TRANSPORT and ROAD
RESEARCH LABORATORY

Department of the Environment
Department of Transport

TRRL LABORATORY REPORT 806

THE CLASSIFICATION OF CHALK FOR USE AS A FILL MATERIAL

by

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Crowthorne, Berkshire
1977
ISSN 0305–1293

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ABSTRACT

This Report describes an investigation of chalk as a freshly placed fill material and the development of a new classification for chalk in relation to the stability of the material during construction. From measurements made on eleven chalk earthworks sites the onset of unstable conditions in the fill has been related to values of moisture content and degree of crushing. The proposed classification is based on the prediction of these two parameters and depends on the measurement of the saturation moisture content and the impact crushing value (using a newly developed test) of the chalk. The classification includes recommendations on the selection, when necessary, of methods of earthwork construction which minimise the risk of instability in the freshly placed material, while at the same time using a degree of compaction compatible with a satisfactory long-term performance of the embankment.

1. INTRODUCTION

Earthworks in chalk continue to be required over large areas of southern and eastern England where the chalk deposits appear near ground level. The behaviour of freshly placed fill material resulting from chalk cuttings varies considerably depending on the strength and moisture content of the chalk being used. Chalk fills resulting from soft chalk at high moisture contents frequently become unstable during the formation of embankments, high positive pore water pressures make compaction impractical, and work sometimes stops altogether due to the inability of the fill material to support the construction plant. Delays, disruption of the construction programme, and greatly increased costs can result. Conversely, with less serious results, very hard chalk can be difficult to excavate and the coarse particle size of the resulting fill material also causes compaction problems. Chalk with physical properties between these two extremes poses fewer problems.

The difficulties arising from the instability of chalk fill, especially the inability to operate compaction plant efficiently on the spread material, have caused doubts to be expressed about the suitability of soft chalk as a fill material. However, the extra cost of using imported fill material, and the ability of initially unstable chalk to gain strength over a few weeks to form a stable embankment, have led to its continuing use.

The wide variation in the quality of chalk as a fill material demonstrates clearly the need for methods of predicting, at the site investigation stage, the potential behaviour of the material during construction, and particularly the need for means of identifying the more troublesome softer chalk.

A description of previous research on earthworks in soft chalk[1] included the suggestion that the cause of instability in chalk fill is excessive crushing of the chalk; it pointed out the need to preserve the lump content in the fill if unstable conditions are to be avoided and, therefore, warned against the use of scrapers on soft chalk (unless assisted by rippers). The need for further research into the inter-relation between particle-size distribution, moisture content, and the performance of chalk in an embankment was mentioned.

The current research began with a survey, in 1975, of 16 road sites where chalk earthworks were in progress or had recently been completed. Scrapers had been used initially for the chalk earthworks on 12 of the 16 sites. Within these 12 sites, the seven that contained soft chalk all experienced moderate or severe instability problems. However, on three soft chalk sites in Kent, instability problems had been successfully avoided by using vertical-face excavation and a reduced compactive effort. Additionally, on two sites excessive settlements were reported in chalk that had been used as backfill behind bridge abutments. These settlements are understood to have occurred during periods of heavy rain.

This Report describes an investigation of chalk as a freshly placed fill material and the development of a new classification for chalk in relation to the stability of the material during construction. The proposed classification incorporates the use of a new impact crushing test for chalk and includes guidance on methods of earthwork construction which, when necessary, minimise instability problems in chalk fill.

2. ASPECTS OF CHALK GEOLOGY

Chalk is a soft, white, porous limestone which was laid down during the Cretaceous period when most of the British Isles and north-western Europe were covered by sea. It is not surprising that chalk is a very variable engineering material as the conditions under which it settled as an ooze on the sea bed varied considerably during its long deposition period. The electron microscope has shown that the ooze was composed almost entirely of organic skeletons of two different origins[2]. Firstly, a finer fraction, which usually contributed about 70 to 80 per cent of the whole, was composed of microscopic calcareous bodies and their disintegration products down to single calcite crystals. These bodies, known as coccoliths, yielded particles in the range 0.5 to 4 μm. Secondly, a coarser fraction, which contributed about 20 to 30 per cent of most types of chalk, was composed of skeletal remains of micro-organisms, known as foraminifera, and the broken down remains of large-shelled organisms such as molluscs and sea urchins. These yielded particles in the range 10 to 100μm. The finer fraction formed a matrix for the coarser material and it is probable that the proportion in which these quite separate ranges of particle sizes are mixed in the naturally occurring chalk contributes to the variations in physical properties exhibited.

The first layers of ooze which settled became mixed with clay muds and this resulted in the greyish or buff coloured chalk marl in the lower layers of the Lower Chalk. The marl sometimes forms separate layers or alternatively is homogeneously distributed in varying proportions. In the latter case contents of non-chalk constituents as high as 40 per cent have been measured during the current research. In the upper layers of the Lower Chalk, and in the Middle and Upper Chalk, however, the chalk becomes much purer, generally with greater than 95 per cent calcium carbonate. The Middle and Upper Chalk contain bands or nodules of flint which are not present in Lower Chalk.

Relatively thin layers of extremely hard chalk occur at intervals in the chalk mass. The most important of the hard layers are the Totternhoe Stone in the Lower Chalk, the Melbourn Rock at the base of the Middle Chalk, and the Chalk Rock which occurs at the division of the Middle and Upper Chalk.

The horizon between the chalk and the overlying deposits, where they exist, is often sharply undulating and solution holes in the chalk also allow extensive intrusion of these deposits. This makes for difficulty in the estimation of the relative volumes of chalk and the overlying deposits from site investigation records. This feature also causes the chalk to become mixed with the overlying material during excavation.

3. FACTORS AFFECTING THE STABILITY OF CHALK FILL

The natural moisture content of chalk remains at, or very near to, its saturation moisture content, individual values of which varied from as low as 8 per cent to as high as 36 per cent in chalk encountered in the current research. During earthworks the excavation and compaction processes partly break down the natural rock structure of the chalk, releasing some of the contained water. Chalk fill therefore consists of a mixture of chalk lumps and chalk fines, the latter forming a slurry or "putty chalk" at higher values of moisture content. A fill material which is temporarily weak and unstable results if the proportion of putty chalk is high enough to control the behaviour of the whole. It follows that the stability of the freshly placed fill depends on its moisture content and its fines content, and a classification of chalk, for use as a fill material, must be based on the prediction of these two parameters.

4. THE IMPACT CRUSHING TEST

The percentage of fines in the fill is dependent on the susceptibility to crushing of the chalk being used and the crushing action to which it is subjected during the earthwork construction processes. The prediction of the fines content in chalk fill, therefore, requires the measurement of the susceptibility of chalk to crushing and the establishment of relations between such measurements and the degree of crushing produced by various methods of earthmoving currently in use. Thus, a rapid and simple crushing test is required which would be applicable to chalk samples available at the site investigation stage.

It was considered that none of the existing methods of measuring the strength of soils or rock, if applied to chalk, would accurately represent its susceptibility to crushing. The French vibro-crushing test[3] had recently been proposed but it was considered that a less complicated test, less susceptible to possible operator variability, would be more appropriate. It was decided, therefore, to develop a new test for the purpose.

An apparatus (Plate 1) was currently under development at the Laboratory for the rapid measurement of the moisture condition of soils[4]. It was found that this apparatus could also be used to test the susceptibility to crushing of chalk samples and fulfilled the requirements of speed and simplicity of use. A detailed description of the apparatus and test procedure are given in Appendix 1.

Susceptibility to crushing is taken to be the rate at which a 1 kg sample of single-sized chalk lumps (passing 20 mm and retained on the 10 mm BS sieves), contained in a mould 100 mm in diameter, crushes under a series of impacts delivered by a 7 kg rammer falling freely through a height of 250 mm. The amount of crushing is determined during the test by measuring the penetration of the rammer into the mould by means of a scale attached to the side of the rammer. The rate of crushing, or "crushing value", of a sample is defined as one-tenth of the slope of the straight section of the relation between penetration (mm) and the logarithm of the number of blows. A steep slope indicates a fast rate of crushing and, therefore, a soft chalk. Crushing values vary from about 4.2 for a very soft chalk to about 2.4 for a very hard chalk.

Crushing value has been found to be independent of the moisture content of the test sample. Figure 1 shows the relations between the penetration of the rammer and the logarithm of the number of blows for a soft and a hard chalk in both the saturated and the air dry states. The relations are displaced with variations in moisture content but the slopes of the lines, and hence the crushing values, are effectively the same for samples of the same chalk. This confirms a previous statement[2] to the effect that the strength of a given chalk sample is comparatively little affected by its degree of saturation.

A comparison of the results achieved with the impact crushing test with those obtained with the French vibro-crushing test is given in Appendix 2.

5. EXPERIMENTAL PROCEDURE

A programme of research was implemented to provide information appropriate to a chalk classification procedure based on the prediction of moisture content and degree of crushing in the compacted fill.

Eleven road construction sites where chalk earthworks were in progress were visited during 1975 and 1976 to measure the relevant physical properties, including the crushing value, of the chalk being used, and to relate these properties to the condition of the fill material.

The sites visited are given in Table 1. They were distributed over most of the area of southern and eastern England where chalk is found near the surface and the chalk encountered varied widely in properties.

A total of 15 visits were made to the 11 sites, more than one visit being made to some sites to investigate the behaviour of chalks of different crushing value fround on the same site, or to investigate varying conditions of the freshly placed chalk. Each visit was usually for a period of three days, the same procedure being repeated on each day.

TABLE 1

Road construction sites included in the investigation

Motorway or trunk road	Section	Geological stratum
M27	Funtley – Portsbridge	Upper Chalk
M25	Dartford – Swanley	Upper Chalk
M20	Swanley – West Kingsdown	Upper Chalk
A2	Lydden – Dover, Contract 2	Upper Chalk
A45	Newmarket – Bury St Edmunds	Upper Chalk
M180	Brigg By-pass	Lower Chalk
A27	Lewes Southern By-pass	Upper, Middle and Lower Chalks
A3	Butser Hill	Middle/Lower Chalk
A34	Chilton–Drayton	Lower Chalk
A15	Brigg – Barton	Middle Chalk
A36	Whaddon – Peters Finger	Upper Chalk

5.1 Measurement of chalk crushing value

Each day six samples of chalk, representative of the material being excavated, were taken from the excavation area. The type and size of the excavation plant in use were recorded. Crushing values were measured on site, using the impact crushing test (see 4), on sub-samples obtained from each of the six samples. The moisture content of each sample was determined by oven drying (Test 1A, BS 1377:1975)[5], and the remaining chalk retained for further testing.

5.2 On-site determination of the properties of the chalk fill

5.2.1 Degree of crushing in uncompacted fill. To provide data on the proportion of crushing of the chalk caused by the excavation process, and exclusive of the compaction process, six samples for sieve analysis were taken daily from the loose fill material immediately after unloading from the earthmoving vehicles. The procedure was to select a vehicle being loaded with chalk in an area already sampled for the impact crushing test, and then to take a sample, of mass about 30 to 40 kg, from the same material unloaded in the fill area. Samples taken in this way were, therefore, uniquely related to particular methods of excavation and transportation.

To simplify the test procedure the degree of crushing was defined as the percentage passing the 20 mm BS test sieve. Whenever possible the sieve analyses were carried out on site at the natural moisture content of the chalk. However, some samples were too wet for sieving immediately and were air dried before sieving. Particular care was always taken during sieving to ensure that no coagulated chalk fines were retained on the sieve and all discrete lumps which were retained were cleaned of fines adhering to them. All flints and other non-chalk materials, eg clay, were removed from the sample prior to sieving on the 20 mm sieve.

5.2.2 Degree of crushing and moisture content of compacted fill. The general deposition area in the fill, tested as described in 5.2.1, was noted, and six samples for sieve analysis and moisture content determination were taken daily after compaction had been completed. The type of compactor and the compaction procedure used were recorded. The method of obtaining each of the samples for sieve analysis in the compacted fill was to dig a narrow trench, to a depth approximately equal to the depth of compacted layer, surrounding a block of fill material approximately 300 to 500 mm square. These dimensions varied with the depth of layer so that the mass of the sample was approximately 30 to 40 kg. The block was loosened from underneath and loaded into plastic bags with as little breakdown of the particles as possible, and sealed. The sieve analysis was carried out as described in 5.2.1.

5.2.3 Properties of unstable chalk fill. The condition of the chalk fill with regard to stability was recorded for each position from which the samples described in 5.2.2 were taken. An unstable state was taken to exist when ruts were formed by the passage of the earthmoving plant and additional measurements were made where ruts occurred in any part of the fill area under construction. A sample was taken from under the rut for the determination of the degree of crushing, using the same procedure as that carried out with samples from the compacted fill (see 5.2.2). A sample was also taken for moisture content determination by oven drying.

Further measurements made when ruts occurred included the determination of the depth of the rut below the original surface of the fill (with a note of the type of machine making the rut and its tyre size), the shear strength of the chalk fill at the bottom of the rut (using a portable shear vane), and the dry density of the compacted material immediately adjacent to the rut (using the core cutter method, Test 15D, BS 1377:1975[5]). The data obtained from these further measurements were found to be unnecessary to the development of a classification of chalk as a fill material and have not been included in this Report.

5.3 Laboratory measurements of chalk properties

Determinations of the saturation moisture contents of intact chalk lumps were made on all samples from the excavation areas of the eleven sites visited. The test used was an extension of the British Standard test for determining the dry density of soil by the "Immersion in water" method (Test 15E, BS 1377:1975)[5]. This test involves weighing a wax-coated intact lump of chalk, volume about 300 to 500 ml, in air and then immersed in water. From the values of dry density obtained, and an assumed specific gravity for chalk solids of 2.70, the saturation moisture content was determined using the following formula:—

$$\text{Saturation moisture content} = \left(\frac{1}{\rho_d} - \frac{1}{2.7}\right) 100 \text{ (per cent)}$$

where ρ_d is the dry density in Mg/m^3.

Determinations of calcium carbonate content, using Collins' method[6], were also made on samples from selected sites to represent as wide a range of types of chalk as possible.

6. DISCUSSION OF RESULTS

6.1 Properties of the natural chalk

The relation between crushing value and saturation moisture content of the intact chalk lump (Figure 2) indicates a general trend of decreasing strength (increasing crushing value) with increasing porosity. However, the scatter of results about the regression line indicates that unacceptable errors could arise if one parameter was used to predict the other. At any given saturation moisture content, the crushing value, representing the strength of the chalk lumps, could vary in a range $\pm$ 0.3 of the crushing value given by the regression line. Each point in Figure 2 is the mean of at least six results, and from values of standard deviation calculated during the investigation, it is estimated that the mean value given for each point would be accurate to $\pm$ 0.14 of crushing value and $\pm$ 1.7 of saturation moisture content at the 95 per cent confidence level. The variation about the regression line shown in Figure 2 is likely, therefore, to be indicative of the real variability of the relation between these chalk properties.

The relation between chalk crushing value and calcium carbonate content is shown in Figure 3. It can be seen from this figure that the samples of Middle and Upper Chalks contained more than 95 per cent calcium carbonate and that those of Lower Chalk contained between 60 and 90 per cent calcium carbonate. There appears to be a slight trend towards an increase in crushing value (weakening) of Lower Chalk with decrease in calcium carbonate content, but it is clear that the wide range of crushing values of the samples of Middle and Upper Chalks is not attributable to variations in calcium carbonate content.

There is strong evidence in Figures 2 and 3 that easily measured parameters such as density, porosity, saturation moisture content or calcium carbonate content cannot be related uniquely to the susceptibility of chalk to crushing as represented by the results of the impact crushing test. Thus the use of such a strength test appears to be fully justified.

6.2 The onset of unstable conditions in the fill area

The relation between moisture content and degree of crushing of the compacted fill is shown in Figure 4. Each of the points representing stable conditions is the mean of all the measurements made in such cases during one site visit. Each point representing unstable conditions was obtained in individual areas of temporarily unstable chalk fill. A straight line has been drawn to separate the points representing stable and unstable conditions. The slope of this line confirms that the onset of unstable conditions is dependent on both moisture content and degree of crushing. The line can be considered to represent the relation between moisture content and degree of crushing at the onset of unstable conditions.

The results indicate that stable conditions are always likely to occur at moisture contents below 23 per cent, and as the moisture content increases above 23 per cent stable conditions can be maintained by progressively reducing the degree of crushing in the fill. This confirms that a classification of chalk related to its behaviour as a fill material must be based on the prediction of both moisture content and degree of crushing, especially with soft chalk with moisture contents in excess of 23 per cent.

6.3 Prediction of moisture content in the compacted fill

Parameters relating to moisture content which can be determined at the site investigation stage are the natural moisture content of the chalk and the saturation moisture content of the chalk lump. Because of the length of time between the site investigation and the start of earthmoving, and the effects of the weather conditions at and prior to the excavation of the material, it is by no means certain that the moisture content of the chalk during excavation will be the same as that measured at the site investigation. However, it is not likely to exceed the saturation moisture content to any great extent.

Figure 5 shows the relation established between the moisture content of the compacted fill and the saturation moisture content. The results were obtained during two earthmoving seasons with drier than average weather conditions so, ideally, results for a "wet" earthmoving season are also needed. Nonetheless, during the period of the research, the moisture content of the compacted fill was, on average, 0.85 of the saturation moisture content. Extreme values ranged from just above saturation moisture content to 0.65 of saturation moisture content (Figure 5).

Results of a similar nature to those in Figure 5 indicate that the moisture content of the chalk at the time of excavation was, on average, 0.91 of the saturation moisture content.

For the purpose of predicting the moisture content of compacted chalk fill it is concluded that the saturation moisture content could be used to indicate the highest possible value and 0.85 of the saturation moisture content the mean summer level.

6.4 Prediction of the degree of crushing

It has been stated in 5 that records were kept, during the site visits, of the type of plant in use in the different phases of the earthworks process. The types of excavation plant observed can be divided into four main categories:

1. Face shovels
2. Backacters
3. Scrapers
4. Tractor shovels with bulldozer assistance.

On one site a dragline was used as a supplementary item of excavation plant.

The methods of compaction observed can be divided into two major categories:

1. Compaction to Clause 609 of the Specification for Road and Bridge Works[7] (normal compaction specification).

2. Compaction to a special specification which, when compared with the normal compaction specification, increased the depth of compacted layer and reduced the number of passes required, while restricting the size and type of compactor (relaxed compaction specification).

To determine the effect of variations in the crushing value of the chalk on the degree of crushing attributable to the different earthwork processes, it was necessary to make estimates of the degree of crushing where measurements were not or could not be taken. These estimates were:

1. Of the degree of crushing of the loose uncompacted material where such measurements were not made during visits in the early stages of the investigation.

2. Of the degree of crushing with a normal compaction specification where a relaxed compaction specification was in use.

3. Of the degree of crushing with a relaxed compaction specification where a normal compaction specification was in use.

All the estimates were made by interpolation, using the available measured values of the degree of crushing of the uncompacted and compacted chalk fill.

Relations have been established between the degree of crushing of the fill material achieved by each of the categories of excavation plant observed and the crushing value (Figures 6 to 8). Figure 6 shows the relations obtained for loose uncompacted chalk, Figure 7 for the material after application of a relaxed compaction specification, and Figure 8 after application of the normal compaction specification.

For a given method of excavation the degree of crushing increased with increase in crushing value at all stages, but the different types of excavation plant produced significantly different relations. Tractor shovels and scrapers caused the greatest crushing of the chalk and the two methods of vertical-face excavation, backacters and face shovels, the least. The degree of crushing produced at high crushing values (soft chalk) by backacters is noticeably greater than that produced by face shovels. Because of a lack of data it has been concluded that excavation by tractor shovel with bulldozer assistance would have produced a similar degree of crushing to that produced by scraper excavation at high crushing values.

A comparison of the values of the degree of crushing before compaction (Figure 6) with those after compaction (Figures 7 and 8) demonstrates the increase in crushing caused by the compaction process over that already achieved by the excavation process. With soft chalk it is particularly noticeable that the greater proportion of the crushing occurred before the fill material was compacted in the embankment. For scrapers working on a soft chalk with, say, a crushing value of 3.7, the degree of crushing in the compacted fill (normal specification) was about 84 per cent (Figure 8), the first 61 per cent of which was due to the action of the scrapers alone (Figure 6). For a face shovel working on chalk of the same crushing value the degree of crushing in the compacted fill was about 66 per cent, the first 34 per cent of which was due to the action of the face shovel alone. Again, for the same type of chalk, the additional degree of crushing caused by the normal compaction specification over that by a relaxed compaction specification is shown to be only of the order of 6 to 13 per cent. The opportunity to control the degree of crushing of the softer chalk, and therefore its behaviour, clearly lies more with the choice of excavation plant than with the compaction specification.

6.5 Compaction of chalk fill

The differences in the degree of crushing associated with compaction to a normal specification as compared with a relaxed compaction specification (see 6.4) are shown to be relatively small in the softer chalk (Figures 7 and 8), and the benefits of relaxed compaction, therefore, are limited. It can be expected that low states of compaction would result on occasion with the use of a relaxed specification. For example, if a particular method of excavation is selected for the purpose of reducing the degree of crushing, the coarser fill material which results would be more difficult to compact to a low air content than would be the case if it had undergone more severe crushing. Additionally, the possibility of dry weather conditions, similar to those experienced during the summer of 1976, could lead to the chalk being at such a low moisture content that a satisfactory state of compaction would be more difficult than normal to produce.

As a general principle, an adequate state of compaction is necessary in an embankment in order to minimise the risk of settlement, to reduce the permeability of the fill, and to maximise the long-term strength of the material. It is proposed, therefore, that the classification of chalk in relation to its behaviour as a fill material, should be based on maintaining stable conditions, whenever possible, with compaction to the full requirements of Clause 608 of the latest edition of the Specification for Road and Bridge Works[8]. For this purpose, the prediction of the degree of crushing can be made from Figure 8. However, even when the degree of crushing of the chalk is controlled by the proper selection of excavation plant, instability may still occasionally result in some types of chalk after the application of normal compaction. For procedures to adopt in these circumstances, see 7.2.

A short discussion of the recorded settlement of chalk fill adjacent to structures is contained in Appendix 3.

7. THE CLASSIFICATION OF CHALK AS A FILL MATERIAL

7.1 The classification chart

Data has been obtained from which the onset of instability of freshly placed chalk fill can be related to the saturation moisture content and the crushing value of the chalk. Using these latter measurements, likely values of moisture content and degree of crushing in the fill compacted to normal specifications can be derived from Figures 5 and 8 respectively and, by inserting these values in Figure 4, an indication of the stability conditions of the compacted fill can be obtained. The effect of changing the method of excavation can also be determined.

To simplify this procedure and to make the choice of excavation plant easier, the information contained in these three figures has been combined to give a comprehensive chalk classification (Figure 9). The chart relates critical values of saturation moisture content and chalk crushing value, at which the onset of unstable conditions is likely when each of the four types of excavation plant is in use. The critical values are based on the assumption that, in winter, the moisture content of the compacted fill will be equal to the saturation moisture content and, in summer, to 0.85 of the saturation moisture content.

Unstable conditions are not expected to occur with chalk in Class A, but chalk in Classes B and C (especially at higher values of saturation moisture content) can produce unstable conditions occasionally, even when the recommended type of excavation plant is in use. Unstable conditions can occur frequently with chalk in Class D.

7.2 Methods of compaction when instability occurs

The classification chart shows that instability might occur even though the recommended method of earthworks construction is in use. When instability does occur during construction the normal compactive effort may be relaxed, but on the basis of day to day decisions only. Such relaxation should initially follow the advice given in Section NG 608 of the Notes for Guidance on the Specification for Road and Bridge Works[9], whereby the number of passes of the compaction plant or the size of the compactor is reduced. In extreme cases of instability increased thicknesses of compacted layer may also be necessary and, in addition, layers of stable granular material may have to be introduced into the fill to provide working platforms for the construction plant. These extreme cases are usually possible only when the chalk is in a potentially unstable condition even before compaction, ie when the coordinates of the degree of crushing associated with face shovel excavation before compaction (Figure 6) and moisture content (equal to 0.85 of the saturation moisture content) indicate an unstable condition (Figure 4).

7.3 Procedure for the classification of chalk

To predict the likely behaviour of freshly placed chalk, saturation moisture content determinations, using the method described in 5.3, should be made on samples of the chalk. If it is established that the saturation moisture contents are all less than 23 per cent, the chalk is Class A and no further classification tests are necessary. If chalk with saturation moisture contents greater than 23 per cent is encountered, then impact crushing values should also be determined.

Each saturation moisture content test requires a discrete chalk lump with a volume of about 300 – 500 ml. Each impact crushing test requires 1 kg of discrete chalk lumps passing the 20 mm and retained on the 10 mm BS sieves. During site investigations such samples are best obtained from trial pits, which have the added advantage of allowing inspection of typical chalk faces, the degree of fissuring and the flint content.

It is recommended that at least six tests are carried out on samples of chalk from any one location. From values of standard deviation calculated during this investigation, it is estimated that the mean value of six tests on samples of the same chalk will be accurate to $\pm$ 0.14 of impact crushing value and $\pm$1.7 per cent of saturation moisture content at the 95 per cent confidence level. If the range of crushing values exceeds 0.7, or the range of saturation moisture contents exceeds 8 per cent, more than one type of chalk is likely to have been sampled.

8. CONCLUSIONS

The onset of instability under construction plant operating on chalk fills has been shown to depend on the moisture content and the degree of crushing of the material. These parameters have been related respectively to the saturation moisture content and the crushing value. The latter was determined using a newly developed test.

A method of classifying chalk in relation to its behaviour as a freshly placed fill material, based on the saturation moisture content and the crushing value of the chalk, has been proposed. The classification includes recommendations on the selection, when necessary, of methods of earthwork construction which minimise the risk of instability in the freshly placed fill material, while at the same time using a degree of compaction compatible with a satisfactory long-term performance of the embankment.

9. ACKNOWLEDGEMENTS

The work described in this Report forms part of the research programme of the Earthworks and Underground Pipes Division (Division Head: Mr J B Boden) of the Structures Department of TRRL. The authors were assisted in the site work by Messrs P Darley, R M Danes and K G Taylor. The cooperation is gratefully acknowledged of those Directors of RCU's, County Surveyors, Resident Engineers and their staffs, on whose sites the investigations were made.

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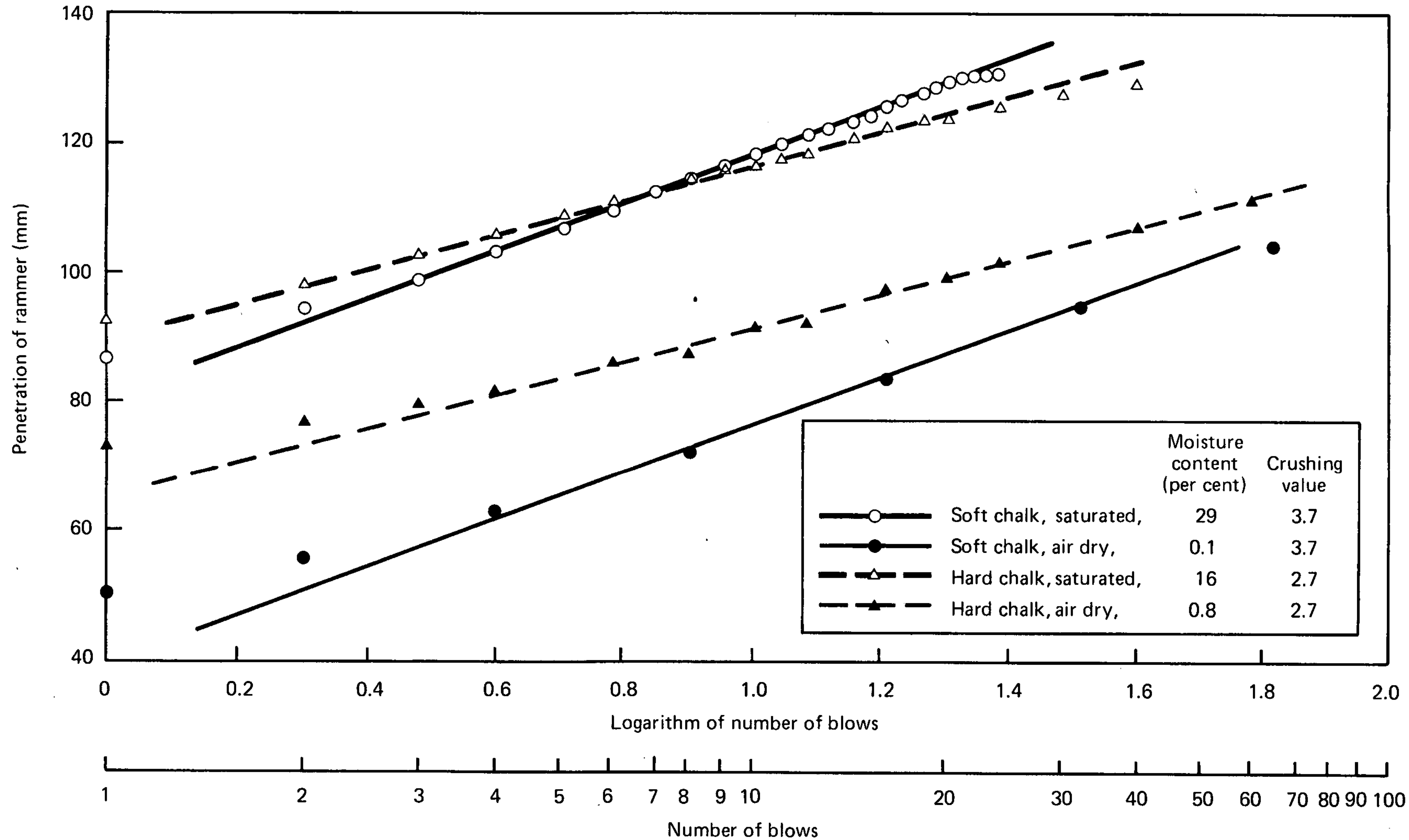

Fig. 1 RELATIONS BETWEEN THE PENETRATION OF THE RAMMER AND THE LOGARITHM OF THE NUMBER OF BLOWS OBTAINED IN IMPACT CRUSHING TESTS WITH TYPICAL SAMPLES OF SOFT AND HARD CHALK IN BOTH SATURATED AND AIR DRY STATES

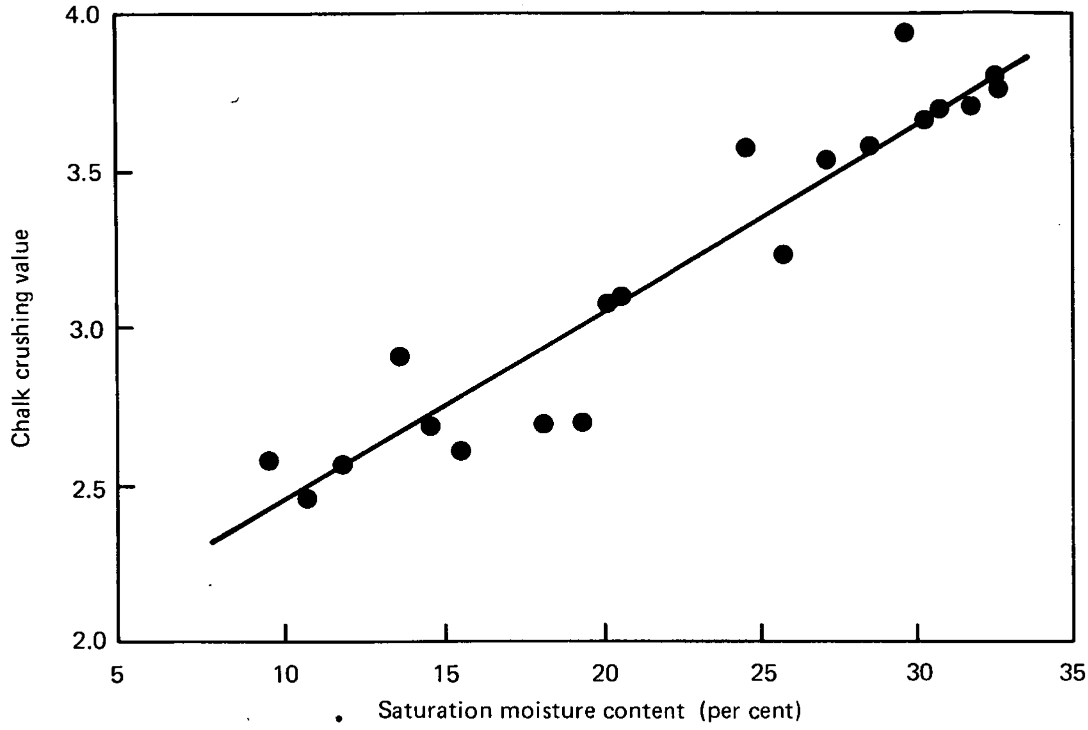

Fig. 2 RELATION BETWEEN CHALK CRUSHING VALUE AND THE SATURATION MOISTURE CONTENT OF INTACT CHALK LUMPS

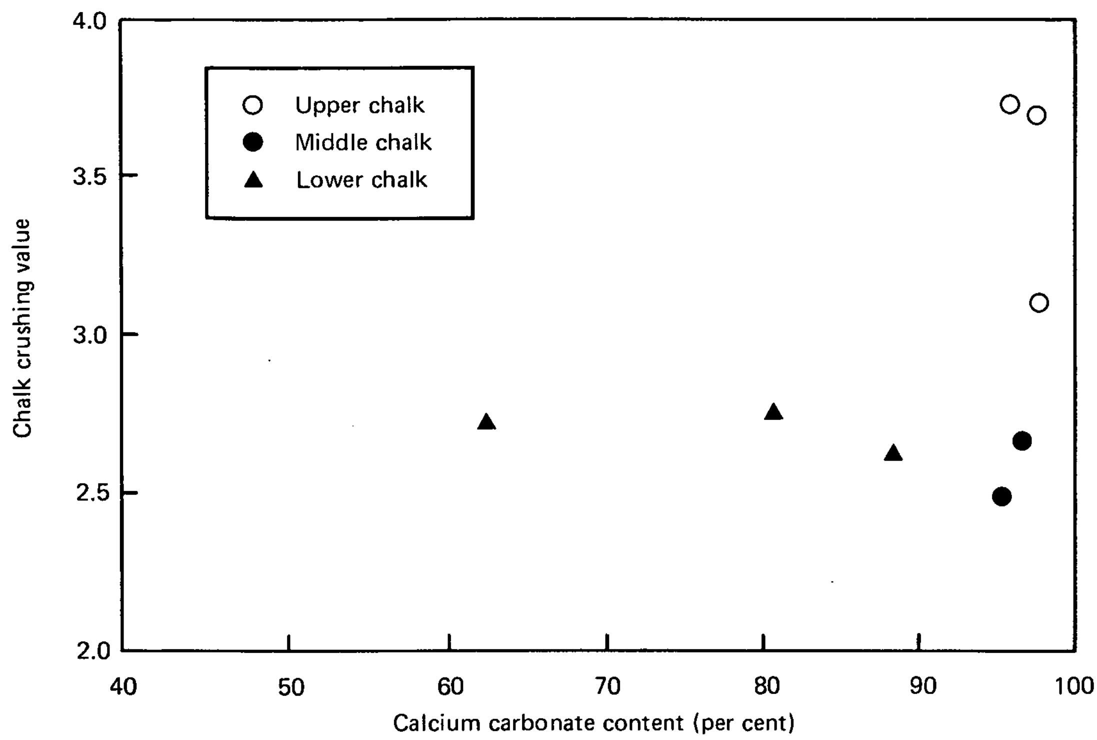

Fig. 3 RELATION BETWEEN CHALK CRUSHING VALUE AND THE CALCIUM CARBONATE CONTENT OF SAMPLES OF UPPER, MIDDLE AND LOWER CHALK

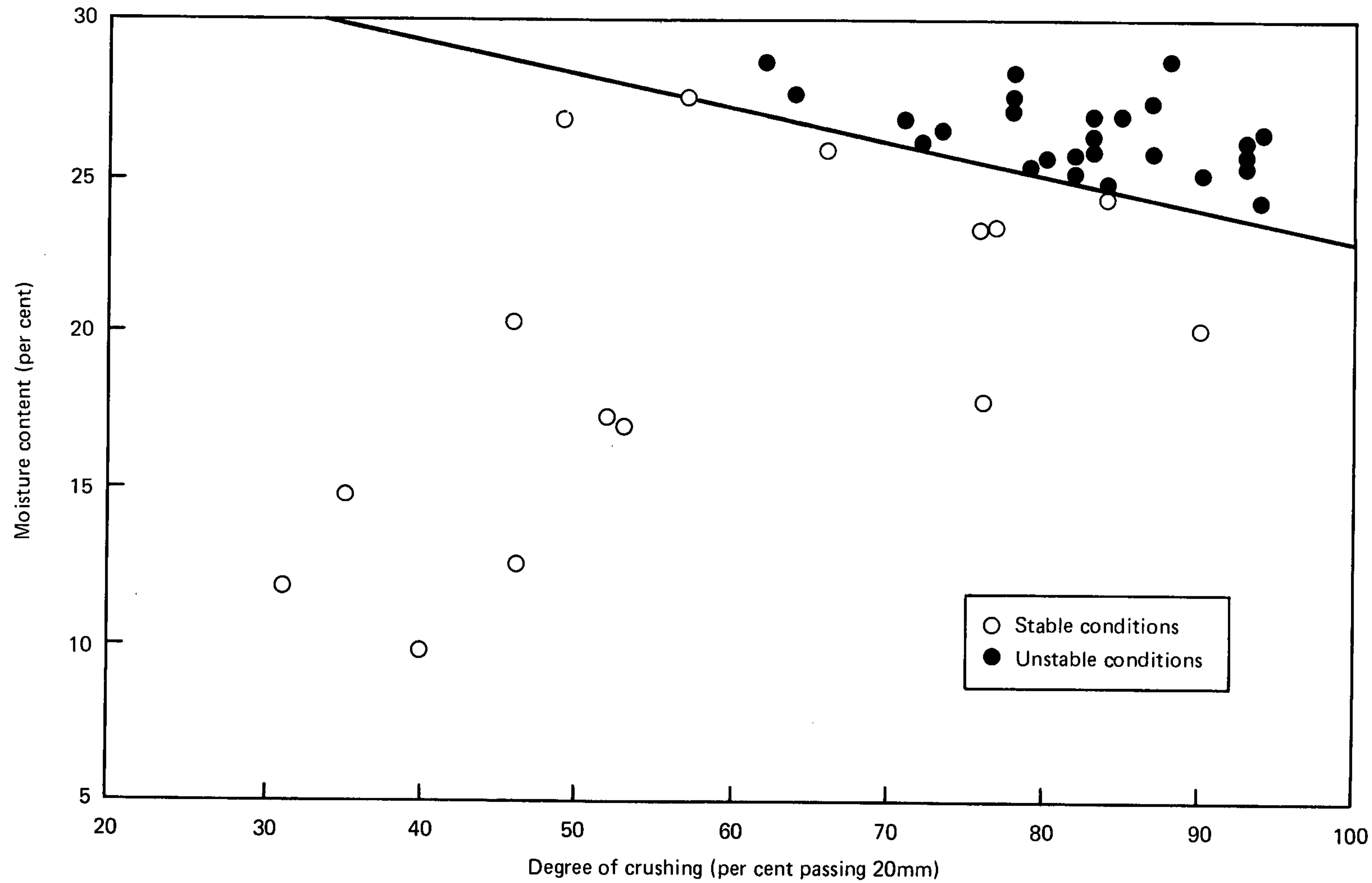

Fig. 4 THE RELATION BETWEEN MOISTURE CONTENT AND DEGREE OF CRUSHING OF COMPACTED CHALK FILL FOR BOTH STABLE AND UNSTABLE CONDITIONS

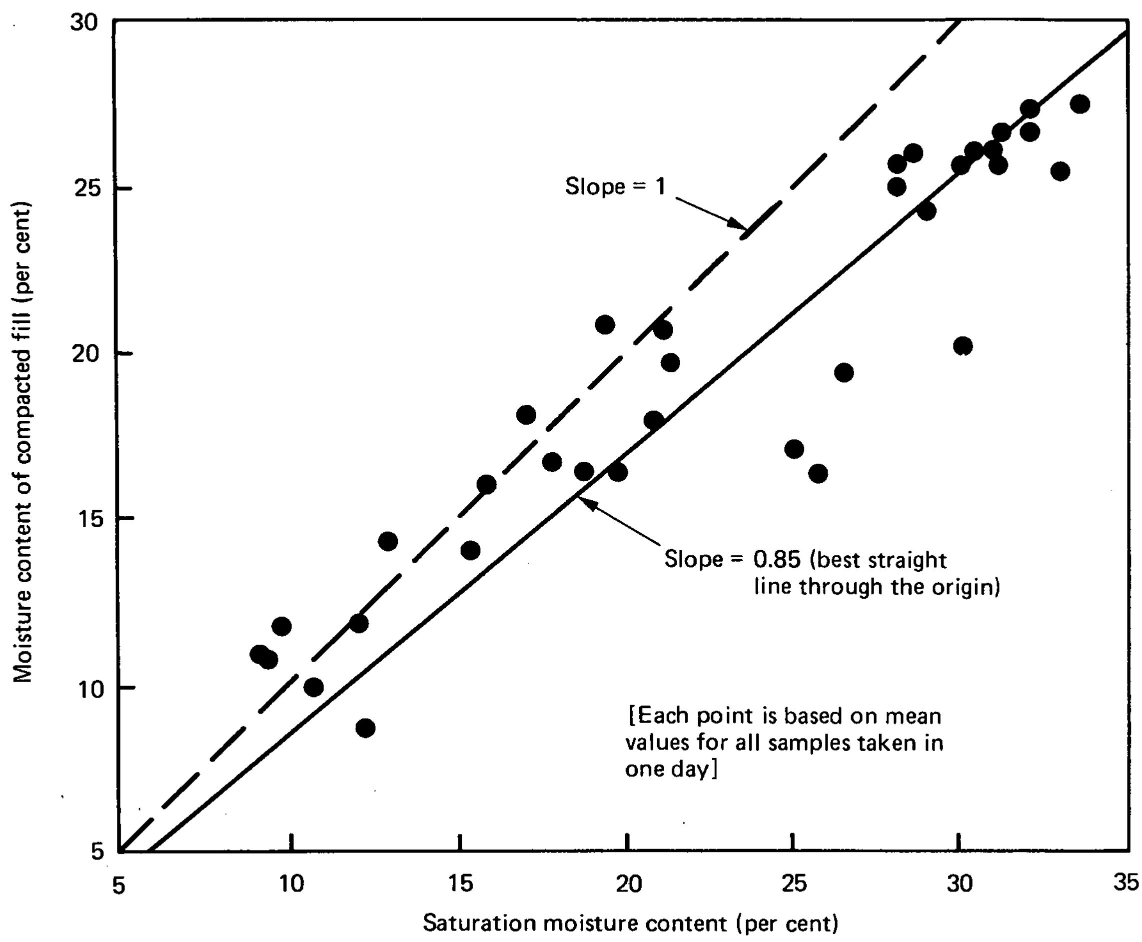

Fig. 5 THE RELATION BETWEEN THE MOISTURE CONTENT OF THE COMPACTED FILL AND THE SATURATION MOISTURE CONTENT OF THE INTACT CHALK LUMPS

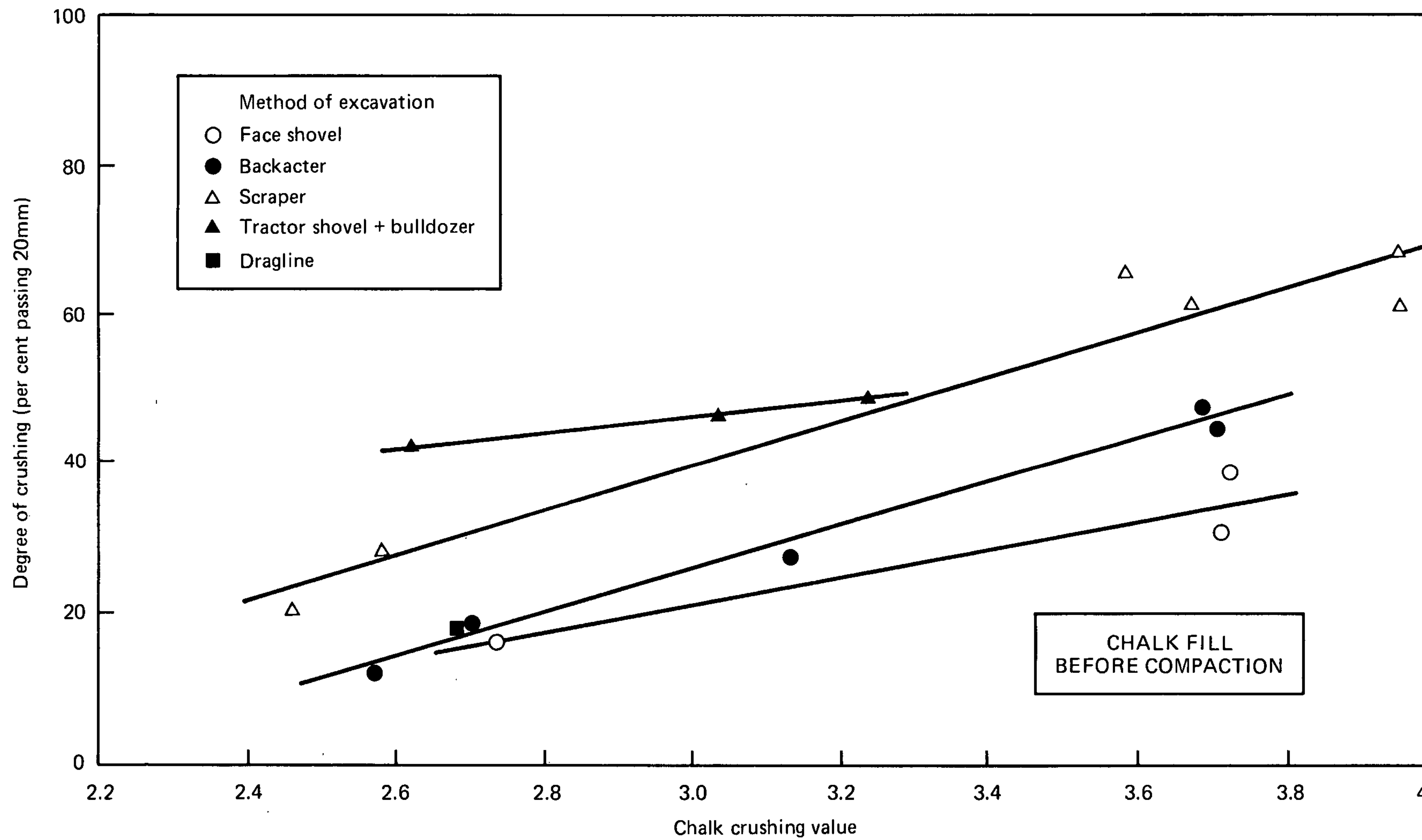

Fig. 6 RELATIONS BETWEEN THE DEGREE OF CRUSHING OF THE FILL MATERIAL BEFORE COMPACTION AND THE CHALK CRUSHING VALUE

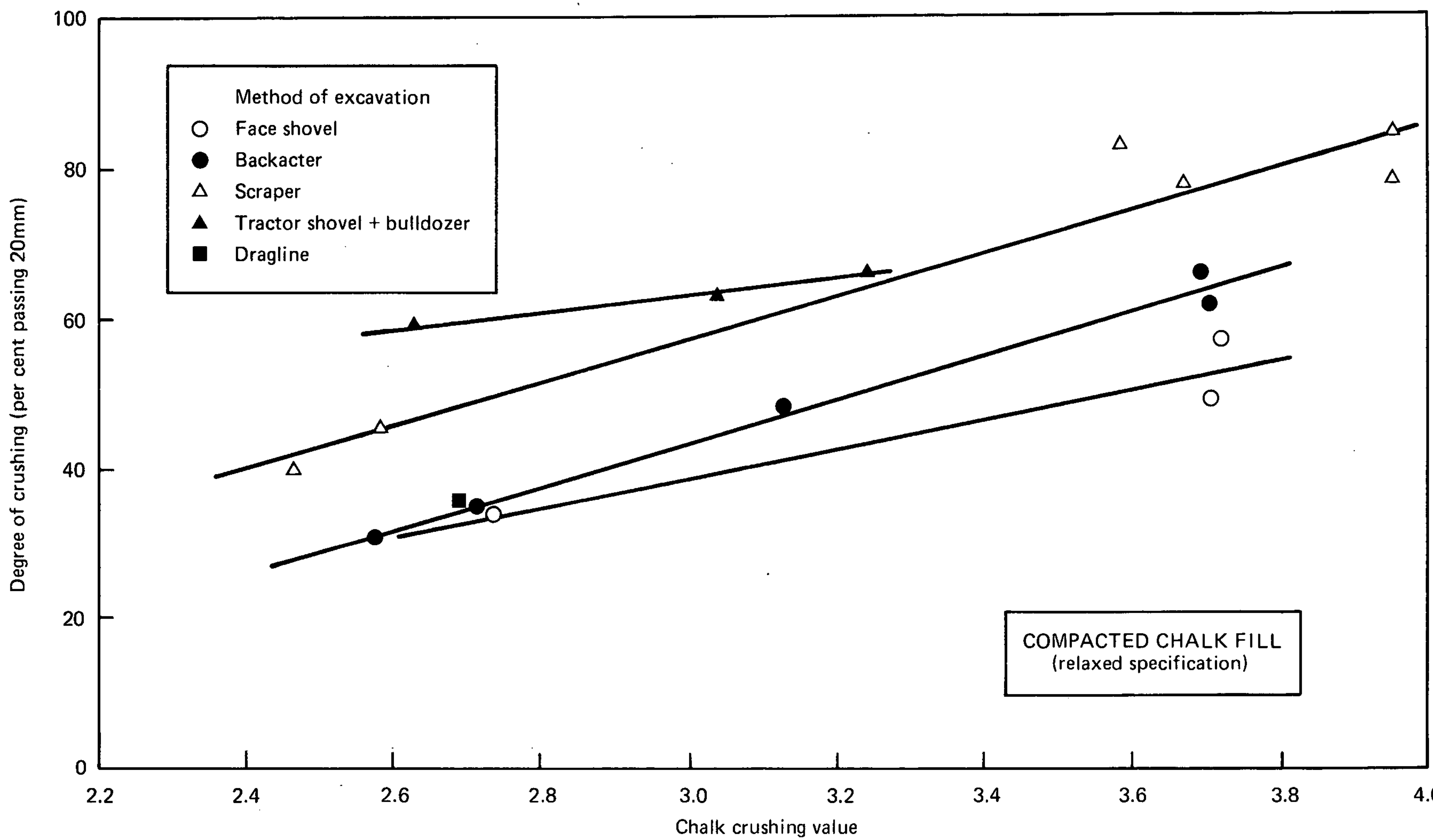

Fig. 7 RELATIONS BETWEEN THE DEGREE OF CRUSHING OF THE FILL MATERIAL AFTER COMPACTION TO A RELAXED SPECIFICATION AND THE CHALK CRUSHING VALUE

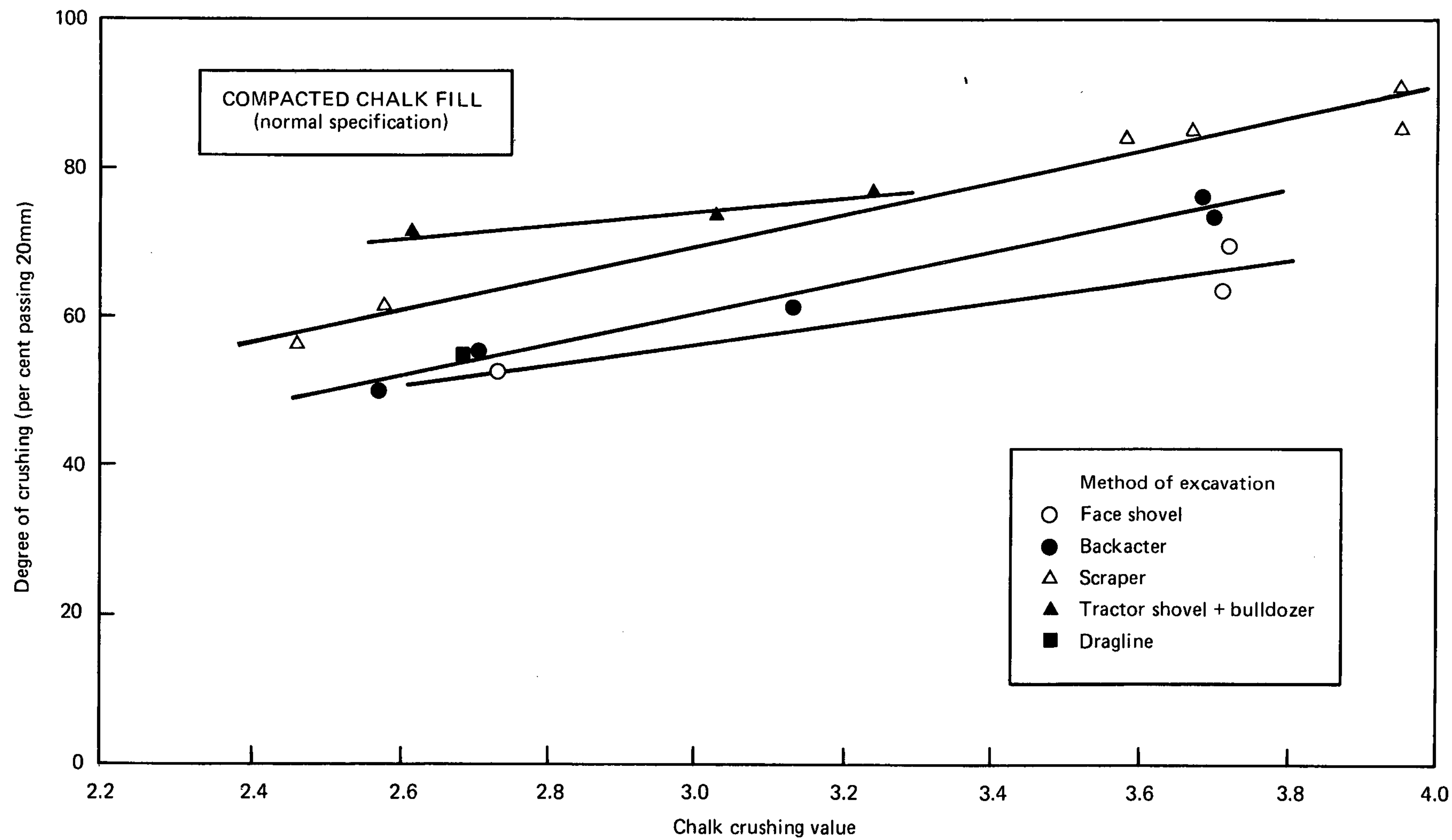

Fig. 8 RELATIONS BETWEEN THE DEGREE OF CRUSHING OF THE FILL MATERIAL AFTER COMPACTION TO THE NORMAL SPECIFICATION AND THE CHALK CRUSHING VALUE

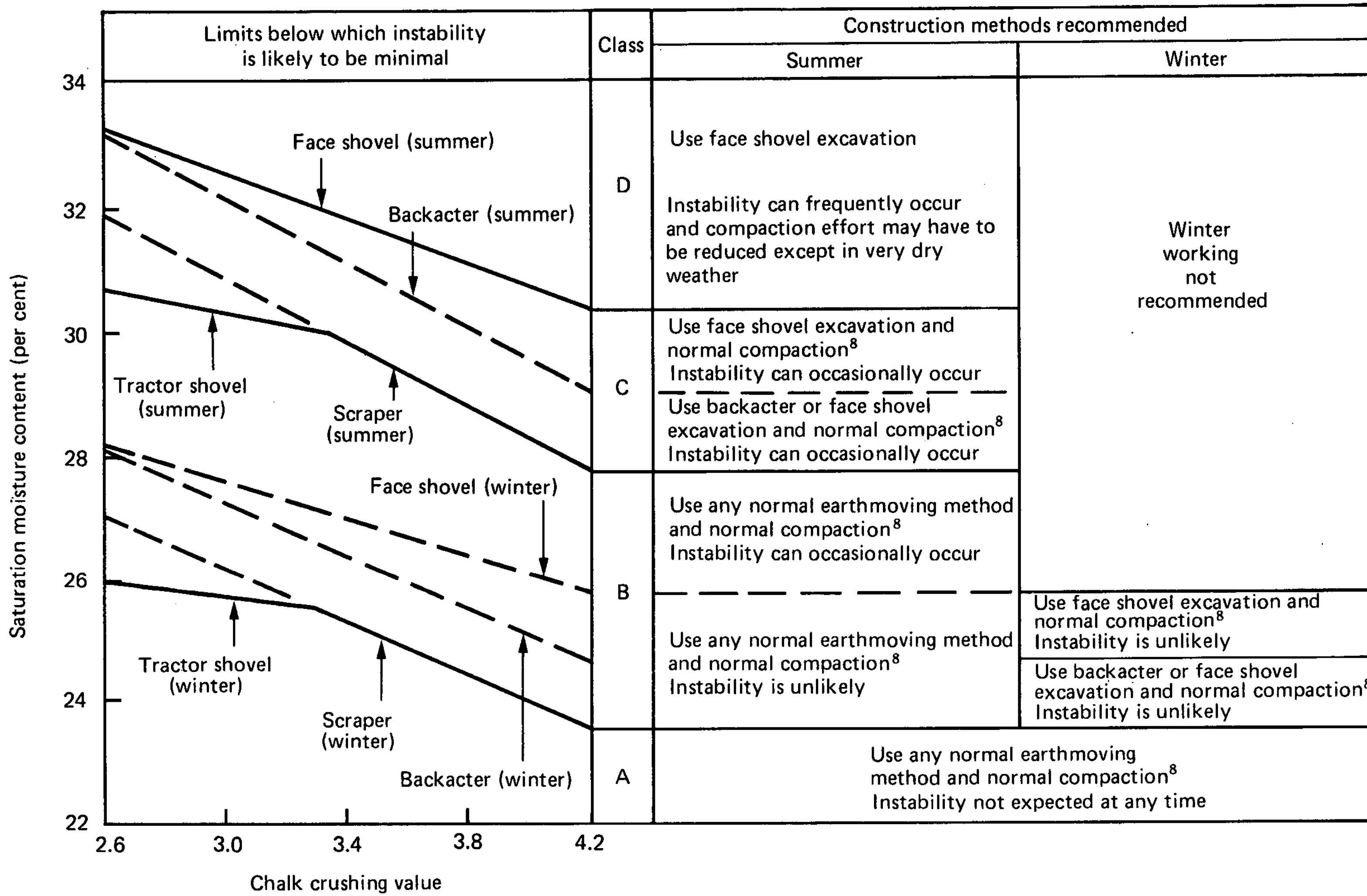

Fig. 9 CHALK CLASSIFICATION WITH MEASURES REQUIRED TO AVOID OR MINIMISE INSTABILITY

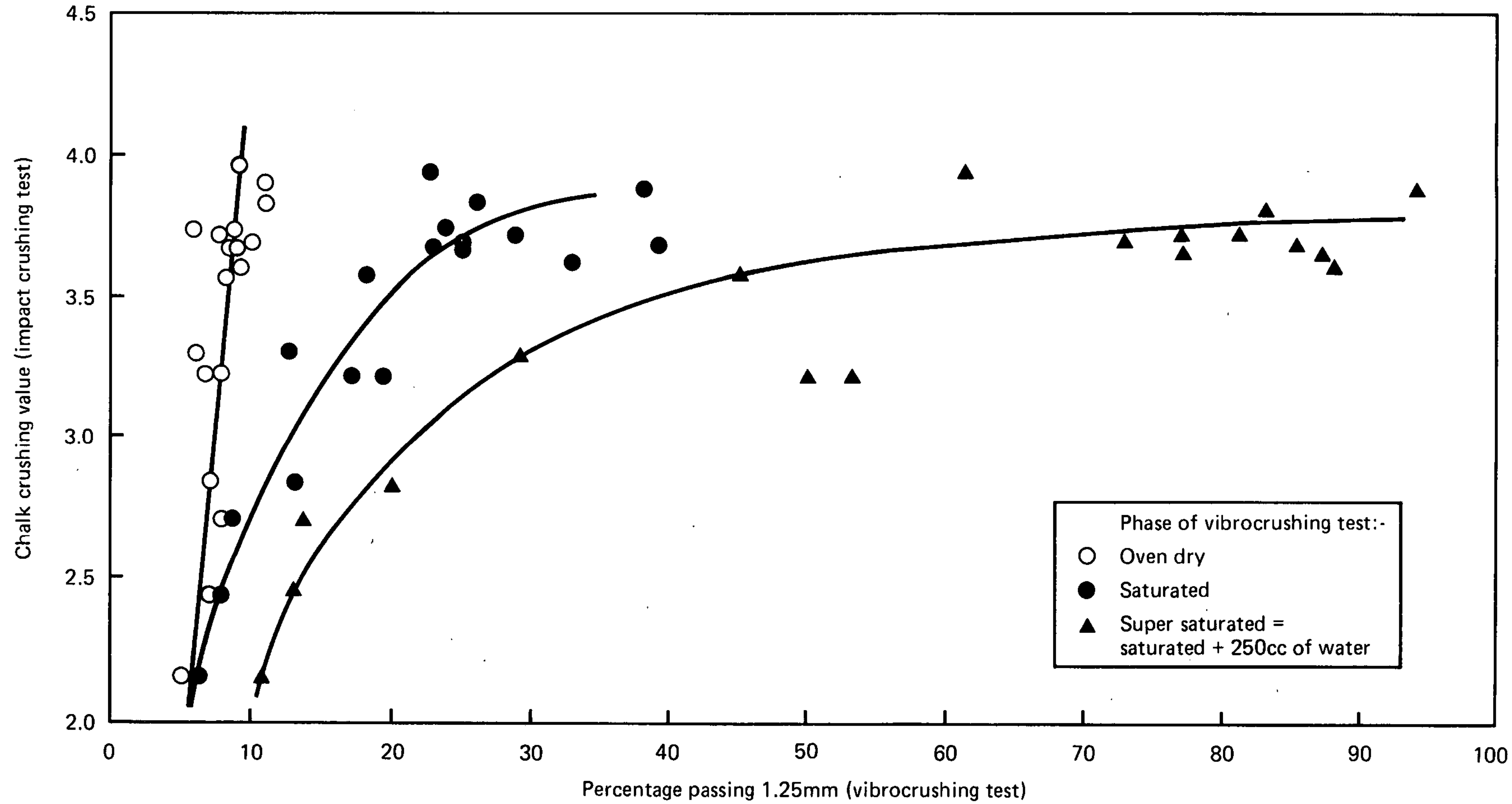

Fig. 10 RELATIONS BETWEEN THE RESULTS OF THE IMPACT CRUSHING TEST AND THE RESULTS OF THE THREE PHASES OF THE VIBROCRUSHING TEST

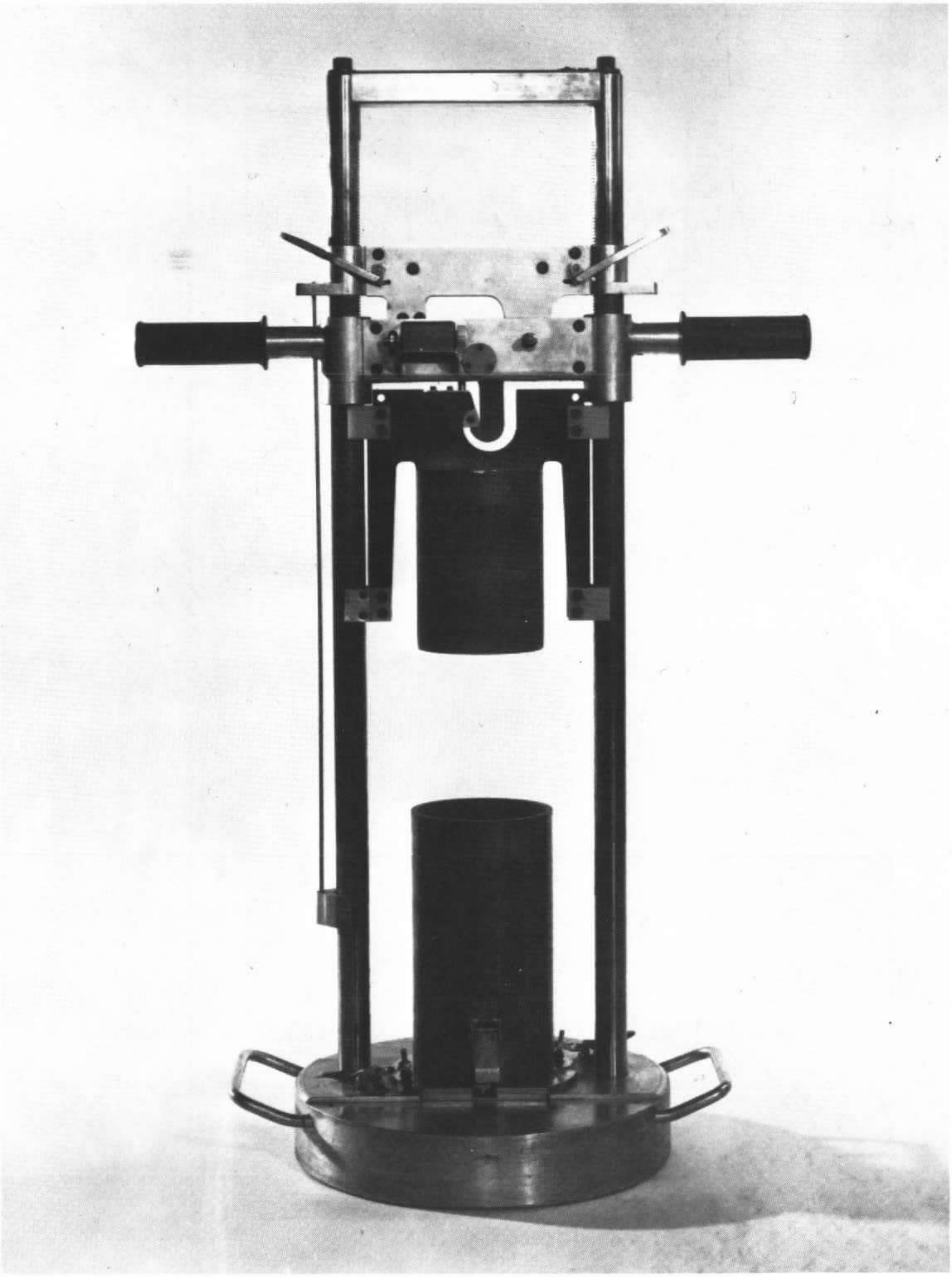

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Plate 1 THE IMPACT CRUSHING TEST APPARATUS

11. APPENDIX 1

THE IMPACT CRUSHING TEST – APPARATUS AND PROCEDURE

The test determines the crushing value to be used in the classification of chalk in relation to its behaviour as a freshly placed fill material.

11.1 Apparatus

The apparatus (Plate 1) used for the chalk impact crushing test is similar to that used in the rapid measurement of the moisture condition of earthwork material[4]. The main details of the apparatus are given in Table 2.

The heavy base of the apparatus is recessed to locate the base of a cylindrical mould. The mould, with its easily detachable base, is held down by simple spring clips. A free falling rammer is located by two guide rods so that it falls accurately into the barrel of the mould.

The rammer is lifted by means of handles attached to a cross-member which slides on the guide rods and incorporates an automatic catch which engages with the top of the rammer structure. When the rammer is lifted to the top of its intended travel, a striker attached to a further cross-member releases the automatic catch and allows the rammer to fall. The striker support cross-member may be raised or lowered, and is located by a pair of spring catches engaging in racks on the guide rods.

One half of a vernier scale is attached to one of the lower guides of the rammer and the other half to a rod connected to the striker support cross-member. The length of this rod may be adjusted, but is pre-set in the impact crushing test so that the height of drop of the rammer is 250 mm when the vernier is zeroed with the rammer resting on the chalk in the mould. The vernier is zeroed by raising or lowering the striker support cross-member.

TABLE 2

Main details of the apparatus used for the chalk impact crushing test

Mass of rammer	7 kg
Diameter of rammer	97 mm
Height of drop of rammer	250 mm
Internal diameter of mould	100 mm
Internal height of mould	About 200 mm
Total mass of apparatus, with empty mould	50 kg
Mass of base of apparatus	31 kg
Mass of chalk sample used	1 kg (passing 20 mm and retained on 10 mm sieves)

The rammer also has a scale attached which can be used to measure the penetration of the rammer into the mould.

The rammer release mechanism has a trip counter to indicate the number of times that the rammer has been released.

A retaining pin is provided to lock the rammer and sliding cross-member to the striker support cross-member (see Plate 1) for easy removal of the mould.

To avoid the entrapment of air within the lower part of the crushed chalk specimen, a loose fitting base to the mould, with gaps through which air can escape, is used.

With wet chalks a further problem to be avoided is the extrusion of crushed chalk between the rammer and the sides of the mould and the adherence of chalk to the bottom of the rammer. For this purpose a light-weight disc of laminated phenolic sheet, 99 mm in diameter and 5 mm thick, is placed on top of the sample of chalk in the mould.

The base of the apparatus is sufficiently heavy to eliminate, as far as possible, the effects of its use under varying conditions. Thus, whether the apparatus is used on soft soil on site or on a concrete floor in the laboratory the results should not be significantly different.

11.2 Test procedure

The length of the vernier support rod is set to give a height of drop of 250 mm.

Lumps of chalk to be tested are broken up and a 1 kg portion of the chalk passing the 20 mm sieve and retained on the 10 mm sieve is placed loosely in the mould, and the fibre disc placed on top of the chalk. The mould is placed into the recess on the base of the apparatus, clamped in position, and the trip counter zeroed. The sliding cross-member supporting the rammer is held steady, the retaining pin removed, and the rammer lowered gently on to the fibre disc and allowed to penetrate into the mould under its own weight until it comes to rest. The height of drop is adjusted to 250 mm by moving the striker support cross-member to give an approximate zero ($\pm$ 5 mm) on the vernier scale.

The sample is then given one blow with the rammer, the penetration scale on the rammer read, and the drop height vernier re-zeroed by adjusting the striker support cross-member. The process is repeated with readings of penetration being taken after selected numbers of blows (Figure 1) and the drop height vernier re-zeroed as necessary until no further penetration occurs or a maximum of 50 blows of the rammer is reached. The rammer attached to the sliding cross-member is then carefully raised and the retaining pin inserted.

The mould is unclamped from the apparatus, its base removed, and the crushed chalk removed.

The penetration of the rammer (mm) is plotted against the logarithm of the number of blows. The greater part of the relation should form a straight line, the slope of which represents the rate at which the chalk sample has crushed (Figure 1). The chalk crushing value is taken to be one-tenth of the slope of the straight line.

$$\text{Chalk crushing value} = \frac{P_a - P_b}{10\,(\text{Log}\,a - \text{Log}\,b)}$$

where P_a = the penetration (mm) after a impacts as read from the straight line,

P_b = the penetration (mm) after b impacts as read from the straight line.

12. APPENDIX 2

A COMPARISON OF THE IMPACT CRUSHING TEST AND THE FRENCH VIBRO-CRUSHING TEST

The vibrocrushing test[3], recently developed in France, has been used for the same purpose as that intended for the impact crushing test[10,11]. In the vibrocrushing test, three specimens of chalk are made up to a specified particle-size distribution and crushed in a disc mill, for a period of 30 sec, at each of three moisture content levels, oven dry, saturated and super saturated. The particle-size distributions of the specimens after test are determined and the chalk is classified[12] according to whether the percentage passing the 1.25mm sieve exceeds 30 in none of the tests, in only the super saturated test, or in both the super saturated and saturated tests. The relations between the results of the impact crushing tests and the vibrocrushing tests on samples of the same chalk are shown in Figure 10.

A straight line relation was produced between the results of the impact crushing test and the oven dry phase of the vibrocrushing test. However, in the saturated and super saturated phases of the vibrocrushing test, the samples of softer chalk exhibited a much larger range of results than was obtained with the impact crushing test. It is possible, therefore, that the vibrocrushing test is too vigorous for soft chalk.

Factors contributing to the excessive variability of the results of the vibrocrushing test may be the complicated nature of the test, with the need for particle-size distributions to be measured before and after the chalk is crushed, and the critical nature of the timing (30 sec) of the crushing of the chalk in the disc mill.

13. APPENDIX 3

SETTLEMENT OF CHALK FILL ADJACENT TO STRUCTURES

Reports of settlement of chalk fill adjacent to structures were received during the survey which preceded the research described in the main report and such settlements have continued to arise during the current research programme. These settlements appear to have taken place suddenly, and to have been associated with a concentrated flow of water in the affected area. No data is available upon which to base an explanation of the settlements but it is likely that they have been caused by hydraulic compaction, ie a redistribution of chalk fines, carried by water, from the upper parts of compacted layers into the voids below.

The likelihood of this condition arising is minimised if the lowest possible air content is achieved in the compacted chalk and the possibility of a concentrated flow of water through the chalk is avoided. The recommendations given in 6.5 regarding compaction are highly relevant to this problem, and a compaction effort to the full requirements of Clause 608 of the Specification for Road and Bridge Works[8] should therefore be used. The main source of a concentrated flow of water is likely to be incompleted surface water drainage systems in the adjacent embankment areas.

(1911) Dd443233 1,500 11/77 HPLtd So'ton G1915
PRINTED IN ENGLAND

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ISSN 0305–1293

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