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CONTROL OF FIRES IN LARGE SPACES WITH INERT GAS AND FOAM PRODUCED BY A TURBO-JET ENGINE

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SUMMARY

Terylene ducting coated with neoprene can be used to convey hot, moist, inert gas and high expansion foam; uncoated terylene ducting can be used for diffusing gas or conveying high expansion foam. Such ducting of 30 in (0.77 m) diameter can be prevented from collapsing or whipping by the incorporation of a wire helix and by tensioning the duct by ties secured to the duct.

If the diameter of the ducting is increased to 4 ft 6 in (1.4 m), it may be made from lightweight fabric with lightweight reinforcement, because the stresses resulting from conveying a given rate of flow of gas are greatly reduced from those found with 30 in (0.77 m) ducting.

MINISTRY OF TECHNOLOGY AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

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INTRODUCTION

The development and testing of an appliance based on a turbo-jet engine for producing inert gas and high expansion foam has been described elsewhere[1]. Rigid or flexible ducting of 0.77 m (30 in) was used to convey inert gas to the compartments in which its value as an extinguishing medium was being examined[2,3,4] but because the high velocity in the duct would destroy the high expansion foam this foam was made in an apparatus attached to the end of the duct[4,5,6,7]. A prototype appliance is being designed and manufactured, and as it is desirable to make the foam at the appliance and then convey the foam through ducts to the compartment at risk, the ducts would have to be of larger diameter in order to reduce the velocity in them. The effective use of the appliance in most situations would require the use of flexible ducting.

This note describes tests on permeable and impermeable flexible ducting for conveying gas from the J.F.R.O. experimental inert gas and foam generator, which can supply inert gas at 120°C at rates of up to 1270 m^3/min (45,000 ft^3/min). The selection of ducting for conveying inert gas and foam from the prototype appliance is also discussed.

Requirements for flexible ducting

Certain properties of flexible ducting are required to ensure that it can be used effectively and will have a reasonable life under the conditions of use on the fire-ground. It was estimated that about 30.5 m (100 ft) of ducting should suffice to ensure that gas or foam could be conveyed from an appliance to the building or compartment at risk.

The properties that were considered necessary for delivering gas from the J.F.R.O. experimental appliance were:

(1) Flexibility, so that the duct could be taken round tight bends of up to 180°, such as might be met on stairways and in corridors.

(2) Ability to retain a large proportion of its cross-section under conditions of use.

(3) Resistance to hot moist gases (maximum temperature of hot spots 140°C, moisture content 45 per cent.)

(4) Ability to withstand pressures of up to 0.070 kg/m^2 (1 lbf/in^2) and possibly, in the event of a blockage, up to 0.211-0.362 kg/cm^2 (3-5 lbf/in^2). The turbo-jet engine in both the experimental and prototype appliances delivers gas at 0.211-0.362 kg/cm^2 (3-5 lbf/in^2), but for stable operation, the pressure loss should not exceed 0.070-0.141 kg/cm^2 (1-2 lbf/in^2).

(5) Arising from (4), ability to convey 1270 m^3/min (45,000 ft^3/min) of inert gas with a pressure drop not exceeding 0.070 kg/cm^2 (1 lbf/in^2).

(6) Dependent upon the purpose of the ducting, either low permeability to avoid undesired losses of gas, or sufficiently permeable to allow the gas to diffuse evenly through the fabric of the duct.

To these must be added the operational requirements:

(7) Ability to be folded or compressed into small bulk for stowage. (This would probably require the ducting to be in lengths of about 7.7 m (25 ft)).

(8) A rapid, secure and reasonably gas tight system of coupling the ducting to the appliance and coupling separate lengths of ducting.

(9) Incorporation of means of securing the duct to prevent whipping or sagging.

(10) The weight of the sections of duct to be such that one or at the most two firemen could manipulate the sections.

(11) Ability to resist scuffing on surfaces such as brick, gravel or concrete.

(12) Ability to resist deterioration due to contamination by agents such as oil, chemicals and microbiological organisms.

The prototype appliance, with its higher output of gas and foam will need ducting meeting the same requirements except that, because the appliance will use 1.4 m (4 ft 6 in) dia. ducts, the pressure drop (4) should be less than 0.007 kg/cm^2 (0.1 lbf/in^2) when conveying gas at 2000 m^3/min (70000 ft^3/min). Moreover, because of provision of additional cooling the maximum temperature that the duct need withstand is unlikely to exceed 90°C.

Suitable types of ducting

Only fabric ductings are likely to meet the requirement (1) of flexibility. Inorganic fibre fabrics, such as glass or ceramic, and certain synthetic or man-made fibre fabrics, such as nylon or terylene, would withstand the design temperature of the inert gas from the J.F.R.O. appliance, requirement (3). Fabrics from natural fibres such as wool or cotton are borderline in this respect; they would also be expected to be prone to microbiological attack, requirement (12).

The remaining requirements are design requirements, and should be met by suitable construction of the fabric and the duct. For example, requirement (4) can be met by using fabrics of adequate strength, requirement (2) by the incorporation of some form of semi-rigid reinforcement and requirement (5) by the choice of a suitable diameter for the duct.

EXPERIMENTAL

Ducting

The following types of ducting were obtained.

(a) Unsupported ducting of glass fibre fabric, coated on both sides with neoprene.

(b) Ducting as at (a) but supported inside a free spring steel wire helix by means of eyeletted fabric lugs.

(c) Ducting as at (a) but supported by a spring steel wire helix stitched into a pocket formed by the edges of the helical strip of fabric used to make the ducting.

(d) Ducting as at (a) but made of terylene fabric coated with neoprene.

(e) Ducting as at (c) but made of terylene fabric coated on the outer surface only with neoprene.

(f) Ducting as at (d) but with the wire helix pocket covered by a stitched on scuffing strip of PVC

(g) Uncoated permeable cotton fabric ducting.

(h) Uncoated permeable woollen fabric ducting.

(j) Uncoated permeable terylene fabric ducting.

The impermeable ducts, (a) to (f), were fitted with fabric eyeletted lugs for securing the duct; all ducts were finished with plain cuff ends. The ducts were 0.77 m (30 in) diameter, the same as the outlet of the J.F.R.O. appliance. The permeable ducts were 11 m (36 ft) long and the impermeable ducts 7.7 m (25 ft) long. Longer lengths were made up when needed by clamping ducts together over the ends of a short 0.77 m (30 in) diameter sheet steel cylinder.

The estimated pressure loss on straight lengths of 0.77 m (30 in) diameter ducting under slight tension with air flowing at 1270 m^3/min (45,000 ft^3/min) is approximately 15.2 cm WG per 30.5 m (6 in WG per 100 ft). A 90° bend with centre line radius of four diameters results in an equivalent loss of 18 diameters length, and a 90° bend with a centre line radius of one diameter results in an equivalent loss of 31 diameters length. A recommended safety factor for normal ventilation installation is an additional loss of 45 per cent of the calculated value. Thus for a 30.5 m (100 ft) length with the equivalent of two sharp bends of 90°, the loss of head along the duct would be 38 cm (15 in) WG or .039 kg/cm^2 (0.55 lbg/in^2). Thus, if this condition represents what would happen in practice, requirement (5) above would be satisfied.

Test assemblies

Tests were made with the ducts either coupled directly to the J.F.R.O. appliance outlet, about 1.52 m (5 ft) centre above ground, or to a sheet steel extension duct which brought the outlet to about 0.77 m (30 in) centre above ground. (Fig.1). The duct was laid on the ground from either of the above outlet positions for the tests at the National Gas Turbine Establishment and in the Models Laboratory at the Fire Research Station. The duct was taken to an opening about 4 m (12 ft) centre above ground (Fig.2) or over a 0.9 m (3 ft) wall (Fig.3) for tests in the 4-storey tower at the Fire Research Station. Tests at a disused brewery were made with the duct either taken 3.1 m (10 ft) down a basement stairway (Fig.4) or taken up a 9.2 m (30 ft) stairwell (Fig.5).

RESULTS

Properties of duct fabrics

Some tests were made of the temperature resistance, abrasion resistance and strength of the duct fabrics.

Glass fibre, nylon and terylene fabrics were not changed in appearance by heating to 100°C for one hour, but woollen and cotton fabrics were slightly darkened (yellowed). The tensile strength of neoprene coated glass fibre fabric was unchanged after 20 min at 150°C; that of PVC coated nylon was reduced to half its original value for the same treatment. Neoprene coated terylene had somewhat superior temperature resistance than PVC coated nylon, and its tensile strength reduced to one-third of its original value after 90 min at 200°C; under these conditions the PVC coated nylon became charred and brittle. The embrittlement of PVC coated fabrics was noted for all tests where the temperature exceeded 100°C. Neoprene coatings showed some darkening and hardening when heated to 150°-200°C, but remained flexible.

Scuffing was simulated by an abrasion machine in which a strip of fabric was held in tension against a serrated roller. Glass fibre fabric failed after 50 rotations of the roller, nylon after 3,900 rotations and terylene after 4,700 rotations. The fabrics used in these tests were similar to those used for the ducting.

Although there was little to choose between nylon and terylene in the above tests, terylene was chosen because of its higher melting point under wet conditions. The wet melting point of terylene has been given as 217°C, whilst that of a nylon of similar dry melting point (250°C) has been given as 172°C[7].

TESTS OF DUCTS

Tests of the performance of ducts conveying inert gas from the J.F.R.O. appliance were made as opportunities arose during tests of the extinction properties of the inert gas, and were made with the ducts available at that time. Results are therefore presented in terms of the property being examined and not in chronological order.

Stability of ducts

Exploratory tests showed that although a free duct was stable at about 140-420 m^3/min (5000-15000 ft^3/min) it would whip severely at the higher rates of gas flow from the J.F.R.O. appliance unless it was restrained in some way. Restraint by tensioning the duct with cords tied to the open end was not successful; the passage of inert gas caused the duct to flex and loosen the ties, the duct failing by splitting at the attachment to the appliance outlet. Similar failures occurred when the end of the duct was attached to a heavy wooden platform in an attempt to damp out the movements of the duct; the platform was thrown from side to side when high rates of gas flow were used. It was found that impermeable ducts could be made stable by attaching a steel mesh lateral diffuser, with a free area about the same as the area of the open end of the duct (Fig.6) or by reducing the area of the duct outlet to about 0.31 m (1 ft) diameter. The first mentioned system was preferred because it caused less distension of the duct and a much smaller loss of pressure. A cotton mesh fabric bag attached to the end of the duct (Fig.7) also gave stability to the duct at maximum gas flow. Permeable ducts were stable if the free end was closed or restricted in area to about 0.31 m (1 ft) diameter.

Experiments on the method of restraining and securing ducts along their length showed that ducts, supported inside a free wire helix by lugs fitted at intervals to the duct, readily ruptured. The passage of inert gas through the duct produced a reduction of diameter of the duct 1 m or 1.3 m (3 or 4 ft) from the attachment to the J.F.R.O. appliance from which pulses of reduced diameter passed along the duct to the open end. Ducts with a sewn in wire helix were much more stable, although there was still a tendency for the duct to reduce in cross section a short distance from the attachment to the appliance. The ducts tended to vibrate when passing the full inert gas output and this caused the fabric to be worn away where the sewn in wire helix was in contact with the ground; the ducts fitted with PVC scuffing strips were satisfactory, and the amount of wear of the scuffing strip was small.

It was found necessary to secure ducts at close intervals along their length when they were not laid in a straight line from the appliance outlet, otherwise they tended to straighten themselves. Ducts, secured by tying cords (at about 2 m (6 ft) intervals) to the lugs sewn on to the duct, were stable when taken up stairwells (Fig.5), or into high openings, (Fig.2). It was not found necessary to secure ducts along their length when they were laid over low walls or obstructions (Figs.3 and 8). (A more convolute course for the duct might require anchorages).

Provided that the ducts were secured and restrained by one or more of the above methods, it was possible to convey inert gas at rates up to 1270 m^3 (45,000 ft^3/min) through ducts of lengths up to 15.3 m (50 ft) without excessive vibration and without rupture of the duct occurring.

Behaviour of duct materials

The impermeable glass fibre fabric ducting satisfactorily resisted the temperature rise from the passage of the inert gas, but failed readily from the imposed forces. Failure occurred by the fabric pulling apart at the stitching.

The permeable and impermeable terylene ducting was satisfactory for conveying inert gas at a temperature up to 150°C, but failed by melting at gas temperatures exceeding 200°C. The permeable ducting failed by the melted fabric shrinking and forming holes; the impermeable ducting failed in the same way but could be protected from failure because darkening of the light coloured neoprene coating indicated overheating and allowed adjustments of gas temperature to be made before failure could occur.

Permeable terylene ducts, closed or restricted at the end, behaved satisfactorily when diffusing inert gas, at temperatures up to 150°C without any whipping or instability. Both the cotton and woollen permeable ducting failed rapidly when conveying inert gas at temperatures in excess of 100°C, the fabric turning yellow or brown and becoming weak and brittle. Failure occurred by the fabric splitting at these weakened areas, which developed a few feet from the attachment of the duct to the J.F.R.O. appliance. No direct experiments were made to determine the resistance of cotton and woollen fabrics to microbiological attack, but in tests in the basement of a brewery, the cotton mesh bag attached to the end of ducting failed severely after 2 days exposure in the basement (Fig.9). During this time, the mesh bag was used for making foam four times on the first day, and for passing hot inert gas three times on the second day, for a total time of 130 min. No weakening or failure of the impermeable terylene duct occurred during these tests.

Pressure loss in ducts

Some measurements of pressure loss were made during tests with the impermeable terylene ducts supported by a stitched in wire helix. These are given in Table 1. In all except one condition of use, the losses were greater than the values for carefully installed ducts given earlier in this note. A large loss of pressure was observed when excess water from the vaporiser system of the J.F.R.O. appliance collected in a bend in the duct during tests on the 4-storey tower at the Fire Research Station in which the ducting was taken over a low wall. Emergency relief from this loss was obtained by slitting the duct at the bottom of the water pool, which allowed the water to escape with very little loss of gas.

Table 1

Pressure loss of impermeable terylene ducts

Condition of use	Fig.No.	Gas flow ft³/min	Pressure loss in W.G.	Pressure loss/100 ft in W.G.	
				Experimental	Calculated
Foam making straight run 25 ft		27000	0.4-0.5 in	1.6-2.0 in	3.0 in
4-storey tower to upper window 50 ft	2	34000	4.0-10.0	8.0-20.0	5.1
4-storey tower over low wall 25 ft	3	34000	up to 12.0*	up to 48.0*	15.6
Brewery basement Down 10 ft stair	4	26000	1.4	5.6	4.5
Brewery basement Down 10 ft stair	4	38000	1.6	6.4	7.8

Note: The calculated values in the last column do not include the recommended safety factor (0.45 times listed value).

*This value may have been particularly high because a pool of water had collected in the duct.

Table 1

Pressure loss of impermeable terylene ducts

Condition of use	Fig.No.	Gas flow m^3/min	Pressure loss cm W.G.	Pressure loss/100 ft cm W.G.	
				Experimental	Calculated
Foam making straight run 25 ft		765	1.02-1.27 cm	4.1-5.1 cm	7.6 cm
4-storey tower to upper window 50 ft	2	965	10.2-25.4	20.3-50.8	13.0
4-storey tower over low wall 25 ft	3	965	up to 30.5	up to 12.2	39.6
Brewery basement Down 10 ft stair	4	740	3.5	14.2	11.4
Brewery basement Down 10 ft stair	4	965	4.1	16.3	19.7

Note: The calculated values in the last column do not include the recommended safety factor (0.45 times listed value).

It may be concluded from the results that where there is a straight duct or an occasional smooth bend, pressure drops may be predicted from theoretical figures; an extrapolation of the results indicates that a flow rate of 1270 m^3/min (45000 ft^3/min) the pressure drop would be about 25 cm W.G. (10 in) for a 31 m (100 ft) length. Where there are convolutions in the duct, however, then very much higher pressure drops might occur, particularly if water can accumulate in the trough of a convolution.

DISCUSSION

Pressure losses

The tests of ducting reported here have shown that it is possible to convey inert gas at the maximum rate of the J.F.R.O. inert gas and foam generator and at temperatures at least as high as the design temperature of 120°C, through 30 in diameter flexible fabric ducting with acceptable pressure losses. Of those tested the preferred material was a neoprene coated terylene. The weight of material used, 680 gm/m^2 (20 oz/yd^2), in the coated state, was sufficiently strong for all normal conditions tested.

The pressure losses were however high under adverse conditions, for example, where the number of convolutions were high or where water could collect in the duct and reduce its cross-section. It is therefore possible that where a long length ducting is required to be used under such conditions, the efficiency of the generator might be impaired or the maximum output might not be reached.

This situation could be avoided, and the duct little if at all increased in weight, if a somewhat larger diameter ducting were used.

Prototype generator

A prototype generator at present being constructed has been designed so that it can deliver inert gas or foam through one or two ducts 1.4 m (4 ft 6 in) diameter. Because head losses through a duct are inversely proportional to the fifth power of the diameter, the head losses with one 1.4 m (4 ft 6 in) duct would be 1/19 of the losses with an 0.77 m (2 ft 6 in) duct, and a quarter of this if two ducts were used. The velocity of the output of the experimental type generator, 1270 m^3/min (45000 ft^3/min) through one 1.4 m (4 ft 6 in) duct would be 14.4 m/s (47 ft/s) and through two such ducts 7.2 m/s (24 ft/s) compared with the velocity 46 m/s (150 ft/s) for an 0.77 m (2 ft 6 in) duct. Taking the maximum velocity for conveying foam as 4.6 m/s (15 ft/s)[5] then two 1.4 m (4 ft 6 in) ducts could convey about 850 m^3/min (30000 ft^3/min) of foam, the expected output of the prototype generator.

The lower velocity of gas in the larger diameter ducts would reduce considerably the stresses imposed on the fabric, allowing much lighter fabrics to be used than were found necessary for the 0.77 m (2 ft 6 in) ducts, and it might well arise that the limit on the minimum weight of fabric would be imposed because of the required wear resistance. The 7.7 m (25 ft) long neoprene coated terylene ducts used in the present experiments weighed 29.5 kg per 7.7 m (65 lb per 25 ft) length, about half this weight being contributed by the wire helix. If a fabric weighing 164 gm/m^2 (5 oz/yd^2) were used for the 1.4 m (4 ft 6 in) diameter ducting, without the supporting helix or reinforcement, the total weight of the 2 ducts each 30.5 m (100 ft) long would be 45 kg (100 lb). Such ducting could be rolled up and have small bulk. If any reinforcement were found necessary this could perhaps be in the form of heavy stitching or fabric webbing. With such or no reinforcement it would be a simple task to install the ducting, which would conform to the shape of small openings, such as narrow doorways, without loss of area. An additional advantage of the large diameter ducts would be that a much simpler system would be needed to join individual ducts since duct stresses are much lower; probably zip fasteners would suffice.

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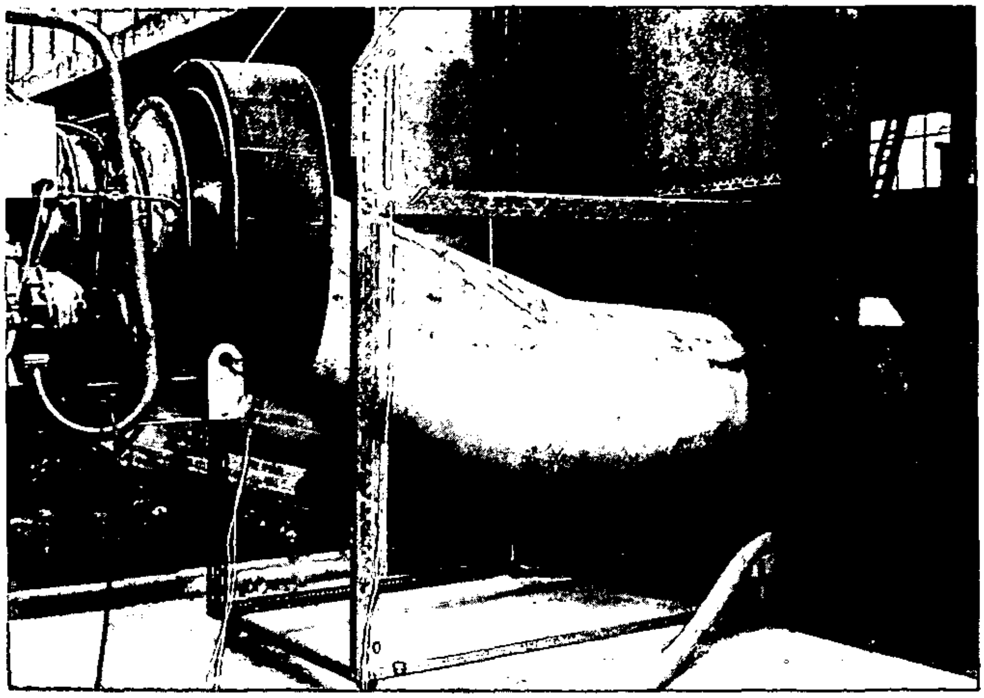

FIG.1. INERT GAS DELIVERY. RIGID STEEL EXTENSION DUCT ATTACHED TO GENERATOR

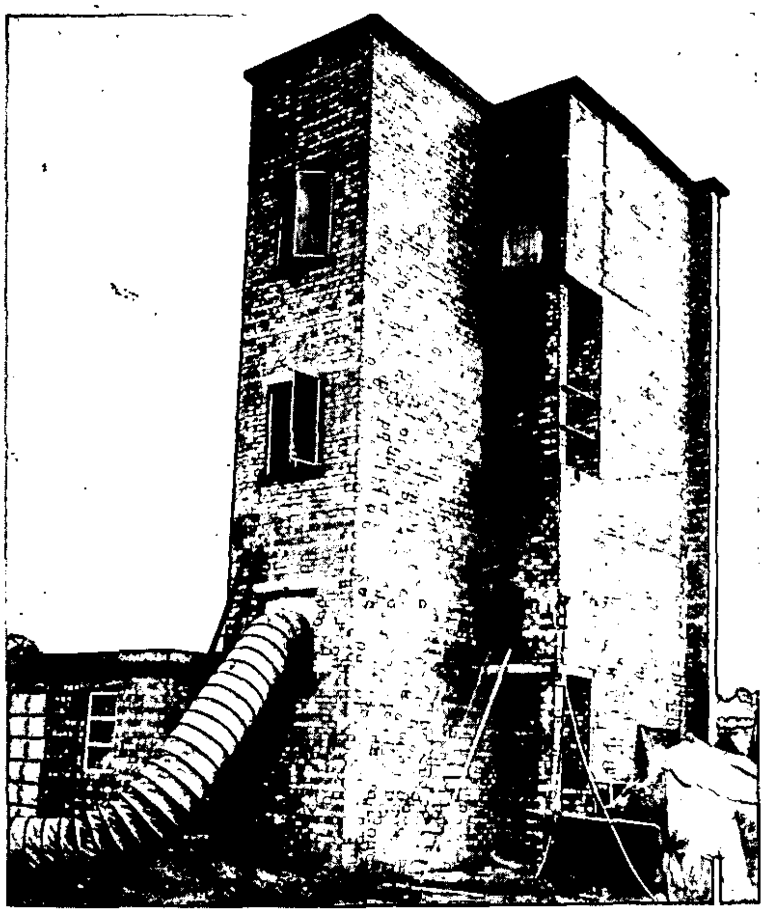

FIG.2. INERT GAS DELIVERY. FITTING OF FLEXIBLE DUCT TO 4m (12 ft) HIGH OPENING

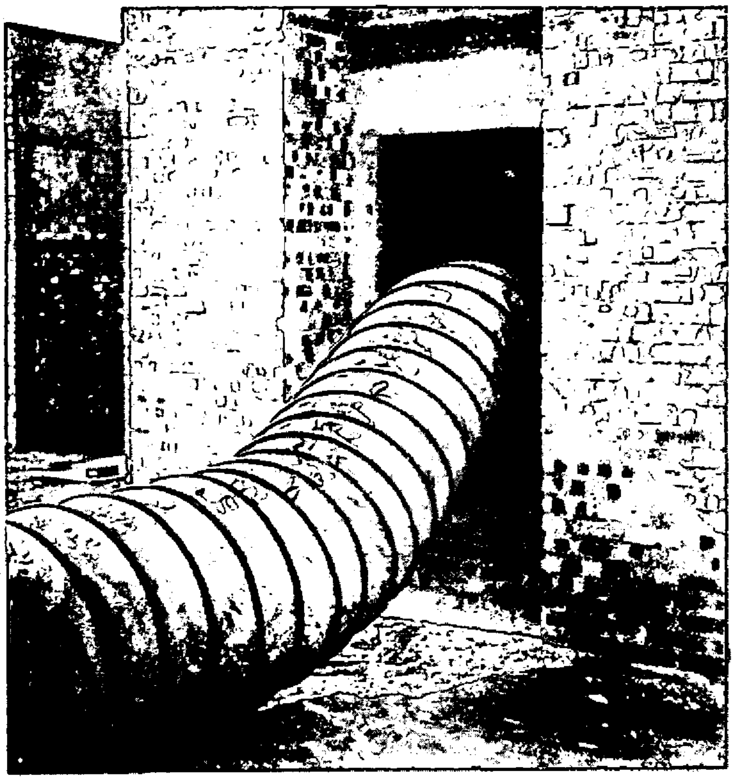

FIG.3. INTRODUCTION OF DUCT OVER 0.9 m (3ft) WALL

FIG.4. INTRODUCTION OF DUCT INTO BASEMENT 3.1 m (10ft) BELOW GROUND

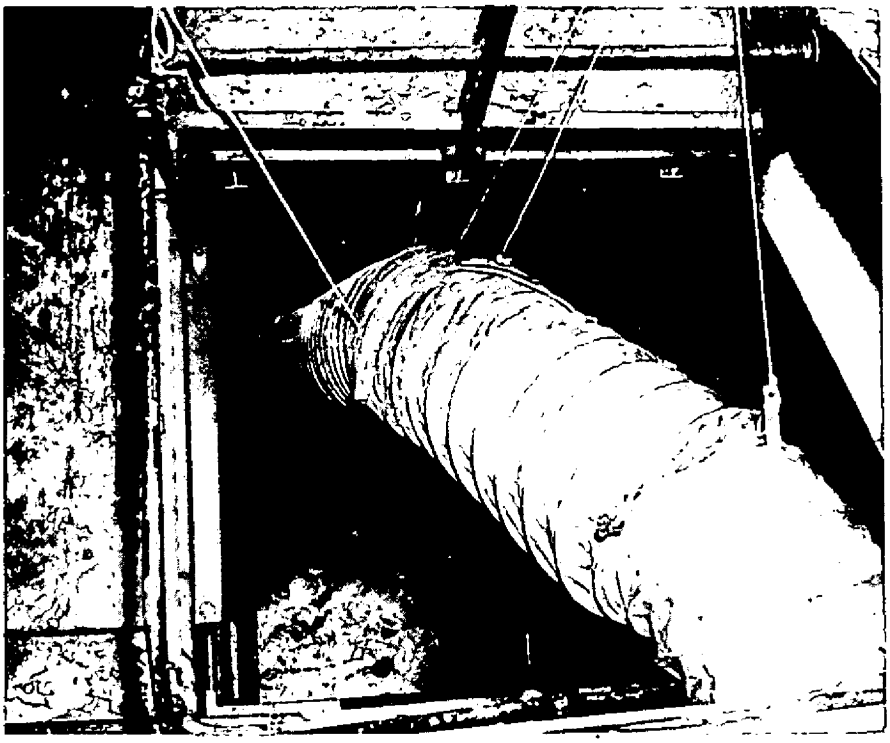

FIG.5. INTRODUCTION OF DUCT UP STAIRWAY
9.2 m (30 ft)

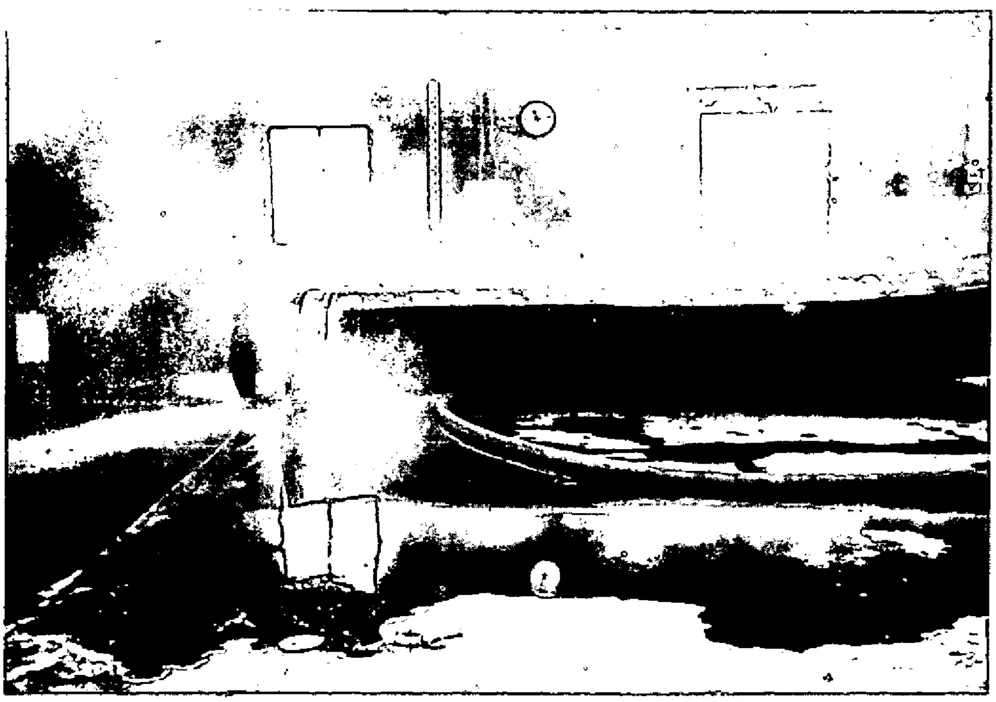

FIG.6. STABILISATION OF DUCT WITH USE
OF STEEL GAUZE DIFFUSER

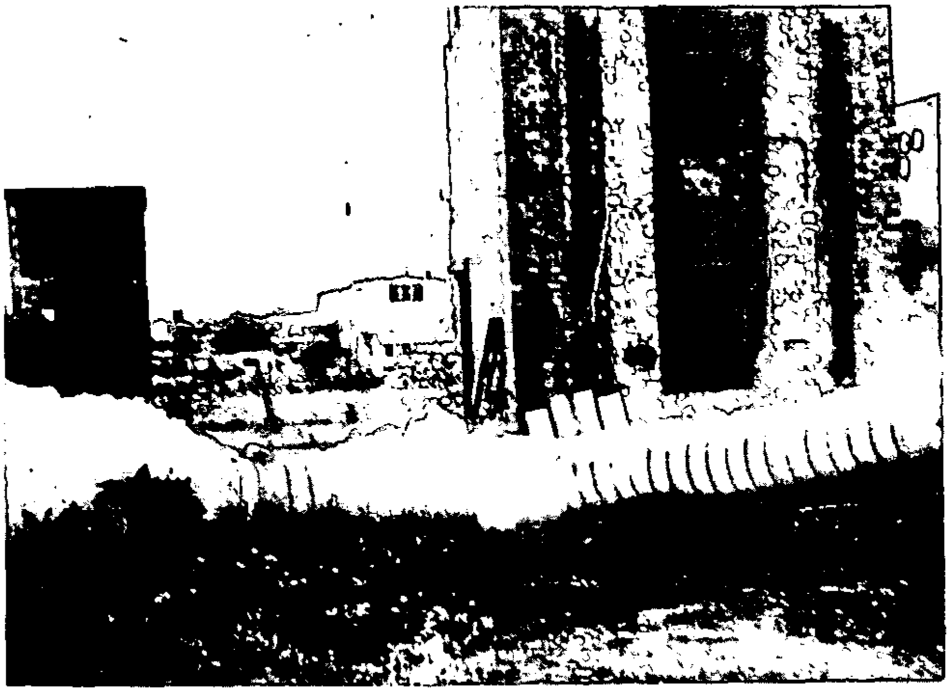

FIG. 7. STABILISATION OF DUCT WITH USE OF MESH FABRIC BAG

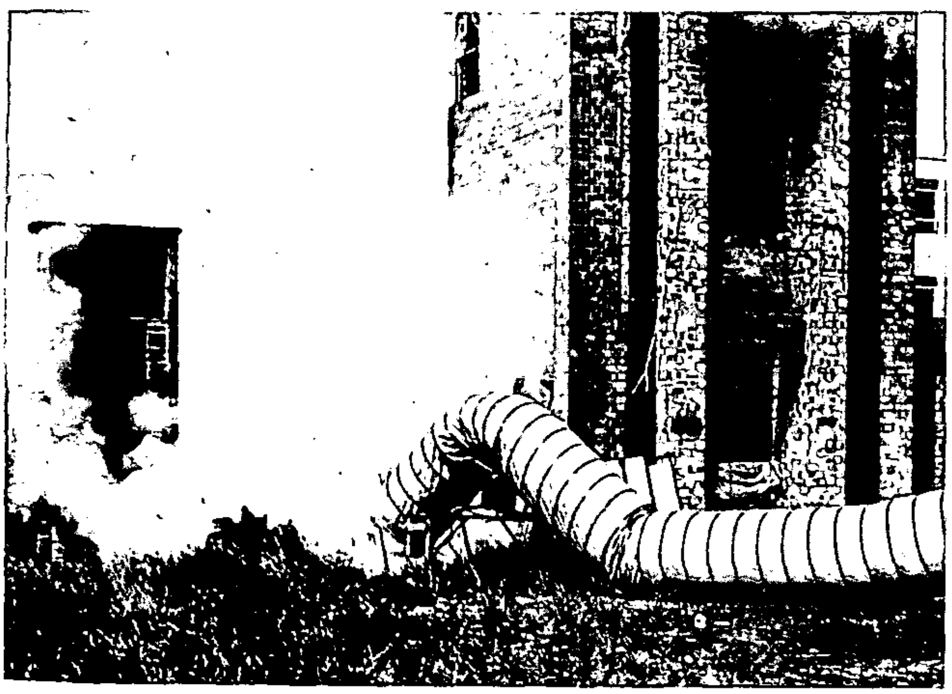

FIG. 8. STABILISATION OF DUCT, EFFECT OF LOW WALL

FIG. 9. FAILURE OF COTTON MESH BAG