GROUTING MATERIALS AND METHODS

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Review of Grout Material Properties and Grouting Methods for Micropiles.

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1.0 Introduction.

Grouts are materials used to fill a void and to transfer the load from the structure to the load-bearing stratum. It therefore follows that the principle properties required must be:-

* fluidity, to allow efficient pumping and injection.
* consolidation or strength development.
* durability to resist erosion after strengthening.

In addition, in a competitive world, the material must be as cheap as possible, commensurate with its prime properties.

The choice of materials and the design of the grout enable these properties to be met in accordance with the specification for the contract and the requirements of the specialist contractor.

An ideal material for this purpose is typically a cementitious grout, often with the addition of a filler of sand or perhaps a mixture of sand and fine aggregate.

The principle variable affecting the properties of cementitious grouts is the water/cement ratio. The amount of water present determines the rate and degree of bleeding of the mix, its fluidity for pumpability, its subsequent plasticity, its ultimate strength and the long term durability of the grout. However, the effect of the water/cement ratio is determined by the choice and properties of the constituent materials used.

The finer the voids to be filled, the greater the restriction upon the grain size of the aggregate and sand it is possible to incorporate into the grout. In many cases, especially when grouting small diameter piles or when high pressures are being used, neat cement grouts containing simply cement and water (and sometimes admixtures) are used.

2.0 Grout constituent materials.

2.1 Cement.

In the UK, the cement used in grouts is normally specified as being Ordinary Portland cement complying with BS 12 Class 42.5N. Exceptionally, sulphate resisting cement may be specified.

In the UK, Portland cements complying with BS 12 are available in classes 32.5R, 42.5N, 52.5N and 62.5N. Table 1 shows the primary differences between the classes of cements available.

CLASS 32.5R cement is normally used for concrete, mortar, render or screed in a wide range of building applications. It has the lowest C_3S percentage and surface area requirement and therefore gains strength at a slower rate than the other classes and will achieve lower ultimate strengths.

CLASS 42.5N is used for concrete, mortar or grout in a wide range of end uses from the small DIY job to the largest civil engineering project.

CLASS 52.5N is used to produce high early strength in a wide variety of concretes, mortars and grouts. It is chemically similar to Class 42.5 cement but is more finely ground to provide a greater surface area and hence give higher early strength properties. It stiffens and sets at a similar rate to Class 42.5 Ordinary Portland cement.

CLASS 62.5N is normally of high C_3S and very low C_4AF content and is normally sold as white Portland cement. Due to its high C_3S content and surface area it has a high early strength development.

Cements also available in the U.K. include :

* Sulphate Resisting Portland Cement to BS 4027 Class 42.5N (low alkali).

* Masonry Cement to BS 5224

* High Alumina Cement to BS 915: Part 2

* Pozzolanic Cement to BS 6588 Class 42.5N.

By far the commonest Class of cement used for micropiles is Class 42.5N. Blended cements (pozzolanic cement) or low heat cements are currently rarely used in normal practice.

Because of past problems in the Civil Engineering and Building industry, high alumina cements are almost never acceptable for permanent works.

2.2 Water.

Water suitable for drinking is normally considered suitable for cement grout usage. However for high strength applications in the presence of steel, water containing under 0.1% sulphates and under 0.5% chlorides should be used.

Also water containing sugars, algae or with a high alkali content should not be used.

In UK practice, the water used should comply with BS 3148.

2.3 Sand.

Sands are often added to cement/water suspensions for use in conventional micropiles, especially for Type A piles (see later) with diameters in excess of 150 mm.

In the UK, sands are required to comply with BS882, which categorises sand into three types according to grading - Coarse, Medium and Fine, as shown in Table 2. The Standard also gives a maximum clay, silt and dust content of 3% by mass.

The chloride content of sands should not be greater than 0.08% (total chloride ion by mass).

2.4 Aggregates.

Aggregates up to 10 mm size have been used for micropiles of 250 - 300 mm size: typically utilising the technology developed for continuous flight auger piling, with high pressure concrete pumps.

2.5 Admixtures.

Admixtures are often used to achieve a low water/cement ratio and impart good fluidity, minimum bleed and volume stability to the grout. There is an extremely wide choice of admixtures available which can be used to achieve these properties, and hence careful choice and dosage is required.

For common grouts, admixtures are usually added on site during the mixing process and used in accordance with the manufacturers' recommendations.

There are also available a wide range of special grouts in the form of pre-blended components. These are not commonly used for micropiles in the UK, and are not covered in this report.

3.0 Grout Properties and Tests.

The properties displayed by the grouts are dependent on the properties of the constituent materials used and their proportions.

3.1 Flow Properties.

Flow properties are affected principally by dynamic inter-particle forces of attraction and repulsion and, in dense grouts, by dilatancy of the moving particles. A dense grout can only be pumped easily when it contains sufficient fluid to prevent expansion of the particle matrix during shear, and, generally speaking, a well-graded range of particles is preferred since the better the grading the lower the critical porosity at which the grout becomes pumpable. A reasonable percentage of fine particles is also desirable to increase the specific surface of the grout particles and thereby inhibit the separation of the liquid and solid phases.

Grout fluidity on site is generally measured by one of two methods:

* The Flow Trough. (Figure A)
  (Often known as the Colcrete flowmeter in the UK).

* The Flow Cone. (Figure B)

For the flow trough test the reading relies mainly on friction properties between the flow channel and the grout. The further the sample of grout flows through the flow trough, the greater its fluidity.

With the flow cone the fluidity of the material and proportion of solids in suspension are the main factors, hence the time for a specific volume of grout to flow through the cone decreases with increase in water content of the mix.

The Baroid mud-balance is also used by some practitioners as a quality control tool to monitor and control the wet density of the mix, which is again related to water content and fluidity.

3.2 Bleed Capacity.

When the grout is mixed the constituent particles are dispersed and suspended in water. The resultant suspension is initially unstable, and, under the action of gravity, the particles settle until the forces between particles are sufficient to counteract their weight. This settlement, known as bleed, depends on such factors as:

* The ratio of the volumes of solids and suspending fluid.

* The specific gravities of particles.

* The specific surface of the particles.

The test for bleed consists of measuring the quantity of water remaining on the surface of a sample of the grout which has been allowed to stand protected from evaporation. A transparent cylinder 40 to 60 mm internal diameter and greater than 175 mm in height and graduated in millimetres is used. The grout is poured into the cylinder to a height of approximately 150 mm and the cylinder sealed to prevent evaporation. The height to the top of the grout is noted. After 3 hours the depth of the water on top of the grout is measured and after 24 hours a check is made whether the water has been re-absorbed.

When tested in this fashion the bleeding should be less than 2% of the initial volume of the grout. The water should be re-absorbed by the grout during the 24 hours after mixing.

3.3 Volume Change.

Shrinkage of cement grout is related principally to the amount of water removed. Thus a moist cured grout remaining moist throughout its life will not shrink and may in fact expand slightly with time. Shrinkage is not normally a serious problem in ground engineering where the environment is damp or submerged. However, where shrinkage leading to the formation of micro cracking is likely to affect the permeability of water proofing grout, positive steps may be taken to counteract the shrinkage by introducing expanding agents into the grout. This is a relatively unusual step.

If necessary, a volume change test can be performed on site using the same apparatus and technique used for the bleed test. However, to calculate volume change, the height of the grout in the cylinder after 24 hours is measured. The percentage change in volume is calculated and recorded.

For long term shrinkage/expansion evaluation, which is dependent on cement properties, a laboratory test to ASTM C157-91 must be performed. This is typically quite an extended test, and is an unusual requirement on most projects.

3.4 Initial Set.

The setting process of cementitious grouts has two stages: an initial stage in which the fluidity of the grout decreases to a level at which it is no longer pumpable and a second stage in which the set grout hardens and increases in strength. Generally speaking, rates of *setting* and *hardening* are not related.

The initial set is measured in accordance with BS 12, the UK Standard for testing cements, by needle penetration. Initial setting time of Ordinary Portland cement grouts is generally within the range of 80 to 200 minutes.

It has been indicated by Greenburg that there is a near exponential increase in shear strength and viscosity with time which means that during the initial period following mixing these increases are small and do not affect pumping and grouting operations.

The rate of development of shear strength to initial set is affected by water/cement ratio and the rate of hydration, which is primarily governed by cement chemistry and particle size. Cements with high C_3S contents and greater fineness lower the time to achieve initial set. The use of retarders or accelerators readily changes the rate of shear strength development. Retarders are normally used to reduce setting rates in hot conditions and when pumping over long distances.

3.5 Strength.

Ultimate strength and rate of strength development is governed by cement type, water/cement ratio and, where fillers are used, by cement content. The dominant factor is the water/cement ratio.

Addition of plasticisers permits a reduction in water/cement ratio at a given fluidity, and results in a proportionate increase in set grout strength.

A site evaluation of the grout strength development is made by making and crushing cubes. Although contract specifications often (if not usually) define grout strength in terms of 28-day Characteristic strength, grouts under optimum curing conditions and not subjected to chemical attack will continue to increase in strength over a prolonged period. The proportion of the 28 Day strength to ultimate strength will be dependent on cement type and water/cement ratio.

3.6 Thermal Properties.

The heat of hydration of cement dictates the degree of temperature rise within the grout and is therefore dictated by cement type, cement content, placing temperature and insulation.

Where heat evolution and therefore the risk of cracking is of concern the placing temperature must be controlled by the use of cooled mixing water and, in addition, where possible, low cement contents and low heat cements (coarse ground) could be used. Also the possibility of replacing some of the cement with PFA or slag must be considered.

4.0 Types of Cementitious Grout Mixtures.

4.1 Neat Cement Grouts.

Specifications for neat cement-water grouts often limit the water/cement ratio of the mix to a maximum of 0.4, using OPC to BS 12, Class 42.5. For special grouts, i.e. those which are pre-bagged and contain various admixtures, the water/ cement ratio is often a maximum of 0.35.

Higher w/c ratios can be of assistance in certain ground conditions, however : particularly in sandy conditions, which often allow excess water in the setting mix to be readily absorbed.

Table 3 shows results of trials using grouts from different sources but all at a 0.4 water/cement ratio. For Class 42.5 OPC (different manufacturers) although 7-day strengths are all in the range 49.5 to 55 N/mm2 it can be seen that fluidity (using the trough meter test) can vary from 240 to 380 mm and initial set from 100 to 272 minutes.

Table 3 also shows properties of a grout made with Class 32.5R cement inadvertently used on a ground anchor contract which used neat cements grouts of micropile quality. On this contract, initial proving trial mixes with the low-strength cement (as shown by the results in Table 3) gave good fluidity and bleed results at a water/cement ratio of 0.45, with initial setting time and density only slightly lower than might have been expected. Unconfined compression strength at 7 days (35 N/mm2) exceeded the design target of 30 N/mm2 by a smaller margin than expected, but was considered adequate. The trial was deemed acceptable.

However, it was found that the anchorage grout for the subsequent suitability test anchorages often failed to reach its design strength of 30 N/mm2 within 7 days, as would be expected with grout of this water/cement ratio. (see Table 4). One test anchor did not reach its specified 28 day strength of 40 N/mm2. Despite these apparent low strength gains, all the anchorages performed perfectly satisfactorily under load and over the required long term monitoring programme. It was found on further investigation that the wrong grade of OPC had been supplied to the site (42.5N had been specified by the specialist) for use in the anchoring trial work.

It can be seen that although the proving trial mix achieved a strength value greater than the required 30 N/mm2 at 7 Days, the margin was not high enough to ensure that all subsequent site mixes achieved the required value.

In this case the problem might not have arisen if adequate Quality Assurance procedures had been followed when ordering the cement (Documentation should have included the Class of OPC required) and acceptance on site.

With cement-water grouts, the major influence on grout properties is thus the water/cement ratio used. Increase in water/cement ratio results in:

* Lower strength development.

* Greater bleed capacity.

* Lower shear strength development / lower setting time.

* Decreased durability.

* Increased permeability.

The interdependence of these effects is illustrated on Figure 1. It should be noted that these should be regarded as general trends, and actual values will be dependent on the cement type used: possible variations in performance can arise from such factors as different manufacturers, the age of the cement or the standard of sampling, curing and testing the grout mix: quite apart from the variations of the site mixing process and site practices.

4.2 Cement replacement materials.

For reasons of economy, cementitious replacements are sometimes used in cementitious grouts. The replacement materials used are either pulverised fuel ash (PFA) or blast furnace slag (PBFS).

Table 5 shows some results from trials made with various degrees of replacements by PBFS and PFA, and compared to neat OPC class 42.5N cement grouts. All mixes were made at water/ cement ratio of 0.4. As seen, replacement by slag of up to 4:1 produce acceptable 28 Day strengths, however, the rate of strength development is substantially reduced. Due to the cementitious properties of slag, even at very high replacements ultimate strengths are good. However, the fluidities of the grouts containing slag progressively diminish with increased slag content, as does wet density. It is also found that the introduction of slag into the mixes increases the potential to bleed.

With PFA however, fluidity is maintained at high percentages due to the spherical nature of the material grains. Replacement by PFA reduces significantly the rate of strength development and ultimate strength. Therefore to maintain strengths, replacement by PFA should be kept low.

PFA replacement at high proportions is however ideal if low strength grout is required. In these cases hydrated bentonite clay may be added to reduce the permeability of the grout. In these cases expected strengths would be in the region of 1 N/mm2 at 7 Days with a permeability of 10^{-9} m/sec at 90 Days. Densities in the region of 1100 kg/m3 are expected.

Cement replacement materials are not commonly used in current standard micropiling practice.

4.3 Sand-Cement Grouts

With sand-cement grouts, again the water/cement ratio is the dominant factor affecting the properties of the grout. However, the type and quantity of sand greatly influences the water/cement ratio achievable at a given fluidity. In addition, plasticising admixtures are widely used in order to achieve lower water/cement ratios.

Sanded grouts often require a water/cement ratio of up to 0.55 or 0.6 depending upon the amounts of plasticiser/super-plasticiser used to achieve fluidity and pumpability.

Typical trends of grout properties are illustrated in Figure 2, and show that at a particular water/cement ratio, percentage bleed is reduced with increased sand content, whilst workability or fluidity is reduced.

Figure 2 also demonstrates that the fineness of the sand significantly influences the workability of the grout at a particular water/cement ratio. The finer the sand the lower its workability, or, conversely the greater the water demand for a particular workability.

It is apparent from the results illustrated on Figure 2 that if a specification gives a maximum water/cement ratio of 0.4, for example, then in order to achieve a flow trough value of 300 mm, a plasticising admixture must be used in the mix at sand/cement ratios of 1.5 to 2.5.

Figure 3 shows the typical relationship between water/cement ratio and 28-day unconfined compression strength for a series of grout mixes using a medium grade sand and OPC class

42.5N.

Table 6 summarises the results achieved from a series of trial mixes for a ground anchorage contract which utilized 200 mm diameter drillholes and was thus suitable for sanded grouts of micropile quality. The results demonstrate that even at sand/cement ratios as low as 0.4:1 a water/cement ratio above 0.4 is required to achieve adequate fluidity of the grout. When a super plasticiser was used, then it became possible to achieve adequate flow characteristics with a water/cement ratio of 0.4 and a sand/cement ratio of 0.8:1.

When using sand-cement grouts, due to the influence of sand properties, it is possible that problems can arise on site due to a variation in the sand quality. Water/cement ratios can easily increase due to increased fineness of the sand requiring additional water for fluidity, and leading in turn to low compressive strengths.

Also, due to the increased water demand, excessive bleeding can result, which could in extreme cases cause segregation in the grout matrix. This can in turn lead to the formation of voids around the reinforcement.

In extreme cases, where this effect is combined with the presence of ground water, the result can be complete segregation, with the formation of water channels running up the pile. Such cases can result in the pile cross section illustrated in Figure 4.

4.4 10mm aggregate grouts.

In certain applications a 10mm aggregate can be incorporated into the mix. In theses mixes the large aggregate is used as a bulking agent. Here it is essential that plasticising/ water-reducing admixtures are used to achieve fluidity at low water/cement ratios.

5.0 Grouting methods.

5.1 Micropile types and grout characteristics.

A report prepared by the Federal Highways Authority (FHWA) on micropiles proposed a classification of micropiles based on the type and pressure of grouting used for piling construction. This classification may be summarised as follows.

Type A - Grout placed under gravity.

Type B - Additional grout placed by low pressure (0.3-1.0 MPa).

Type C - Grouted as for Type A, but with an additional high pressure (>1.0 MPa) injection some 15-25 minutes later.

Type D - Grouted as for Type A, but with additional grout injection or injections some hours later, when the primary grout has hardened. Post-grout pressures of 2-8 MPa are common.

Sanded grouts may be used as the primary grouts for any of the above pile types. The choice of grout materials is primarily dependent upon borehole size, plant availability, and the expertise of the specialist company.

As a rough guide to UK practice, neat cement grouts are almost universally used for pile diameters up to 150 mm. Above 150 and up to 200 mm either sanded or neat cement grouts are commonly used. Above 200 mm diameter sanded grouts become increasingly preferable because, with neat cement grouts, the large volume of material in the pile can cause difficulties with high heats of hydration. Above 250 mm diameter, coarse-sized, generally 10mm aggregate grouts or concretes become increasingly viable, especially with short piles with no ground water problems. For such piles with no placing difficulties, even 20 mm aggregate concrete has been used.

Almost universally, because of the long pipe-like nature of micropiles, the primary grout is pumped in place through a tremie pipe. A tremie-grouting system should be mandatory where there is ground water or drilling water present or suspected in the pile bore. Even a deceptively small amount of water within the bore can destroy the integrity and stability of the grout and instigate a disastrous bleed problem.

Post-grouting or high pressure primary grouting techniques almost universally employ neat cement grouts. Such high pressure/low volume applications do not favour the use of sanded or filled grouts which can segregate and block in pipework and injection valves.

A consideration of the use of high-pressure, post-grouted piles suggests that an ideal primary grout would be one that has a relatively low gain in strength, but which nevertheless will still, in time, reach the necessary load transfer strength. Most design values would suggest that this design transfer strength need only be, say, 30N (30 MPa), provided the bleed and durability requirements of the grout are satisfied. This is lower than the typical specified design strength of 40N (40 MPa), which has grown up from ground anchor technology on the basis that typical neat anchorage grouts using 42.5N cement should develop 40N "without problems" at the typical range of water/cement ratios used in ground anchor construction.

The previous discussion on material properties and constituents, in Sections 3.0 and 4.0 above, indicates that a soundly engineered cement/cement replacement grout or a cement/bentonite grout would provide a more suitable primary grout for Type D micropiles. It should be noted that French practice does often, in fact, utilize such cement/bentonite grouts for this purpose. The use of such grouts, together with adequate cleaning, de-sanding and re-circulating systems, would also provide, in many ground conditions, adequate support to the borehole sides without recourse to the use of heavy temporary drill casings common in the UK.

Such uncased techniques have yet to gain wide-spread usage in the U.K., but several contracts for compaction and consolidation grouting works are known to have utilized this method very successfully in the U.K. They have been used on the Jubilee Line tunnel works, for example.

In due course of time it would be expected that this technique would be operated routinely by one or two specialists in the U.K.

High pressure post-grouting (also known as secondary grouting) almost invariably employs neat cement grouts: Typically a dilute neat cement mix, or even plain water, is used to open the post-grout valves, followed by the thicker injection grout. Even so, secondary injection grouts typically have a higher w/c ratio to facilitate high pressure pumping and injection.

5.2 Grout mixing plant.

The use of high-shear colloidal-type grout mixers is widespread in U.K. practice, but probably equally common are standard paddle-type mixers. The U.K. ground anchorage code BS8081:1989, allows both types of mixer, although expressing a preference for colloidal-type mixers for neat cement grouts in water-bearing ground. The mix design data quoted earlier in this report was derived from tests on both high-shear colloidal and low-shear paddle mixers. Interestingly, although the high-shear concept "feels" more technically correct, there seems to be little real difference in the characteristics and properties of the end product. It would be of interest and fairly inexpensive, to undertake a series of trials to determine whether there are any discernible technical differences between the two mixing techniques.

When coarse aggregates are used then recourse is usually made to conventional pan or drum-type mixers.

It is normal good practice (although not uncommonly honoured in the breach rather than the practice), to pass the mixed grout through a sieve before delivering it into the pump holding tank.

5.3 Grout pumping plant.

5.3.1 Primary grouting.

Neat cement and sanded grouts are usually pumped into place using mono-pumps or ram-pumps. Also commonly used are air-operated diaphragm-type pumps as used for pumping sludges. Sand-cement or aggregate-cement grouts are commonly pumped using piston-type concrete pumps of the Putzmeister or Schwing type.

5.3.2 Secondary or Post grouting.

Post-grouting injection typically utilizes positive displacement pumps such as ram or piston pumps to allow the injection and control of relatively small grout volumes at high pressure.

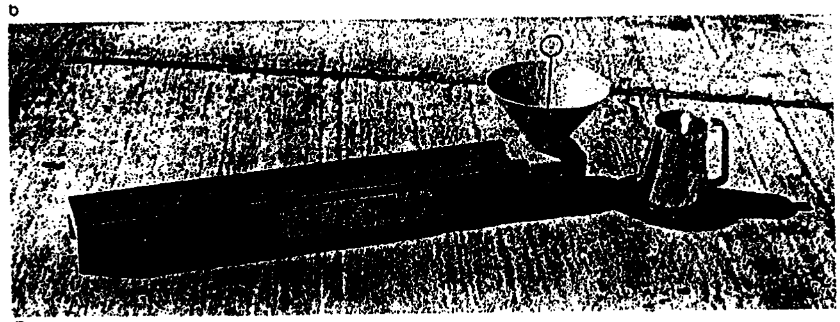

Figure A.

Flow trough

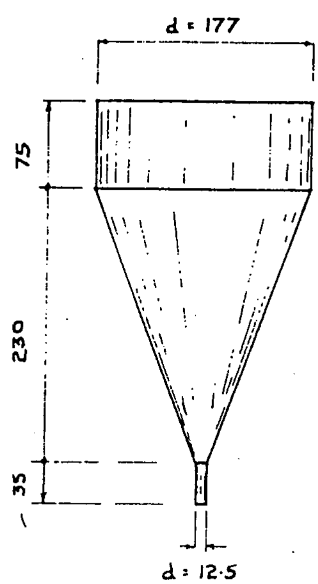

Figure B.

Flow cone

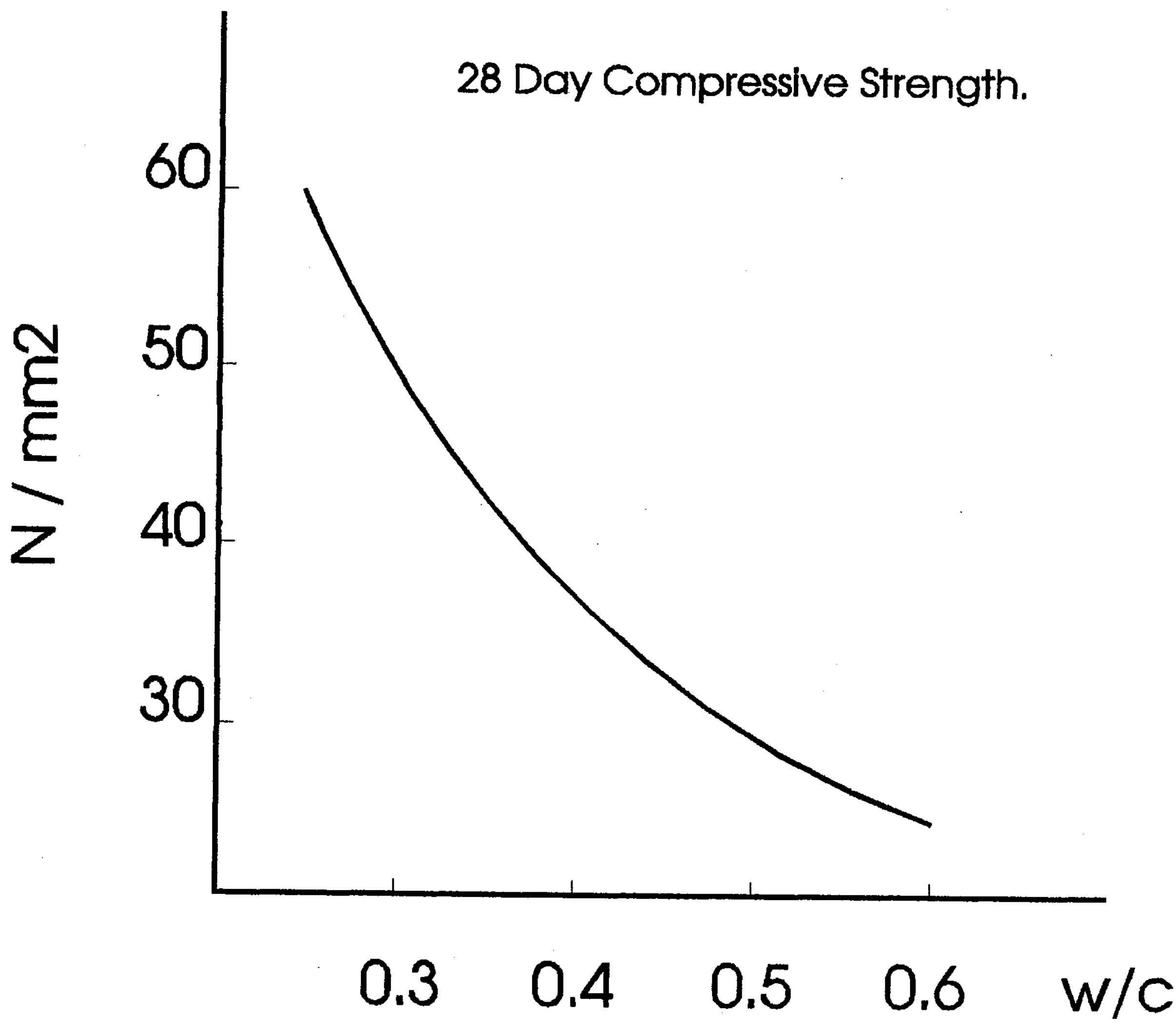

Figure 1(a):

Typical properties of cement grout at varying water/cement ratios: 28 day compressive strength.

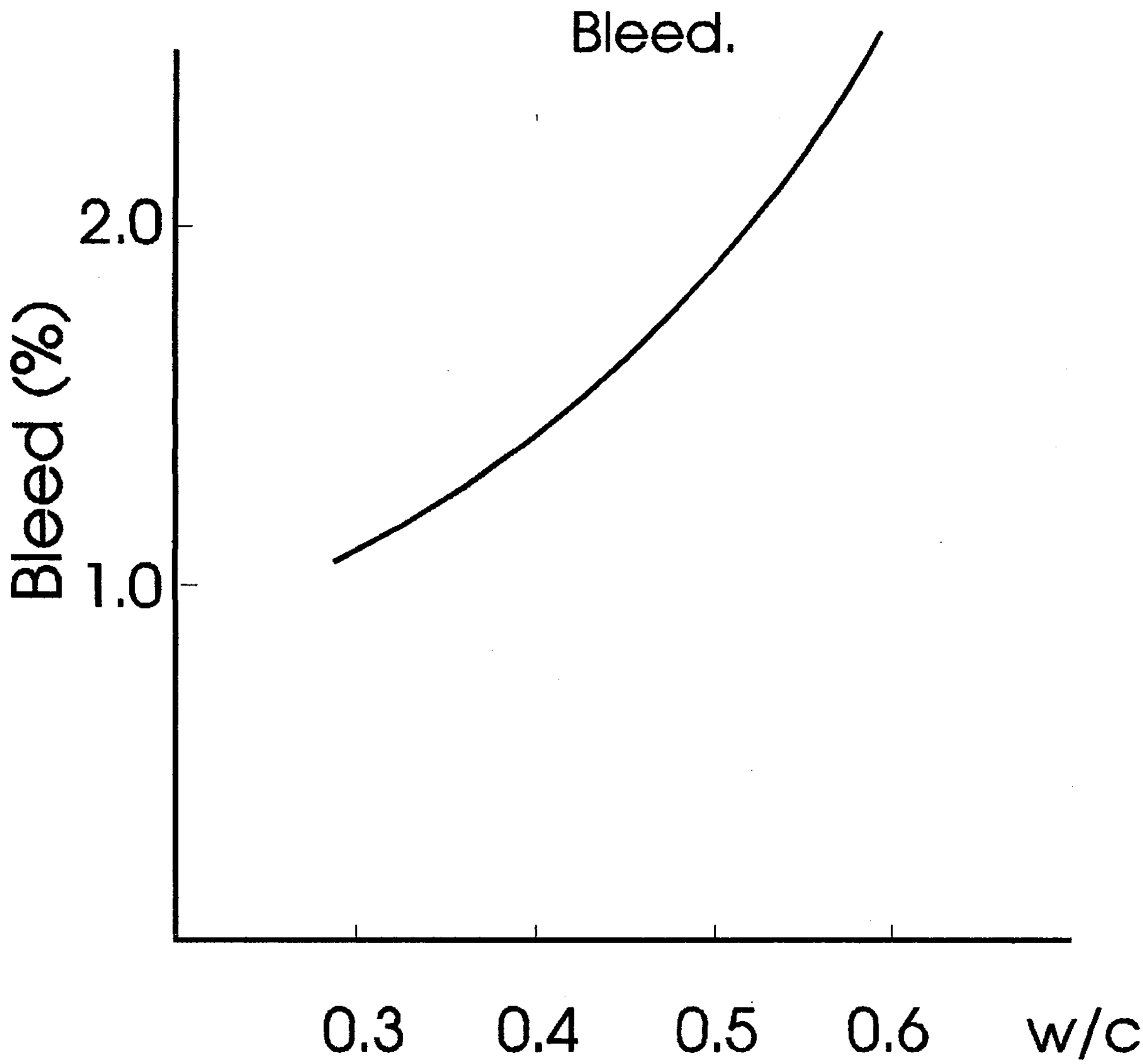

Figure 1(b):

Typical properties of cement grout varying water/cement ratios: bleed.

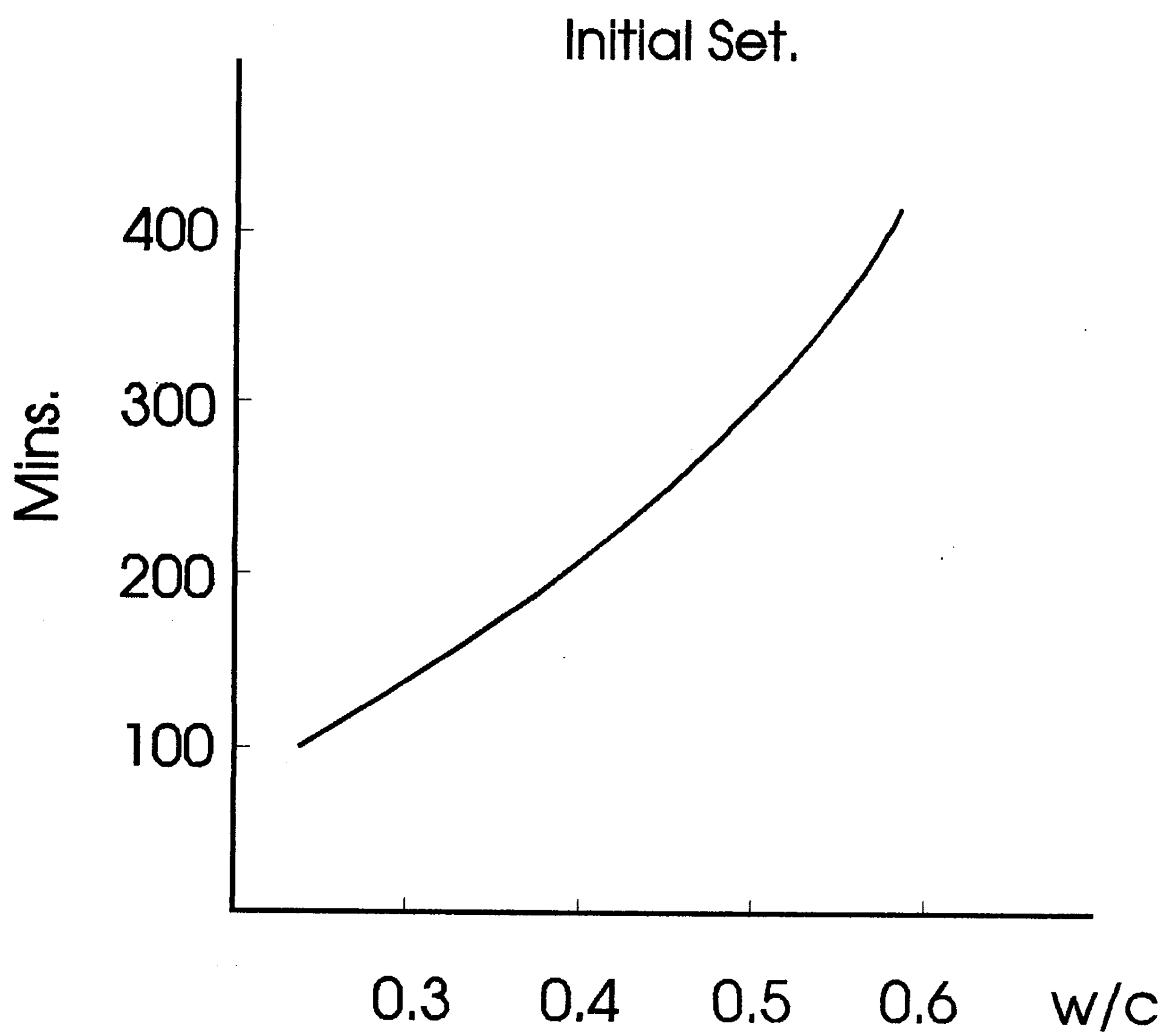

Figure 1(c):

Typical properties of cement grout at varying water/cement ratios: initial set.

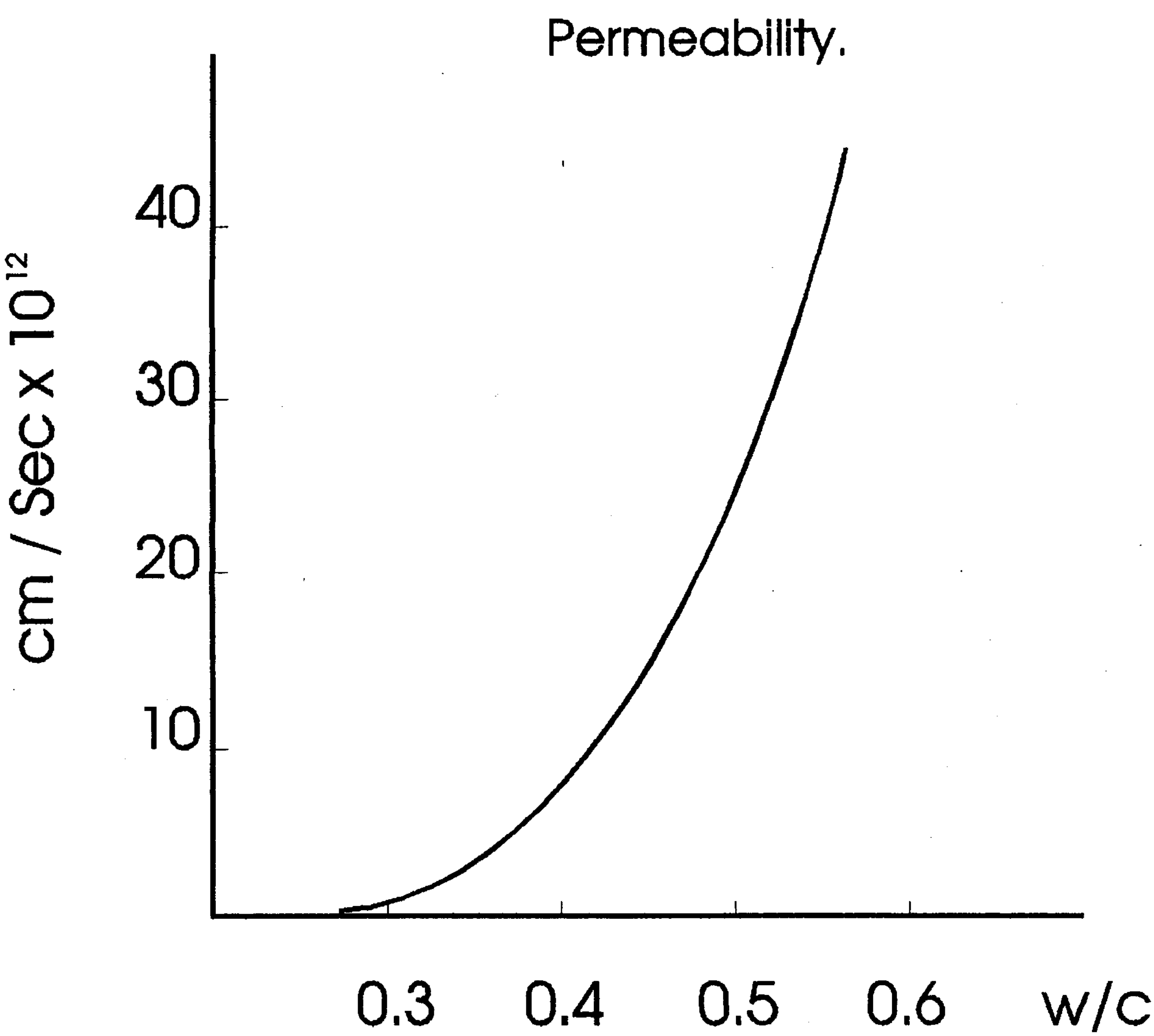

Figure 1(d):

Typical properties of cement grout at varying water/cement ratios: permeability.

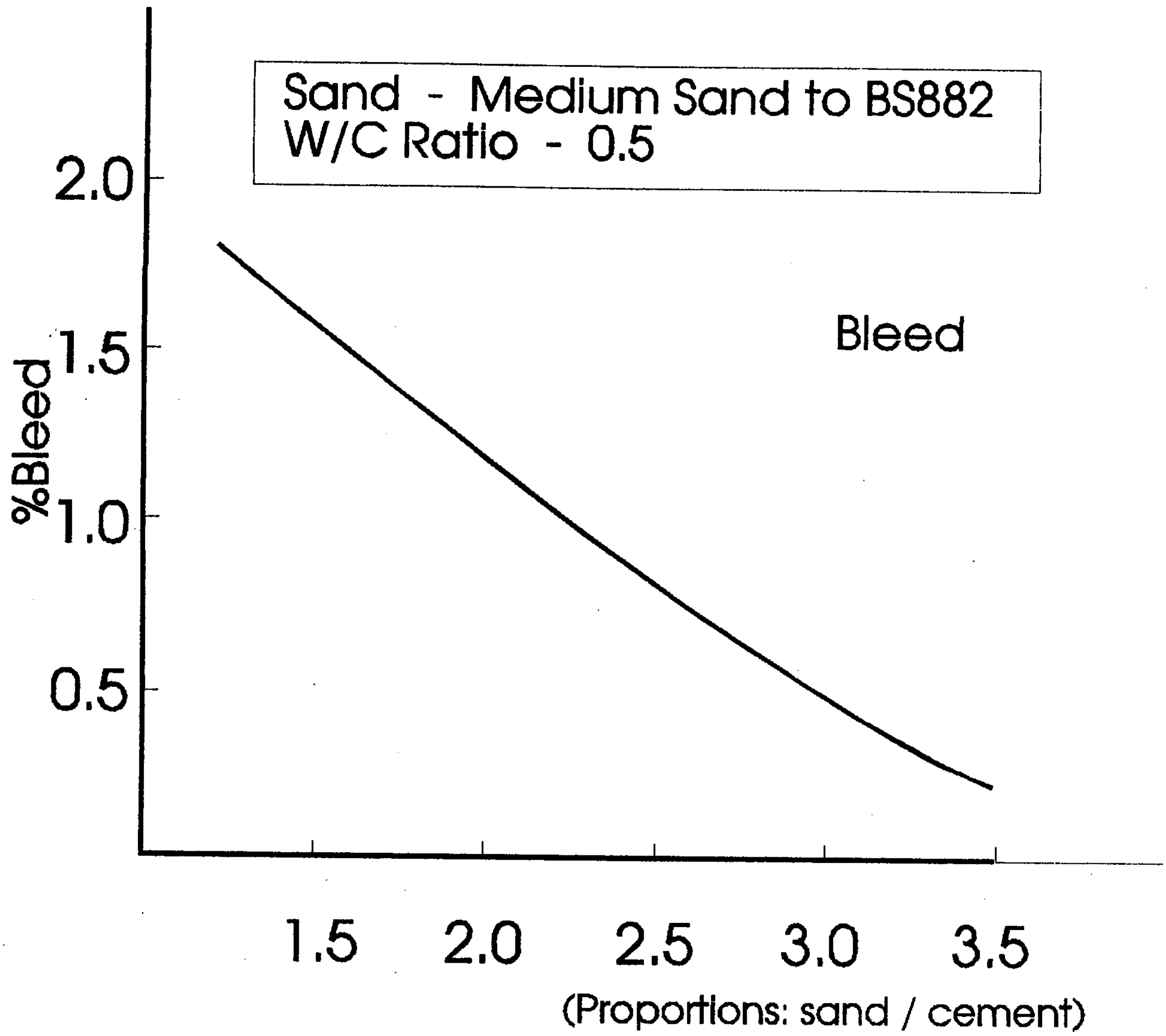

Figure 2(a):

Typical properties of Sand-Cement Grouts: Bleed

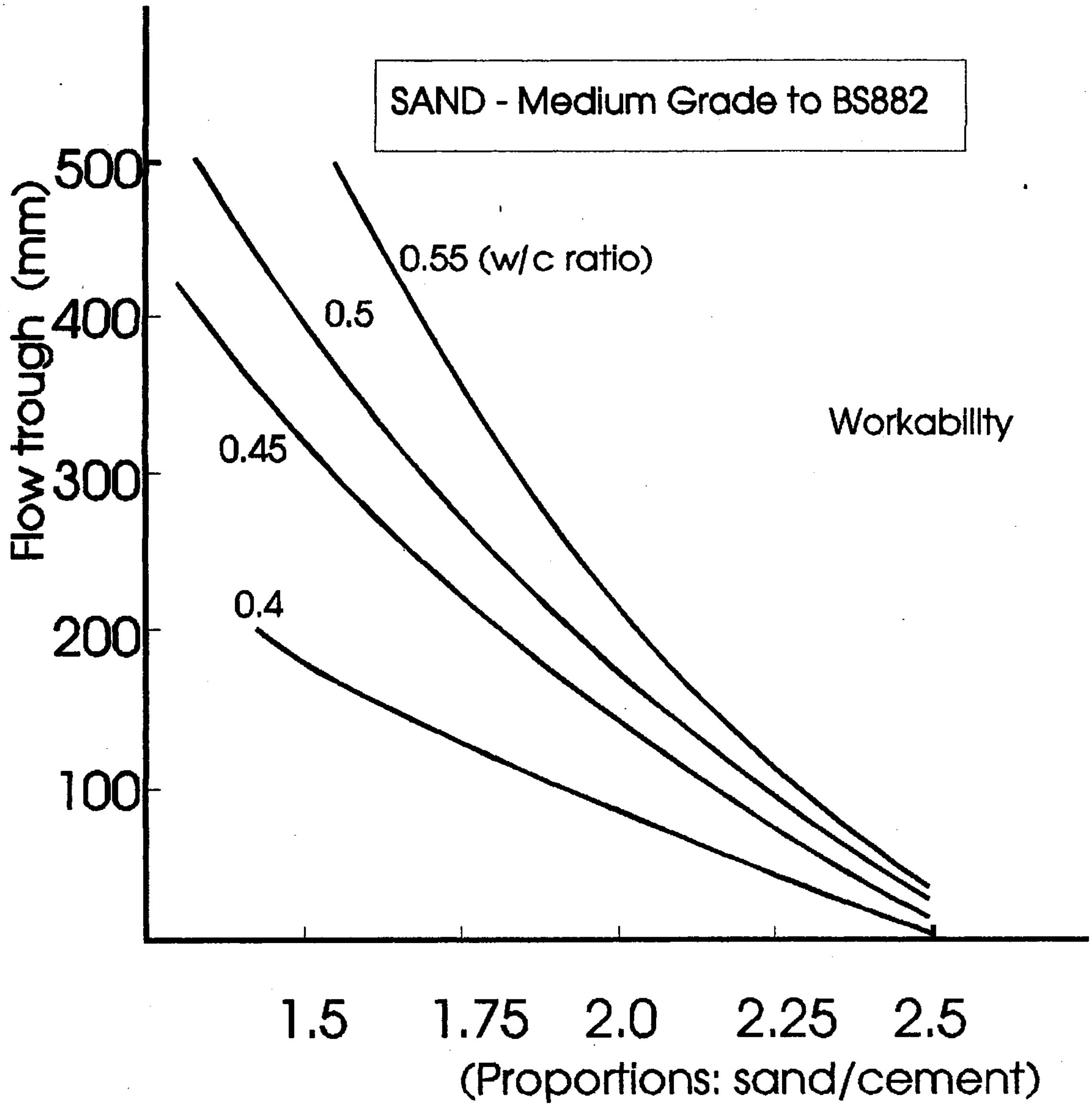

Figure 2(b)

Typical properties of Sand-Cement Grouts: workability at varying water contents

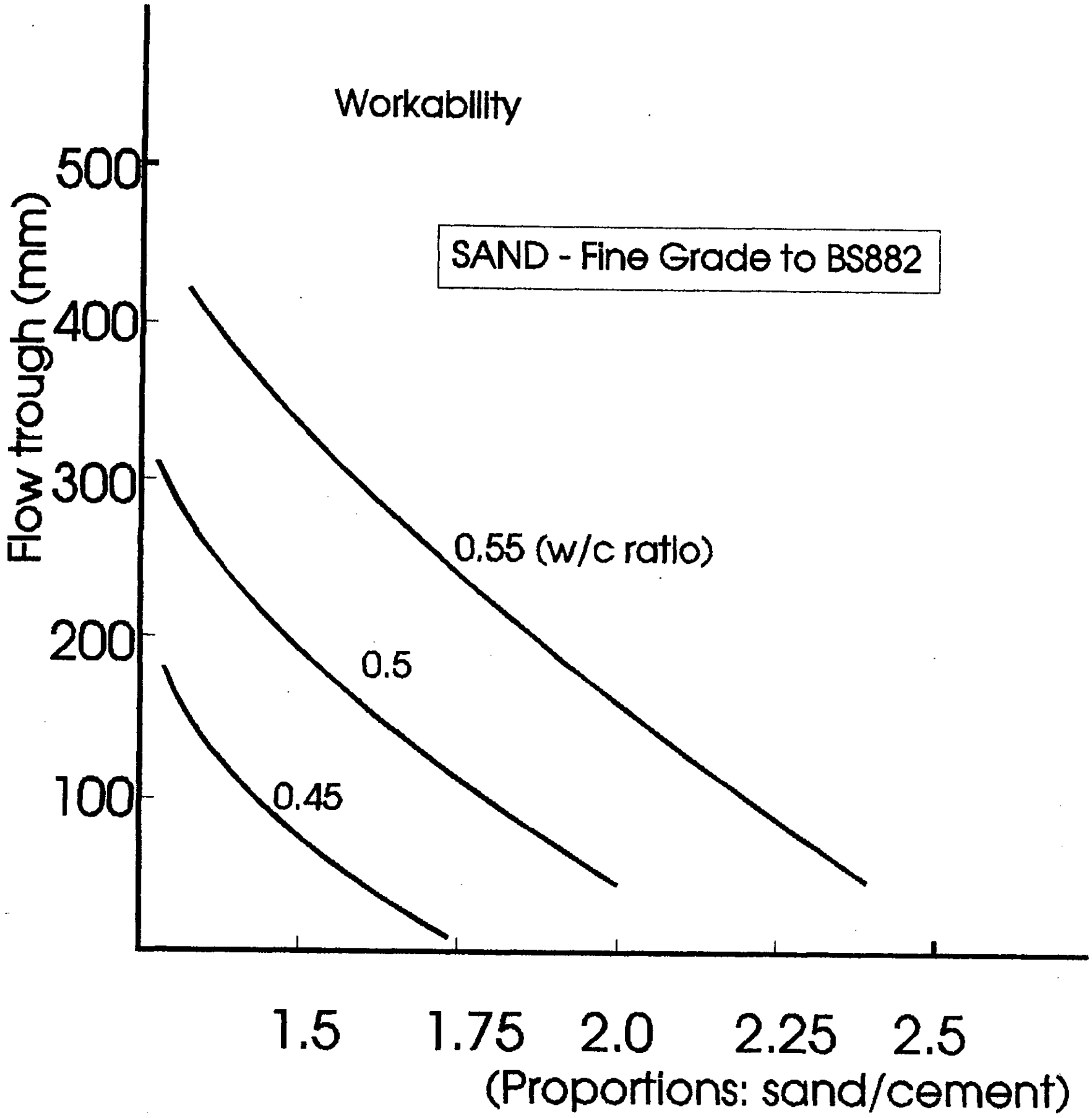

Figure 2(c)

Typical properties of Sand-Cement Grouts: workability at varying water contents (fine sand).

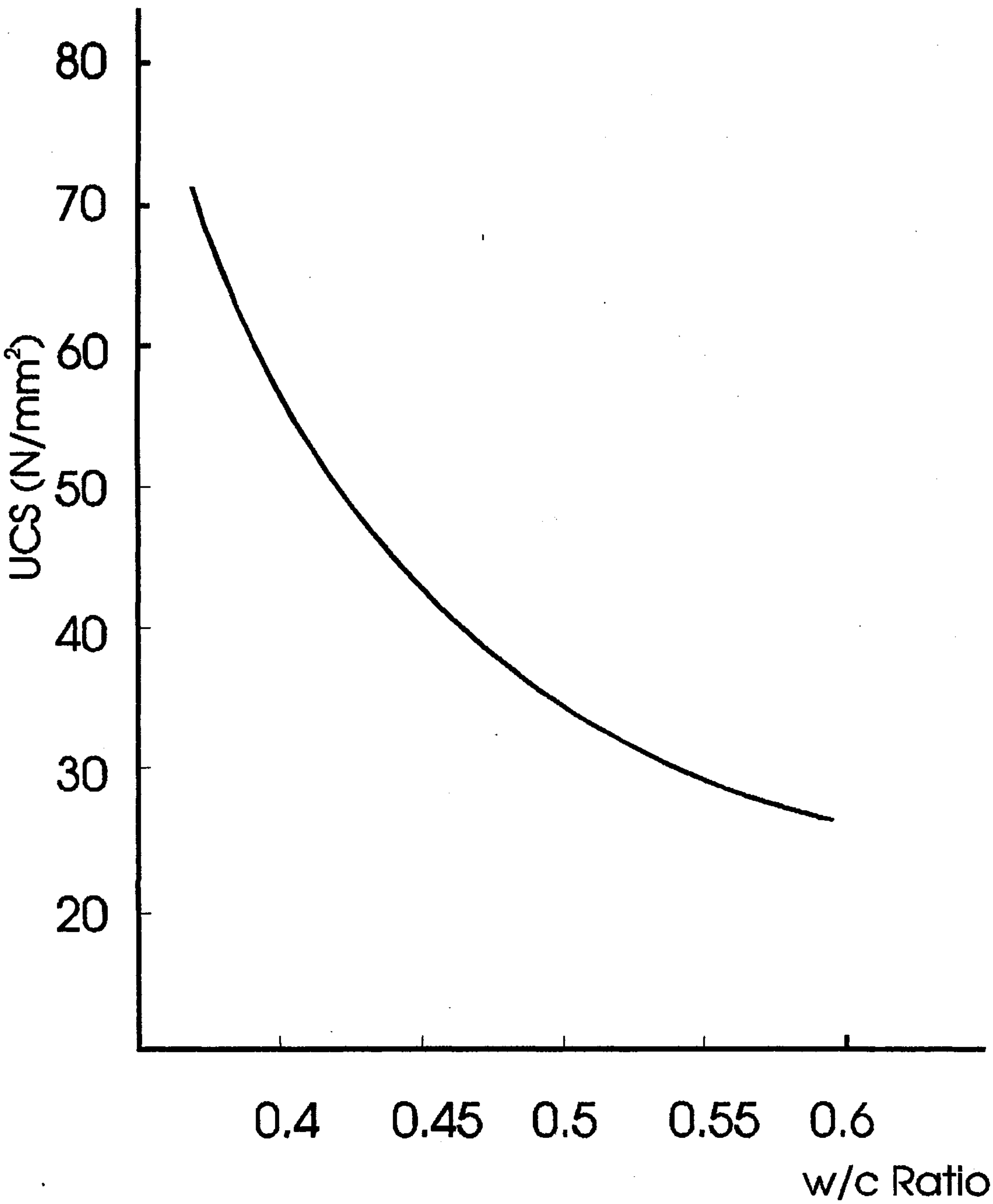

Figure 3.

Typical 28 Day Strength vs Water/Cement Ratio for Sand-Cement Grout. (Sand: Medium Grade to BS882).

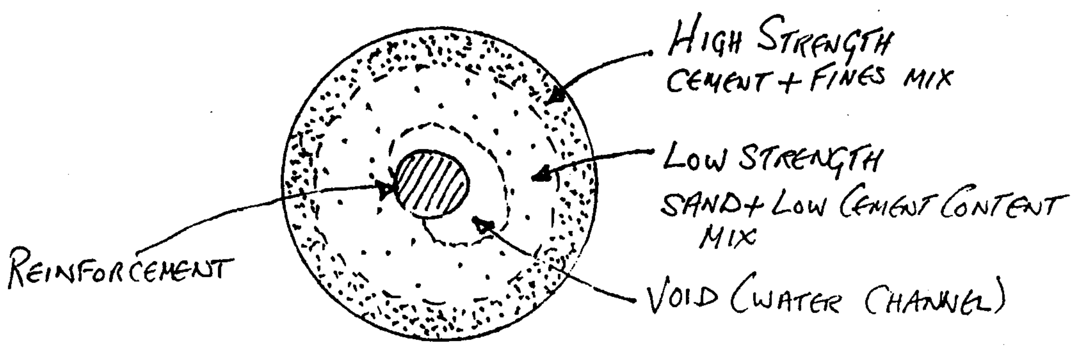

Figure 4.

Typical severe bleed effects in a pile or micropile.
(Water content too high and/or poor hydraulic
continuity of mix)

TABLE 1.

BS12 Ordinary Portland Cement Properties (Blue Circle Cement).

	Classes.			
	32.5R	42.5N	52.5N	62.5N
Surface Area (m2 / kg)	300-390	320-390	400-475	390-470
Initial Setting (mins)	80-200	80-200	60-180	100-180
Compressive Strength				
(N/mm2) 2 Day	16-26	21-31	30-40	30-35
7 Day	27-37	40-50	45-55	48-55
28 Day	37-47	52-62	58-70	65-75
Particle Density (kg / m3)	3080-3180	3080-3140	3080-3150	3050-3150
Bulk Density (kg / m3)	1300-1450	1300-1450	1300-1450	1300-1450
Sulphate SO3 %	2.5-3.5	2.5-3.5	3.0-3.5	2.0-2.5
Chloride Cl %	<0.03	<0.03	<0.03	<0.02
Alkali Eq. Na20	0.4-0.85	0.45-0.85	0.45-0.85	0.1-0.3
Tricalcium Silicate C3S %	40-60	45-60	45-60	65-75
Dicalcium Silicate C2S %	12.5-30	12.5-30	12.5-30	13-21
Tricalcium Aluminate C3A %	5.0-12.0	7.0-12.0	7.0-12.0	3.0-6.0
Tetracalcium Aluminoferrite C4AF %	6.0-10.0	6.0-10.0	6.0-10.0	0.8-1.2

TABLE 2.

BS 882 Classification of Fine Aggregate.

Sieve Size.	% by mass passing BS Sieve.		
	Coarse	Medium	Fine
5.00 mm	-	-	-
2.36 mm	60-100	65-100	80-100
1.18 mm	30-90	45-100	70-100
0.60 mm	15-54	25-80	55-100
0.30 mm	5-40	5-48	5-70
0.15 mm	-	-	-

Contract Trials	Cement Class	Fluidity Flow Cone (sec)	Fluidity Flow Trough (mm)	Wet Den (gm/m^3)	Setting Time Init (min)	Setting Time Final (min)	Bleed (at 3 Hrs) %	Strength (N/mm^2) 3D	7D	14D	28D
Pen-y-Clip	42.5	14-22	240-340	1945	272	325	2	45	49.5	60	-
Castle Cem	42.5		265	1983	135	-	-	44.5	55	-	72
Coventry	42.5		300-380	1960	100	230	2.4	44	53.5	66	-
Coventry	32.5R		310-475	1920	90	190	1.3	30	35	37	52

Note: all tests were Pre-contract proving tests.

TABLE 3: Typical Properties of OPC+Water grouts at 0.4 w/c ratio

Coventry Contract

Anchor No.	*Unconfined Compressive Strength (N/mm2)*				
	4 Day	*6 Day*	*7 Day*	*14 Day*	*28 Day*
TAE/E69C		*20.1*	*23.8*	*27.3*	*37.8*
TAW1/W67C		*23.1*	*28.9*	*35.2*	*42.7*
TAW2/W60C	*37.7*		*37.7*	*38.7*	*52.4*
Trial	*30.2*		*35.1*	*37.0*	*52.4*

Table 4: Typical strength range and development for OPC & water grout (Cement 32.5R Grade) at 0.4 W/C ratio.

GROUT TRIAL
MIX RESULTS - *Table 5*

				Compressive Strengths						
Mix Designation	Cement Type	Flow mm	Plastic Density	1 Day	2 Day	3 Day	4 Day	28 Day	56 Day	90 Day
Slag/OPC										
-	OPC	265	1983	20.4	-	44.4	55.2	71.5	81.0	83.4
1:1	PBFC	210	1939	10.0	-	23.7	38.7	73.3	81.0	82.0
2:1	PBFC	230	1925	-	9.6	15.8	29.6	61.3	-	77.0
3:!	PBFC	220	1920	2.6	-	11.4	28.4	53.4	65.4	73.2
4:1	PBFC	160	1920	2.2	6.9	11.0	27.5	48.0	62.0	73.0
6:1	PBFC	170	1925	-	6.1	12.0	23.6	39.6	51.2	51.8
7:1	PBFC	180	1900	-	-	11.0	22.1	39.0	48.2	49.2
9:1	PBFC	175	1900	1.3	-	9.3	20.5	38.8	45.7	49.0
PFA	P/PFA									
2:1	P/PFA	230	1800	-	6.9	8.7	10.9	18.8	26.3	34.3
8:1		250	1740	-	-	-	1.2	1.9	2.1	2.7

Table 5: Grout trial mix results (PBFC and PFA mixes)
(Cement 42.5 Grade - Castle Cement)

Super Plasticiser % Cement	Sand / Cement Ratio	Water / Cement Ratio	Fluidity Cone Secs	Meter Mm	Setting Time Intial min	Setting Time Final min	Wet Density Kg/m3	Bleed 3 Hrs l	Compressive Strength 3 day	Compressive Strength 7 Day	Compressive Strength 14 day	Compressive Strength 28 day
1.8	2:1	0.50	Too thick				2220	nil	34.5	39	39	48
0.4	2:1	0.5	45	180	192	230	2180	1.5		37.5	40	56.5
0.4	2:1	0.61	14-20	330-410	216	304	2170	2.0	21.5	29	33.5	
nil	1:1	0.50	28-36	200-270	181	264	2175	2.0	34	40	44	
nil	1:1	0.52	16	380	215	306	2130	2.0	22		44	
nil	0.8:1	0.50	14	380			2100	0.7	32.5	45	49	51
0.4	0.8:1	0.45	14	560			2100			50	56	
0.4	0.8:1	0.40	25	360	178	257	2200	1.0		52	54	
nil	0.4:1	0.45	15	370			2100			50	56	
nil	0.4:1	0.42	17	430	225	320	2100	1.5		53	59.4	
nil	neat cement	0.40	14-22	240-340	272	325	1945	2.0	45	49.5	60	

Table 6: Grout trial mix results: cement and cement/sand. (Cement: 42.5N Grade).