

Assessment of the Performance of Trial Trenches Backfilled with Cementitious Materials

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Longitudinal and transverse trial trenches backfilled with unbound graded granular material. Lytag:cement and PFA:sand:cement were monitored over a period of one year. Permanent deformation, elastic deflection and ease of break-out of backfill were used to assess the performance of the trenches. Granular backfill exhibited settlement of 2 and 5mm for the transverse and longitudinal trenches respectively. The corresponding settlement for cementitious backfill was 1 and 2mm. For all types of backfill materials, longitudinal trenches showed greater settlement than the corresponding transverse trenches. Settlement of the trenches took place mainly in the first two months after construction and the rate of settlement became insignificant after that period. Field trials showed that cementitious materials performed better than granular backfill both in terms of permanent deformation and less elastic deflection.

Falling weight deflectometer tests were conducted to estimate the elastic modulus of the backfill. It was found that after about one year the deduced elastic modulus of granular backfill became similar to that of the surrounding soil. The deduced elastic modulus of the two cementitious backfills became higher than for the control section, but poor bond between fill and trench wall may have limited the deduced value for Lytag cement mix. One metre length of each transverse trench was excavated to assess ease of break-out. Whilst the granular backfill was the quickest to excavate, Lytag:cement backfill was favoured by the operatives as it could be broken out and handled as easy as the granular backfill.

The initial cost of PFA:sand:cement was very close to the granular backfill whereas Lytag:cement was 12–28% more expensive. If long-term performance is considered, cementitious backfill may be more economical even though the initial cost is higher.

Keywords: Trench, fill, utility cut, permanent deformation, lytag, fly ash

INTRODUCTION

The New Roads and Street Works Act (1991) in England and Wales placed the duty for all aspects of reinstatement with the Utilities. The Act also encourages the Utilities to reinstate the openings in roads in accordance with the Specifications for Openings in

Highways developed by the Highways and Utilities Committee (HAUC).

In general granular material is used for backfilling trenches. This material is produced from high quality rock and requires compaction when placed. Thus, research was required to investigate possible use of cheaper materials that need little or no compaction for backfilling trenches.

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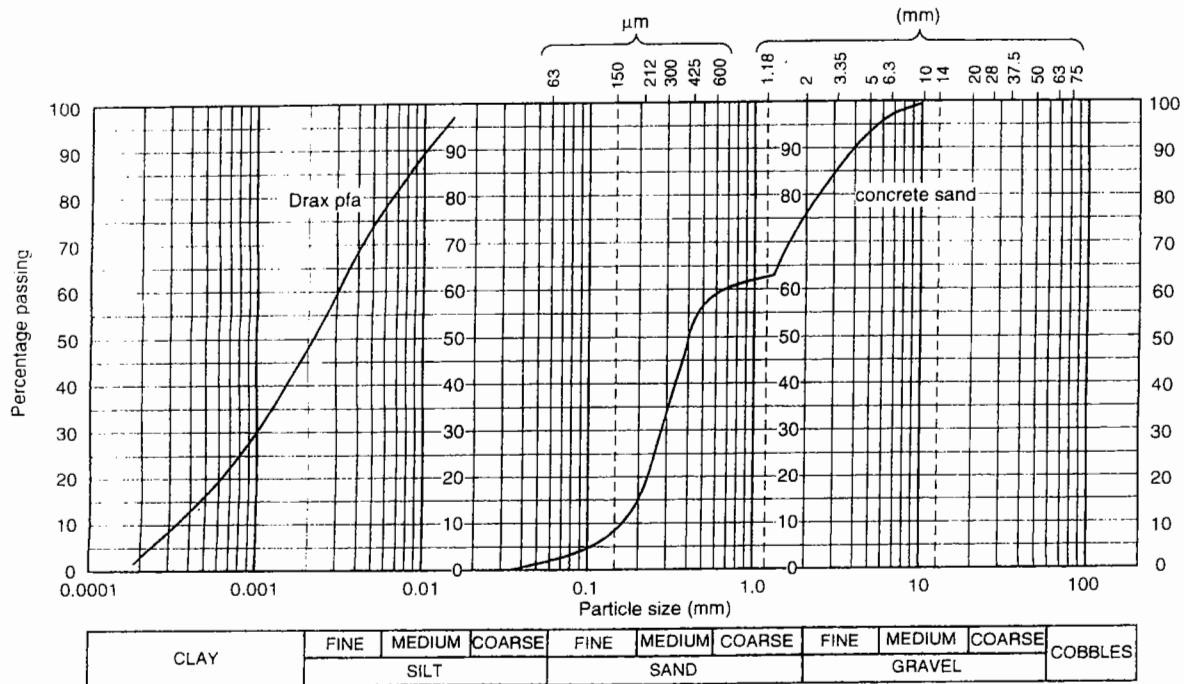


FIGURE 1 Particle size distribution of PFA and sand used in the investigation

The findings reported in this paper arise from part of an EPSRC (Engineering & Physical Sciences Research Council) LINK funded investigation into backfill of shallow trenches.

The aim of this research was also to develop cementitious free flowing materials which complied with all the existing standards and specifications. Seven backfill materials were investigated. Backfill materials based on PFA:sand and Lytag were developed to a field trial stage. The results of the field trial of these two materials and the conventional granular backfill are described in this paper. The granular backfill was used as a benchmark to gauge the performance of the newly developed cementitious mixes.

REVIEW OF PREVIOUS WORK ON CEMENTITIOUS BACKFILL

The use of cementitious materials in backfilling trenches is intended to overcome the problem of com-

paction, to speed up the backfilling operation, to ensure better performance and to reduce the whole-life cost. Research has been conducted on the use of materials such as foamed concrete, lean concrete and cement based mortars for backfilling trenches.

Foamed concrete is free flowing and requires no compaction. It is therefore an efficient material for use in trenches where irregularities and cavities are encountered. However, its disadvantages are: high cost, potential danger faced by road users before it has set and difficulty in filling trenches on sloping ground.

Lean concrete differs from normal concrete in that it has a much lower cement content. Lean concrete is used for road bases as specified by DOT Specification (1991). Kepler (1986) recommended the use of cement mortar as an alternative to granular backfill in narrow trenches where application of adequate compaction to backfill would be difficult. A field trial

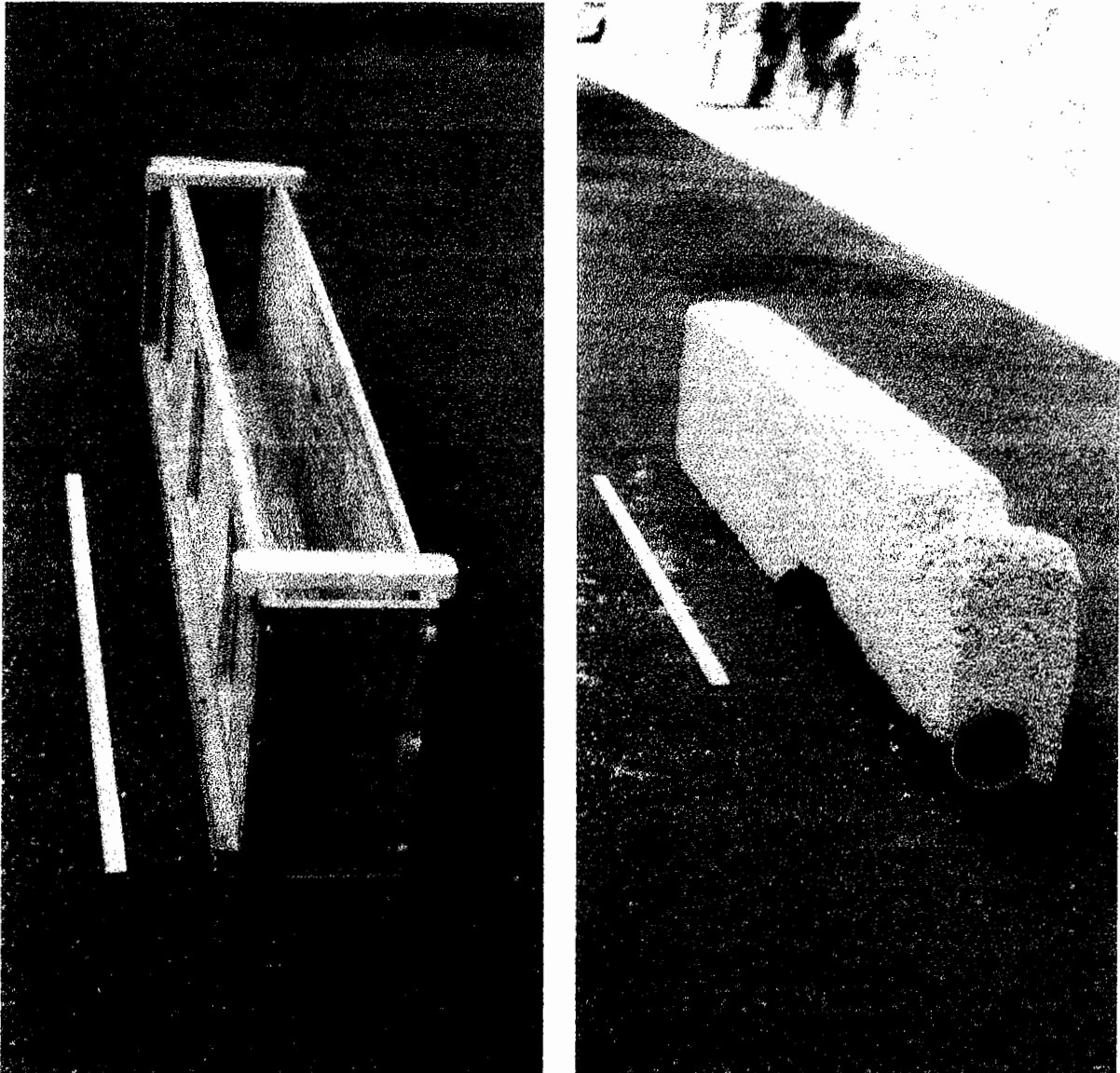
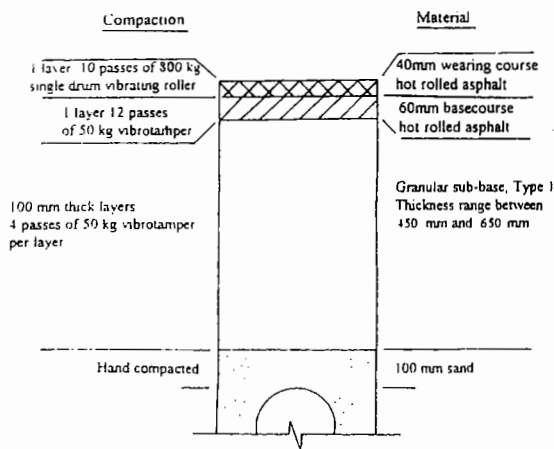


PLATE 1 Large scale laboratory trials

Was carried out by British Cement Association (BCA) in which lean concrete was employed as a trench backfill along with two control sections of granular backfill (Taylor, 1988). The results showed that the lean concrete trench settled much less than the control trenches. It was also found that a 200 mm PVC pipe in the lean concrete trench compressed 0.8 mm as compared to 6.0 and 6.8 mm for the con-

trol sections. This experiment showed significant improvement in the performance of a trench when cementitious backfill was employed. Owen (1985) showed that trial trenches filled with the granular material and lean concrete performed well with no sign of distress after two years. The main disadvantages of lean concrete are that it is expensive and less resistant to frost action than foamed concrete.



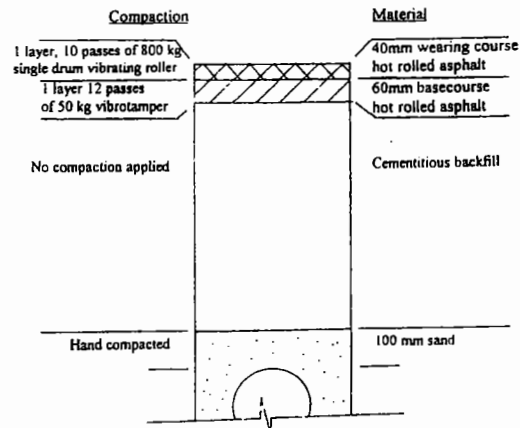
Note

- i. Hot rolled asphalt wearing course and basecourse 30/14, Type F, 50 pen
- ii. Clegg readings for sub-base were 22 (prior to surfacing).

FIGURE 2 A Typical trench section for granular sub-base backfill

A cement:ash mortar (known as flowable fly ash) was first investigated in the United States in 1979 and was used to construct a railway embankment where the material was placed under water. The success of this trial has led to the use of this material as a backfill for utility trenches (Funston et al., 1984).

Peindl et al. (1992a, 1992b) performed field trials to compare the performance of a flowable fly ash as a trench backfill with the conventional compacted fill. The study included both static and dynamic loading conditions. The materials used in the field trials comprised pulverised fuel ash ("fly ash", PFA), cement, super-plasticizer and water. Three, trenches 1.22m deep \times 0.61m wide \times 7.62m long, were constructed using this backfill, spaced equally across a two-lane road connecting a power station plant to a fly ash landfill. Two types of pipes were used: 200 mm diameter clay pipes and 300 mm diameter concrete pipes. It was found that flowable fly ash was cheaper, showed minimum amount of settlement under heavy traffic loading, reduced strain in the embedded pipes and needed less long-term maintenance.



Note:

- i. Hot rolled asphalt wearing course and basecourse, 30/14, Type F, 50 pen.
- ii. Cementitious material comprised Lytag/cement and pfa/sand/cement mixes.

FIGURE 2 B Typical trench section for cementitious backfill

Maher and Balaguru (1993) used a mixture of cement, sand and PFA in various proportions to produce a flowable ash:sand:cement composite. A cement to materials ratio of as low as 1 cement : 10 PFA : 20 sand was employed. They found that the compressive strength of the mix continued to increase for approximately six months. A flowable mixture was obtained by using a water:cement ratio over 0.45 or by using water reducing admixtures. However, they did not recommend using a sand:cement ratio of 20 for mixes of low water cement ratio because of the high admixture requirement.

Stresses in Pipes

Backfill material significantly affects surface settlement of the trench and stresses in the buried pipe(s). In addition to the stiffness of the backfill materials, there are other important factors, which affect stresses in pipes in trenches such as bedding condition, stiffness of the surrounding soil and interface friction at the sides of trench.



PLATE 2 Site mixing

Jeyapalan and Jiang (1986) performed finite element analyses to study the effect of various bedding conditions and degree of compaction of backfill on stresses on buried clay pipes. They found that using poorly compacted silty sand and clayey sand backfill increases vertical stresses on a pipe by 20% to 25% for various bedding conditions.

Pocock et al. (1980) reported that the majority of failures in water pipes are associated with transverse fractures in shallow buried pipes of 150 mm diameter or less. The high bending stresses which cause such transverse failures are due to improper bedding and the lack of flexural stiffness in backfill material. It can thus be envisaged that the use of cementitious backfill with a higher flexural stiffness compared to unbound backfill will reduce bending stresses in pipes and reduce the probability of such failures.

A field trial was conducted by BCA (Taylor, 1988) to study the effect of cementitious backfill materials on the behaviour of a pipe in a trench. Four sections of trial trench were constructed. Two of them were



PLATE 3 Placing trench backfill

backfilled with poorly compacted and well compacted granular backfill materials. The other two were backfilled with lean concrete and foamed concrete. UPVC pipes of 200 mm diameter were placed in the base of the trenches at a depth of 600 mm. The stresses in the pipes were monitored indirectly by measuring the vertical deflection of the pipes. Both permanent deformation and dynamic deflection of the pipes were measured for the various trenches. It was found that using well compacted backfill slightly reduced the dynamic and permanent movement of the pipes whereas cementitious backfill reduced these movements down to one fifth of those for unbound backfill. In general lean concrete performed better than foamed concrete.

A similar conclusion was reached by Peindl et al. (1992a) who found that a PFA:cement backfill greatly reduced circumferential strain in pipes compared to unbound backfill.

Placement and compaction/settlement

Self-levelling cementitious materials have several advantages over unbound material in terms of stresses

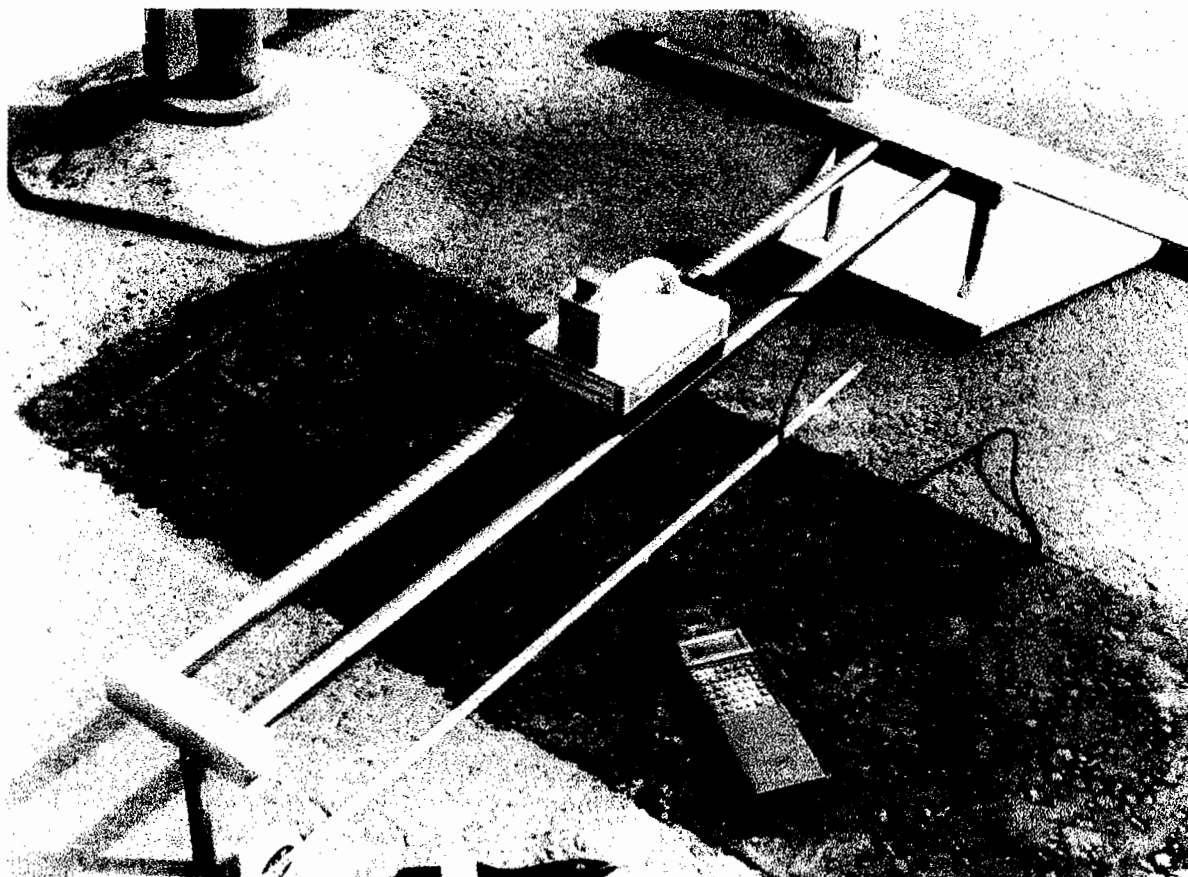


PLATE 4 "Flatmate" – used to measure trench surface profile

transferred to the pipes. Firstly, they reduce residual stresses due to compaction. Secondly, they reduce the probability of flexural breakage by bridging soft bedding points. Thirdly, they distribute stresses more evenly due to flexural stiffness.

One of the key aims of using cementitious backfill for trenches is to reduce surface deformation. British Gas conducted field trials using wet mix macadam, dry lean concrete (18:1 aggregate:cement, 6% moisture content) and crushed dolomite stabilised with 4% cement and at a moisture content of 11% (Owen, 1985). Initial settlement after the road was opened to traffic ranged between 1 to 2 mm for the cement stabilised materials, However, for unbound material the settlement was 4 mm. Little increase in settlement was

noticed in the first six months but over a two year period settlement increased by 2 mm for all the sections.

Taylor (1988) reported settlements of trial trenches of up to 59 mm and 73 mm for well compacted and poorly compacted unbound materials respectively. Settlements for trenches backfilled with lean concrete and foamed concrete were 9 and 11 mm respectively. This result shows that cementitious materials reduced settlement of the trench by a factor of 6 to 7.

Based on the above studies it can be concluded that the use cementitious materials reduce settlement of the trench, reduce stresses in pipes and are less sensitive to workmanship on site than is the case with granular backfill materials, Thus, research was required to develop cheap cementitious backfill materials and

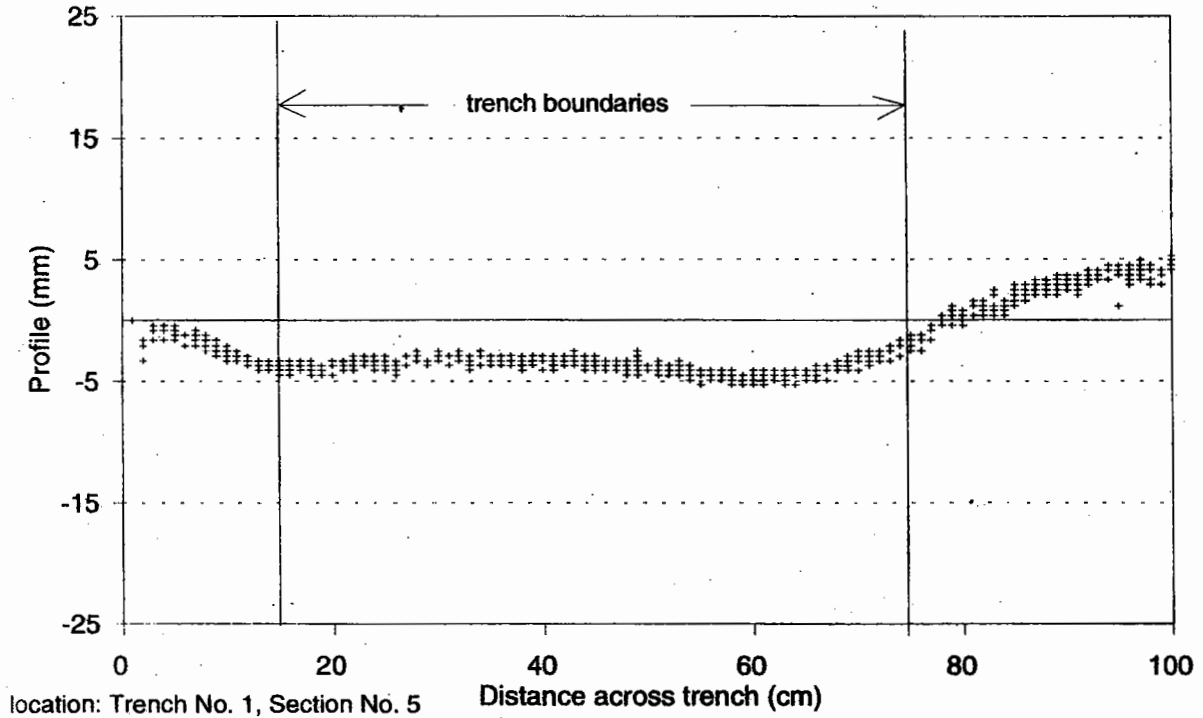


FIGURE 3 Calibration profile for longitudinal trench

techniques that required no special equipment. This paper presents the details and assessment of the field trials conducted on two types of cementitious materials: PFA:sand:cement and Lytag:cement, and a granular backfill. The latter was used as a control.

LABORATORY TESTS AND RESULTS

Laboratory investigation was carried out to characterise the constituents of the backfill materials and design mixes that complied with the existing national specifications. The following tests were conducted to develop trench backfill materials: particle size distribution, 10% fines value, compression strength, permeability, frost susceptibility, flow characteristic and indirect tensile strength.

The particle size distribution curves of sand and PFA used in the trials are shown in Figure 1. The

Lytag was nominally single sized of 3 mm diameter and contained approximately 10% of sintered PFA from the manufacturing process. The ten percent fines value for Lytag was 177 kN measured in accordance with the British Standard BS 812:Part 111:1990.

The unconfined compressive strength of backfill materials was determined using cylindrical samples, which had a diameter of 68 mm and were 140 mm high. The samples were cured in a humid environment in the laboratory at a temperature of $20 \pm 2^\circ\text{C}$.

Based on the findings of the laboratory investigations the following mix designs (by mass) were selected for the field trials:

<i>Materials</i>	<i>Mix ratio</i>	<i>Water: cement ratio</i>	<i>Air entrainment</i>
PFA:sand:cement	4:8:1	0.5	0.6%
Lytag:cement	7.5:1	0.36	nil

TABLE I Clegg hammer readings of backfill

Time	Clegg Hammer Readings					
	Longitudinal Trenches			Transverse Trenches		
	Trench No.			Trench No.		
	L1	L2	L3	C4	C5	C6
16 hrs.	21	22	0	22	18	0
2 days				22	34	18
3 days	27	20				

Key: L1, C4: Type 1 granular subbase L2, C5: Lytag:cement L3, C6: PFA:sand:cement

FIELD WORK

Preliminary Trial

Prior to the field work a large-scale laboratory model trench (0.15 m width \times 0.35 m depth \times 1.5 m length) was made of plywood and Perspex, see Plate 1. It was filled with the mixes chosen for the trials to evaluate the flow and strength of the materials. Compression tests were conducted on cores taken from the model trenches seven days after casting. The results showed good agreement with tests on specimens made when the model trench was cast and cured separately. Thus, the small scale work correlated well with the large scale mixing and placing trial.

Field Trial

A field trial was carried out to assess the behaviour of the materials developed by comparison with the conventional granular backfill. The trial trenches were situated in an industrial estate in a Type 3 road (roads carrying over 0.5–2.5 million standard axles).

The trial comprised six sections of 0.55 m wide trench: three transverse sections, 2.5m in length across the road and three longitudinal sections, each about 10m in length and located about 0.75m from the kerb line (in the wheel path). Three types of backfill material were used: PFA:sand:cement, Lytag:cement and a granular backfill. Each material was used to backfill one transverse and one longitudinal trench. Typical trench sections for the granular and cementi-

tious backfill materials are shown in Figure 2. Both the PFA:sand:cement and Lytag:cement mixes were batched and mixed on site as shown in Plate 2.

The backfilling operations, for the cementitious backfill, were conducted by labourers using standard concrete mixing plant. The mixed material was poured into the trench as shown in Plate 3. No special plant, equipment or skills were necessary for the backfilling operations. The trenches were covered with plastic sheets overnight. Some water did, however, enter the trench from rainfall but this did not result in any wash-out effects. Temperature at the time of trial ranged from 5 to 10°C. The granular backfill was placed in the trench by operatives who undertook trench backfill work on a regular basis.

A Clegg hammer was used to determine the suitability of the backfill for surfacing. Conventional wisdom was that a minimum Clegg reading of 18 was required to enable surfacing to be compacted satisfactorily. British Gas use this criterion in their trench backfilling practice (Fallow, 1994). After 16 hours from casting, Lytag:cement mix was strong enough for surfacing while the PFA:sand:cement was not yet strong enough so it was decided not to surface the backfilled trenches until the next day. Clegg hammer readings measured 16 hours after backfilling and prior to surfacing are given in Table I. The surfacing was placed on transverse trenches 2 days after casting while the surfacing of the longitudinal trenches was delayed by one more day due to operational problems.

The trial trenches were monitored over a period of one year using a surface profile meter, Falling Weight

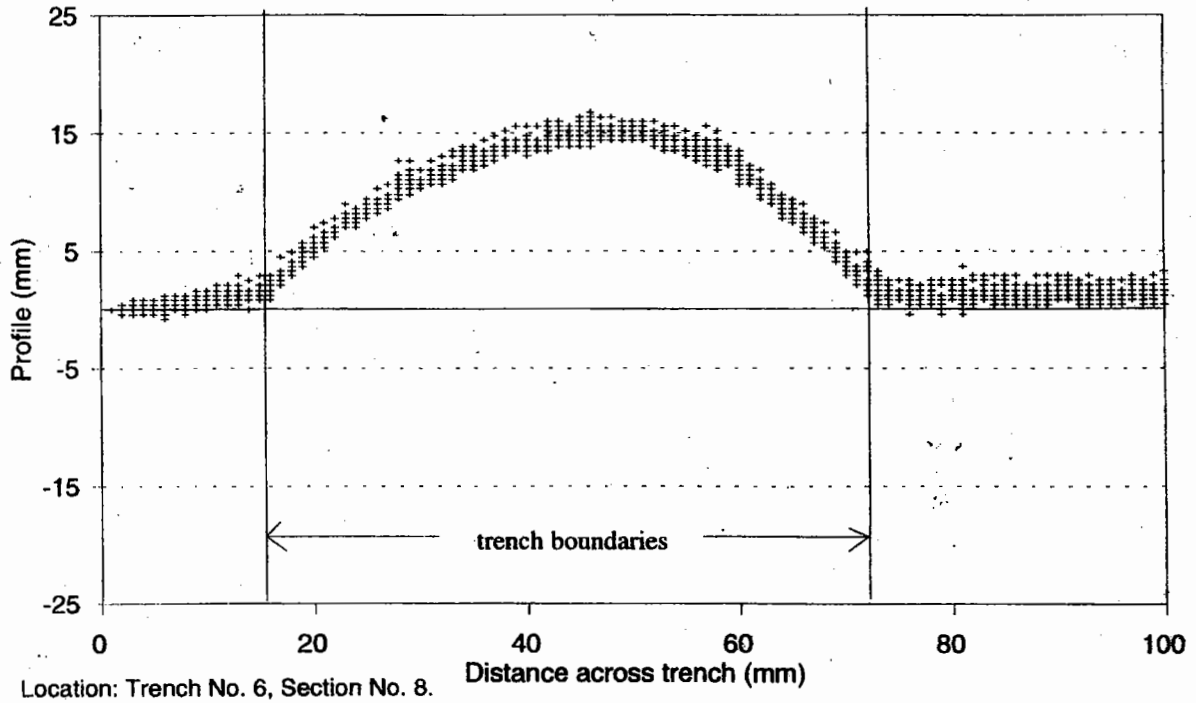


FIGURE 4 Calibration profile for transverse trench

Defelctometer (FWD), core samples and, finally, by arressing breakoutability (the ability to break out backfill materials in the long term). The results and discussions of these tests are presented in the following sections.

Surface Profile

Surface profiles were measured after reinstatements of trenches using a two dimensional profile measurement device called "Flatmate", see Plate 4. In order to determine the accuracy of the measurements two sections of trench were chosen: one across a longitudinal trench and one across a transverse trench. For each of the sections, the profile was measured twenty times. After each measurement the Flatmate was reset.

The calibration data thus collected for each of the two sections are presented in Figures 3 and 4. The band widths for the longitudinal and transverse sections were 2.0 mm and 2.5 mm respectively. This

indicates that the measured profile was correct within ± 1.25 mm. The standard deviations for the measurements at each point across the sections are in the range of 0.223 to 0.759.

Surface profile measurements over the first nine months after reinstatement are given in Figures 5 to 10. In order to assess the overall settlement of each trench, the level of the trench surface at each specific section was taken as the average of the middle 30 points for that section. The standard deviation of the twenty average readings was 0.225, which is about half of the maximum standard deviation obtained when each point was considered separately. The settlements of a trench over a period of time were calculated from the difference between the average datum measurements and the average readings at any particular time. A smoothing technique was applied to the data presented in these graphs using the following equation:

$$S_a = (a_{n-1} + a_n + a_{n+1})/3 \dots \dots \dots (1)$$

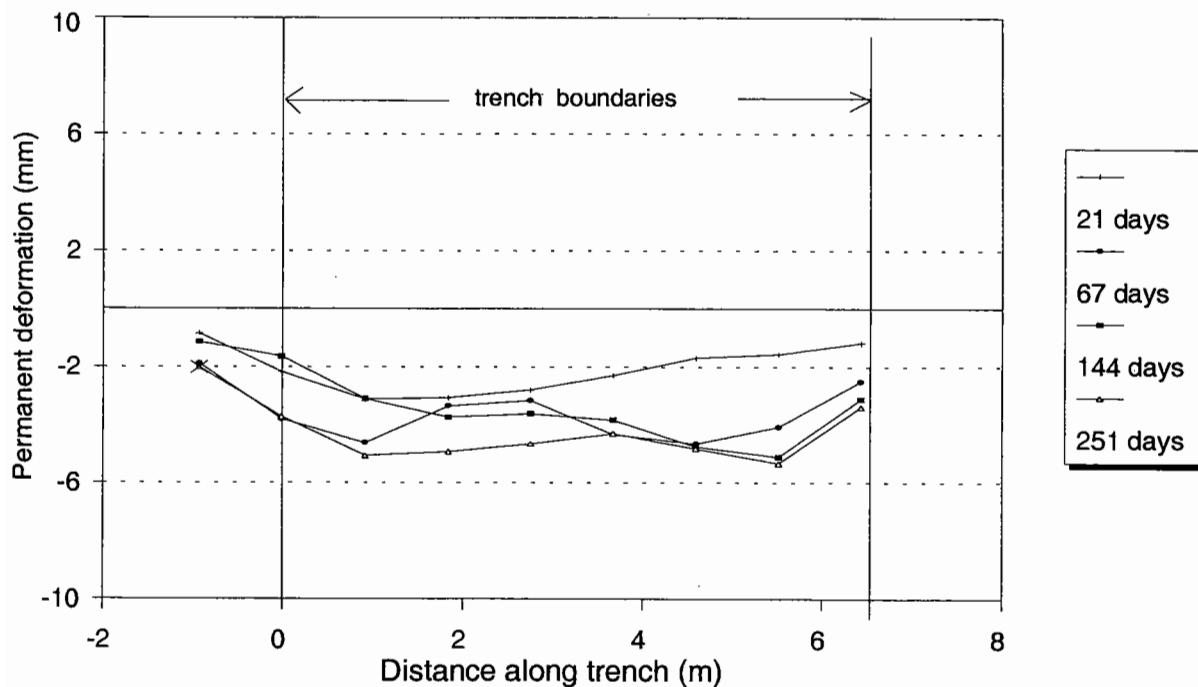


FIGURE 5 Permanent deformation of longitudinal trench backfilled with Type 1 material

Where:

S_n = smoothed reading at point n

a_{n-1} = actual reading at point $n-1$

a_n = actual reading at point n

a_{n+1} = actual reading at point $n+1$

This equation gives equal emphasis to all points thus producing a smoother curve.

The settlement along the longitudinal trench backfilled with the granular material is presented in Figure 5. The results show that the edges settled less than the middle of the trench. This was thought to be due to the resistance of the original road formation to settlement at the edge. Most of the settlement in the trench took place in the first two months after which the settlement was insignificant. The effect of edge on settlement of longitudinal trenches backfilled with Lytag:cement and PFA:sand:cement is less apparent as shown in Figures 6 and 7 respectively. This is because there is more tendency for such material to settle more uniformly due to the relatively high flexural stiffness compared to the granular material. The

rate of settlement is also less apparent because the total amount of settlement is relatively small.

The settlement along the transverse trench backfilled with the granular material is shown in Figure 8. The behaviour of the transverse trench is different from that of the longitudinal trench. The maximum amount of settlement took place at distances of 0.75 and 2.25 m along the trench, at the positions of the wheel tracks. Most of the settlement took place in the first two months, as was the case with the longitudinal trench backfilled with the granular backfill. The effect of wheel track loading on the transverse trenches backfilled with Lytag:cement and PFA:sand:cement is shown in Figures 9 and 10 respectively. This effect is less apparent compared to that of the granular backfill again because of the stiffness of these backfill materials which ensured more uniform distribution of the load due to their flexural stiffness. The rate of settlement was less apparent compared to that of the granular backfill because the total amount of settlement was small.

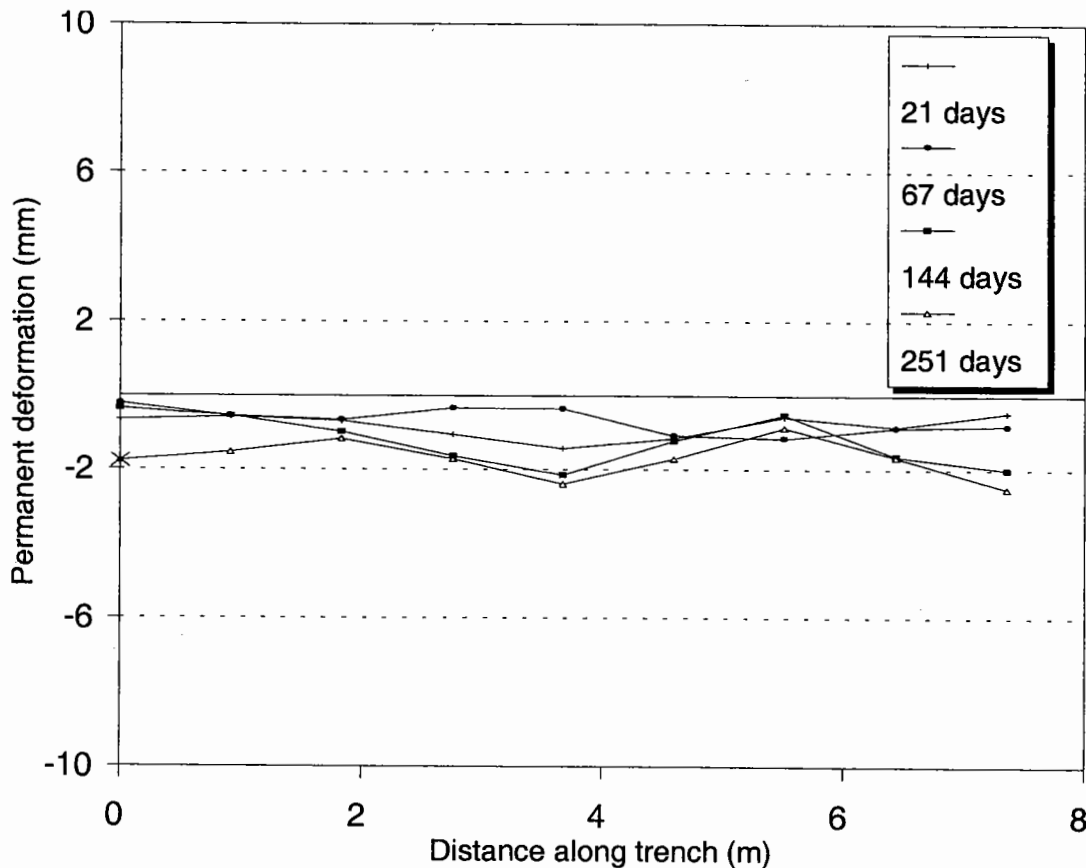


FIGURE 6 Permanent deformation of longitudinal trench backfilled with Lytag:cement mix

TABLE II Elastic modulus of backfill materials determined from core samples

Material	Elastic Modulus (MPa)
Bitumen	1200 ^a
Lytag:cement	9800
PFA:sand:cement	25000

a. Tested at 24°C.

Settlements at 251 days for all the backfill materials examined for longitudinal and transverse trenches are shown in Figures 11 and 12 respectively.

The settlement results of longitudinal and transverse trenches backfilled with PFA:sand:cement were 2 and 1 mm respectively. The corresponding settlement of Lytag:cement were 1 and 2 mm respectively.

The settlement results of longitudinal and transverse trenches backfilled with granular backfill were 6 and 4 mm respectively. This result was expected because cementitious material gains strength with time due to the hydration of cement while the strength of unbound aggregate depends on compaction. However, It should be noted that in all cases settlements are below the intervention limits set in the HAUC Specifications (14 mm for the width of trench used in the trial) (Dept. of Transport, 1992). The satisfactory performance of the granular backfill in this trial suggests that the reported poor performance of such trenches is related to poor site practice and, possibly, inadequate supervision.

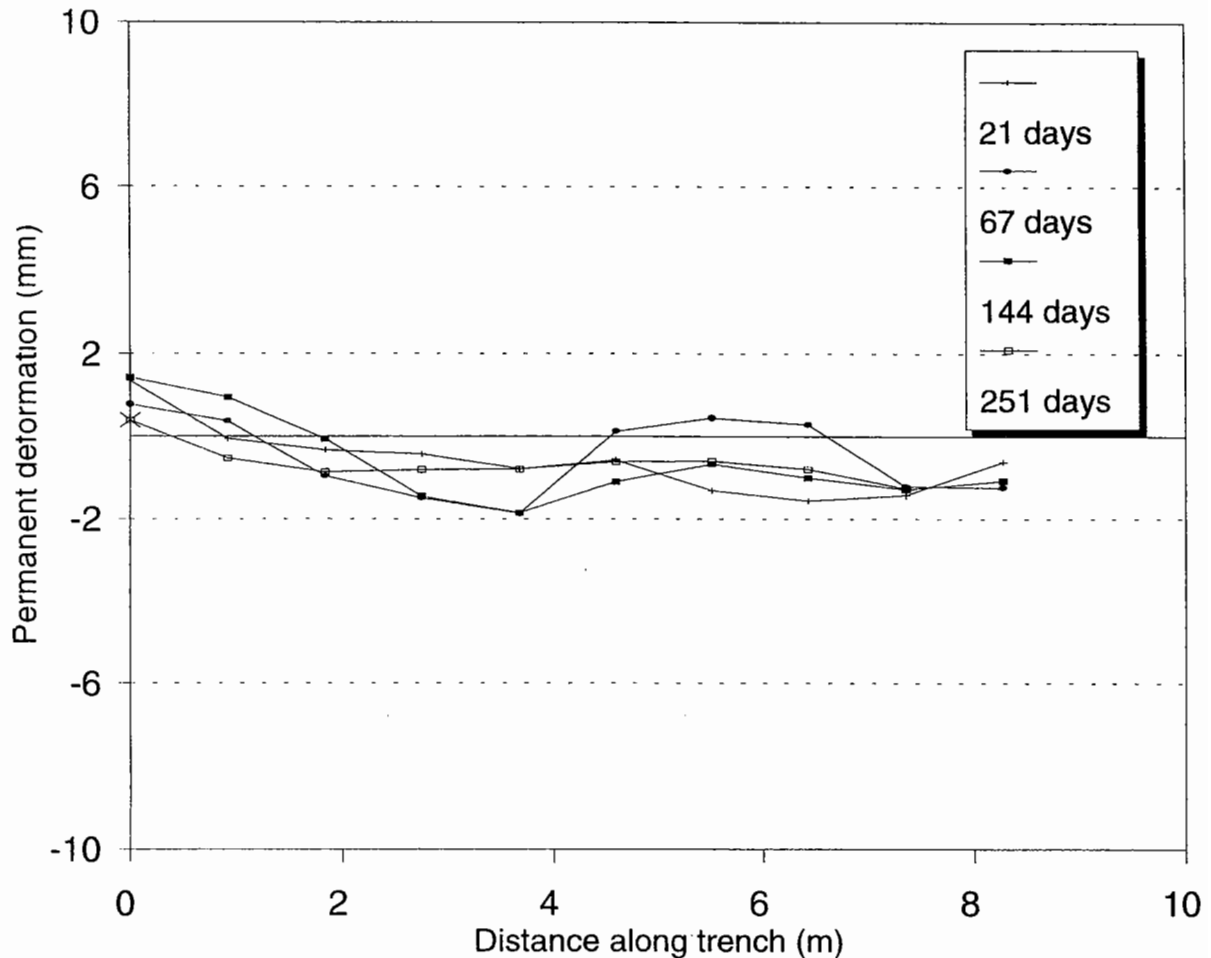


FIGURE 7 Permanent deformation of longitudinal trench backfilled with PFA:sand:cement mix

Peattie (1978) found that settlement (rutting) in the top asphalt layers of flexible pavements contributed up to 50% of the total rutting. Based on this it can be reasonably assumed that a settlement of 1 to 2 mm took place in the blacktop during the monitoring period. This suggests that settlements within the granular backfill were between 1 to 5 mm and settlement within the cementitious backfill was negligible.

For all types of backfill materials, longitudinal trenches showed greater overall settlement than the corresponding transverse trenches. This may be attributed to the fact that the longitudinal trenches were located in the wheel track area of the road while

in the case of a transverse trench most of the traffic is limited to perhaps two locations.

Settlement of trenches took place mainly in the first two months after construction and the rate of settlement became insignificant after that period. This behaviour was only noticeable for the granular backfill.

Core Samples

Core samples of the cementitious backfill materials were recovered one year after the construction of the trenches. Elastic modulus determinations of both the

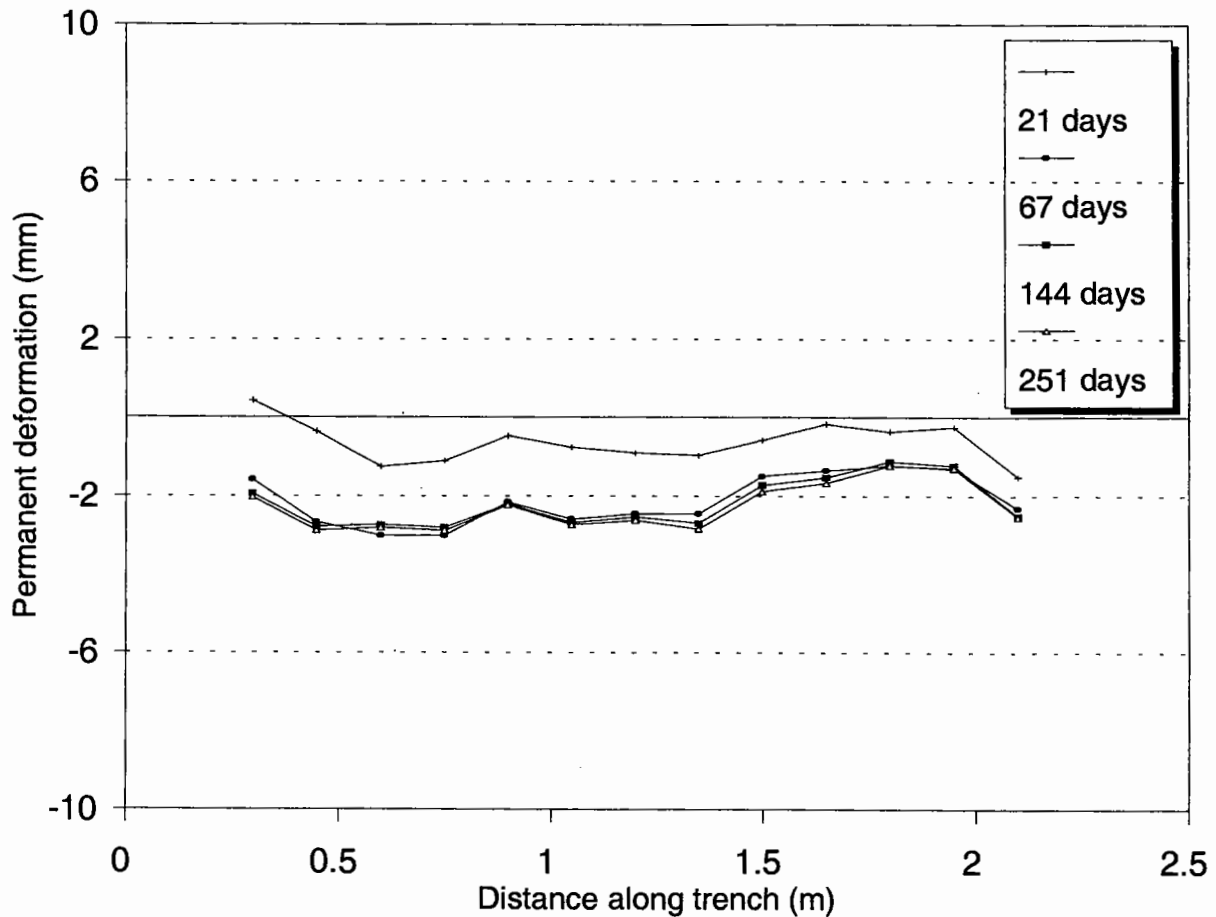


FIGURE 8 Permanent deformation of transverse trench backfilled with Type 1 material

bituminous and the cementitious backfill materials were conducted. The elastic modulus was determined by the indirect tensile test using the Nottingham Asphalt Tester (NAT). The results of these tests are shown in Table II.

Elastic modulus was determined at 24°C so that a comparison could be made with the back calculated modulus from FWD which was carried out at the same temperature. The elastic moduli for both Lytag:cement and PFA:sand:cement were much higher than that of the top asphaltic layer, the PFA:sand:cement mix has a modulus much higher than the other materials. This suggests that the mix was over-designed and a lower cement content may be possible. However, this may require an accelerator

such as calcium chloride to be added to ensure early strength.

Falling Weight Deflectometer Tests

Falling weight deflectometer (FWD) is an important non-destructive test to evaluate the existing structural capacity of pavements. In this project, FWD tests were carried out one year after construction of the trial trenches to study the effects of various backfill materials on the performance of trenches. Details of the FWD testing and numerical analysis for back-calculating elastic modulus values for various layers of the trench section are given elsewhere (Ghataora et al, 1996).

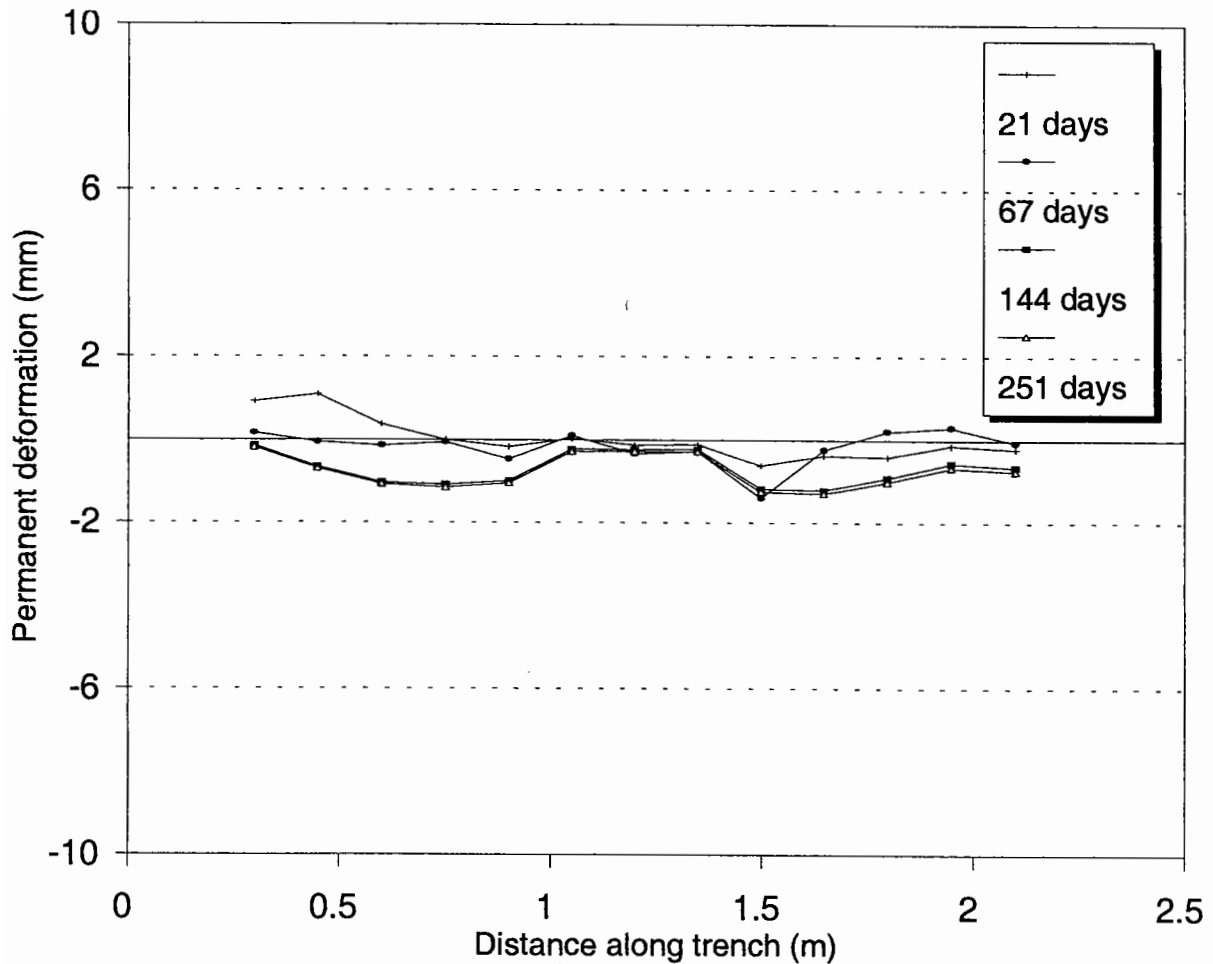


FIGURE 9 Permanent deformation of transverse trench backfilled with Lytag:cement mix

TABLE III Operatives' comments on "break-out-ability" of trench backfill

<i>Trench Type</i>	<i>Time Required to Excavate (minutes)</i>	<i>Operatives' Comments</i>
Granular Type 1	10	Material needed loosening and was easy to excavate.
Lytag:cement	13	As above, but it broke in larger pieces and it was therefore easy to clear out the trench.
pfa:sand:cement	30	Difficult to loosen but easy to clear trench once loosened.

A summary of FWD results for longitudinal trenches is presented in Figure 13. The results show that the elastic deflection of Lytag backfilled trench was slightly smaller than that of the granular backfill, whereas the one with PFA:sand:cement backfill gave only 25% of that with the granular backfill. The low

value of elastic deflection for the PFA:sand:cement backfill reflects the high elastic modulus of the materials as was confirmed by the results obtained in the laboratory on core samples (Table II). Although the surface response of the Lytag:cement backfill to FWD loading was very similar that of the granular backfill,

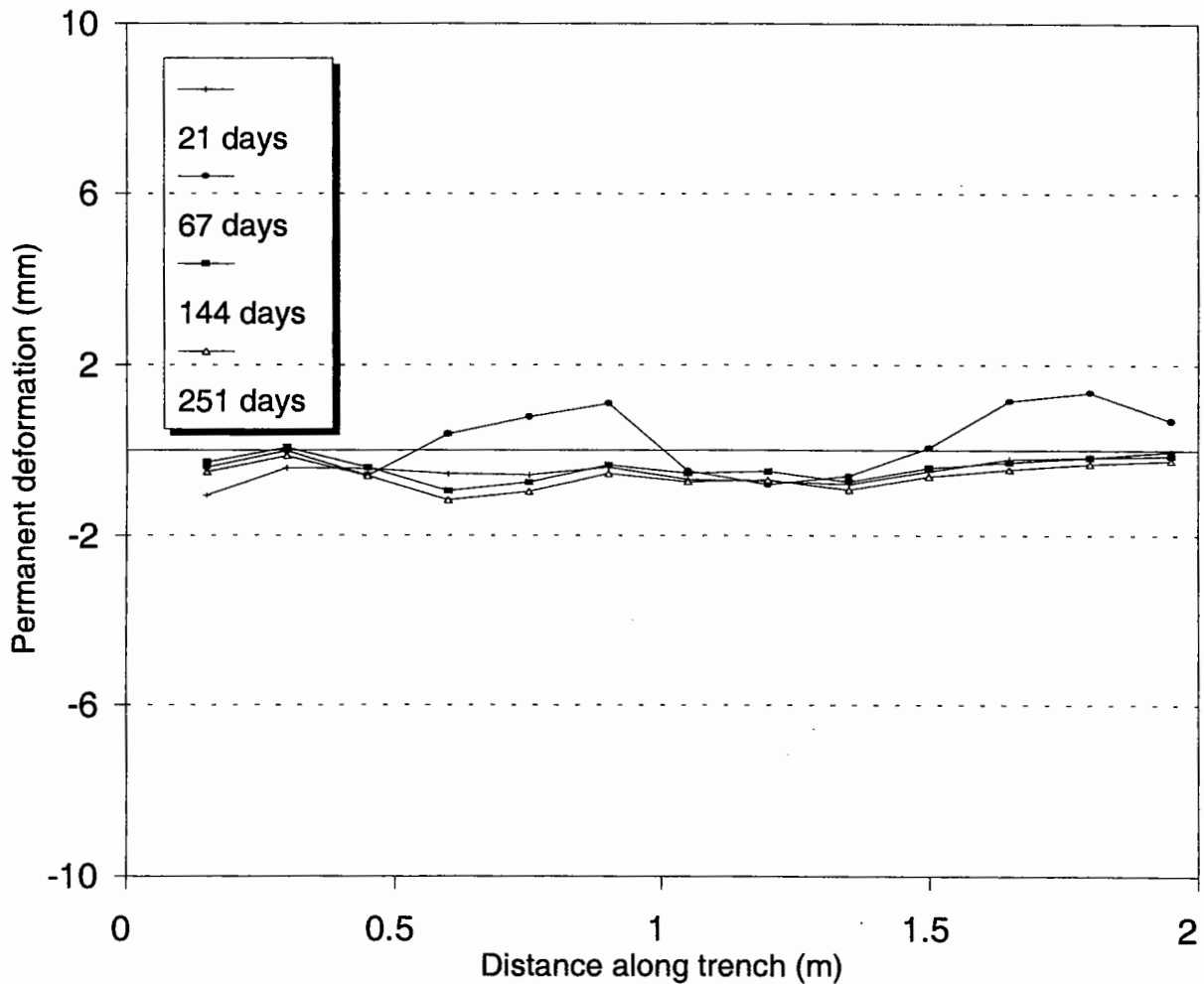


FIGURE 10 Permanent deformation of transverse trench backfilled with PFA:sand:cement mix

laboratory tests (Table II) gave a resilient modulus of 9800 MPa which is much greater than the nominal value for the granular backfill (140 MPa).

This discrepancy may be attributed to the lack of interface friction at the sides of the Lytag:cement trench which led to an elastic deflection that was not compatible with the measured resilient modulus in the laboratory. A more detailed study is required to confirm this explanation. The reduction of elastic deflection for cementitious backfill material is an indication of more efficient distribution of surface loads and therefore is indicative of lower stresses on buried pipes in trenches.

BREAK-OUT-ABILITY

In order to assess the ease with which the new backfill materials can be excavated a one metre length of each of the three transverse trenches was excavated by British Gas personnel. A "Kango" hammer was used to breakout the surfacing and the backfill materials, and a mini excavator was used to remove the loosened material from the trench.

The break-out-ability of the trenches was assessed qualitatively in terms of time required to excavate and operatives' comments. These are listed in Table III. Taking into account that the cementitious materials

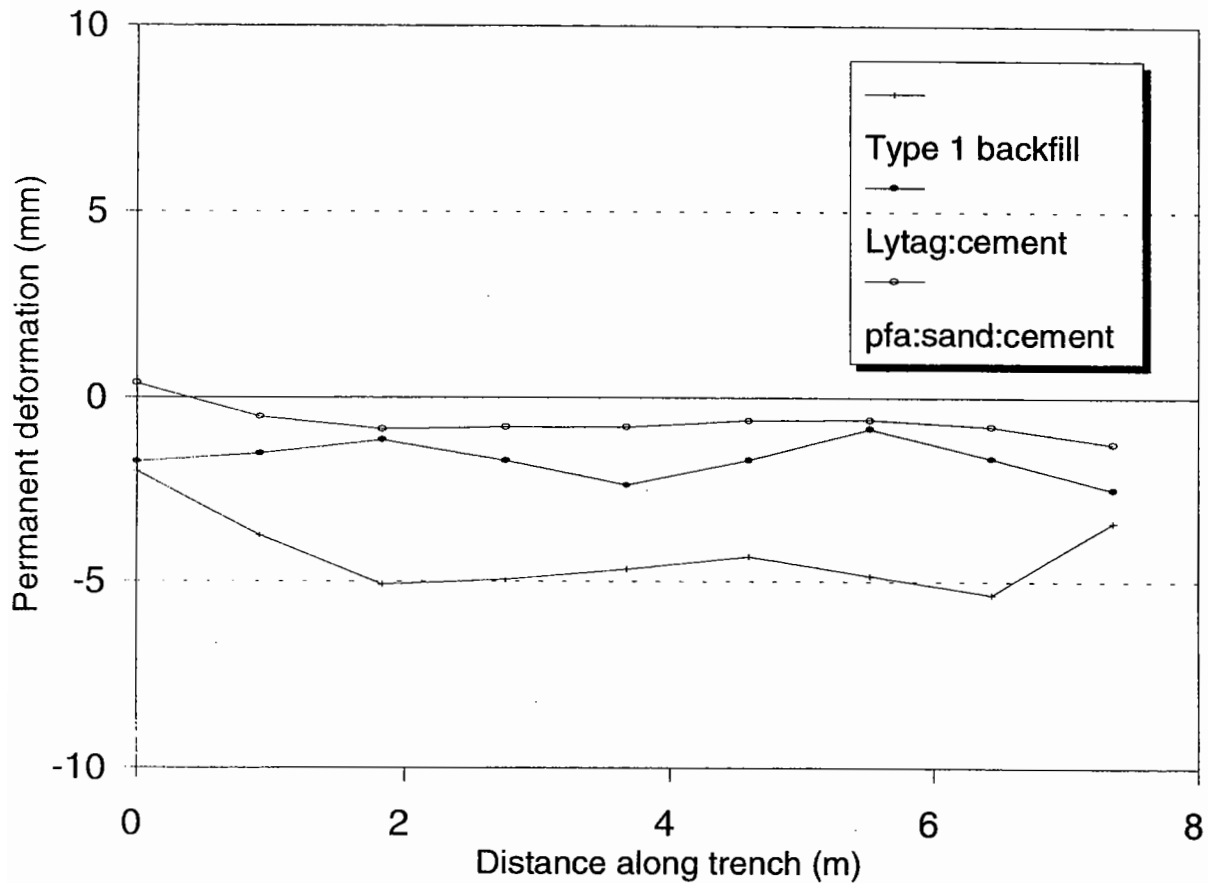


FIGURE 11 Permanent deformation of longitudinal trenches at 251 days

are easy to use for backfilling, Lytag would appear to be the best of the materials tried. The PFA:sand:cement mix was more difficult to break out, therefore a lower cement content may be beneficial provided that an accelerator is used to improve early strength.

COST

Cost analysis was conducted based on prices at the time of the trial. A breakdown of the initial costs for Lytag:cement, PFA:sand:cement and granular backfill is shown in Table IV. These costs include material, labour and equipment. The cost per metre length was

based on a trench cross section of 0.55 m width and 0.5 m depth. Generally the cost of PFA:sand:cement was very close to that of the granular backfill while the cost of Lytag:cement was 12–28% greater than that of the granular backfill. The use of cheaper alternative aggregate to Lytag may reduce the cost.

If one takes long term maintenance cost into consideration, then cementitious material may be more economical than granular materials.

CONCLUSIONS

The following conclusions were drawn from this investigation.

TABLE IV Cost analysis of trench backfill

<i>General Gang Build Up</i>		<i>£/Day</i>	
Excavator		£100.00	
Van		£60.00	
General Labour		£104.00	
Mixer		£8.00	
Labour in mixing		£52.00	
	Total cost per day	£324.00	
Min Charge = 1 day			
Max Output		30 m	
<i>Quantity of Trenching (m)</i>	<i>Time in Days to Nearest Whole Day</i>	<i>Total Cost of Labour & Plant etc.</i>	<i>Equivalent Cost per (m) of Trench</i>
1	1	£324.00	£324.00
5	1	£324.00	£64.80.
10	1	£324.00	£32.40
25	1	£324.00	£12.96
50	2	£648.00	£12.96
100	4	£1,296.00	£12.96
250	9	£2,916.00	£11.66
500	17	£5,508.00	£11.02
600	20	£6,480.00	£10.80
750	25	£8,100.00	£10.80
<i>Summary of material costs per (m³)</i>			
		<i>Cost per (m³)</i>	<i>Cost per (m)</i>
Lyttag:cement		£39.44	£11.93
PFA:sand:cement		£22.51	£6.81
Granular backfill		£23.00	£6.96
<i>Examples of Costs for Various Options</i>			
<i>Based on total quantity of 500m</i>			
	<i>Labour & Plant etc. per (m)</i>	<i>Material Content per (m)</i>	<i>Total Rate per (m)</i>
Lyttag:cement	£11.02	£11.93	£22.96
PFA:sand:cement	£11.02	£6.81	£17.83
Granular backfill	£11.02	£6.96	£17.97
<i>Examples of Costs for Various Options</i>			
<i>Based on total quantity of 10m</i>			
	<i>Labour & Plant etc. per (m)</i>	<i>Material Content per per (m³)</i>	<i>Total Rate per (m)</i>
Lyttag:cement	£32.40	£11.93	£44.33
PFA:sand:cement	£32.40	£6.81	£39.21
Granular backfill	£32.40	£6.96	£39.36
<i>Cost of backfilling various lengths of trench</i>			
<i>Total Quantity</i>	<i>Lyttag:cement</i>	<i>PFA:sand:cement</i>	<i>Granular backfill</i>
10	£44.33	£39.21	£39.36
25	£24.89	£19.77	£19.92
50	£24.89	£19.77	£19.92

75	£24.89	£19.77	£19.92
100	£24.89	£19.77	£19.92
125	£24.89	£19.77	£19.92
250	£23.59	£18.47	£18.62
500	£22.95	£17.83	£17.97
600	£22.73	£17.61	£17.76
750	£22.73	£17.61	£17.76

All in Rate per (m)

Approximate exchange rate £1 = \$1.5 = Euro 1.6

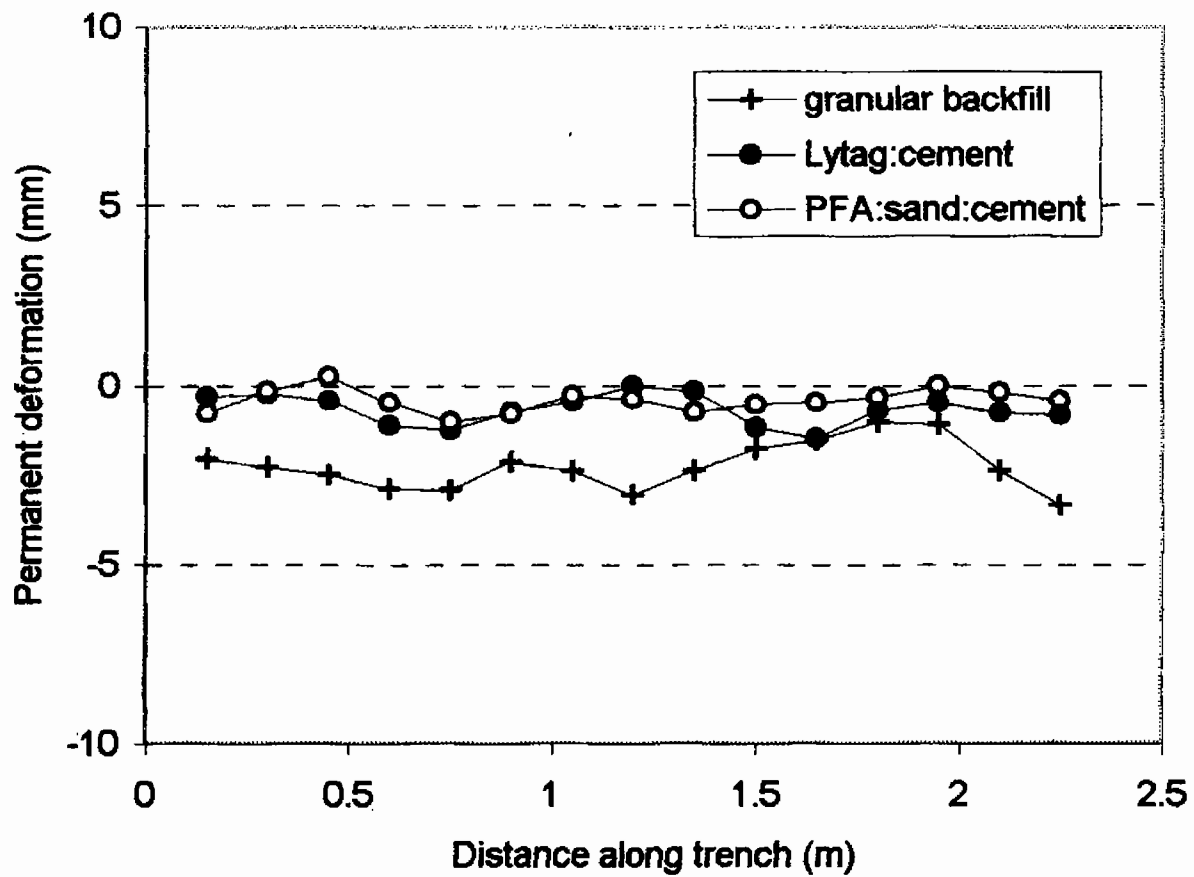


FIGURE 12 Permanent deformation of transverse trenches at 251 days

- The new backfill materials could be successfully batched and placed in a trench with inexperienced labour using standard mixing plant.
- Settlement with the granular backfill ranged between 2 and 5mm while cementitious material exhibited settlements between 1 and 2mm.

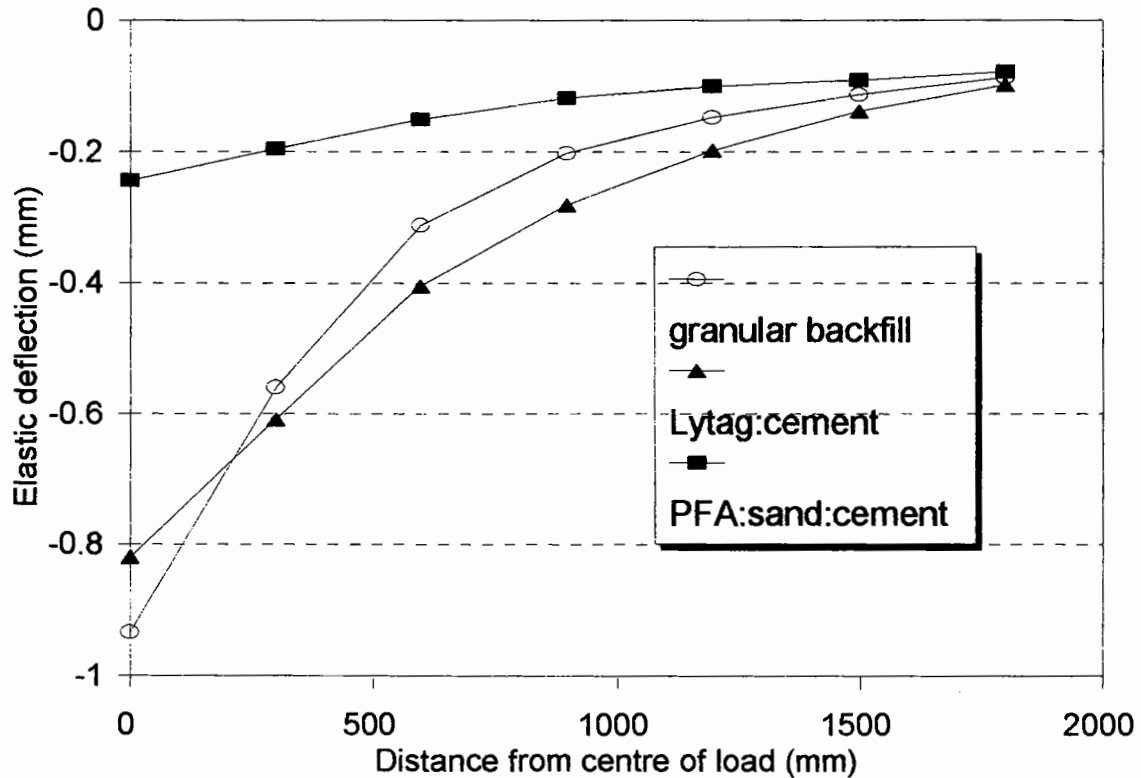


FIGURE 13 Effect of various backfill materials on FWD deflection bowls

- For all types of backfill materials, longitudinal trenches showed more settlement than the corresponding transverse trenches.
- Settlement of trenches took place mainly in the first two months after construction and the rate of settlement became insignificant after that period of time.
- Field trials have shown that cementitious materials performed better than the conventional granular backfill both in terms of having less permanent deformation and less elastic deflection.
- Lytag:cement backfill was favoured by the operatives as it could be broken out and handled as easy as the granular backfill.
- The initial cost of PFA:sand:cement was very close to the granular backfill whereas Lytag:cement was 12–28% more expensive. If

long-term performance is considered, cementitious backfill may be more economical even though the initial cost is higher.

Thus, in summary, it has been shown that cementitious materials can be used for backfilling trenches at a competitive price to granular backfill and need less maintenance in the long term.

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