

INCREASING PILE AND ANCHOR CAPACITY IN ROCK BY USING EXPANSIVE CEMENT ADDITIVES

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ABSTRACT : The use of an expansive cement admixture to increase pile and anchor capacities in rock is discussed. The admixture promotes internal sulphate attack of the concrete forming the pile, which, in turn, results in the concrete expanding against the surrounding rock. If the rock is capable of withstanding this expansion, then substantial stresses normal to the concrete-rock interface can be developed. The fundamental model of friction prescribes that if the stresses across the concrete/rock interface are increased, then the frictional resistance of the interface should also rise, thereby resulting in an increase in pile and anchor capacity. The results of laboratory investigations into the determination of the likely increases in pile capacity are described.

1 INTRODUCTION

When large structural loads are to be supported on rock, a common form of foundation is a rock socketed pile. Generally between 0.5m and 2.0m in diameter, these piles are constructed by drilling a vertical shaft through the weaker overburden soils into the stronger rock at depth. The action of drilling the shaft through rock, results in the shaft wall having a certain level of roughness which depends on rock type and strength and the drilling techniques used. Once the shaft has been excavated, reinforcement is placed, and the shaft is back-filled with concrete. The portion of the pile that is located in rock is called the rock socket. Rock socketed piles derive their capacity from both side and base resistance, with the side resistance dominating at working loads.

Rock anchors which are generally between 70mm and 150mm in diameter are used to stabilise both open cut and underground mines, hold down foundations subjected to uplift and stabilise retaining walls. As rock anchors carry tensile loads, their capacity is exclusively derived from the side resistance developed across the grout/rock interface. Although rock socketed piles and rock anchors are used for different applications, the means by which they achieve their capacity is identical. For the purpose of this paper, the term pile is used as a generic term to describe both piles and anchors.

The side resistance developed in a pile depends upon a number of factors including the strength and stiffness of the rock, the roughness of the interface between the concrete pile and the rock, the angle of friction of the interface, and the pressures that develop across the interface. An increase in pile capacity can be achieved if the pressures, or lateral stresses, developed across the concrete/rock interface can be increased. One way of increasing the lateral stress is by inducing expansion of the concrete against the stiffness of the surrounding rock by using expansive cement additives. This increase in lateral stress should be accompanied

by an increase in interface shear resistance and a corresponding increase in pile capacity.

It appears from the literature, that the use of expansive additives for this purpose is essentially unexplored. In the past, some mining groups have investigated using expansive grouts in rock anchors, but their efforts were abandoned due to the unfavourable side-effects that the expansive agents, which were available at the time, had on the steel reinforcement and grout. New forms of expansive additives, that do not have detrimental effects have since been developed. As a result, it is now relatively common practice for construction and mining companies to use expansive additives to offset the detrimental effects of excessive grout shrinkage, but none appear to have extended the process beyond this use.

One group of researchers (Sheikh, O'Neill and Mehrazarin, 1985; Sheikh and O'Neill, 1986) have investigated using expansive concretes to increase the capacity of large bored piles in clay. They reported moderate success with a 25% - 50% increase in capacity by using expansive cements. For the reasons discussed below, the authors expect significantly greater increases in the capacity of piles in rock.

In the current study, the expansion of the concrete is achieved by use of an expansive cement additive called Denka CSA (or calcium sulpho-aluminate). This particular additive invokes expansion via a chemical reaction known as sulphate attack. In unconfined situations, sulphate attack is highly undesirable as it leads to the decay of the concrete and loss of durability and strength. However, it has been shown via a number of laboratory tests (Chamberlain, 1993, Urquhart, 1993), that under certain confined situations, the uniaxial compressive strength of the concrete can be increased as a result of forced internal sulphate attack. A fortunate side effect of the use of expansive cement is that under confined situations, the hydraulic permeability of the concrete decreases. Such levels of

confinement are commensurate with those associated with piles and anchors in rock.

This paper presents experimental evidence to show that the capacity of rock socketed piles and rock anchors can be increased substantially by using expansive additives. In particular, the paper describes a series of laboratory tests that have been conducted to determine the influence of the lateral stress and confining stiffness on the frictional resistance of rough concrete/rock interfaces.

The work carried out to date has involved a wide range of concrete and grout mixes to accommodate the different types of mixes used in piles and anchors. The mixes used have ranged from cement paste (cement only), through grout (sand and cement) to concrete (aggregate, sand and cement). The arguments presented herein are equally applicable to all three mix categories. To avoid confusion, concrete has been used throughout as a collective term to describe the mixes whether or not they include sand or aggregate.

2 EXPANSIVE POTENTIAL IN PILES

The degree of expansion of an expansive concrete pile depends upon three main factors. These are the proportion of CSA in the concrete mix, a plentiful supply of groundwater to cure the cement and the radial stiffness of the rock surrounding the socket.

From thick-walled cylinder theory, it can be shown that the radial stiffness, K_m , of the rock surrounding the socket can be approximated by Eq. 1, where E_m and ν_m are the mass Young's modulus and Poisson's ratio of the rock, r is the average pile radius, $\Delta\sigma_n$ is the change in lateral stress and Δr is the radial displacement (or the amount of expansion) of the socket wall due to the change in lateral stress.

$$K_m = \frac{E_m}{1 + \nu_m} \frac{1}{r} = \frac{\Delta\sigma_n}{\Delta r} \quad (1)$$

Eq. 1 predicts that an expansive concrete pile will expand more if the confining stiffness is lower, given the same CSA content and curing conditions. Soil may not be capable of resisting the expansion, thereby endangering the strength and durability of the concrete. Rock and even very weak rock, with a much greater Young's modulus, may be able to provide sufficient confinement to maintain the structural integrity of the concrete, simultaneously improving the pile's frictional capacity.

Chamberlain and Haberfield (1993) reported the results of a number of laboratory tests that investigated the influence of CSA content and confining stiffness on the lateral stresses developed within piles and anchors in rock. The results of these tests are summarised here in Fig. 1 and show that the lateral stress or "prestress"

developed can be substantial and depends upon the CSA content and the confining stiffness. The values of confining stiffness shown in Fig. 1 are appropriate for piles and anchors in rock.

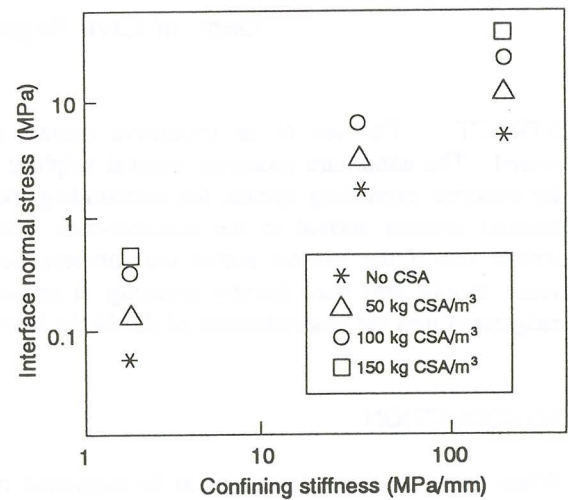


Fig. 1: Interface normal stress generated from CSA (After Chamberlain & Haberfield, 1993)

3 INCREASE IN PILE CAPACITY

From the discussion above, it has been established that the addition of CSA to a concrete pile can result in a substantial increase in the lateral stress acting on the rock socket portion of the pile shaft. However, the extent that this increase in lateral stress transfers to an increase in pile capacity still needs to be established. For a perfectly smooth socket, the fundamental model of friction predicts that the increase in pile capacity will be directly proportional to the increase in lateral stress and the friction angle between the concrete and the rock. However, rock sockets are never perfectly smooth, but contain a certain level of roughness which can influence the capacity of the pile. As a result this simple relationship between lateral stress and pile capacity may no longer hold. A large number of Constant Normal Stiffness (or CNS) direct shear tests on rough concrete/rock joints were therefore carried out to determine the influence of lateral stress on pile capacity.

3.1 Constant Normal Stiffness Testing

The CNS direct shear test has been used extensively in the past by other researchers (Johnston and Lam, 1989, Carter and Ooi, 1988) to determine the performance of rock socketed piles. It is generally accepted that the CNS test is the most appropriate laboratory test for this application. This is because the interface between a concrete pile and its rock socket is a discontinuity similar in most respects to a rock joint. This interface has a roughness, and when shear displacements are imposed by structural loading, the

roughness causes an interface dilation, just as for rough natural rock joints. For piles in rock, this dilation causes the rock socket to expand radially (assuming that the concrete is stronger and stiffer than the rock). This behaviour was shown in idealised form in Johnston and Lam (1989) and is reproduced in Fig. 2.

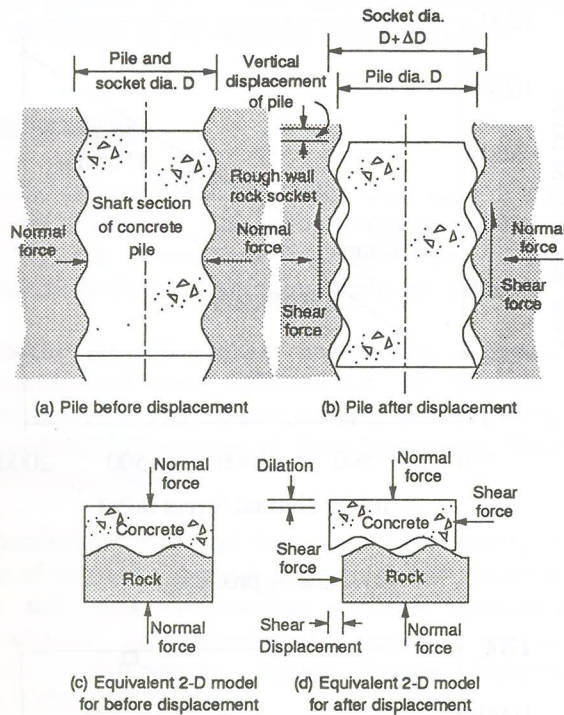


Fig. 2: Idealised displacement behaviour of a pile socketed in rock (After Johnston & Lam, 1989)

The macro behaviour of the pile/socket system can be analytically modelled by Eq. 1. Since r is much larger than Δr , and since both E_m and ν_m can be considered constant for the stress range considered, the normal stiffness K_m is effectively constant. The development of shear resistance in a rough rock socket is, therefore, governed by a condition of constant normal stiffness (CNS) rather than the more common constant normal load (CNL) condition. The CNS condition profoundly effects the performance of the joint by imposing additional confinement, thus suppressing dilation and increasing the lateral stresses acting on the joint.

This process is very similar to that caused by the addition of CSA to the concrete. However, there is one important difference. The increase in lateral stress from the addition of CSA occurs before any shear displacement of the pile; i.e. it can be considered to be an initial lateral or normal stress. As the pile displaces, the lateral stress will increase further as a result of socket dilation and the CNS condition. The CNS shear apparatus used to carry out these tests is described by Johnston et al. (1993).

3.2 CNS Test Results

A number of CNS direct shear tests on rough concrete/rock interfaces were carried out to assess the influence that initial normal stress and normal stiffness had on the shear strength of the joint. The rock used in the tests was a synthetic soft rock called Johnstone (Johnston and Choi, 1986) with a uniaxial compressive strength of approximately 4 MPa. The engineering behaviour of the Johnstone closely models the behaviour of the natural Melbourne mudstone, and as such has been used extensively as a modelling material for Melbourne mudstone.

The CNS tests were carried out for a range of normal stiffnesses and initial normal stresses that are considered appropriate for expansive piles in moderately weathered Melbourne mudstone. The values of normal stiffness adopted ranged from 150 to 2000 kPa/mm while initial normal stresses ranged from 150 to 2000 kPa. The range of initial normal stresses correspond to those values of lateral stress likely to be obtained by varying the CSA content between 0 and 150 kg of CSA per m^3 of concrete, for the range of stiffnesses considered.

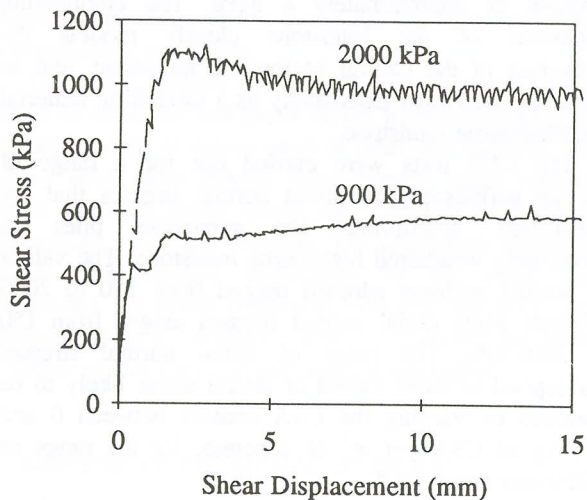
As has been alluded to earlier, the roughness of the joint also has a marked influence on the shear strength of the concrete/rock interface. The CNS tests were therefore carried out for two different roughness profiles designated Class A and Class C. Class A roughness corresponds to a Joint Roughness Coefficient (or JRC) of 2-4 while Class C corresponds to a JRC of 8-10 (ISRM, 1981). A summary of the tests carried out is given in Table 1. The CNS interface samples were prepared as described by Seidel (1994).

Table 1. Constant normal stiffness tests

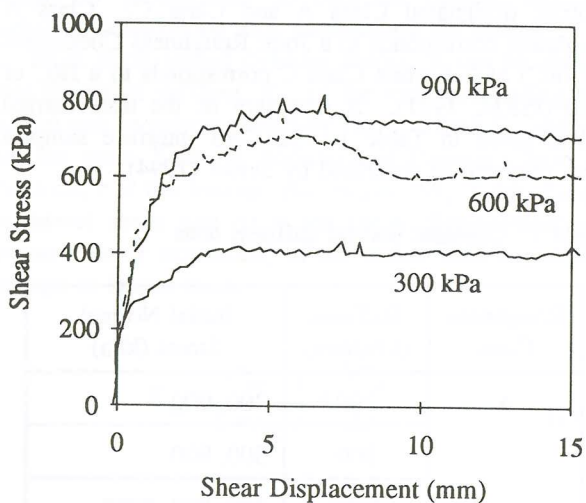
Roughness Class	Stiffness (kPa/mm)	Initial Normal Stress (kPa)
A	300	300, 900
	900	300, 900
	2000	300, 900, 2000
C	150	150, 300
	300	300, 600, 900
	600	150, 300, 600, 1500
	900	300

In Fig. 3, the shear stress v shear displacement curves for several tests are compared. In Fig. 3(a) the results of tests on Class A profiles with a normal stiffness of 2000 kPa/mm and involving two different values of initial normal stress, ie. 900 and 2000 kPa,

are compared. Fig 3(b), shows a similar comparison between tests on Class C profiles, a normal stiffness of 300 kPa/mm and initial normal stresses of 300, 600 and 900 kPa. These results clearly indicate that an increase in initial normal stress generates a considerable increase in interface shear resistance.



(a) Class A profiles

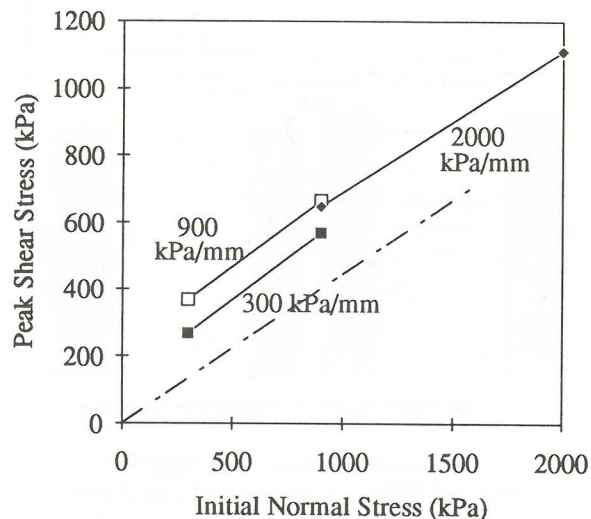


(b) Class C profiles

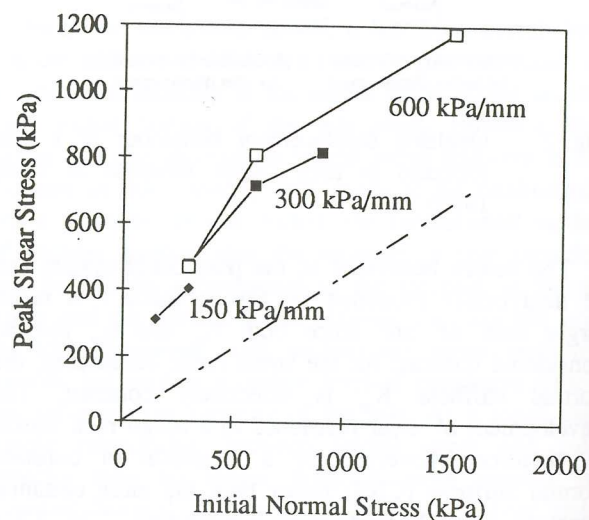
Fig. 3: Influence of initial normal stress on interface shear stress-shear displacement response

Fig. 4 shows the variation of peak shear stress with initial normal stress as determined from the CNS tests. The results have been grouped in accordance with stiffness and profile roughness. Results for Class A profiles are plotted in Fig. 4(a) and for Class C profiles in Fig 4(b). Both plots indicate substantial increases in peak shear stress with increases in initial normal stress. Also plotted in each figure is a line inclined at $\phi = 24^\circ$. This line represents the maximum peak shear stress that would be expected for a smooth profile without any

roughness; $\phi = 24^\circ$ is typical for the interface friction angle of smooth concrete/Johnstone joints. The difference in shear strength between the CNS test results and the 24° line is due to the roughness of the interface. As would be expected, this difference is larger for the rougher Class C profiles (Fig. 4(b)) than the Class A profiles (Fig. 4(a)).



(a) Class A profiles



(b) Class C profiles

Fig. 4: Influence of initial normal stress and stiffness on peak shear stress

4 CONCLUSIONS

The proposal of using expansive additives in cement grouts to improve the capacity of piles and anchors in rock has been discussed. From the laboratory tests conducted to date, it is clear that the use of expansive cement additives, such as CSA, should result in substantial increases in the capacity of these foundation units. A comprehensive field testing programme is

currently underway to determine whether the predicted increased capacity obtained in the laboratory can also be obtained in the field.

5 ACKNOWLEDGMENTS

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