

Alternative Compaction Specifications for Non-uniform Fill Materials

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SUMMARY The difficulties that arise in enforcing standard compaction specifications where the fill materials are not uniform, are described. A case is made for alternative specifications that permit much more straightforward and reliable control testing in non-uniform soils. The alternative air voids - strengths approach is described for soils ranging in type from clays to sands.

1 INTRODUCTION

We excavate, prepare and compact a wide range of natural materials to alter the landscape in civil engineering works. In most cases we handle fine grained soils, natural gravels or processed aggregates. The compaction specifications for these materials are extensively expressed in standard terms related to one laboratory compaction test method, despite the wide variety of materials handled and the varying service conditions of the compacted fill. A tradition of standard specification use has been built up that discourages many of us from seeking alternative compaction specifications that may be more appropriate in certain circumstances.

Situations are often encountered where the material covered by the compaction specification does not have uniform compaction characteristics, or in effect comprises a range of different materials. Large difficulties can arise in interpretation of control test results and in these circumstances the standard specification approach is inadequate. Effort has been put into developing field testing techniques that attempt to ease the problem of interpretation but surprisingly little effort has been put into developing alternative specifications that allow accurate or more practical interpretation of field control tests.

The desire to set rational and readily enforceable compaction specifications has led to experience in New Zealand in the use of alternative compaction specifications, principally covering clays, silts and sands. This experience is generally known but many engineers still persist with standard type specifications in circumstances where they are better avoided. It seems appropriate to describe some of the alternative specification methods that can be used successfully and remind all engineers that we do not fulfill our proper technical role if we become hidebound to outdated traditions.

2 STANDARD SPECIFICATIONS AND REFERENCE TESTS

Most compaction specifications follow much the same pattern and relate to a standard laboratory compaction test method which is usually the Proctor test or a modified version of it. The criteria laid down may vary from case to case but the terms used are usually consistent and specifications of

this form may be termed standard specifications. They require the fill material to be compacted so that its dry density exceeds a certain percentage of the maximum dry density obtained in the standard test, and the fill water content to be confined within limits referenced to the standard test optimum water content.

What is the justification for these particular standards? We nearly always seek high strength and low compressibility, and to aim for a dense state of packing of the soil particles referenced to the maximum dry density, will help achieve these objectives. We know from experience that if the fill is too dry it will be difficult to compact to the specified dry density, and if it is too wet, the desired strength may be too low even if the specified dry density is achieved; hence we also impose compaction water content limits.

We know that the standard laboratory test, involving a particular compactive effort and procedure, does not uniquely describe the compaction performance of a soil: a particular piece of field equipment operated in a certain way will have its own water content/dry density relationship, possibly significantly different from the standard test results. Although there are logical reasons for setting specification criteria in the terms that are used, it is basically empirical evidence that supports expression of compaction standards in terms of the standard test for a wide range of materials. If standard specifications have been developed in this way, the door must be wide open for alternative and improved approaches.

3 ENFORCEMENT OF STANDARD SPECIFICATIONS IN PRACTICE

To establish whether fill complies with a standard type specification, it is necessary to establish the as-compacted dry density and water content and be able to compare these results with the maximum dry density and optimum water content for the particular soil being tested. Testing for field density and water content is a relatively straightforward matter for a wide range of material types, using several techniques: compacted aggregates are not physically easy to test other than by nuclear test methods. However, the field measurements are of little practical use unless they can be readily

related to a previously determined dry density/water content relationship.

Some sites or portions of sites do have essentially uniform fill material with consistent maximum dry density and optimum water content as measured in the standard test, and use of standard specifications is acceptable. However, at least in New Zealand, these circumstances are the exception rather than the rule and even very small sites can contain highly varied soils, such that a scraper may uplift and deposit in one pass a mixture of materials with no characterising standard compaction properties. Fig 1 illustrates the order of variation that can be met.

A further complication arising with some soils (especially those of volcanic origin containing allophane), is that their compaction properties vary depending on the history of wetting and drying and any manipulation prior to final compaction. For these soils there is less relevance between the field results and the laboratory results unless the laboratory test models the field sequence of water content adjustment and soil manipulation. This difficulty does not preclude the use of, or prejudice the contractual validity of standard specifications based on a standard test, but adds further to the complications of assessing variable fill specified this way.

Under the conditions outlined, the controlling engineer has either to abandon the strict terms of the specifications and employ subjective judgement of fill standards, or to prove the case, must perform a standard compaction test on the particular

material tested in the field to obtain reliable reference properties. Use of subjective judgement is contractually unacceptable and to undertake a large number of standard compaction tests is too costly and time consuming to be regarded as a practical solution.

4 BASIC SPECIFICATION REQUIREMENTS

A satisfactory specification is one that adequately describes the designer's requirements, is understood by the parties to the contract, is practically capable of being enforced, and is not unnecessarily costly or time consuming in enforcement.

The key properties we wish to achieve for compacted fill are low compressibility, high strength and long term stability. These properties and how they may vary depending on the initial state of compaction may be described, perhaps in an over simplified manner, by reference to the saturation or zero air voids line that exists for a soil of constant solid density.

Compressibility, stability and strength are all principally governed by the density of packing of the soil particles. Compare points A & B on figure 2 which represent two initial states of compacted fill. The more densely compacted material represented by point A would achieve a state represented by A_1 if saturation can occur by compression at constant water content, and would reach A_2 if saturation were to occur without changing the soil density, say as a result of seepage forces: B representing a less dense initial state of compaction could similarly move to B_1 or B_2 .

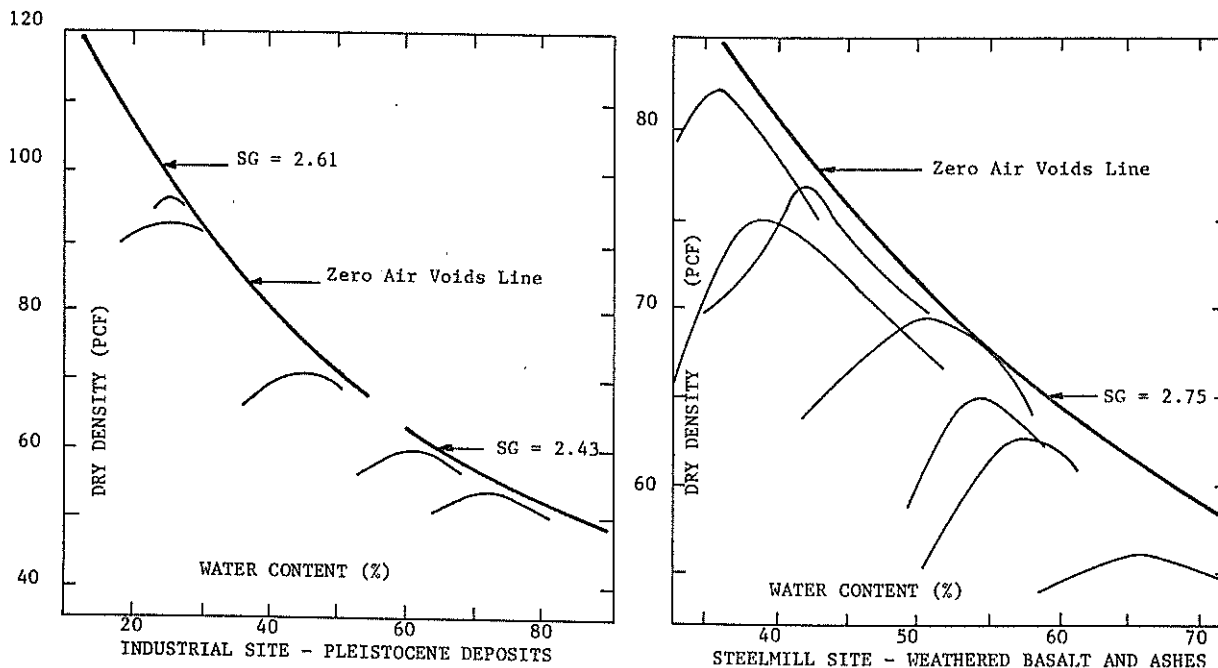


Figure 1 Illustration of Variable Fill Materials

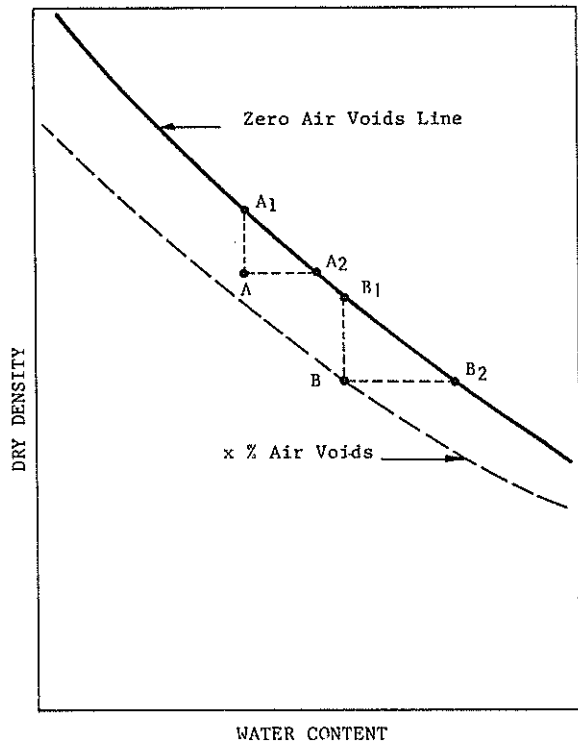


Figure 2 States of Compaction

If the intervals AA_1 and BB_1 are regarded as a measure of potential compressibility (setting aside questions of elasticity and consolidation properties), fill represented by condition A would be expected to be less compressible than B type fill. The stability of the A type fill, expressed in terms of the reduced potential for water content increase and consequent softening ($A_1 A_2$), is better than that of the B type fill ($AA_1 < BB_1$).

Based on experience, we know that the soil strength at point A_1 will be higher than at point A_2 , and at A_2 will be higher than at B_1 and B_2 ; similarly, the initial strength at A will exceed that at B unless the A material is dried to a water content that is unacceptably low.

Developing a feel for the properties of compacted fill in relation to the zero air voids line is believed to be more useful than understanding compaction curves, and assists in understanding the workings of the alternative specifications described below.

The compaction standards specified and the related control testing should eliminate reliance on personal judgement in measuring the adequacy of construction. The control tests should be kept simple and inexpensive if possible, and permit quick response on site to avoid difficulties such as having to reject fill placed three days previously and now buried below another two metres of fill.

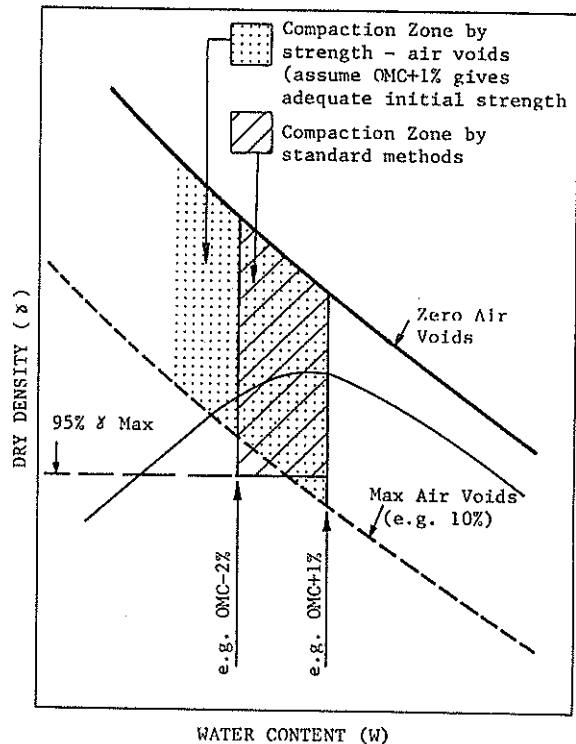


Figure 3 Comparison Alternative Specifications

5 AN ALTERNATIVE APPROACH FOR COHESIVE FILL MATERIAL

5.1 Description

A specification and control test approach based on air voids and soil strength has been proved suitable for variable cohesive soils. A maximum tolerated air voids is specified together with a minimum undrained shear strength after compaction. Strength is usually defined and measured by unconfined compaction, C.B.R., or in-situ vane with the latter preferred where the fill behaves as a clay. The pre-specification soil testing necessary before the particular limits are set depends on the nature of the project.

The differences in state of compaction resulting from use of strength-air voids and standard specifications are illustrated in Figure 3.

Specifications in terms of strength and air voids permit the reliable measurement of fill standards and removal of the use of personal judgement commonly employed where the soils are variable. Generally when earthmoving jobs are running in an orderly manner, low air voids are easily met and the largest problem encountered is avoidance of excessively wet fill that leads to low density and low strength. The strength-air voids approach is particularly useful here in that the low strength can be demonstrated in a matter of moments using field vane apparatus and the contractor can be notified immediately that the fill does not meet the specified requirements.

5.2 Field Control

In order to measure air voids, it is necessary to know the field density, the field water content and the specific gravity or solid density of the soil particles. Density and water content are measured by usual methods. The specific gravity is a factor that does not require frequent measurement. It varies by only a small amount within a locality where the soil is of uniform geological origin, even though the compaction properties of the local soils may vary considerably, and the effect of small variations of specific gravity on the position of the zero air voids line is not significant. Usual practice is to do several specific gravity tests at the design stage, select an average value and write into the specification that this value shall be adopted until such time as specific gravity tests done during construction, show that a change in average value is warranted. Check specific gravity tests are done on an infrequent basis as a part of control testing.

This specification method does not reduce the problems of rapid evaluation of water content and dry density which form part of the measurements. Interim results obtained via rapid water content test methods and involving possible inaccuracies have to be used as necessary. However, with the specific gravity pre-established and described in the specification, no further tests are required to identify fundamental soil characteristics and the air voids control test result can be confirmed with confidence and related to the specification requirements regardless of the standard compaction characteristics of the soil.

Strength, the other parameter, is measured directly and quickly. Where the in-situ vane method is used, small hand operated vane apparatus with about 19 x 29 mm blade dimensions has been found suitable on fills of lesser importance, whereas a landrover mounted vane with 47 x 94 mm blade and torsion spring measuring device has been used on a major earthfill dam.

In practice, the field supervisor begins with a large scale graph sheet on which the zero air voids line and relevant per cent air voids lines are drawn. Each measured dry density/water content point is then plotted to see whether it falls within the specified air voids zone. The corresponding strength result is generally unimportant providing it exceeds the minimum value specified: more often than not where the fill standard is high and vane strength is being used the supervisor will just record, "too hard to penetrate".

5.3 Standards and Examples

Experience in New Zealand with a wide range of cohesive soils has shown that sufficiently low compressibility is obtained if the air voids of the fill are less than 10% and the fill has a reasonable initial undrained shear strength (say not less than 100 kPa). The minimum strength should be sufficient to ensure safety of typical fill slopes and also support the earthmoving equipment without excessive deformation occurring. Special studies are required to determine appropriate values for critical fills such as in earth dams.

The strength below which the excessive deformation or overcompaction phenomenon occurs, varies with soil type and construction machinery, but has been observed to be about 70 kPa for light equipment on plastic clays and about 100 kPa for heavy equipment on very silty, low plasticity clays.

Therefore a typical specification for cohesive type general fill, based on experience rather than a comprehensive testing programme, would read:

average air voids < 10% (10 consecutive tests)
 maximum air voids 12% (any one test)
 average undrained > 150kPa (10 consecutive tests)
 shear strength

The strength air voids approach is being used increasingly in the north of New Zealand where soils are particularly variable. It has been used predominantly for general purpose earthworks but has been used successfully on larger projects where high compaction standards are important. Three cases involving important fills located in the Auckland region are described in summary form by way of illustration.

A Earth Dam

Eighty metre high earthfill dam of 3,000,000 cubic metre fill volume, built from residual greywacke and argillite origin materials varying in type from plastic clay to moderately weathered rock. Construction period 1973 - 1977. Central fill zones comprising cohesive type materials specified and controlled in accordance with the following:

maximum air voids single test result	10%
average air voids for 10 consecutive tests	8%
minimum vane shear strength, single test result	69 kPa
average vane shear strength for 10 consecutive tests	103 kPa

Supplementary test requirement, used where judged necessary, was maximum compaction water content, optimum plus 3%

B Steelworks Site Development

Basic site levelling for steelworks expansion, 1977-1978, involving 500,000 cubic metres of fill comprising weathered basalt and ashes.

General filling carried out in accordance with the following:

maximum air voids, single test	10%
average air voids	8%
minimum vane strength, single test	110 kPa
average vane strength	150 kPa

C Urban Motorway Extension

3.5 kilometres motorway extension involving 800,000 cubic metres of fill, mainly consisting of weathered volcanic ash, built 1973 - 1974. Specification as follows:

embankment fills:	
maximum air voids	12%
minimum C.B.R.	10
subgrade:	
maximum air voids	10%
minimum C.B.R.	15

Specific gravity for interpretation taken at 2.8. Proctor needle permitted for control in place of C.B.R.

(Construction tests showed that most fill was compacted to about 5% air voids: specific gravity varied between 2.7 and 2.8 and was re-adjusted to 2.75 for test interpretation).

6 AN ALTERNATIVE APPROACH FOR SANDY SOILS

Variable soils of a sandy and silty nature can be encountered that also present considerable difficulties in enforcement of standard specifications. Extensive variations in materials of this type within a site may be more common in New Zealand than Australia. For example, the centre of the North Island contains volcanic ashes and lapilli that are often closely banded and variable in grain size. In some districts weathered sandstone with variable silt content occurs below a shallow zone of weathered clays and silts and earthmoving work can involve the sandstone or sandstone mixed with overburden.

The strength-air voids specification approach can be used for these sandy materials in a similar manner to that described for cohesive clays and silts. However, the simple in-situ shear vane cannot be used with reliability and it may not always be feasible to prepare unconfined compression samples. In these circumstances it is necessary to measure strength by means of methods such as C.B.R. or Scala dynamic penetrometer. The Scala penetrometer (Scala, 1956) appears to be a satisfactory control test tool and has advantages over the C.B.R. in the scale of equipment required and ease and cost of test. The following two recent examples of specifications based on use of the Scala penetrometer for sandy fills illustrate the approach.

In the first project, some 150,000 cubic metres of volcanic ashes were required in two small dams and a large canal. During investigations Scala penetrometer tests were conducted in the laboratory on material compacted at different water contents within the proposed air voids limits. From these tests a minimum penetration value was determined corresponding with the lowest acceptable fill strength and stiffness. The blows required to penetrate the top 50 mm were discounted to allow for likely disturbance at the top of each layer after compaction. The final specification was expressed in the following terms:

maximum air voids single test	10%
average air voids	↗ 8%
average Scala value (50 - 200mm penetration)	↖ 7 blows
lowest single Scala value (50 - 200mm penetration)	↖ 5 blows

It should be noted that the material on the project generally had the consistency of a silty sand after handling: for clean sands a higher air voids value may have to be adopted.

In the second project, weathered silty sandstone was used in a foreshore reclamation. In this case, provision was made in the contract to calibrate Scala blows against undrained shear strength during the early stages of earthmoving. Subsequent control testing for strength relied on the Scala penetrometer alone. The specification and results of the calibration testing were as follows:

maximum air voids single test	12%
average air voids	↗ 10%
average undrained compressive strength	↖ 300 kPa by triaxial test at 15 kPa confining pressure
established minimum corresponding Scale value	9 blows (100mm - 250mm penetration)

7 CONCLUSIONS

Non-uniform fill materials are found in practice, that present large difficulties in the evaluation and enforcement of compaction specifications expressed in terms of standard laboratory compaction test results. Such specifications do not have a rigorous scientific base and are in part empirically based. There is justification for adopting alternative specifications if they are equally well based, and those that reduce the problems of controlling variable fills are particularly valuable.

Specifications that relate to the density of packing of the soil particles and the actual compacted strength of the soil are felt to describe desired fill properties better than current standard specifications. Specifications in terms of air voids and strength are of this type and cope satisfactorily with variable soils ranging from clays to sands without involving extensive reference testing. Shear vane testing is convenient for materials that behave as clays after compaction and the Scala penetrometer is suitable for sandy fills.

8 REFERENCES

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