J. agric. Engng Res. (1982) **27**, 529–535

Field Drainage — A Specification for Permeable Backfill

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Numerous types of permeable material are used over field drainage pipes, principally as a hydraulic connection between mole drainage channels and the pipe itself. To date such materials have simply been required to be clean and within a certain size range. Data are presented here which cover mechanical strength, size and fines content while the possible complications of toxicity and solubility are also briefly discussed. It is demonstrated that a more detailed, performance based, specification may now be written which covers the majority of materials encountered.

1. Introduction

Some 60% of field drainage work in England and Wales[1] involves the use of a permeable material placed over the pipe field drains. Such material is most commonly used to provide a hydraulic connection between mole drainage channels and the deeper pipe drains while more occasional uses are to improve radial flow to the pipe[2] or to intercept surface and near surface flow of water. More unusual uses, which are outside the scope of this paper, are control of pipe sedimentation[3] and special surrounds designed for the control of, for example, iron ochre. Considering the mainstream of uses, the material involved must be reasonably clean and not too small if adequate flow of water through it is to occur. Similarly, it must not be too large if physical damage to the pipe during material placement is to be avoided. Thus, material grading is of major importance. Reasonable strength is needed in order to limit breakdown during transport and handling. Finally, the material should be non-toxic and reasonably insoluble. Most of these aspects are embraced, if not quantified, by the Ministry of Agriculture, Fisheries and Food[4] requirement that permeable backfill "is to be clean gravel, stone chips, slag, foam slag, hard clinker or other Ministry approved durable material with no dimension greater than 50 mm or less than 5 mm".

The purpose of this paper is to review developments which now make it possible to specify materials rather more rigidly. This will be done by considering each of the properties involved.

2. Strength

Permeable backfill needs to be sufficiently strong to prevent the creation of significant quantities of fines as a result of the various crushing, impact and abrasive loads which occur during transport, handling and stockpiling. Such fines are likely to be deposited around the drain pipe and inhibit water entry.

Strength is an aspect of the use of backfill which does not feature in the literature of field drainage; there is no mention of it in the review of trench backfill carried out by Fausey and Hundal[5] while the work of Hautala and Menefee[6] concentrated on the properties of backfill produced *in situ* by sintering soil rather than on conventional, transported, materials. There is an extensive literature on aggregates produced for roadstone and concrete, this has given rise to British Standards 812[7] and 882,[8] respectively. In these impact and crushing tests are detailed but only in the case of the Standard for concrete, somewhat removed from the field drainage application, are test levels set. Circumstances were similar in 1969 when strength evaluation of permeable backfill by MAFF began. At that time the decision was made to develop an "in house" method of evaluation. To this end samples from numerous locations in England and Wales

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Received 26 November 1981; accepted in revised form 7 August 1982

0021-8634/82/060529+07 $03.00/0

TABLE I

Percentage of material reduced to less than 2 mm diameter after 10 min on the tumbling machine

Material rating	*Tested dry*		*Tested wet*	
	No. in sample	*Sample mean %*	*No. in sample*	*Sample mean %*
Unsatisfactory	5	39	5	40
Marginal	10	50	9	56
Satisfactory	52	13	52	10

were tested. Each of these had been categorized by the despatcher—on the basis of experience of their performance in field drainage works—as "satisfactory", "unsatisfactory" or "marginal" in terms of mechanical strength. Two 100 g samples were taken, one for use dry while the other was soaked in water for 24 h and then tested. The test involved loading the fill sample together with 2 cylindrical weights of mass 922 g and 260 g, respectively, into a cylindrical steel drum, the walls of which consisted of perforated metal of aperture 2 mm. The 13 cm diameter drum was rotated at 35 rev/min for 10 min, during which breakdown of the fill occurred and any which passed through the apertures fell into a receiving tray. At the end of the test all material of diameter less than 2 mm, both inside and outside the drum, was weighed and expressed as a percentage of the starting weight. A summary of the results is presented in Table I.

Interpretation of the results in Table I was complicated by the fact that "unsatisfactory" materials were generally stronger than "marginal" materials. This anomally, which is not statistically significant, was probably because 4 out of the 5 materials rated as "unsatisfactory" were derived from one particular district, where the standards set were unusually severe. However, there are highly significant differences between both "unsatisfactory" or "marginal" and "satisfactory". On the basis of this work it was decided that a laboratory test could be established whereby materials in the range 0–40% were rated as "satisfactory", those in the range 40–60% as "marginal" and those over 60% as "unsatisfactory". Some dozens of materials, ranging from mine waste and ex-railway ballast to crushed limestone and granite, were evaluated on this basis between 1971 and 1977.

The next development was the provision of further information by Butler and Croote,[9] who located a site where relatively weak power station clinker from a production plant 40 km away was being used.

Samples were taken from the conveyor belt of the permeable backfill trailer as it discharged into the open trench and transported to the laboratory. The standard tumbling test and sieve analysis demonstrated that while the grading of the material at the production plant was entirely within the 5–50 mm diameter limit, by the time the material was about to be delivered into the drain trench 15% was less than 5 mm in diameter. Not all of this will have derived from the backfill, some unmeasured proportion was soil. Work by MAFF[10] indicates that fill typically contains 1–2% of soil. Thus the figure of 15% may be adjusted to 13% to give an indication of the level of actual degraded backfill. Further, the performance of the material in the tumbling test was such that 65% was reduced to less than 2 mm diameter. Assuming linear correlation between practical and laboratory performance this suggests that 40% reduced to fines in the laboratory grinding test, i.e. the pass level, is equivalent to 8% of material less than 5 mm in diameter as a result of transport and handling.

Thus, the limited calibration work suggests that the laboratory strength test imposes a limit of around 8% of degraded backfill to which may be added 2% of soil, i.e. a total of 10% with respect to the 5 mm diameter sizing. The significance of this level of fines, in terms of possible impairment of water entry, is considered in section 4.

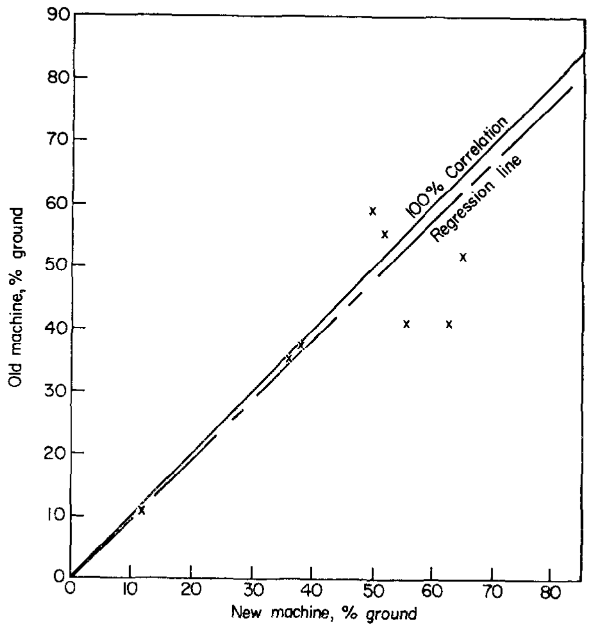

Fig. 1. Comparison of new tumbling machine with the old using dry materials. (New machine—400 g of material for 40 min. Old machine—100 g of material for 10 min. Each plotted point is the mean of three tests)

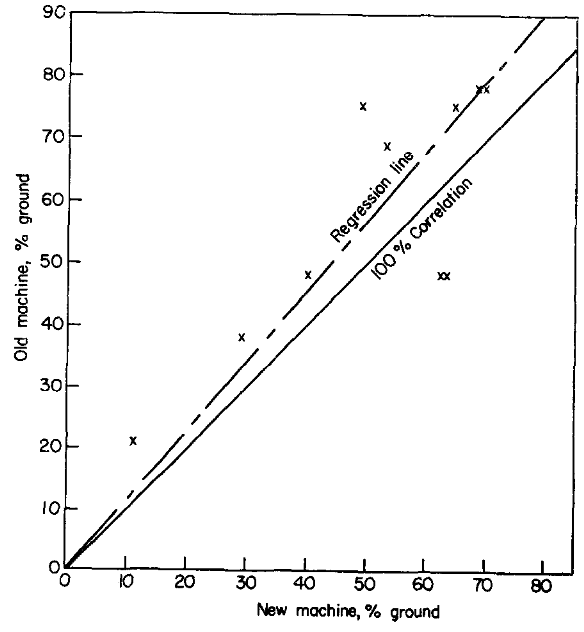

Fig. 2. Comparison of new tumbling machine with the old using wet materials. (New machine—400 g of material for 40 min. Old machine—100 g of material for 10 min. Each plotted point is the mean of either 2 or 3 tests)

Then followed work on the actual methodology of the laboratory test. A disadvantage of the machine used was its small size, this led to 2 difficulties. First, with the larger materials 1 or 2 pieces were often enough to fill the cylinder, with the result that the steel bars became wedged and the tumbling–grinding action ceased. Secondly, the small quantity of material tested resulted in very little attention being paid to the inherent variability. Both these difficulties were substantially overcome by introducing a larger, scaled-up, machine. New machine parameters—dimensions, rate of revolution, mass of the cylindrical weights, grinding time, sample size—were selected so as to give similar percentages ground as the old machine. Detail of this comparison exercise is given in *Figs 1* and *2*. From these it may be seen that in the case of dry materials the new test is marginally more severe than the old, while with wet it is some 12% less severe. Thus, there is reasonable continuity of test standards. The new machine employs steel mesh cylniders of length 20·5 cm and diameter 17 cm which are rotated at 30 rev/min; 2 cylindrical steel weights of mass 2 and 0·6 kg are used.

3. Size

There are 2 major considerations. If the permeable backfill is too small it will have insufficient hydraulic conductivity to provide an adequate connection between mole drainage channels and the pipe. Conversely, if too large, it will give rise to handling problems of which the most important is damage to the pipe during trench backfilling.

The first of these aspects was considered by Dennis and Croote,[11] who took the case of mole drainage at 2·5 m centres over pipe drains spaced 80 m apart at a drainage rate of 60 mm/day. This gave a flow rate of 0·14 l/s, which was delivered through simulated mole drainage channels into a full-scale section of backfilled trench in the laboratory. A number of sizes of fill were so tested and it was concluded that, for typical trench widths, the minimum particle diameter should not be less than 5 mm. A hydraulic conductivity of 2500 m/day may be associated with such material. Permissible maximum size of backfill when being placed on clayware pipe was also assessed by full-scale simulation. A random sample of 20 75 mm pipes was obtained and their quality first determined by subjecting half to the crushing test specified in BS 1196.[12] Three of the 10 pipes failed, and it was concluded that the sample was representative of the poorer pipes used in field drainage. The other half was used to investigate the relevance of the existing MAFF limit of 50 mm which, assuming rounded material and a specific gravity of 2·6, is equivalent to a mass of 170 g. A drop weight impact test was used with double this mass falling from 1·5 m. This resulted in 7 out of the 10 pipes fracturing at the first blow, so indicating that any significant increase from the maximum size of 50 mm would have to be at the expense of more stringent, and in other respects unjustifiable, requirements for clayware pipes.

In the case of plastic pipes, BS 4962[13] in effect states that the height at which 50% of the impact test samples fail should be not less than 65 cm when using a drop hammer of mass 250 g. Mass and height are not strictly interchangeable but it may be taken that if a mass of 170 g were to be used, i.e. 50 mm backfill, the equivalent drop height would be 96 cm, a value which is quite often exceeded in practice. From this it is clear that the existing test is not very rigorous and the absence of field failures must be at least partly attributable to the quality of existing products. Continuation of this situation could not be guaranteed if the maximum size were to be increased, particularly in the case of impact sensitive p.v.c. pipe. Overall it may be concluded that any increase in size would have to be accompanied by an increase in the impact strength, and hence cost, of both clayware and plastic pipes.

4. Fines content

There is, inevitably, always a small quantity of fine material incorporated into the coarser base material. In the case of mechanically strong fills which have been carefully graded at the production plant these fines will consist almost entirely of soil from the stockpiling area, while with weaker backfills they will consist of a mixture of soil and abraded fill. Whatever the origin of such fines they are, since dimunution of water flow could result, undesirable and must be considered in some detail.

In those cases where the combination of base material and fines have a continuous grading from large to small, as might be when some of the mechanically weak backfills are contaminated with soil, there is likely to be little movement of material within the trench as a result of water flow. However, situations can be envisaged where a mechanically strong coarse fill is heavily contaminated with soil, or a somewhat weaker material—of similar size—as well as being partially contaminated with soil has had small particles abraded from its surface. In such instances the flow of water will result in movement of fines; some of these will be held in the smaller pores of the base material but others will find their way via the larger pores to the pipe at the bottom of the trench. Depending upon the relative sizes of pipe openings and fines the latter may either enter the pipe and be flushed away or be deposited in the vicinity of the pipe. It is the material deposited within the interstices of the larger pieces of fill which is the potential danger; if this accumulates to the extent that direct access to the pipe is restricted water acceptance will be drastically curtailed. On the other hand, no case can be made for limiting fines content to the extent that only a negligible amount accumulates next to the pipe. It is proposed that an acceptable compromise is to restrict the zone in which the interstices between the larger pieces of fill become occupied by fines, as a result of washdown, to below the centre-line of the pipe. The fines content, defined as a percentage of the total volume of fill, needed to meet this condition will depend upon a number of variables. Thus, a wide trench, a large pipe and a flat trench bottom will all reduce the risk of blockage by fines. Vertical distance between the mole channel and permanent pipe is also important since it is this that determines the total quantity of fines involved. In Table II a number of cases are considered, factors common to each case being a voids percentage of 40 and a vertical distance between mole channel and pipe centre lines of 20 cm.

TABLE II

Maximum acceptable percentage of fines for various combinations of pipe diameter, bedding and trench width

Pipe	*Bedding*	*Trench width, cm*	*Maximum percentage of fines*
60 mm o.d. corrugated plastic	Radiused groove	10	0·4
60 mm o.d. corrugated plastic	Flat bed	15	6·9
100 mm o.d. clayware	Flat bed	15	7·9
100 mm o.d. clayware	Flat bed	20	10·1
135 mm o.d. clayware	Flat bed	20	10·6

From the table it is clear that some combinations of pipe and trench will tolerate quite high percentages of fines while others will not. Only 2 of the 5 figures given are in excess of the fines figure which the strength test in section 2 suggests, i.e. 10%, so in the 3 other situations there is a risk of reduced drainage performance. However, this is to some extent offset by the fact that those combinations particularly at risk will not necessarily be used in conjunction with a weak fill, and even if they are, the fines produced will not necessarily be deposited in the vicinity of the pipe. Also, taking a completely different approach, there is no history of field failures. Thus, considering Table II in the light of a 10% limit is to consider the worst case. Notwithstanding this, small diameter corrugated pipe in a groove radiused to improve bedding does seem to be particularly at risk.

5. Toxicity

Toxicity effects are likely to be only an occasional problem but situations can be envisaged where materials such as clinker or other industrial wastes satisfy the other requirements but release unacceptable quantities of, for example, heavy metals.

The first consideration is uptake by plants (and thus potentially by farm animals and humans) which are grown above or close to the former drain trench. Typically, the trench only constitutes 0·5–1·0% of the field area, and this figure may be further reduced since the backfill is normally well below the surface. However, the possibility of a problem should be remembered if, for example, a close drain spacing is associated with a wide trench and the backfill has been brought right up to ground level.

The second consideration is contamination of the drainage water itself. This is complicated by the fact that some elements are more susceptible to leaching than others. However, the degree of dilution will invariably be considerable and further dilution by mixing with other waters prior to any involvement with the public water supply is likely to be enormous. All in all, it seems unlikely that drainage water could be a cause for concern but, as with phytotoxicity, the possibility should be borne in mind.

6. Solubility

As in the case of permeable backfill with appreciable toxic content, high solubility is only likely to be an occasional problem and it seems realistic to confine testing to cases where chalk or limestone backfills are being used on sites with acid soil. Specifically, it is suggested that chalk or limestone should not be used if the pH of the soil within the depth range 0–100 cm is less than 5·8.

7. Conclusions

Permeable backfill, particularly in the mole drainage context, should be such as to satisfy the following requirements:

(i) *Strength.* When both wet and dry samples are subjected to the tumbling test discussed in section 2 not more than 40% should be reduced to less than 2 mm diameter.

(ii) *Size.* The bulk of the material should be within the size range 5–50 mm diameter.

(iii) *Fines.* Total fines, i.e. at source, resulting from transport and handling, plus soil, should be limited to about 10%.

(iv) *Toxicity.* This is unlikely to be a problem; however, the possibilities of crop and watercourse contamination should be borne in mind.

(v) *Solubility.* Chalk and limestone, as well as satisfying (i)–(iii), above, should only be used where the soil pH is greater than 5·8.

Acknowledgements

The author is grateful to staff of the Anglian Water Authority, Department of the Environment, Water Research Centre and to colleagues within MAFF for assistance and guidance.

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