Some New Backfill Materials for Cut-off Diaphragm Wall Construction

by

R.L. Makol*

R.K. Bhandari**

Introduction

In sandy formations, where the engineering requirement is seepagae control rather than retaining of earth, cut-off diaphragm walls constructed using reinforced cement concerete as well as steel sheet pile walls are uneconomical Cheaper backfill materials in lieu of reinforced cement concrete seem to hold considerable promise as revealed by the field study presented in the paper. Generally speaking a back fill material should be such that it is practically impermeable, having coefficient of permeability (k) in the range of 10^{-6} cm/sec to 10^{-10} cm/sec; its strength is not less the ground in which it is constructed it is sufficiently deformable so as to withstand, without cracking, the strains due to ground deformation; it is not susceptible to erosion by passage of water through the wall; shrinkage upon setting does not lead to cracking; it could be easily mixed and poured into slurry trenches through tremie pipes; are its ingredients are easily available at the construction sites. The findings presented in the paper leads to, definite recommenations on the backfill materials which satisfy the above requirements.

Review of Previous Work

Mohan, Makol and Jaid (1975) have recommended the use of thin reinforced cement concrete diaphragm walls as an effective and economical alternative to the steel sheet pile walls. Hetherington et.al (1975) reported the use of backfill materials prepared from the sand and gravel excavated in situ plus bentonite and cement. They however, did not study whether the backfill material fullfilled all the essential requirements. Little (1975) has reported on the use of three different specifications of plastic concrete in construction of three embankment dams and also the use of a self setting slurry in the construction of yet another embankment dam. Bentonite flyash and cement with lignosulphite were mixed with water to make self setting slurry. In the case of self setting slurry, the use of stop end tubes for jointing of panels and use of tremie pipe for filling the backfill material in the trenches were eliminated. Because the slurry in the trench itself hardened with time and freshly laid slurry in one panel had the same composition as the adjacent panel after setting, the joints could be easily made by excavating a key into the set material. Annon (1976) has described a method in which cement slurry and chemical gelling agents were mixed with bentonite slurry present in the trench. The mixing was

* Scientist, Central Buildiug Research Institute, Roorkee, India.

** Scientist Co-ordinator, Central Building Research Institute, Roorkee, India.

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done for about ten minutes with the help of air sent through a hose pipe. The compressive strength of the hardened wall material after 28 days was found to be 10 kg/cm². This method has all the advantages of the one described earlier (Little 1975). But both of these methods do not seem to ensure the uniformity of wall material upto full depth, because of the varying proportions of suspended materials at different depths. A method in which the bentonite slurry present in the trench is fully displaced with a suitable backfill material by termie pipe is therfore considered as more desirable. Makol and Bhandari (1979) have tested the strength, impermeability and deformability of a number of mix compositions prepared in the laboratory from the point of view of their use in backfill materials in diaphram wall construction. Basic relationships of above properties with the proportions of their ingredients were determined and based on the study, specifications of a few backfill materials were recommended.

Laboratory Study

Specifications af the ingredients like sand, sandy soil, clay, gravel, cement, flyash and Bentonite used in the preparation of new backfill materials are given in Table 1. The ingredients were dried and proportioned by weight. Dry mixing was done and then water was gradually added in stages. The mixing was continued till the slump of the mix reached a

TABLE 1

Sl. No.	Material	Specification
1.	Portland Pozzolana Cement	Conforming to IS : 1489-1976 fineness $\nless$ 3000 cm²/gm Setting time 30 minutes minimum, initial 600 minutes minimum final 1 : 3 Cement—Sand 7 days compression strength = 220 kg/cm² min. 28 days compression strength = 310 kg/cm² max.
2.	River sand	fine sand......98 per cent medium sand.. 2 per cent coarse sand... Nil } poorly graded sand SP
3.	Clay	Liquid limit = 42 per cent Plastic limit = 20 per cent Plasticity Index = 22 per cent } Clay with medium compressibility CI
4.	Bentonite	Liquid limit = 288 per cent Plastic limit = 48 per cent Plasticity Index = 240 per cent } Sand = 5.9 per cent Silt = 12.9 ,, Clay = 81.6 ,,
5.	Flyash	Conforming to IS : 3812—1966 Part I 1. fineness.... $\nless$ 3200 cm²/gm 2. Lime reactivity hydrated lime and flyash 1 : 2 7 days compressive strength.... > 40 kg/cm²
6.	Aggregate	< 20 mm well graded rounded particles GW

value of 15-20cm which is generally used in tremie concreting. The mix was then cast in a number of laboratory moulds. After setting, the specimens were demoulded and kept under water for curing. The bulk density, moisture content, compressive strength and percentage strain at failure for confined and unconfined conditions were measured after curing. The mix was also cast in the moulds for variable head permeability tests. Continuous flow of water through the specimen was maintained for 28 days and coefficient of permeability was determined at various intervals of time. The details of mix compositions studied and the test results are given in Table 2 through Table 6.

Construction of cut-off diphragm walls

Using CBRI diaphragm walling technique, Mohan, Makol and Jain (1975), eight cut-off diaphragm wall panels were constructed in the field. Mechanical analysis of the sandy soil at the construction side is given in Table 1. Each wall panel was 1.50m long, 0.225m thick and 3.50m deep.

The proportioning of ingredients of backfill materials at the site was done by volume as generally adopted in the RCC wall construction. Mixing was done manually till the slump of the mix was 15-20 cm. The mix was filled in the slurry trench with special tremie pipe arrangement. Use of stop-end tubes or semi circular cutter was not necessary for joining of panels with each other in as much as cutting of a key into the freshly set material was possible within them. After the construction of all the wall panels in a line, the panels were exposed by excavating the soil upto 1.75m depth on both faces, Figure 1. The chunk samples of wall panels were taken from a depth of 1.50m. A number of cylindrical specimens were prepared from each chunk sample and stored under water. The specimens were tested in the laboratory after 28 day of casting. The test results are shown in Tables 3 through Tables 6.

TABLE 2

Mix Compositions

Panel No.	Proportions of air dried materials by volume
1	Cement : Bentonite : Sand 1 : 1 : 8
2	Cement : Sand 1 : 4
3	Cement : Bentonite : Silty Sand : Gravel 1 : 1 ; 6 : 2
4	Cement : Clay 1 : 6
5	Cement : Sand : Gravel 1 : 1½ : 3
6	Cement : Sand : Gravel 1 : 2 · 4
7	Cement : Bentonite 1 : 1
8	Cement : Bentonite : Flyash 2 : 1 : 2

TABLE 3

Permeability test results Slump of freshly prepared backfill material 15-20 cm

Panel No.	Laboratory specimens K cm/See $X\,10^{-6}$					Field Specimens K cm/Sec. $X\,10^{-6}$
	one day	4 days	7 days	14 days	28 days	28 days
1	4.2	2.09	1.19	0.573	0.298	1.87
2	160	—	43.3	14.0	4.2	4.1
3	—	0.54	0.054	—	—	—
4	7.2	—	—	0.71	0.34	2.2
5	2.08	0.463	0.209	0.062	0.028	—
6	4.72	1.24	0.70	0.24	—	—
7	0.90	0.28	0.055	0.043	—	0.90
8	—	0 0102	—	—	—	0.16

TABLE 4

Bulk Density and Moisture Slump of freshly prepard backfill fluid 15-20 cm

Panel No.	Laboratory		Field		Remarks
	Bulk Density kg/m³	moisture (per cent)	Bulk Density kg/m³	moisture (per cent)	
1	1891	30.2	1930	26.0	Chunk Sample
2	2070	20.6	1940	23.9	Chunk Sample
3	2040	27.7	—	—	No field sampling due to aggregate
4	1770	39.5	1660	43.2	Chunk Sample
5	2277	19.1	—	—	No field sampling
6	2254	10.4	—	—	No field sampling
7	1530	76.5	1510	76.1	Chunk sample
8	1600	46.6	1730	47.8	Chunk sample

Measurement of Wall Thickness

The excavated wall panels are shown in Figure 2. The thickness of the wall panels at the points marked in a grid of 30 cm$\times$30 cm was measured to an accuracy of $\pm$ lmm using arrangement shown in Figure 3.

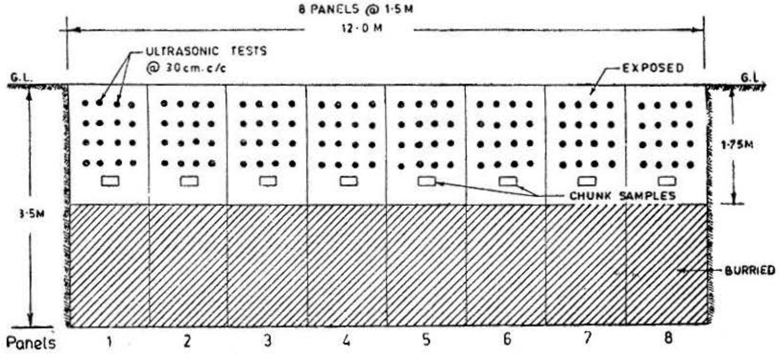


FIGURE 1 Details of wall Panels

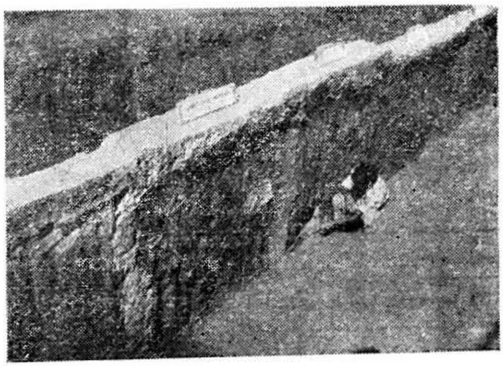


FIGURE 2 Exposed wall panels

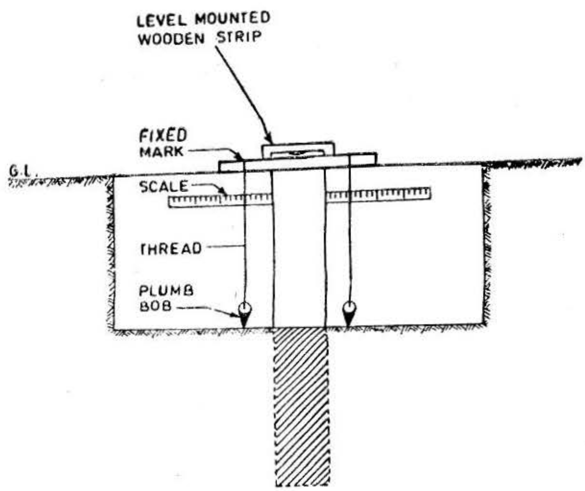


FIGURE 3 Measurement of wall thickness with scale and plumb bob arrangements

TABLE 5

Unconfined compression strength and percentage of strain at failure Slump of freshly prepared backfill fluid 15-20 cm

Panel No.	Uneonfined compression strength kg/cm²				Percentage Strain at failure		
	Laboratory Specimen		Field Specimen	Strength of field specimen / Strength of laboratory specimen	Labora-tory	Specimen	Field Specimen
	14 days	28 days	28 days	28 days	14 days	28 days	28 days
1	7.1	8.16	6.36	0.86	0.2	2.66	2.0
2	13.7	16.3	9.2	0.575	2.33	2.33	2.0
3	—	—	—	—	—	—	—
4	5.75	—	3.7		2 0	—	1.66
5	—	—	—	—	—	—	—
6	—	—	—	—	—	—	—
7	21.3	34.4	12.0	0.348	4.0	6.0	2 66
8	16.09	—	33.67	—	3.34	—	4.62

TABLE 6

Consolidated Drained Triaxial Test Results

Panel 1	Cement 1 Bentonite 1 Sand 8 Curing period 4 days		Panel 4	Cement 1 Clay 6 Curing period 14 days	
Lateral pressure kg/cm²	Effective Compression stress at failure kg/cm²	Strain (per cent) at failure	Lateral pressure kg/cm²	Effective compressive stress at failure kg/cm²	Strain (per cen) at failure
0	2.40	1.66	0	5.75	2.0
1.038	7.70	6.20	1.038	7.40	4.0
2.07	9.40	8.50	2.07	10.50	4.7
3.114	13.0	10.0	3.114	12.80	4.7

Ultrasonic Testing

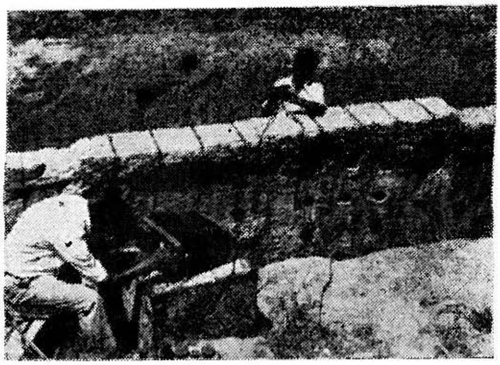
The non-destructive testing of wall panels was carried out, using ultrasonic pulse velocity technique, used by Rajagopalan(1975). This technique had been ealier used in the laboratory testing of mortar and concrete cubes and in the field testing of a pile foundation, Rajagopalan (1976, 1977). This technique, for the first time has been used by the authors in the field testing of cut-off diaphragm walls. The time required for the ultrasonic pulse to transmit from one face of the wall to the other was measured to an accuracy of 1 micro second, Figure 4. The velocity of pulse at 16 different points on each wall panels is shown in Figure 5.

Discussion

Referring to the composition of the eight panels cast (Table 2), the major constituents of the fiirst four panels are seen to be sandy soil, clay soil and gravel, all of which are usually available at any construction site. In these panels only 15 per cent to 20 per cent of fine materials like cement and Bentonite are added. The materials of panels 5 and 6 contain 350 to 400 kg of cement per m^3 of concrete. Because aggregate is comparatively costlier than sandy and clayey soils, these materials are uneconomical on comparison with the materials of the first four panels. The panels 7 and 8 consisted of Bentonite, cement and flyash which have proved still costlier in view of the large quantity of cement required. However, in camparison with reinforced cement concrete, materials of all the eight panels prove economical.

Study of Table 3 reveals that permeably co-efficient (k of all the eight materials range between 10^{-6} cm sec and 10^{-8} cm sec. The coefficient of permeability of gravelly or sandy soils in which the cut-off walls are generally constructed ranges between 10^{-1} cm sec and 10^{-4} cm sec. Therefore, seepage of water after the construction of cut-off wall of adequate depth having the above ranges of k value could be expected to reduce to one 100th to 10000th of its initial value. The coefficient of permeability in all cases is found to reduce with curing period. Therefore, the actual value of permeability in the field should be still smaller than the values because of curing periods being longer than 28 days. Higher lateral confinement of the wall at greater depths may further reduce the permeability. It coule therefore, be concluded that all the eight materials are suitable from the consideration of impermeability.

Deformability of backfill material is indicated by the percentage of strain at failure. The results shown in Table 5 indicated that during unconfined compression tests, the value of strain at failure ranges between 1.66 per cent and 6.0 per cent. Results shown in Table 6 reveal that for materlals of panel 1 and 4 the strain percentage at failure considerably increases with effective lateral pressure. For panel 1, it increased from



FIGURF 4 Ultrasonic pulse velocity measurement

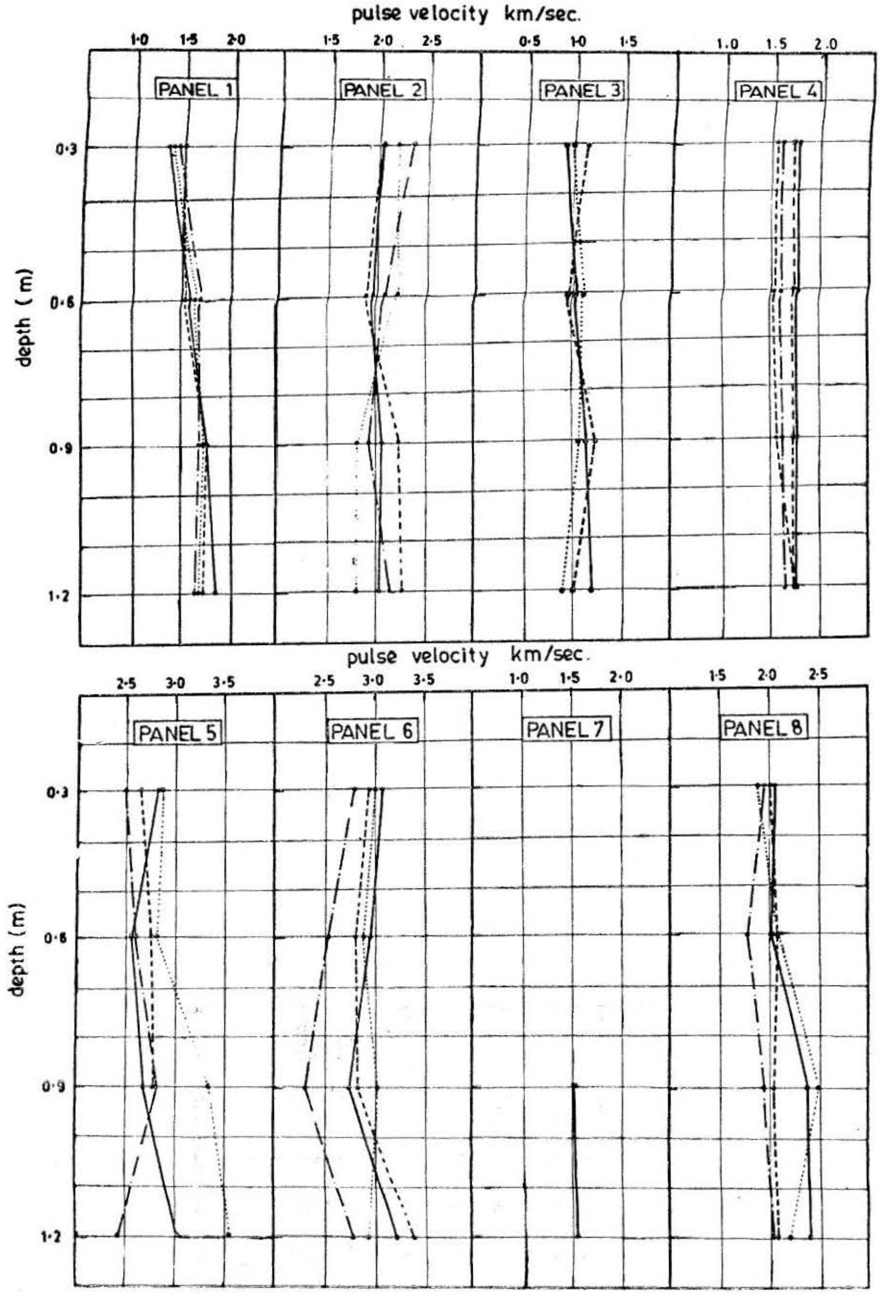


FIGURE 5 Pulse velocity of wall Materials.

1.66 per cent to 10 per cent and for panel No. 4, it ranged from 2.0 per cent to 4.7 per cent for increase in effective lateral pressure from 0 to 3.114 kg/cm². The cut-off walls have to accommodate vertical and horizontal movements and a figure of 5 per cent deformation without rupture is suggested by Dupeuble and Habib (1969). The study of above results shows that material of panels 1 to 4 are suitable. The concretes (Panel 5 and 6) are rigid materials which could fail at a strain as low as 0.5 per cent and are unsuitable for this reason. The materials of panel 7 and 8 are also quite deformable as indicated by values of 6 per cent and 4.62 per cent given in Table 5. Therefore, from this consideration, material of panels No. 1 to 4 and 7-8 are suitable backfall materials.

The compressive strength of all the materials shown in Table 5 varies from 3.7 kg/cm² to 34.4 kg/cm². The compressive strength of concretes samples would be higher than these. It is clear from above data that the strength of all these materials is higher than the strength of the ground in which the walls are made. Moreover, the results shown in Table 6 indicate that the strength of materials (panel 1 and 4) will further increase with the effective confining pressure in the field. From the considerations of strength, therefore, all the eight compositions are satisfactory.

The thickness of all the cut-off wall panels constructed in the field was kept as 22.5 cm. On measurement it was found to vary between 21 cm and 24 cm. This shows a variation of ± 7 per cent from the average value. It is considered acceptable and indicates the accuracy of CBRI diaphragm walling process used in the construction of thin cut-off walls of greater thickness.

The ultrasonic pulse velocity of all the wall panels, Figure 5, varies between 1000 m/sec and 3500 m/sec. The higher value is for the denser and stronger materials and the lower ones for lighter materials. Distribution of velocity with width and depth of panels indicates that the materials are fairly uniform. The variations of pulse velocity in panels 1 to 4 are quite small and therefore they indicate the suitability of mix composition used. Scatter of values was observed in panels 5 and 6. This may be due to high percentage of coarse aggregates. In panel 7 only a few values of velocity could be recorded. This may be due to discontinuity of cracks developed consequent upon shrinkage in the panel due to high proportion of Bentonite used. The results of panel 8 also show appreciable scatter and indicate the backfill materials containing more than 10 per cent Bentonite show problems in uniform casting of wall panels.

Concluding Remarks

Most locally available soils when mixed with suitable proportions of cement, flyash and Bentonite yield backfill materials which could be used in lieu of reinforced cement concrete in the construction of cut-off diaphragm walls. The admixtures for local soils, classsified as CI, SP, SM and GW, are recommended in Table 7. Following the recommendations, the backfill materials could be trusted for their strength impermeability and deformability provided they are fully burried and exist without differential earth loading, They prove economical in comparison with reinforced cement concrete and steel sheet pile walls when used for seepage control.

TABLE 7

Recommended proportions

S. No.	Local basic material	IS Classification	Proportion by volume (Dry materials)
1	Clayey soil	CI	Cement : Clayey soil 1 : 6
2	Clean Sand	SP	Cement : Bentonite : Sand 1 : 1 : 8
3	Clean Sand	SP	Cement : Sand 1 : 4
4	Silty Sand and Gravel	SM & GW	Cement : Bentonite : Silty Sand : Grave 1 : 1 : 6 : 2

The CBRI diaphram walling process hitherto applied for constructing reinforced cement concrete diaphragm walls could also be successfully employed when backfill materials other than reinforced cement concrete were used. Measurements made on eight continuous panels of different compositions, 22.5 cm thick and 3.50 m deep revealed the wall thickness within $\pm$ 7 per cent. Jointing of panels for backfill materials studied was also relatively simpler in as much as a key could be easily cut into the freshly set wall materials.

The ultrasonic pulse velocity technique seem to hold a great potential in the non-destructive testing of the exposed cut-off diaphragm walls and determining the degree of homogeneity of materials in each wall panel. In the present study panels 1 to 4 were found to be fairly homogeneous, panels 5, 6 and 8 were found to be hetrogeneous and panel 7 reflected certain amount of cracking. The reliability of pulse velocity technique was reassuring when exposed wall panels were visually studied. The cracking was attributed to excess of Bentonite and it would be concluded that more than 10 per cent Bentonite should not be used.

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