Some Questions Related to The Design of Soil Nails
쏘일네일설계시 관련되는 몇가지 중요한 문제점 연구

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SYNOPSIS : 현재로서는 인발저항 메카니즘에 많은 불확실성들 즉, 구속된조건에서의 다일레이션, 인발저항영역, Transition zone의 존재, Debonding 메카니즘, Boundary condition등 이 내포되어있어, 아직까지 확립된 이론이 존재하지 않는다. 인발저항력 추정을 위해 그 동안 수많은 시도와 노력이 있었음에도 불구하고, 현장 인발시험이 현재 지반설계에 가장 적합한 방법으로 지금까지 통용되고 있는 실정이다. 쏘일네일설계시 요구되는 몇가지 중요한 문제들을 제기하고 그에 대한 나름대로의 해석과 결론을 제시하였다.

Key words : 쏘일네일, 인발저항 메카니즘, 다일레이션, Transition zone

1. Introduction

The use of soil nails for the support of steep excavated slopes is well established, and their installation as temporary support for tunnel faces is finding increasing acceptance. The basic function of the nails is the same in each case, namely to counter the reduction in horizontal stress resulting from the excavation and hence maintain stability of the soil close to the face. The nails act by developing tension as a result of the movements of the surrounding soil; this tension may then be thought of as holding back the wedge or plug of soil which would otherwise fall away from the slope or tunnel face (Figure 1). Conventional designs are based on the concept of active and reactive zones of soil, separated by a failure plane. The effective operation of the nails depends on their being able to bond adequately with the surrounding soil in both zones (in the active zone this may be aided by a facing of some kind attached to the nails).

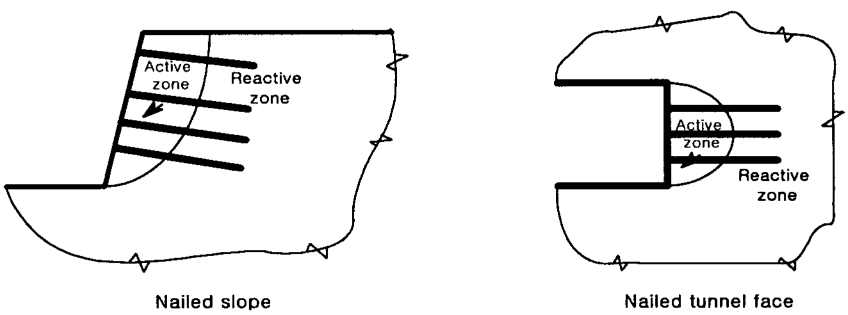

Fig1. Nails in steep slope and face support

The mechanism of bond between nail and soil may be quite complex, and is affected by a number of factors, including soil type and density, size and type of nail, and method of installation of the nail. Calculation of nail bond from soil mechanics principles is at present uncertain, and recent research projects at Imperial College and Oxford University have attempted to shed light on the mechanisms involved in active and reactive zones respectively (Standing 1998 and Milligan et al. 1997). Estimates may be made by assessing the stresses existing in the ground at the nail location, and multiplying these by a soil/nail interface friction angle to determine the shear stresses resisting 'pull-out' of the nail; this approach is included in Advice Note HA68 (Department of Transport 1994). However it is often argued that the actual resistance is much higher, due to the effects of 'restrained dilatancy' whereby the dilatancy in the soil as it is sheared adjacent to the nail surface is restrained, by the surrounding soil (the process is akin to cavity expansion), increasing the normal interface stresses and hence the frictional resistance (see Recommendations Clouterre (1991) p.29-32). As a result of the uncertainty, nails are usually designed on the basis of experience in similar ground conditions, and their design validated by tests on full scale nails on site. The correct methods for carrying out these tests has been a matter for some discussion, notably at the conference on Ground Improvement Geosystems, Densification and Reinforcement (Barley et al., 1997 a and b). It is probably now generally accepted that the bond in the reactive zone can be determined by pull-out tests, with the test nail sleeved to debond it from the soil along the length expected to lie within the active zone (Figure 2); push-in tests have been proposed as being appropriate for assessment of bond within the active zone.

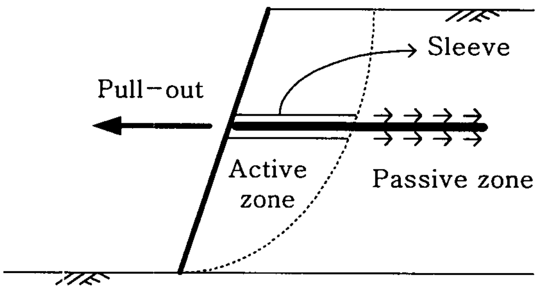

Fig2. Pull-out resistance in reactive zone

Another question concerning nail bond which has been raised is that of progressive failure, particularly if nails are long or rather extensible (e.g. made of glassfibre rather than steel (Barley and Graham 1997). In dense soil the shear stresses at the front end of the anchor length of the nail may have passed their peak values before the shear resistance at the far end has been fully mobillsed. It is sometimes recommended that interface friction angles in such cases should be related to critical state values rather than peak strengths. A final uncertainty in connection with nail bond concerns the relation between short term resistance (as measured in pullout tests) and long term resistance in clay soils. The purpose of this article is to raise the following questions in relation to soil nail design, in the hope of stimulating some debate as to their importance and the best means of answering them; some evidence and discussion will be offered on certain aspects, but final answers may require much further research, and in particular measurement of nail performance under service and failure conditions: 1. Is the simple separation into active and reactive zones sufficiently realistic? 2. Are stresses enhanced in the reactive zone due to restrained dilation? 3. Are site pullout tests adequately representative of actual failure conditions? 4. Is progressive failure a problem with soil nails in practice, or is it a function of pullout test procedures? 5. Can long-term performance of nails in clay be adequately predicted from site pullout tests?

2. PULL-OUT TESTS

There is no doubt that soil-nail interactions in pullout tests are different from those in a slope or tunnel face approaching active failure. In the latter case, lateral (horizontal) stresses are decreasing and the soil is approaching a limiting stress state; in the former, horizontal stresses are increasing and the soil is not close to failure. In a failure condition, relative movement of soil to nail is zero at the failure plane and a maximum at the nail end, while it is a maximum at the front end of the anchor zone in a pull-out test and a minimum at the far end (Figure 3). One result may be that progressive failure is less of a problem in practice than is suggested by analyses of pull-out tests, since at failure both nail and soil are extending in the horizontal direction while in a test the nail is extending but the soil being compressed. Certainly the distributions of axial force in nails, where these have been measured in the field, do not resemble the distributions resulting from pull-out tests, though most of the measurements have been made under service rather than failure conditions. In this case, shear stresses tend to be zero near the failure plane and a maximum at the nail ends (Figure 4).

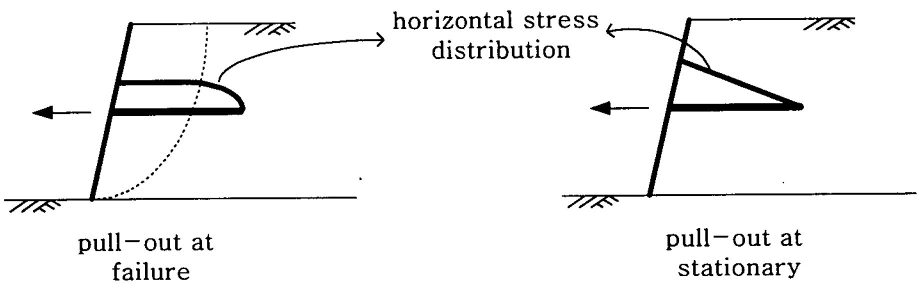

Fig 3. Horizontal stress distributions(pull-out at failure & at stationary)

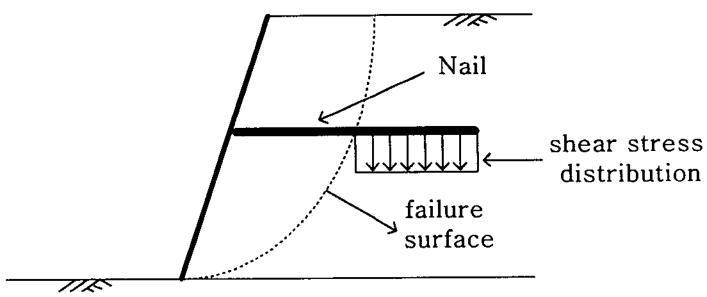

Fig4. Shear stress distribution at failure

3. SMALL SCALE MODEL TESTS

Several of the questions listed have been investigated in a preliminary fashion in small scale laboratory model tests at Oxford (Chang and Milligan 1996). In these tests a single nail was pulled out of a test box containing fine sand under a uniform vertical stress, with the force on the nail measured with a load cell. Nails of various lengths were used, but the sleeved length at the front of the nail was similarly varied so that the anchor length was kept constant but at different distances behind the front wall (Figure 5). Standard pull-out tests were modelled by having a fixed front face through which the nail was pulled; conditions at active failure were modelled by allowing the front face to rotate outwards, with no relative displacement between nail and face, so that an active

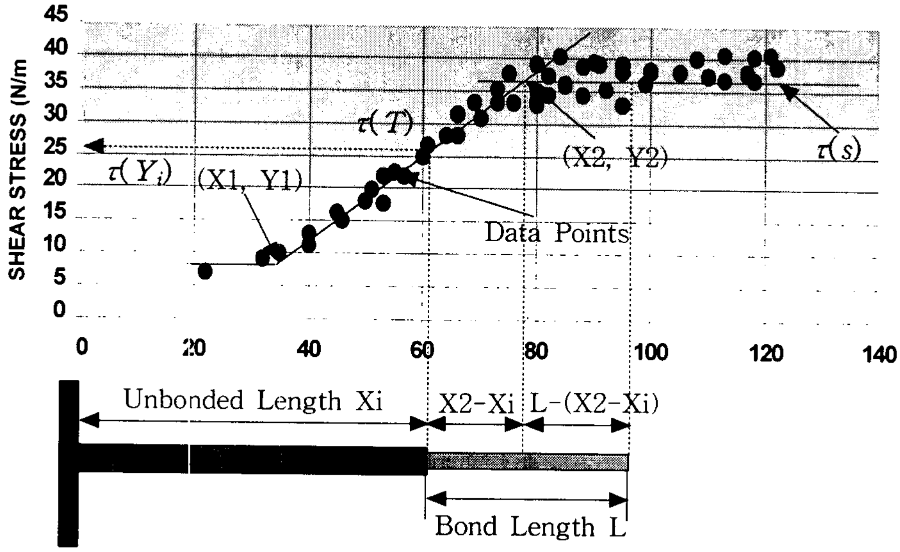

Fig 5. Calculation of local shear stress

failure zone developed behind the wall. Resulting pullout forces are summarised in Figure 6. Data points are plotted such that x is the distance to the front end of the anchor zone. With the fixed front wall, the pullout resistance was the same irrespective of the distance of the anchor zone from the wall. With the rotating front wall, the resistance was the same as for the fixed wall provided the anchor zone was far enough behind the wall; however as the nail length was reduced below a particular value the pull-out resistance decreased almost linearly before levelling out at a much lower value. These variations in overall resistance can be explained in terms of three zones in the soil behind the wall. In a 'stable zone', sufficiently far behind the wall, the soil/nail shear stresses are high and equal to those obtained with a fixed front wall. The start of this stable zone was found to coincide with the line from the toe of the wall at an angle equal to the friction angle of the sand. In a 'transition zone', between the stable zone and the active zone, the shear stresses are approximately constant but much lower than in the stable zone (Figure 7).

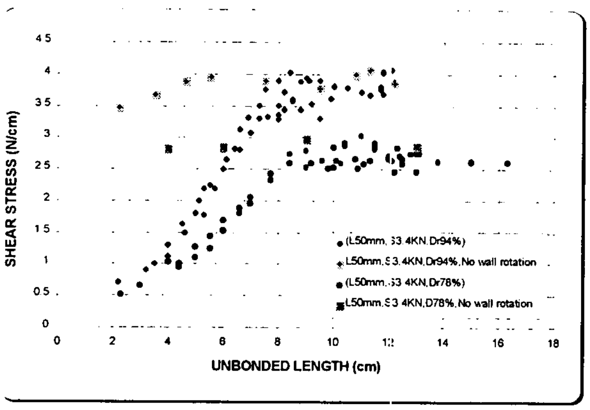

Fig 6. Comparison of Peak shear stress distribution with/without wall rotation

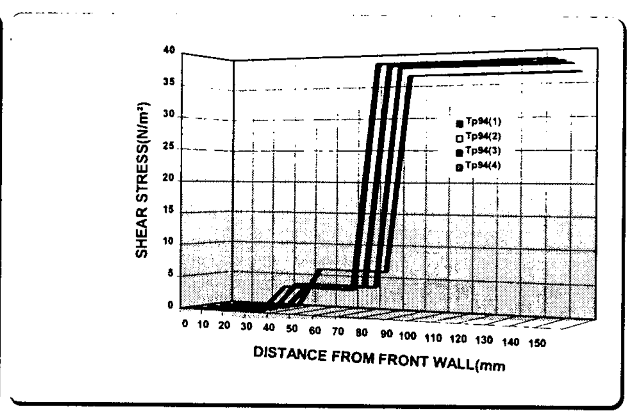

Fig 7. Local peak shear stress distribution for Dr94% sand

The linearly-varying pullout resistance with nail length reflects varying proportions of the nail anchor length within the two zones. Resistance within the active zone could not be investigated as the zone was too small. Very similar patterns of behaviour were observed with series of tests in sand of two different densities, and with two different anchor lengths for the nails. The difference between the local shear stresses in the stable and transition zones is very marked. Those in the transition zone are approximately those that are estimated from the applied stress and an appropriate interface friction angle, while those in the stable zone are very much higher. This suggests that effects of restrained dilatancy are operational within the stable zone, but not within the transition zone, perhaps because of the high stress ratios in the soil within this zone. It is necessary to realise that restrained dilatancy is likely to have very marked effects in these tests, due to the high dilatancy of the sand at the low stress levels in the tests, and the very small diameter of the nail in relation to the grain size of the sand. The effect would be expected to be very much smaller for full-scale nails in realistic soil conditions. However two tentative conclusions may be drawn from the tests: That enhanced pullout resistance due to restrained dilatancy may only operate when nails are long enough to reach the 'stable zone', and then only over the length of nail within that zone. Site pullout tests in stable soil will if anything overestimate pullout resistance, Particularly if there are any effects from restrained dilatancy.

4. NAILS IN CLAY

Soil nailing was initially mainly used in soft rocks and sandy soils with some short term cohesion due to cementing, clay content or capillary suction. More recently their use has been extended to glacial tills and also more plastic clays. In clay soils, there may be some doubt concerning the extent to which results of site pullout tests, necessarily of relatively short duration, provide confidence in the long term performance of nails. There is of course considerable experience of both piles and ground anchors in cohesive soils, but in neither of these is the soil mass around the structural unit in a near-failure condition. Preliminary results from long-term loading tests on nails in clay by TRL (Johnson, P. 1997) are encouraging, but in these tests the nails are of course in stable slopes.

5. CONCLUSIONS

Comments on, but not necessarily answers to, the questions listed above are as follows:

1. The concept of active and reactive zones is useful, but it may be necessary in some cases to consider the reactive zone as having two parts, representing a fully stable zone and a transition zone between it and the active zone.

2. Restrained dilation may help to increase pull-out resistance in suitable conditions, however it is not likely to be as effective as in reinforced soil construction using coarse granular fill, except in stiff and partially cemented materials. Where it does occur, it could lead to unsafe conclusions being drawn from site pullout tests.

3. Even the best site pullout tests do not accurately reproduce conditions in a slope or tunnel face approaching failure. However it is difficult to envisage a more representative method of test. Advances in understanding of soil/nail interaction behaviour under working and failure conditions

may eventually reduce or remove the need to base designs on site tests.

4. Progressive failure may affect nails in service much less than nails undergoing pullout testing. In this case the results of pullout tests may be conservative.

5. There is at present limited information published on pull-out resistance of nails in clay, and the reliability of relatively rapid pull-out tests in predicting the long term performance of nails under sustained load is not yet established. Confidence based on experience with piles and ground anchors may be misplaced due to the very different stress conditions relating to soil nails.

None of the reservations expressed above should be taken a sign of antipathy towards as soil nailing on behalf of the authors. It is an extremely useful technique and its use should be encouraged in appropriate situations. However when failures have occurred they have nearly always been due to insufficient pull-out resistance (see for example Recommendations Clouterre (1991) p.61), and this aspect of design should be treated with caution until understanding of the mechanisms and factors involved has improved.

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