by Dr. G. S. Littlejohn, Ground Engineering Division, Cementation Co. Ltd.

Ground anchors in civil engineering: 2

Recent developments in Ground Anchor Construction

During recent years there has been an increasing demand for a means of anchoring both temporary and permanent structures, due primarily to the increasing tendency to design buildings with a number of basement floors. This makes it necessary to carry out very deep excavations in both soil and rock, the floor of the excavation being often at considerable depth below the foundations of the neighbouring properties (see Fig. 1.). In such cases, shoring of the piling in the traditional way by means of interior strutting is unattractive since the working space available is often severely limited.

It is the existence of this type of problem in connection with the shoring of sheet piling and support walls, together with the anchoring of foundations, masts and towers that has brought about the development of simple flexible methods of making anchorages in gravels, sands, clays and more recently chalk.

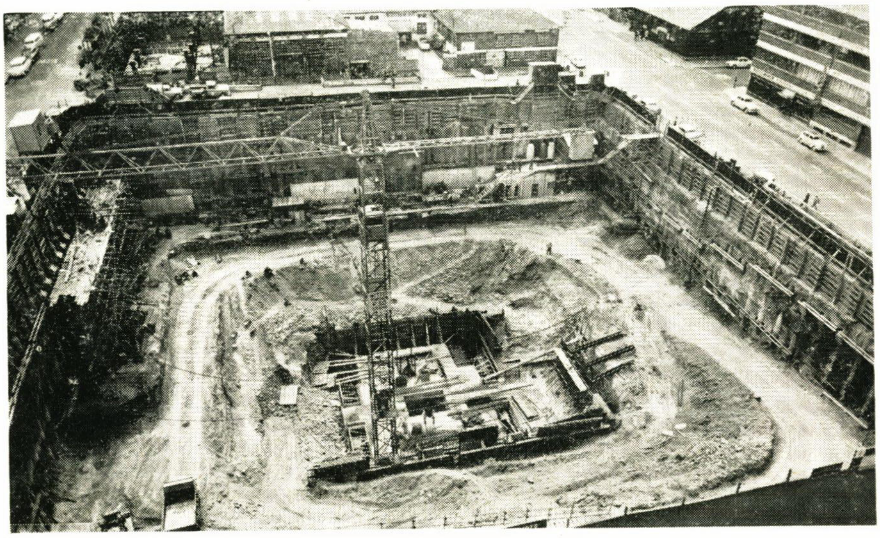


Fig. 1: Basement excavation for Rand Daily Mail Building with piles anchored by 300 steel cables, each of 40 ton load.

1. *ANCHORS IN GRAVEL*

Alluvium anchors can be formed in any load bearing ground down to and including clay but the highest resistances to withdrawal are obtained in gravels and coarse sands where the permeability is not less than 10^{-2} cm/sec. In homogenous ground of this type, anchors are designed to resist safe working loads of up to 80 tons.

Construction

The method which is employed for anchorages in gravel entails a number of working operations as follows:—

(a) Driving a lining tube, 2 in—4 in (5—10 cm) nominal diameter, through the ground to the desired depth (see Stages 1—3, Fig. 2).

(b) Homing of the cable which consists of high tensile steel strands or wires (see Stage 4).

(c) Pressure injection (grouting of hole with neat cement and water) whilst withdrawal of the lining tube takes place (see Stages 5—9).

Grout W/C ratios of 0.5 and 0.65 are recommended for gravels and coarse sands respectively, and the injection pressure may vary from 5 to 150 lb/in^2 (0.35 to 10.5 kg/cm^2) depending on the permeability of the ground. In the case of temporary works, where only a minimum time is required between anchoring and tensioning a high alumina cement is used which enables the cable to be stressed 24 hours after construction.

(d) Withdrawal of the lining tube completely (see Stage 10).

(e) Following hardening of the grout the cable is stressed to the desired load (see Stage 11).

Thus the anchorage is based on grout injection and consists basically of a cable which is bonded into a grouted zone of alluvium and is known as the fixed anchorage. The rest of the cable is encased in a protective sheath to prevent the cable from coming into contact with the surrounding ground and also to provide a safeguard against corrosion.

A special VSL movable anchorage is

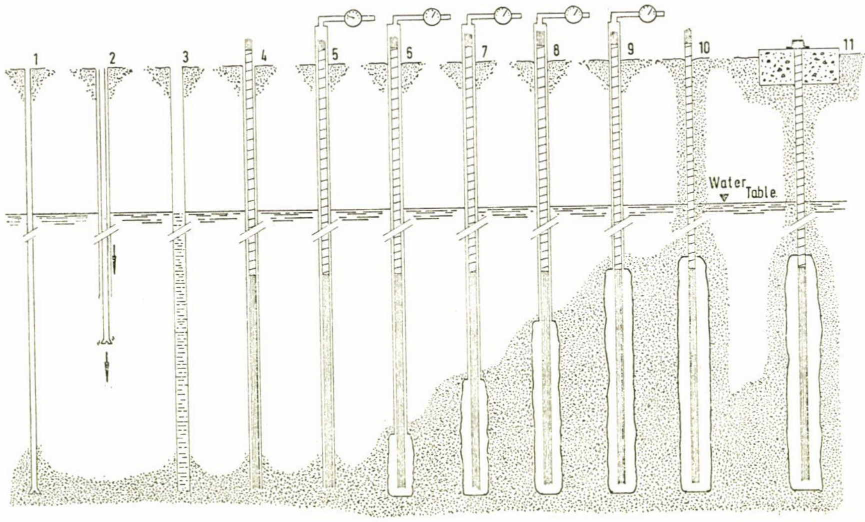


Fig. 2: Stages in the construction of an alluvium anchorage.

used for stressing, which allows the post-tensioning to be carried out in any required number of stages and at any time after construction. This post tensioning pre tests the anchor, thus ensuring its safety.

Safety.

The importance of this feature in prestressed ground anchors cannot be over-emphasised and the following notes are included to define the term "Safety" in more detail.

The notation below is used by the Cementation Co. Ltd. for Ground Anchors.

Tb = minimum breaking load of the steel cable.

Tf = failure load of the grouted fixed anchor.

Tt = maximum allowable test load to which an anchor can be temporarily subjected in order to check its capacity.

Tw = the working load of the anchor.

Sb = Factor of Safety against breaking of cable.

Sf = Factor of Safety against bond failure between grouted fixed anchor and adjacent ground.

The measured Factor of Safety against cable failure (Sb = 1.5 (or greater). The careful checks carried out on all the tensile steel and anchorage components employed guarantees this safety for each ground anchor.

The measured Factor of Safety against withdrawal of the complete fixed anchor (Sf = 1.5 to 3.0) is evaluated on site by carrying out a temporary test loading. The allowable test load (Tt) however is limited by the elastic limit of the steel cable and consequently Sf = Tt/Tw (or greater). This method of testing takes into account the fact that the local ground conditions in the fixed anchor zone, which are of the utmost importance, often vary considerably. It normally establishes, however, only very small minimum values for the safety against fixed anchorage withdrawal.

In homogeneous ground therefore, another form of check is used where a test anchor with an overdesigned cable is pulled to failure, to establish the ultimate resistance to withdrawal of the fixed anchor. In this way the optimum fixed anchor length for the remaining anchors can be determined. If however, the jacking capacity is insufficient to fail a typical working anchor, then a test anchor is constructed with a reduced fixed anchor length whose failure load, Tf is expected to be less than the test load Tt.

It should be noted that the Factors of Safety referred to in this section are measured values and consequently should not be compared with the larger Safety Factors often employed by foundation engineers to take account of situations which defy calculation.

Resistance to Withdrawal

As already indicated, working loads of up to 80 tons can be attained in gravels, and test anchors constructed at depths of 50 ft. (15.2 m) below ground surface have mobilised maximum resistances to withdrawal of 200 tons, when pulled to failure.

Typical ground anchor details to produce these high resistances are as follows:—

Total depth of anchorage = 50 ft (15.2 m)

Length of fixed anchor = 12 ft (3.6 m)

Effective diameter of fixed anchor = 16 in (40.6 cm)

Quantity of cement injected = 6 cwt (305 kg)

Angle of internal friction (ϕ) = 40 deg.

As a result of testing anchorages with different fixed anchor lengths it may be concluded that the tensile force is mainly transferred to the ground by skin friction, and the following empirical rule has been established for the calculation of ultimate resistance to withdrawal (Tf) of anchors constructed in coarse sands or gravels.

Tf = L.N tan ϕ

where

L = Length of fixed anchor (ft)

and N = 12 – 16 tons per foot.

A recent example of a successful contract, carried out by Losinger & Co., Berne, is shown in Fig 3, where a total of 111 temporary anchors of 65 ton capacity (Sf = 3) were installed in semi-coarse gravelly ground.

A reinforced concrete retaining wall had been constructed by the E.L.S.E. (slurry trench) method along one side of the site of an underground car park at the Berne Town Hall. The wall is 380 ft (115.8 m) long, 50 ft (15.2 m) high and 32 in (80 cm) thick and is very close to an existing line of buildings. The anchors were formed in the alluvium beneath these buildings.

2. *ANCHORAGES IN SAND.*

(a) **Alluvium Anchors using Cement Grout**

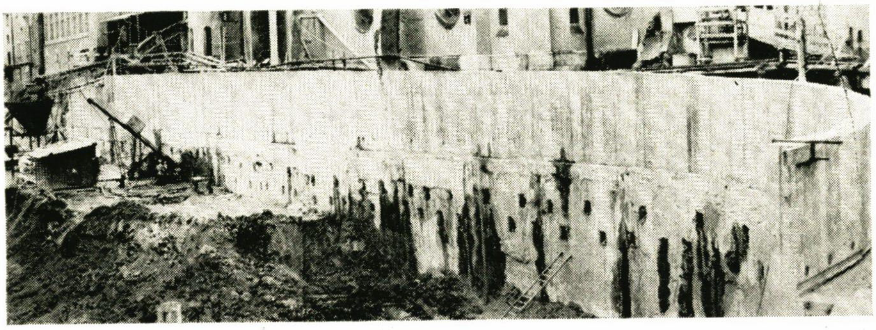
Construction.

When the standard procedure already described for gravels is adopted in fine to medium sized sands, the fixed anchor formed consists of a relatively smooth grout cylinder (see Figs 4 and 5) since the sand does not allow permeation of the dilute cement grout. The diameter of the fixed anchor depends on the size of casing and the injection pressure employed, and in compact medium sand with an injection pressure of 75 lb/in^2, (5.2 kg/cm^2) the diameter of the fixed anchor will vary from 4 in (10.1 cm) to 8 in (20.3 cm) for 2 in (5.03 cm) and 4 in (10.1 cm) casing, respectively.

Resistance to Withdrawal

Typical working loads (Sf = 1.5) for anchors of this type are illustrated in Table 1.

From this table it can be observed that relatively low capacity anchors are formed in fine cohesionless material using cement grout, and since underreaming is not practical, especially under the water table, the loading capa-



Above—Fig. 3: Diaphragm wall for underground car park in Berne with 111 temporary alluvium anchors. Below—Fig. 4: Grout cylinder formed in sand.

Table 1 Anchor Detail	Diameter of Casing 4 in (10.1 cm)	Diameter of Casing 2 in (5.08 cm)
Depth of anchorage	30 ft (9.1 m)	30 ft (9.1 m)
Length of fixed anchor	12 ft (3.6 m)	12 ft (3.6 m)
Effective diameter of fixed anchor	8 in (20.3 cm)	4 in (10.1 cm)
Quantity of cement injected	4.5 cwt (228 kg)	2 cwt (101.6 kg)
Angle of internal friction (ϕ)	35 deg	35 deg
Working Load (Sf = 1.5)	25 tons	10 tons

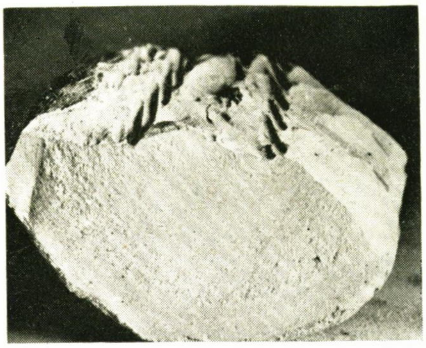


Fig. 5: Grout sample taken from fixed anchorage formed in compact sand.

city can only be improved by increasing the overall depth of the anchor.

(b) Alluvium Anchors using Chemical Grout.

In compact fine sands which do not allow permeation of dilute cement grout and which cannot be under-reamed, high capacity anchors can be formed at relatively shallow depths by the use of highly penetrating epoxy resin grout. These grouts, only recently developed, have very low viscosities (20 cp at 20 deg C) and are formulated for use in formations of low permeability (10^{-2} to 10^{-4} cm/sec) under both saturated and dry conditions.

The grout does not fill the voids of the soil with a gel but deposits from a solution a resin which drains to the contact points between particles and sticks them together. Thus the grout imparts high strength by adhesion to the ground to yield fixed anchor zones having unconfined compressive strengths of the order of 1000—5000 lb/in^2 (70.3 kg—351.5 kg/cm^2)

Construction

The construction stages for epoxy resin anchorages are identical to those already described in Section 1, except for Stage (C) where the grouting technique required is more sophisticated.

Grouting of Fixed Anchor

Prior to the grout injection, a water test is carried out in the hole to evaluate the ground permeability. Following this operation, a flushing fluid is injected at low pressure — 15 lb/in^2 (1.05 kg/cm^2)—to displace the void water in the ground surrounding the injection cell, whilst at the same time it provides a suitable medium for deposition to occur. This flushing fluid may not always be necessary but it provides the best known conditions for the formation of a consolidated system. Without interruption to the flow, the resin grout (basically a diluted resin-hardener system) is then switched into the circuit, and sufficient quantity injected — at 25 lb/in^2 (1.75 kg/cm^2) pressure approx.—to produce the required geometry of fixed anchor.

The shape of the fixed anchor depends on the homogeniety and permeability of the ground but in a reasonably homogeneous soil the shape would approximate to a sphere (see Fig 6)

Fig. 6: Spherical chemical grout anchor in homogenous soil.

Resistance to Withdrawal

At Stevenston in Scotland, anchorages of this type were formed in compact fine to medium sized sands (ϕ=35—39 deg), at very shallow depths, and high resistances to withdrawal were produced, as shown in Figs 7 and 8.

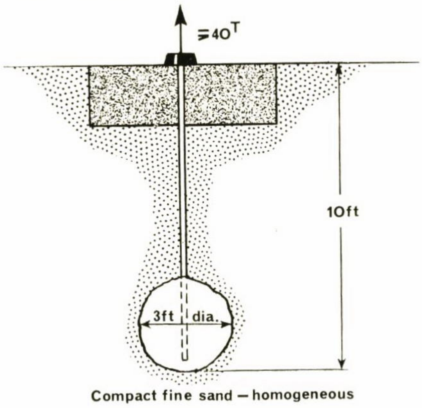


Fig. 7: Chemical grout anchor in homogenous fine sand.

Although the cost of chemicals in this type of anchorage is high compared with the cement grout anchor, it should be noted that the cost of anchorage per ton of working load is the critical factor when considering different applications.

3. *ANCHORAGES IN CLAY*

These anchorages are normally de-

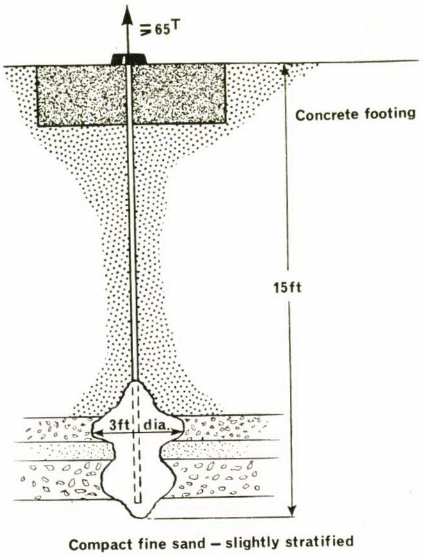


Fig. 8: Chemical grout anchor in stratified fine sand.

signed to carry safe working loads of up to 40 tons, and are constructed in stiff to very stiff clays, cohesion= 2000 lb/ft^2 (97648 kg/m^2) (or greater). Originally the technique of anchoring was simply to auger a 4 in (10 cm) hole to the required depth in the clay, and then grout the cable into the fixed anchor zone using a tremie pipe. Anchorages of this type however, are of low capacity since an adhesion of only (0.3—0.35) C may be mobilised at the grout-clay interface of the fixed anchor. Thus a fixed anchor 30 ft (9.1 m) long and 4 in (10 cm) diameter, constructed in London Clay (C=3500 lb/ft^2) (17088 kg/m^2) may only develop 15 tons at failure.

In view of this situation, the following construction methods have been employed to increase the fixed anchor dimensions whilst maintaining a nominal 4 in (10 cm) borehole for the remainder of the anchorage.

a) Underground craters using explosives
b) Under-reaming using an expanding bit; and
c) Driving irregular gravel into the clay adjacent to the fixed anchor.

a) Construction of clay anchors using explosives

Extremely interesting results have been obtained using this technique and high loading capacities have been de-

Table 2 Anchor Details	Anchorage No. 1	2
Depth of anchorage	30 ft (9.1 m)	30 ft (9.1 m)
Wt. of Gelignite	5 lb (2.2 kg)	2.5 lb (1.1 kg)
Volume of chamber blown	35 ft^3 (.99 m^3)	17 ft^3 (.48 m^3)
Length of fixed anchor zone	4.25 ft (1.3 m)	4 ft (1.2 m)
Effective diameter of fixed anchor.	3.25 ft (.96 m)	2.33 ft (.71 m)
Cohesion of clay	3200 lb/ft^2 (15624 kg/m^2)	3200 lb/ft^2 (15624 kg/m^2)
Maximum Test Load (Tt)	65 tons	55 tons

veloped at nominal depths. The construction procedure is as follows:

1. Auger 4 in (10 cm) dia. hole to required depth.
2. Place explosive charge at bottom of borehole.
3. Fill borehole with compacted sand.
4. Detonate charge (Wt of gelignite=1—5 lb (.45—2.3 kg) depending on size of fixed anchor required.
5. Home cable.
6. Grout fixed anchor chamber using tremie pipe (W/C of grout=0.45)

Resistance to Withdrawal

Vertical anchorages of this type have been successfully constructed to carry working loads of 50 tons on an experimental site at Herne Bay, Kent, and in all cases these loads were sustained for two to three months and the total upward movement of the fixed anchor was less than $\frac{1}{4}$ in (6.3 mm). Table 2 illustrates the anchor dimensions obtained using different explosive charges.

Although high loading capacities may be achieved using the technique described, the blasting operation and associated vibrations may well restrict the application to open sites. This is extremely important in the case of clay since the amplitude of the seismic disturbance depends on the resistance of the ground to distortion. Clay has a lower resistance to stress than rock and so vibrates, though with a low frequency, at a higher amplitude for a given energy input.

(b) Construction of clay anchors using an under-reamer.

The basic idea in this method is to drill the hole to the depth at which it is intended to start under-reaming, and then instal the under-reaming tool. This is rotated whilst air is blown down the rods and through the tool, and it cuts its own hole to a larger diameter in the fixed anchor zone, than the drilled hole. The under-reamer developed by the Cementation Co. Ltd, requires a $3\frac{1}{2}$ in (8.8 cm) hole and can expand out to 9 in (22.8 cm) depending on the size of cutters that are made. For larger sizes, it has been found that the amount of air which can be passed down the rods is insufficient to clear all cuttings from the hole.

Resistance to Withdrawal

At Westfield Properties in Durban, South Africa, it was required that a wall, 64 ft (19.5 m) x 8 ft (2.4 m) high be tied back to prevent disturbance to an adjacent building whilst the wall was deepened by about 12 ft (3.6 m) and underpinned. The ground consisted of a zone of very fine sand underlain by stiff saturated clay and a series of sand anchors and clay anchors were installed as indicated in Figure 9. Sand anchors were constructed above a fluctuating water table, and clay anchors below.

Working loads of up to 34 tons (Sf=2 to 2.5) were applied to fixed

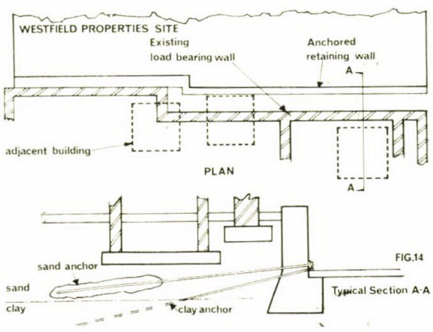


Fig. 9: Use of sand and clay anchors at Westfield Properties site in Durban.

anchors [length=12 ft (3.6 m) diameter=9 in (22.8 cm)] in the saturated clay, but with approximately 16 ft (4.9 m) of cover.

c) Construction of clay anchors using irregular gravel

This simple and flexible method may be employed in a wide range of clays, down to consistencies where under-reaming may not be practical.

After the hole has been drilled and cased to the required depth, irregular fine to medium sized gravel is injected into the hole as the casing is withdrawn the fixed anchor length. Following this stage a smaller casing, fitted with a non-recoverable point, is driven by percussion through the gravel, thus forcing it to penetrate the surrounding clay. The cable is then homed, the point is displaced and the gravel injected with neat cement grout, as the smaller casing is withdrawn the fixed anchor length. When the injection is complete both casings are removed completely from the hole.

Resistance to Withdrawal

In stiff clays (C=2000—3000 lb/ft^2) (9764—14647 kg/m^2) anchors have been constructed, using this technique, to carry safe working loads of 50 tons (Sf=1.5) at depths of 30 ft (9.1 m). Fixed anchor lengths are normally 12 ft (3.6 m) and the effective diameter of the grouted gravel varies from 5 in (12.7 cm) to 8 in (20.3 cm).

As already indicated, the local ground conditions in the fixed anchor zone are all important, and it should be noted that stiff clays often contain weak zones due to the presence of fissures or sand lenses, which may significantly reduce the anchorage capacity. For this reason site pull-out tests are recommended to determine the actual Factor of Safety of the anchorage design.

4. ANCHORAGES IN CHALK.

Although anchor trials have been carried out as far back as 1955 to study the resistance to withdrawal and creep of cables grouted into stiff chalk, it is only recently that the opportunity to construct chalk anchors for retaining walls has presented itself.

Construction.

The construction stages now employed are as follows:

a) Drive a lining tube, 2—4 in (5—10.1 cm) nominal diameter, through the overburden and at least 2 ft into the chalk. Drill beyond this point to a depth where the fixed anchor can be formed in a stable zone of chalk, outside the possible influence of the excavation.
b) Water test borehole to determine severity of fissuring and stabilise hole if necessary, using weak cement grout placed by tremie.
c) Redrill borehole, 12 hours after stabilisation, and repeat water tests.
d) Following a successful water test, home cable.
e) Inject cement grout (W/C=0.5) into borehole using a tremie pipe, and subsequently remove this pipe and pump in additional grout at low pressures (30 lb/in^2 approx.) (2.10 kg/cm^2)
f) On completion of the grout stage i.e. when further grout cannot be injected at 30 lb/in^2 (2.10 kg/cm^2) withdraw casing from borehole. (Normally, $\frac{1}{3}$—$\frac{1}{2}$ cwt (17—25 kg) of cement is injected per foot run of anchor, but experiments in stiff chalk at Ramsgate have indicated that the cement consumption may rise to 2 cwt (102 kg) per foot run).

Resistance to Withdrawal

At the Reading Inner Distribution Road, chalk anchors were installed to tie back a temporary sheet-piled retaining wall nearly 30 ft (9.1 m) high (see Figure 10). Site boreholes show in general that below 10 ft (3.04 m) of made ground, a clayey sandy gravel approximately 6 ft (1.8 m) thick overlies 13 ft (3.9 m) of dense sandy gravel. This material is underlain by a redeposited stiff rubbly chalk which changes with depth to a stiff/very stiff chalk.

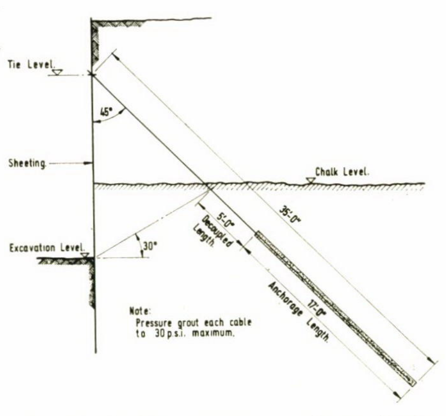


Fig. 10: Reading contract — the anchorage illustrated is capable of resisting a working load of 65 tons (Sf=2) when formed in sound "rock" chalk.

Approximately 80 anchors were successfully constructed in the upper zone of the chalk to resist working loads of 50—80 tons (Sf=1.5 to 2) and this work is particularly significant because the upper chalk layers were heavily fractured with softening along the fissures.

Since this upper chalk provides most of the problems of bearing capacity

continued at foot of page 46

news

Laing Pipelines

A five-year partnership for the construction of natural gas and oil pipelines has been formed by John Laing Construction and two French Companies. The already established and technically advanced pipeline construction unit, comprising Laing and the two leading French pipeline contractors, Société Entrepose and Société des Grands Travaux de Marseille, will operate in the future as "Laing Pipelines".

Jack Stein, B.Sc. (Edin.), A.M.I.C.E., of Laing, and the French civil engineer, Henri de Metz, of Entrepose, have been appointed joint managers.

One of the five 32-ton Link-Belt LS-98 excavators bought by Laing Pipelines.

Having already laid 86 miles (138 km) of the Thames-Mersey pipeline the partnership has just won a new contract worth over £15 m. Using five link-belt-Speeder excavators supplied by Cheshire Utilities, Laing Pipelines expect to complete this project next year.

The Mond Division of Imperial Chemical Industries has just awarded a 10 mile (16 km) pipeline contract to the Project and Pipeline Division of *Lehane Mackenzie and Shand*.

BUYERS' GUIDE

continued from page 44

WATERSTOPS, JOINT FILLERS, WATERPROOFING MATERIALS

EXPANDITE LIMITED, Chase Road, London, N.W.10. *Tel: 01-965 4321.*

WATER PUMPS

ACKER DRILL COMPANY, INC. (see under *Drills and Bits*)

MILLARS' MACHINERY COMPANY LIMITED (see under *Dewatering)*

THE WARWICK PUMP & ENG. CO. LTD. Ferry Lane. Hythe End. Staines. Middx. *Tel: Wraysbury (983) 2256/7.*

Major port extensions urged

A plea for linked port and industrial development of suitable coastal sites is made by the National Ports Council in its 1967 annual report to allow large bulk carriers to berth alongside the plants requiring their cargoes.

Major projects on these lines were already being undertaken in Europe and, although over £50m was spent in 1967 on modernising Britain's ports, compared with £35 m in 1966, the Council warns that investment in major schemes for new bulk facilities must be undertaken at an early date to enable Britain to compete efficiently.

Big pipeline contracts for Mitchell

Contracts valued at more than £1,250,000 have been awarded by the Southern Gas Board to The Mitchell Construction Co. The larger contract is for the laying of approximately 20 miles (32 km) of 41-in (1.04 m) gas main pipeline between Southampton and Portsmouth. The Mitchell Construction Co. will be closely associated on this contract with S.O.C.E.A. (Great Britain), an international pipelaying organisation. The line will be the first of this size laid in the United Kingdom and, therefore, presents technical problems not previously encountered in the United Kingdom. The second contract is for the laying of 19 miles (30.5 km) of 24-in (610 mm) gas main pipeline between Hythe and Staple Cross, Hampshire.

Embankments measuring 15 ft (4.5 m) high for protecting buildings form a feature of a new £730,000 ammunition process area at Kineton, Warwickshire, to be built by *B. Whitehouse & Sons* for the Ministry of Public Building and Works. Some 50,000 yd^3 (38230 m^3) of fill will be imported.

BRIEF

Manufacturing and marketing of the whole range of dumpers previously made by Road Machines (Drayton), under the name of Northfield Road Machines, is the result of an agreement between Northfield Industrial Fabrications and Roinger Engineers.

The Automobile Association's National Motoring Award gold medal for 1967 has been won by The Corporation of London for its £2,700,000 Blackfriars Underpass.

A contract worth over £3m for the construction of the M56 motorway Weaver 3,200 ft (975 m) Viaduct, for the Ministry of Transport (North Western Road Construction Unit) has been won by Christiani-Shand. Because of the low bearing capacity of the ground, the piers will be carried on concrete driven insitu piles up to a maximum depth of 100 ft (30 m).

Consultants, R. Travers Morgan and Partners, have been appointed by the Ministry of Transport to investigate and report on a route 2½ miles (4 km) long of London's proposed C Ring road between its junctions with the A23 in the Norbury area and the A24 at Colliers Wood.

The plant hire companies in the *Grayston Group* including Holdsworth (Yorkshire), have had their names changed to Grayston Plant Ltd. Grayston has also announced the opening of 'plant hire super-markets' in Scotland and the Midlands. The accent will be placed on specialist advice on the correct utilisation of the machines and skilled operators to cover the needs of Grayston clients.

A levy of 0.7 per cent of annual payroll for 1968/69 and payments made for labour only services are proposed by the *Construction Industry Training Board*. The levy for 1967/68 is 1 per cent.

GROUND ANCHORS **. . . continued from page 36**

and settlement of foundations on chalk, the opportunity was taken to study its engineering behaviour. Test anchors were pulled to failure and it was established that the ultimate resistance to withdrawal, due primarily to skin friction, varied from 2.8 to 7.5 tons/ft^2 (28 to 82 tons/m^2) of grouted fixed anchor (cf 8 to 10 tons/ft^2 (87 to 109 tons/m^2) of fixed anchor in Ramsgate chalk). In this range the consistency of the chalk in the fixed anchor zones at Reading changed from rubbly chalk with soft zones (S.P.T.=30 blows/ft) to unfissured 'rock' chalk (S.P.T.=80 blows/ft).

Creep tests are also being carried out on the working anchors over a period of six months to determine the loss of prestress, if any, due to fixed anchor movement under continuous load. After three months the results indicate that the working loads have been sustained, and the main proportion of the relaxation is probably due to cable extension. At Reading, allowance was made for loss of prestress by post-tensioning each anchor to working load plus 15 per cent.

In conclusion, it is considered that this type of field data may help to optimise the factors affecting anchorage design and construction and certainly the type of experience gained at Reading will be of value in cliff stabilisation work on the South Coast of England.