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Cracking Behaviour of Compacted Clay

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1 INTRODUCTION

The behaviour of materials used in earth dams and the nature of the analyses that must be carried out to ensure a satisfactory design are now reasonably well understood. There remain, however, a few areas where further investigative effort is required. One of these areas relates to the cracking susceptibility of materials adjacent to abutment irregularities in homogeneous dams or in the clay cores of zoned dams.

Casagrande (1950 , 1965) has drawn attention to the cracking problem but relatively little research has been directed to this area. Covarrubias (1969) investigated the effect of abutment geometry on the maximum tensile strain developed in a linearly elastic solid, using the finite element method. The use of small physical models of abutment irregularities to determine the incidence of cracking has been described by Carrigan (1972), De Jong (1975) and Moore and Carrigan (1976). They provided relationships between the compaction water content and the tensile strain at which cracking develops for particular abutment geometries. Their work can be criticized however because of the small size of the experimental model. Both Carrigan and De Jong used non-linear finite element analyses to predict the location and magnitude of critical tensile strains with mixed success.

Leonards and Narain (1963) used compacted clay beams to evaluate tensile strains at cracking. They were able to predict the presence of tensile cracks in the crests of dams but their work did not extend to predicting cracking in the body of clay cores adjacent to abutment irregularities. A number of other works have made use of compacted clay beams to study tensile behaviour. Ajaz and Parry (1975), for example, used a beam apparatus with a two point loading system to confirm the findings from several other experimental studies that the tensile strain at cracking increases with an increase in the compaction water content. The ranges of tensile strains at cracking according to several studies are summarised in Table I.

The data quoted above indicates that different estimates are provided of the tensile strain at which cracking occurs depending upon whether bending tests or tension tests are used. It cannot be stated with any confidence that either of these tests could be used to predict tensile strains within the mass of a clay core of a dam adjacent to an abutment irregularity. In fact, there has been some doubt expressed in the literature about the applicability of either of these tests. Clearly there is a need to carry out compacted beam tests and abutment tests of a region adjacent to an abutment irregularity, on the same soil. Further, the abutment tests should be large to overcome the criticism that could be levelled at the use of small scale models in the cases mentioned above.

TABLE I

TENSILE STRAINS AT CRACKING

Compaction Water Content Relative to Optimum Water Content %	Soil	Tensile Strain at Cracking %	Reference
-3 to +4 (OMC = 25.9%)	Limestone Clay	0.13 to 0.31	Leonards & Narain (1963) (bending tests)
-3 to 0 (OMC = 27.5%)	Kaolin	0.21 to > 0.55	Carrigan (1972) (model tests)
-3 to +7 (OMC = 24.6%)	Gault Clay	0.5 to 1.7	Ajaz and Parry (1975) (bending tests)
-3 to +3 (OMC = 13%)	Balderhead Clay	0.14 to 1.6	
-6 to +2	Gault Clay	0.08 to 0.34	Ajaz and Parry (1975) (tension tests)
-4 to +5	Balderhead Clay	0.08 to 0.48	

2 EXPERIMENTAL PROGRAM

A series of tests was undertaken in which a clay was compacted against an abutment irregularity. Various compaction water contents were used with a standard compactive effort of 596 kJ/m^3. The shape and size of the clay sample so prepared are indicated in Figure 1. The sizes of the hardwood abutment blocks representing idealized irregularities are also shown in this figure. The sample thickness was 200 mm.

The clay (kaolin), the properties of which are given in Table II, was thoroughly mixed at the desired water content, then sealed in a container for a week. The compaction was carried out with a specially designed square face compaction hammer, the clay being compacted in 50 mm thick layers, lubricated and stiffened front and back walls being attached to the experimental apparatus during the compaction process. The side walls and base plate were also lubricated with silicone grease and plastic sheet to minimise frictional effects.

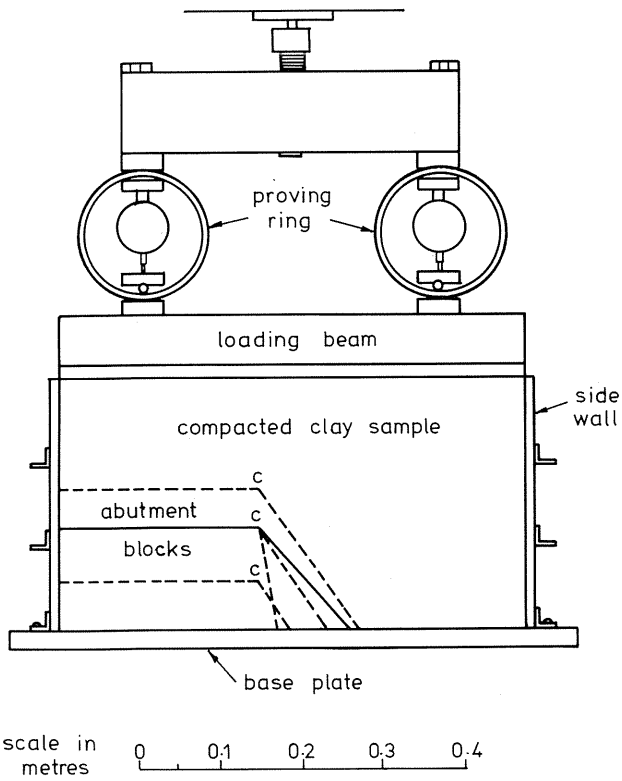

Figure 1 Abutment Test Arrangement

TABLE II

PHYSICAL PROPERTIES OF KAOLIN

Liquid limit	67.2 %
Plastic limit	28.5 %
Particle density	2.6 gm/cm^3
Standard Compaction:	
Optimum water content	25.0 %
Maximum dry density	1554 kg/m^3

After compaction the front and back walls were removed so the clay could be loaded under plane stress conditions. The surfaces of the abutment block had also been lubricated with plastic sheet to reduce frictional effects (measured coefficient of friction was 0.16). The load was applied incrementally through two proving rings and a loading beam, which was designed to apply uniform pressure to the top surface of the compacted clay.

The method used for observing the displacement of the clay sample under load was a photographic technique frequently used in precision photogrammetry. About 240 target points were marked on the face of the clay, these targets being photographed with a Zeiss SMK - 40 stereo camera (9 cm x 12 cm size plates) at each stage of loading until a crack was observed in the clay.

Analysis of the data on the photographic plates was carried out by a mean of a photogrammetric stecometer, which consists of a stereo comparator, a control console and an automatic recorder. The stecometer information is printed on paper tape, then manipulated through several computer programs to yield coordinates of each target point at each stage of loading. From this data the displacements and strains may be calculated.

3 EXAMINATION OF TEST DATA

A total of fifteen tests were carried out in which compacted clay samples were prepared as described above. In these tests the abutment shape and compaction water content were varied as summarised in Table III.

The influence of the compaction water content on the applied vertical stress required to produce a crack in the compacted clay is illustrated in Figure 2. No cracks were observed for the wettest clay samples in test series A, B and C. The applied vertical stress is the average stress acting beneath the loading beam and produced by the forces transmitted through the two proving rings (Figure 1). In all cases the crack in the compacted clay was observed immediately above the edge of the abutment irregularity (marked C in Figure 1). Figure 2 shows that the applied stress required to cause a crack passes through a minimum value,at or slightly below the optimum water content. The experimental points are not spaced sufficiently closely to be more precise about this critical water content. This finding is independent of the slope of the abutment block. De Jong, who carried out tests on a similar soil (with a similar optimum water content), found the same type of behaviour. His data is also plotted in Figure 2. This finding appears to suggest that the soil in an earth dam should not be compacted at a water content in the vicinity of the optimum, if the risk of cracking is to be minimized; a procedure which would be the reverse of normal practice. However, much more research is necessary before this could be looked upon as a firm conclusion. Figure 2 also shows that any any compaction water content the applied vertical stress required to cause cracking decreases as the abutment step becomes steeper.

The effect of the size of the abutment irregularity, as measured by its relative height is illustrated in Figure 3, for a particular value of abutment slope and compaction water content. As might be expected this plot shows that the applied stress required to cause cracking decreases as the relative size of the abutment step increases.

In earth dam construction one of the traditional techniques for reducing the cracking susceptibility of compacted clay has been to increase the com-

TABLE III

TEST DETAILS

Test Series	Compaction Water Content	Dry Density (kg/m^3)	Abutment Details	
			Height (mm)	Side Slope
A	23.5	1533	120	1H : 1V
	25.0	1554	120	1H : 1V
	26.7	1531	120	1H : 1V
	27.0	1525	120	1H : 1V
B	23.0	1506	120	0.75H : 1V
	24.1	1545	120	0.75H : 1V
	25.7	1547	120	0.75H : 1V
	29.4	1464	120	0.75H : 1V
	25.0	1554	120	0.75H : 1V
C	22.3	1452	120	0.25H : 1V
	22.9	1502	120	0.25H : 1V
	26.7	1531	120	0.25H : 1V
	29.6	1457	120	0.25H : 1V
H	23.9	1541	180	0.75H : 1V
	24.0	1544	60	0.75H : 1V

paction water content in order to make the compacted clay more flexible. If cracking susceptibility is expressed in terms of some critical tensile strain then this idea is supported by the data plotted in Figure 4. This plot indicates that for a particular abutment the tensile strain necessary for a crack to form increases as the compaction water content increases. Similar trends have been found by other researchers such as Leonards and Narain (1963), Krishnayya et al (1974), and Ajaz and Parry (1975). The tensile strains plotted in Figure 4 are the major principal tensile strains calculated near the crack location at the time of crack initiation. The grid size of the target points at the crack location was 5 mm square.

Figure 4 also demonstrates that the tensile strain at cracking depends upon the size (height) of the abutment irregularity. At a particular compaction water contact, the tensile strain at cracking

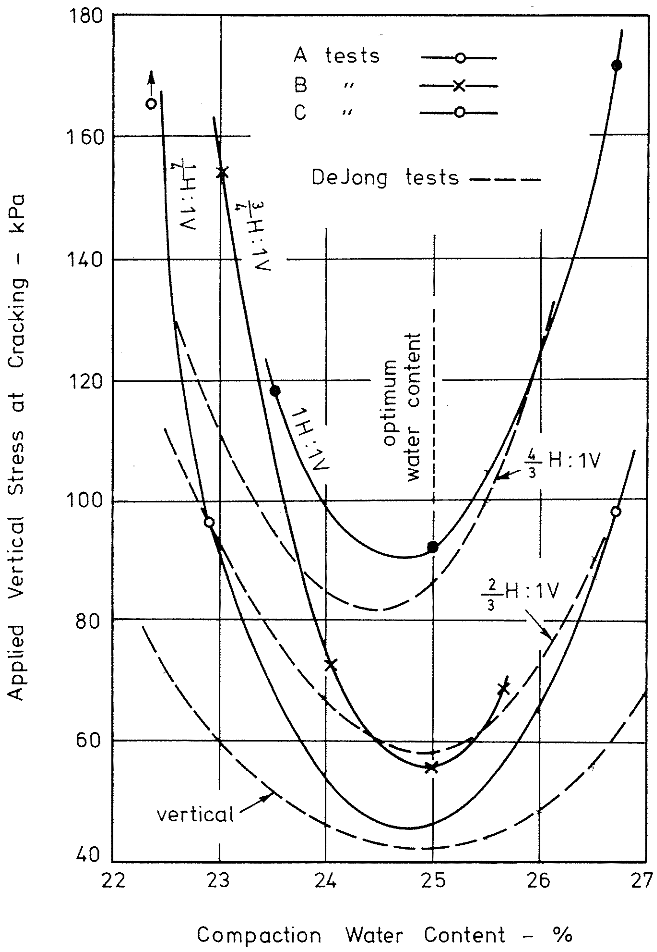

Figure 2 Applied Vertical Stress Required to Cause Cracking

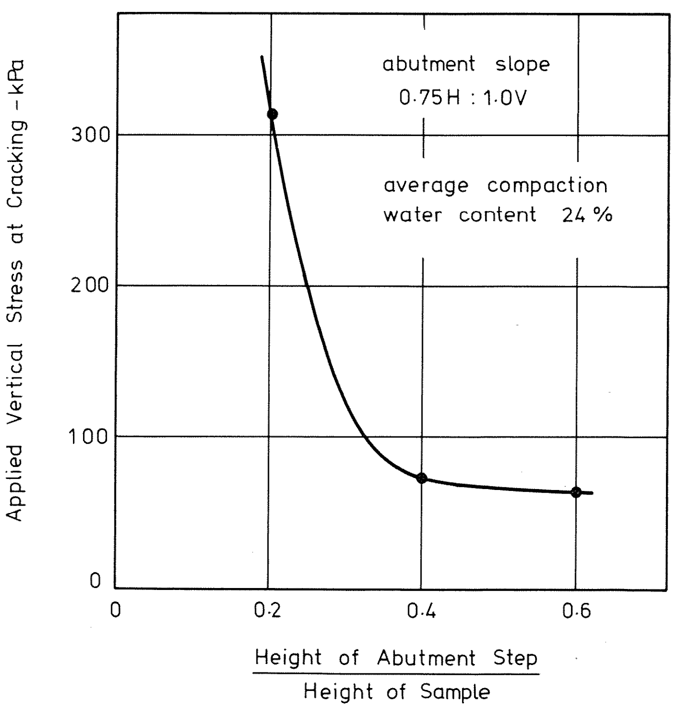

Figure 3 Effect of Size of Abutment Step on Stress Required for Cracking

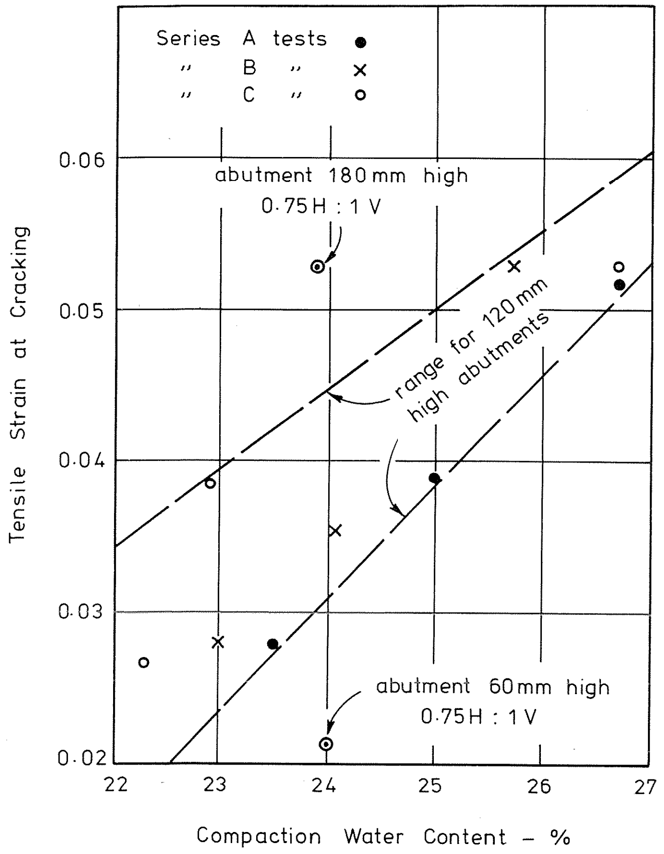

Figure 4 Tensile Strain at Cracking - Abutment Tests

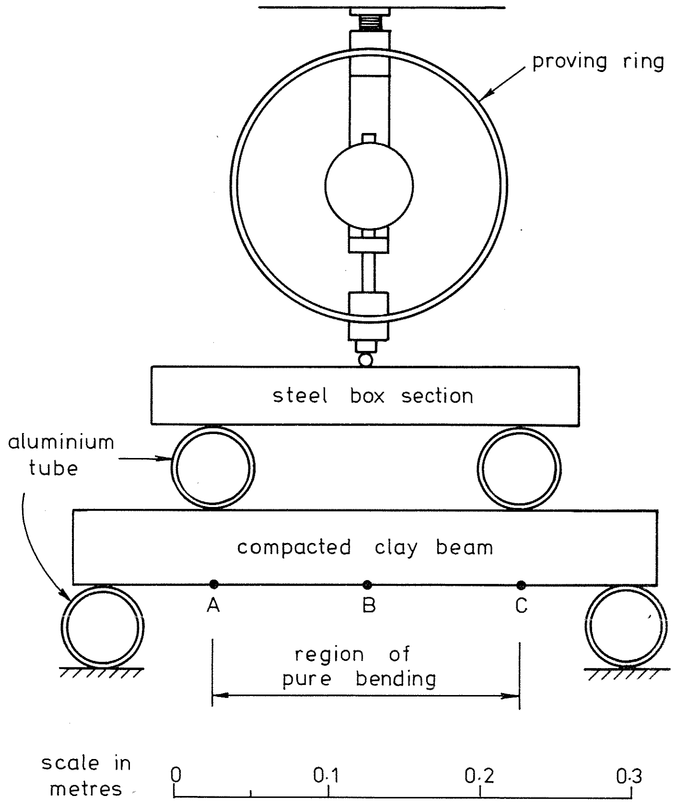

Figure 5 Compacted Clay Beam Test Arrangement

increases as the size of the abutment irregularity increases. This finding is the reverse of what was expected.

4 COMPACTED CLAY BEAM TESTS

In order to determine whether the relationship between the tensile strain required to induce a crack in a compacted clay and the compaction water content, could be found by means of a simpler test than those described above; a series of bending tests on compacted clay beams was carried out. The test arrangement, which is similar to that described by Ajaz and Parry (1975), is shown in Figure 5.

The beam was prepared by compacting the clay in a mould in five layers with a standard compactive effort of 596 kJ/m^3. The size of the completed beam was 50 mm square and 500 mm long. The beam was loaded gradually as illustrated in Figure 5 until cracking occurred. Readings of deflection were made within the region of pure bending at points A, B, and C to permit determination of the mid span deflection relative to the points A and C. From this information the radius of curvature of the beam could be calculated. This, then enables the strain to be calculated from equation (1).

$$\text{strain} = \frac{\text{distance from neutral axis}}{\text{radius of curvature}} \qquad (1)$$

The magnitude of tensile strain at failure, defined as the calculated tensile strain on the underside of the beam when cracking occurred, is shown in Figure 6. In agreement with the results of the abutment tests previously described and the results obtained by other workers, this figure shows that the tensile strain at failure increases as the compaction water content increases. However, a comparison of Figures 4 and 6 indicates that magnitudes of tensile strain at cracking in the abutment tests are significantly greater than those measured in the beam tests. This finding demonstrates that it is not possible to use the results of beam tests to provide indications of tensile strain at cracking adjacent to abutment irregularities. It further suggests that the cracking that may occur in compacted clay adjacent to an abutment irregularity is not caused purely by bending strains.

5 CONCLUSIONS

Based upon the experimental work described, the following concluding comments could be made:

(1) For a particular abutment irregularity, there exists a certain compaction water content at which the applied vertical stress required to cause cracking is a minimum. This water content is in the vicinity of the optimum water content.

(2) The applied vertical stress required to cause cracking decreases as the abutment slope steepens, and as the height of the abutment irregularity decreases.

(3) The tensile strain at which cracking occurs increases as the compaction water content increases and as the height of the abutment irregularity increases.

(4) Bending tests on compacted clay samples are not appropriate in providing measures of tensile strain at which cracking will occur adjacent to an abutment irregularity.

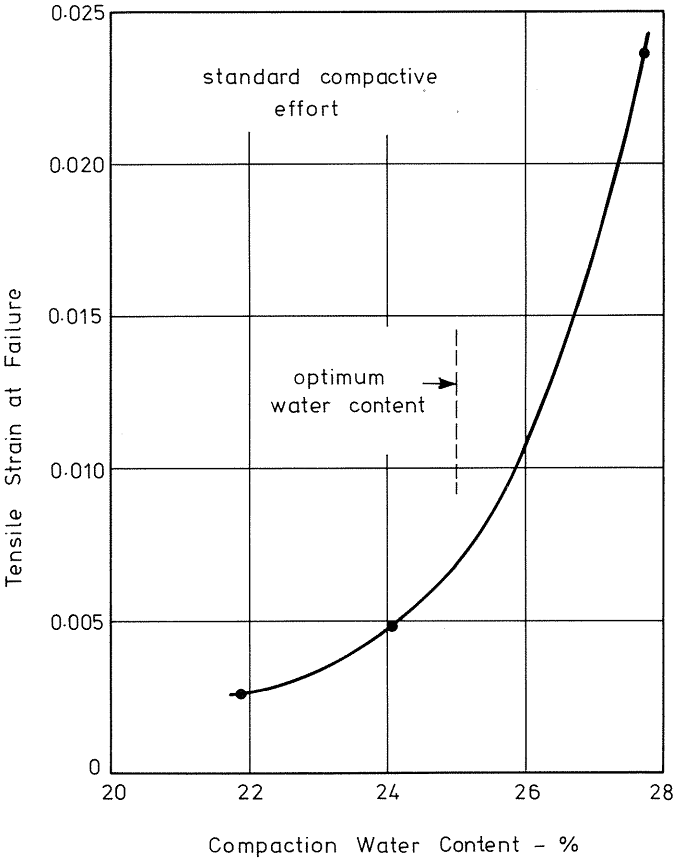

Figure 6 Failure Tensile Strain from Beam Tests

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