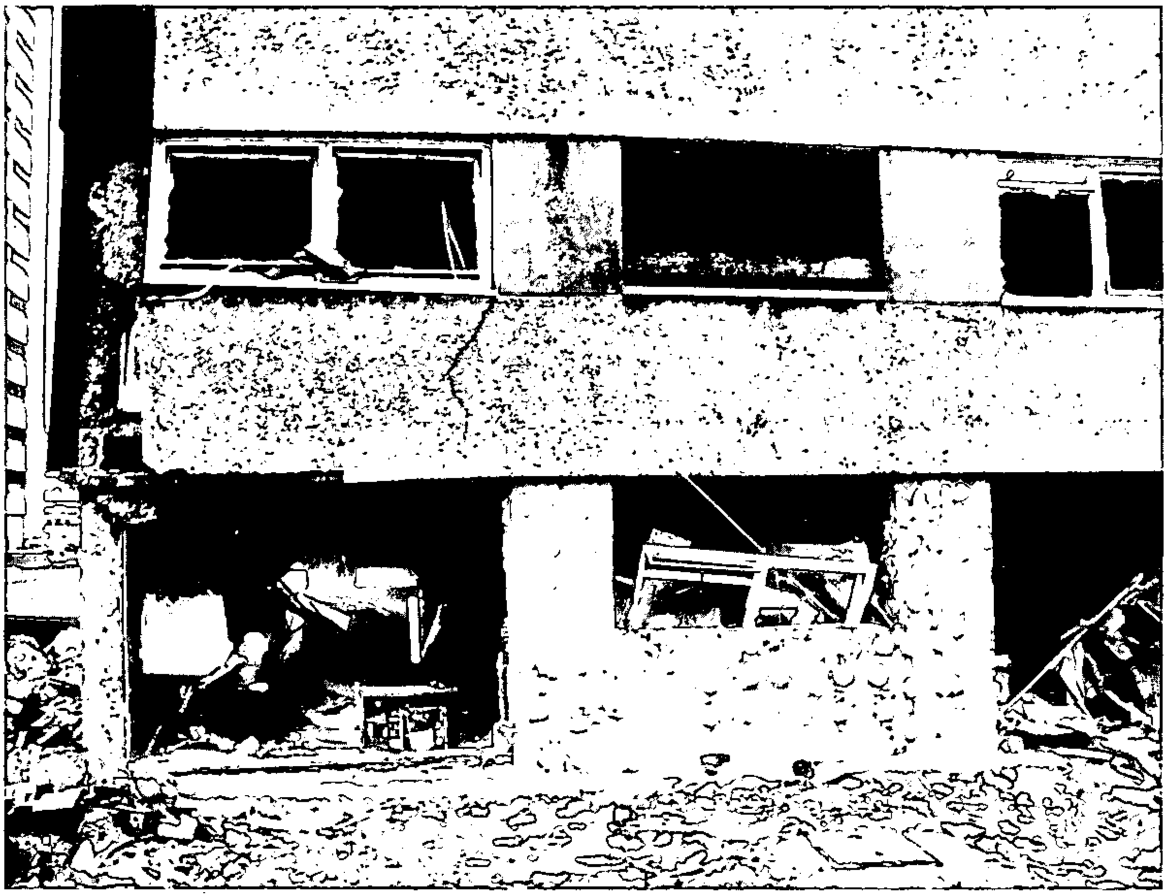

FIG.2 MERSEY HOUSE, BOOTLE GROUND AND FIRST FLOOR
NW CORNER OF WEST FACE. LOUNGE OF GROUND FLOOR FLAT

FIG.3 MERSEY HOUSE, BOOTLE N.FACE OF GROUND FLOOR

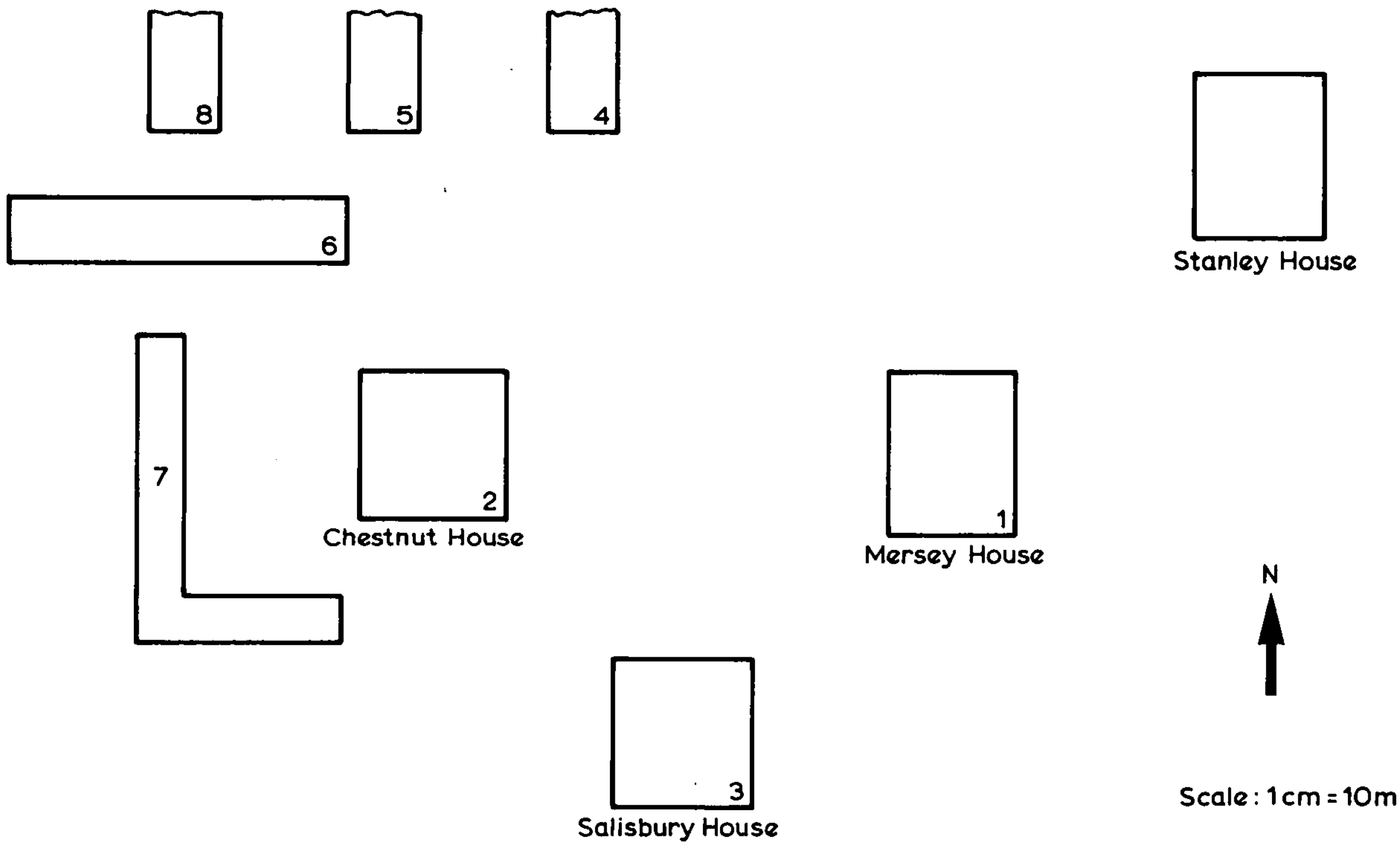

Figure 4 Mersey House and its environs – approximate plan

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