A STUDY ON THEORIES OF PLASTICITY AND THEIR APPLICABILITY TO SOILS UNDER ENVIRONMENTAL FACTORS

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By

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SUPERVISOR'S CERTIFICATE

This is to certify that **Mr. Maaz Allah Khan** has completed the necessary academic turn and the swirl presented by him/her is a faithful record is a bonafide original work under my guidance and supervision. He/She has worked on the topic "A Study On Theories Of Plasticity And Their Applicability To Soils Under Environmental Factors" under the School of Engineering And Technology, Maharishi University of Information Technology, Lucknow. No part of this thesis has been submitted by the candidate for the award of any other degree or diploma in this or any other University around the globe.

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DECLARATION BY THE SCHOLAR

I hereby declare that the work presented in this thesis entitled "A Study On Theories Of Plasticity And Their Applicability To Soils Under Environmental Factors" in fulfillment of the requirements for the award of Degree of Doctor of Philosophy, submitted in the Maharishi School of Engineering And Technology, Maharishi University of Information Technology, Lucknow is an authentic record of my own research work carried out under the supervision of Dr. Anoop Narain Singh and/or co-supervision of Late Dr. Syed Tabin Rushad I also declare that the work embodied in the present thesis-

i) is my original work and has not been copied from any journal/ thesis/ book; and

ii) has not been submitted by me for any other Degree or Diploma of any University/ Institution.

Signature of the Scholar

ACKNOWLEDGEMENT

It is the contribution of many persons that make a successful work. I wish to express my gratitude to individuals who have contributed their ideas, time and energy in this work.

I wish to express my heartfelt gratitude to my guide Dr. Anoop Narain Singh, Assistant Professor Rajkiya Engineering College, Azamgarh and my co-guide Late Dr. Syed Tabin Rushad Assistant Professor Birla Institute of Technology, Patna Mesra campus who passed away due to Covid19 in year 2021. For their active interest, constructive guidance, and advice during every stage of this work. Their valuable guidance coupled with an active and timely review of my work provided the necessary motivation for me to work on and successfully complete the Ph.D. work.

Words are insufficient to express my gratitude to my beloved parents for their inspiration and blessings. I thank God, who has supported me at every moment.

(MAAZ ALLAH KHAN)

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DEDICATION

I dedicate this thesis to my parents Mr. Masha Allah Khan and Mrs. Nayab Khan. I hope that this achievement will complete the dream that you had for me all those many years ago when you choose to give me the best education you could.

STUDY ON THEORIES OF PLASTICITY AND THEIR APPLICABILITY TO SOILS UNDER ENVIRONMENTAL FACTORS

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SUMMARY

CHAPTER 1 INTRODUCTION

1.1 A theoretical model for soils

The investigation of theoretical frameworks for soil has a long history, extending back to Coulomb's 1773 assessment of the collapse of such a porous medium. Even with the most basic of laboratory-generated substances, the fracture toughness of sediments seems far from becoming completely implemented. The implementation of theoretical methods for sediments, a subject that has already been intensively explored over the previous quarter-century, is indeed a point that needs to be thoroughly evaluated. The first one seems to be the investigation of the behaviors and qualities of genuine materials, such as the measured data of a soil's shear strength fluctuation. The second network is indeed the investigation of a scientific theories application to a growing medium: in the prescriptive, the inquiry becomes whether an elasticity stress factor accurately described the soil's performance throughout the desired frequency range. The investigation of the theories is the final main topic: anything syntactically correct concept employing a changeable mechanical property, for example, must satisfy particular underlying theoretical criteria. The main subjects are presented in opposite direction from the sensible response in practice: first, a concept should be established, then its relevance to grounds should always be examined, and ultimately the attributes of particular grounds should be identified. The utility of a concept is highlighted because selecting a conceptual computer-aided design of a material is not really about precision: the optimum version for addressing an unsolvable problem isn't usually the same one that matches the pressure curves for the specified laboratories or confirmatory testing. Soil is a complicated substance, as well as any simulation that reaches a greater accuracy would almost certainly be complicated as well (Yin et al. 2022). The use of isotropic materials, for example, permits the use of numerous sensible approaches for pressures and separations, therefore a simplified formulation might offer significant advantages that offset any sacrifice in resolution.

1.2 Rate independent theories for soils

Even though both clay minerals and fine sand show creep beneath continuous tension and stress release under continuous distortion, these appear to be natural consequences, with the primary reaction becoming frequency variable instead of viscosity. In the course of this article, mainly time independence hypotheses for the foundation soil would be discussed, however rate dependency owing to consolidating processes (reaction of the foundation soil with a viscosity pore solution) might be properly considered (Peñuelas et al. 2019). For sediments, there are many types of rate independence concepts, each of which is distinguished by the pattern of the reaction it predicts on load capacity, emptying, and refilling. However, when the substance is unloaded, the curvature is recapped, and this is an inaccurate representation of a genuine substance. Dilatancy on splitting is impossible to account for in flexibility because if the structural response anticipates primarily for two for sheared in one manner, it should also anticipate compressing for splitting in the other way. The plastic deformation concept would be a more standard technique for maximum load phenomena than hypo-elasticity. The stress is separated into two additional elements in this hypothesis. All variations in stress cause the elastic deformation escalation, which is normally limited by a predecessor (Larson et al. 2020). The endochronic hypothesis for metals but now widely used in masonry and clay seems to be an alternate method. The need for an inherent duration, which would be dependent both on original time as well as substance distortion, is a key component of the approach. With these factors, along with supporting information on plasticity hypotheses utility in sediments, the remaining of this research focuses on plastic concepts instead of any of the frequency independence hypotheses stated above.

1.3 Plasticity theory for soils

In this part, several theoretical models have been used for the soil samples with the help of using either plasticity theory or depending on the increased plasticity concepts. This theory was mainly developed for the study of ductility metals wherein the yield locus seems to be the spaces under pressure and even this seems to be identically failure that has a locus upon the perfection of plasticity (Piovesan, and Biondi, 2021). It was found that the issues related to the failure of the clayey soils mainly focus on the perfect plasticity with the help of upper as well as lower bounded theorems. This theory is mainly used in the study of the undrained behavior of soils. Even though the bounded theorems are considered as weak for such materials under the flow rule that has not been associated yet. As a result, this theory has been applied for the success of the material that is frictional to the surface. The consolidating tendency that used a basic empirical correlation specifies the "elastic wall" as well as tensile stress formula; the work formula is summed to generate a plasticity perspective, and uniformity is postulated to provide the yielding plane. The elastic region is composed of the "State Boundary Surface," and indeed the "Critical State" is usually incorporated (Hakro et al.

2022). The modeling does a good job of not just matching but also describing the characteristics of clayey soil.

The model's performance is mostly qualitatively right; for example, the fluctuation in undrained shear strength with upwards of proportion is adequately represented.

The subject of theoretical models for soils is first introduced, and the range of this dissertation outlined. After a brief explanation of the terminology which will be used, a review of the types of rate independent theories for soils is given, followed by a more detailed survey of plasticity theories. The possible contributions of particulate mechanics are summarized.

1.4 Theoretical Models for Soils

The study of theoretical models for soils is now over two hundred years old, dating from the analysis of the failure of a soil mass by Coulomb in 1773 (see Heyman (1972)). The mechanical behavior of soils is still, however, far from being properly understood, even for the simplest of laboratory prepared materials. The application of plasticity theory to soils, a subject which has been studied extensively during the last quarter of a century, is still therefore a topic which must be examined critically.

The subject of theoretical soil mechanics may be approximately divided into two fields, the characterization of the soil (the study of constitutive relations) and the solution of boundary value problems; this dissertation is entirely concerned- with the former. Within the subject of constitutive relations it is first necessary to distinguish carefully between three regions of study. The first is the study of the behavior and properties of the real material: for instance the experimental measurement of the variation of the shear modulus of a sand. The second field is the study of the applicability of a particular theory to a soil: in the above example the question would arise as to whether an elastic shear modulus reasonably represented the behavior of the soil within the range of interest. The third subject is the study of the theory itself: it may be the case for instance that any properly expressed theory using a variable shear modulus must comply with certain fundamental theoretical conditions. The three topics have been introduced in reverse order from the logical procedure in practice; a theory must be properly formulated first, its applicability to soils assessed and finally the properties for individual soils determined. The topics studied in this dissertation relate to the proper formulation of plasticity theories, and the assessment of the suitability of these theories for soils.

The study of the theory itself is necessary because unfortunately many models for soils are either incomplete or inconsistent with the principles of continuum mechanics. Various theoretical criteria must be satisfied before any study of the usefulness of a theory in its application to soils.

The usefulness of a model is emphasized since in choosing a theoretical idealization of a soil one is not always primarily concerned with accuracy: the best model for solving an engineering problem is not necessarily that which mos-t closely fits the stress-strain curve for the chosen laboratory or field tests. Soil is a very complex material, and any model which achieves a high degree of accuracy is likely also to be complex. A simpler model may have advantages which may outweigh any loss in precision; for instance the use of linear elasticity allows the application of many standard solutions for stresses and displacements.

Complex models also have the disadvantage that· they may involve many parameters and functions which are difficult to determine, and may be of unknown significance if the conditions in the real problem depart in any way from those from which the model was derived.

Finally, and perhaps most importantly, the complex models are unlikely to give an engineer a true understanding of soil behavior. A theory is seen as more than a mere encoding of test data in a concise form, but it should embody some explanation of the mechanisms underlying the behavior. To draw an analogy from astronomy, the approach used in many of today's theories in soil mechanics seems remarkably similar to that of Ptolemy in his system of epicycles which, whilst fitting (at least approximately) the motion of most of the planets, did nothing to explain provided an explanation was found; the purely phenomenological approach is therefore rejected in the following, where theories based on relatively simple hypotheses are studied. Although a certain degree of complexity must be admitted to provide tolerable accuracy, an emphasis is placed on relatively simple theories; it is felt that only by adopting this approach can some progress be made towards an understanding of soil behavior.The work presented in this dissertation is arranged as follows. This Chapter continues with an outline of the terminology which will be used, followed by reviews of three different topics. The different possible structures for rate independent theories are first reviewed, then a more detailed, but selective, review made of plasticity theories for soils. A short survey of the contribution of particulate mechanics to the understanding of soil behavior is given; these ideas provide some background for the continuum mechanics theories which will be examined later.

The remainder of the dissertation is divided into two halves; Part I deals mainly with the study of theories for soils (principally for clays) although it draws slightly on experimental data. In Chapter 2 certain preliminary problems in continuum mechanics are discussed, leading to a study of the restrictions which are usually imposed on plasticity theory and their over-restrictive nature for soils. An alternative approach to plasticity theory is given in Chapter 3, successfully imposing the restrictions of thermodynamics without introducing the unrealistic requirement of normality of plastic strain increments to the yield locus. The new approach is developed in Chapters 4 and 5 where the Modified CamClay model is derived in terms of the thermomechanical method, and it is shown how the method allows proper treatment of some alterations to the simple model. Part I is completed by a Chapter in which some aspects of soil behavior not yet accommodated in the thermomechanical method are discussed.

Part II. is an experimental study, essentially separate from Part I; it begins with a discussion of the ways in which the applicability of plasticity theory to soils may be tested experimentally, leading to a programme of "stress cycle" tests which are used to study the effects of stress and of stress history on the behavior of a sand. A computer controlled triaxle apparatus, necessary for these tests, is described. The results of the tests are presented and I presented in terms of elasticity and plasticity theory.

In Chapter 10 some conclusions from Parts I and II are drawn together, some additional material is presented in Appendices. Appendix A is a copy of a· publication on which Section 2.1 is based, and Appendix B is a brief discussion of an extension of the ideas presented in Chapter 3 to the analysis of non-homogeneous behavior. Details of calculations for the triaxle test are given in Appendix C.

1.5 Rate Independent Theories for Soils

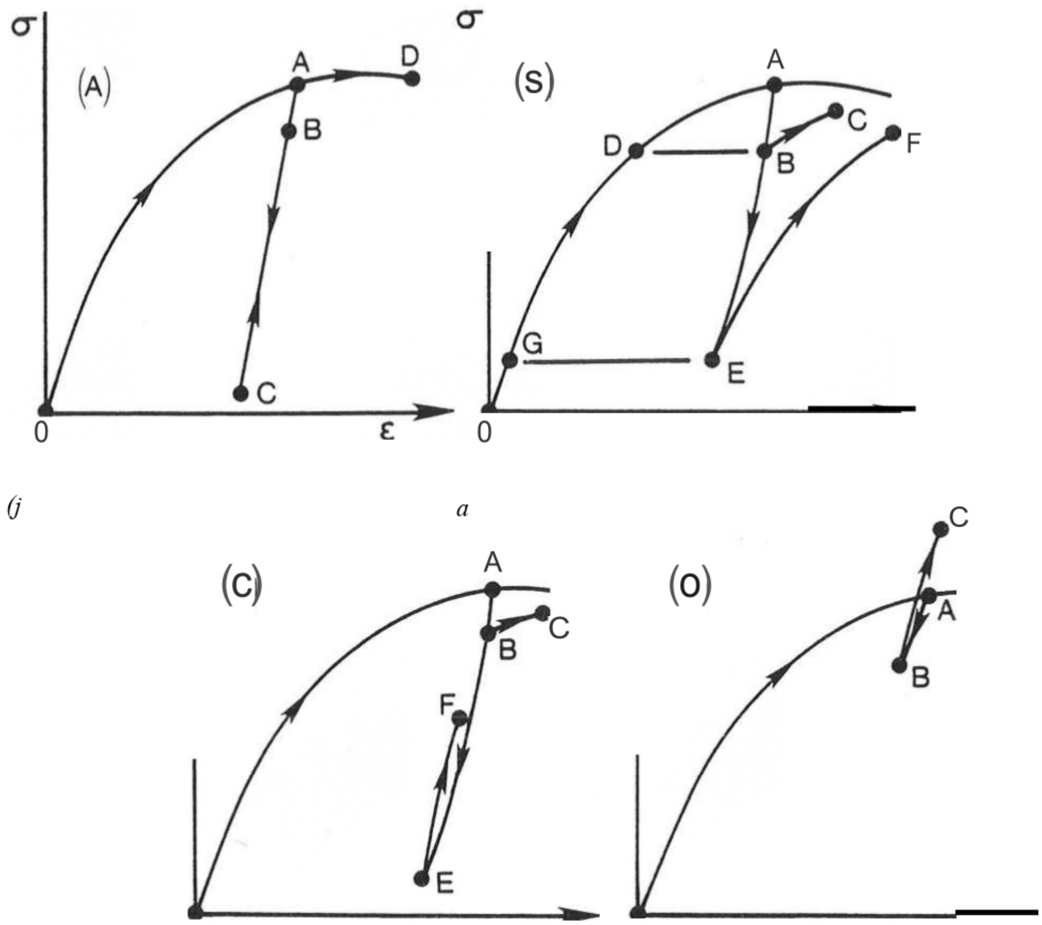
Although both clays and sands exhibit creep under constant stress and stress relaxation at constant deformation, these would largely seem to be secondary effects, with the main response being rate independent rather than viscous in nature. Only rate independent theories for the soil skeleton will be treated in the rest of this work, but rate dependence due to consolidation effects (interaction of the soil skeleton and a viscous pore fluid) may still be accounted for. Several classes of rate independent theories have been used for soils, and these are characterized principally by the nature of the response which they predict on loading followed by unloading and subsequent reloading. Some of the more important types of theory are outlined below.

The simplest rate independent theory is that of elasticity, in which:

$$c_{ijk\ell} \, \varepsilon_{k\ell} \qquad (1.3.1)$$

If variable then non-linear behavior can be described, as in curve OA of Figure 1.1 Hyper-elasticity which shows a typical one dimensional monotonic loading curve. On unloading, however, the curve would be retraced, which is an unrealistic description of a real material. Dilatancy on shearing cannot be accommodated within elasticity, since if the stiffness matrix predicts dilatancy for shearing in one direction it must predict compression on a reversed shearing. As long as attention is restricted solely to loading then elasticity may be useful; for instance the non-linear elastic model of Duncan and Chang (1970) (which includes some additional empirical features) has been extensively used in engineering calculations.

In order to obey the first law of thermodynamics for a non-dissipative system, elastic laws may be restricted to hyper-elasticity such that:



(Fig 1.1: hyper-elasticity)

of the elastic materials.

A wider class of materials consists of those which are hypo-elastic, the simplest form being give

$$1.\dot{J} = c_{ijk\ell}\,\dot{\varepsilon}_{k\ell} \qquad (1.3.3)$$

These materials can accommodate the non-linear loading OA of Figure l.l(b); if more complex first order terms are added to the right hand side of Equation (1.3.3) then unloading of the form ABE in Figure l.l(b) can be achieved. Such a model is described by Gudehus and Kolymbas (1979) , in which the stress rate is taken as a homogeneous but non-linear function

of strain rate. The resulting model is incrementally non-linearize. if it were to be reduced to the form of Equation (1.3.3) the stiffness cijkt would depend on the direction of the strain rate €kt

Although soils may in reality display incremental nonlinearity, this property is undesirable in a simple model since in calculations using methods such as finite element analysis an iterative procedure must be used in which the stiffness matrix must be re-formed according to the response calculated.

A further disadvantage is that in its present form the model of Gudehus and Kolymbas uses stress as the only structural parameter, so that on the reloading curves BC and EF the slopes are the same as for the sections of the initial loading curve at D and Gin Figure 1.l(b) (see Kolymbas and Gudehus (1980)). Whilst the model may therefore be of use in primary loading and first unloading, and can accommodate dilatancy, the behavior on reloading is unrealistic An improvement could be achieved by including other structural parameters, for instance a reconsolidation pressure by including other structural parameters, for instance a reconsolidation pressure.

A more familiar approach to the loading-unloading behaviour than hypo-elasticity is plasticity theory. In this theory the strain is divided into two additive components. The elastic strain increment occurs for all changes of stress, and is usually restricted by hyper elasticity.

The plastic component only occurs if the stress point lies on the yield locus, which is a surface in stress space, and (for a hardening material) the stress increment is outward directed from the yield locus. The magnitude of the plastic strain increment is related to the movement of the yield locus by a hardening law, and the direction of the plastic strain increment is independent of the direction of the stress increment and is given by the normal to a plastic potential. The type of behavior given by plasticity theory can describe the loading curve OA of Figure 1.1(a), and an unloading-reloading curve ABC. On reloading to A the initial curve is re-joined and the path AD followed. Plasticity theories are incrementally bilinear, that is the stiffness matrix can be reduced to the form of Equation (1.3.3) where the stiffness cijki takes two values, one if plastic loading occurs and the other for elastic unloading. If a pointed yield locus is allowed the theory becomes incrementally nonlinear.

An alternative approach is that of endochronic theory, first introduced by Valanis (1971) for application to metals, and since extensively applied to concrete and soils, e.g. Bazant and Krizek (1976), The essential feature of the theory is the use of an intrinsic time which depends both on the real time and on the deformation of the material. For a rate independent material the intrinsic time does not depend on real time and is given by an expression of the form:

$$= \quad D^{(1)}_{ijk\ell} \, \dot{\varepsilon}_{ij} \, \dot{\varepsilon}_{k\ell} \qquad (1.3.4)$$

The incremental behaviour is then given by an expression of the form:

$$D^{(2)}_{ijk\ell} \, \dot{\varepsilon}_{ij} + D^{(3)}_{ijk\ell} \, \sigma_{k\ell} \, \dot{\xi} \qquad (\ 1.3.5)$$

Each of the TENSORS may depend on stress, strain and intrinsic time, so there is scope for considerable complexity of behaviour. Loading and unloading curves of the form OABE in Figure 1.1(c) are possible. On reloading from E a suitable choice of functions gives the realistic behaviour EF , but on reloading after a small unloading the slope BC is approximately the same as the original loading slope at A. Recent modifications to the theory apparently eliminate this unrealistic behaviour, but at the expense of the equally unrealistic reloading curve of BC in Figure 1.l(d).

Endochronic theory is closely related to hypoelasticity, and the equations resulting from the theory are also incrementally nonlinear: they may be approximately linearised, however, for limited loading paths.

The behaviour of loose Leighton Buzzard sand in a drained triaxial compression test is shown in Figure l.l (e) and of Newfield Clay in an isotropic consolidation test in Figure l.l(f). In both of these tests the character of the overall loading, unloading and reloading cycle is most nearly described by plasticity theory rather than any of the alternatives described above. For -

these reasons, and because of ample other evidence of the usefulness of plasticity theory for soils, the remainder of this dissertation is concerned primarily with plasticity theories rather than any of the other rate independent theories discussed above.

1.6 Plasticity Theories for Soils

In recent years the number of theoretical models for soils either using rigorous plasticity theory or based more loosely on the concepts of plasticity has increased enormously. Any review must necessarily be highly selective, and in the following most emphasis is placed on the developments related to the critical state models, on which attention at Cambridge has been principally focused.

Plasticity theory was developed initially for the study of ductile metals, and first involved the use of perfect plasticity (e.g. Prager and Hodge (1951)) in which the yield locus is fixed in stress space and is therefore identical to the failure locus. Perfect plasticity has found much application to the problem of the failure of soils, principally through the application of the upper and lower bound theorems. The theory is particularly useful in studying the undrained behaviour of clay (which may be treated as a purely cohesive material.) Although the bound theorems are considerably weakened for a frictional material with a nonassociated flow rule (Drucker (1954)), plasticity theory has also been applied with success to frictional materials (e.g. the stress field solutions developed by Sokolovskii (1965)) .

Whilst useful in the study of the failure of a soil, perfect plasticity is not so suitable for the study of the development of displace nts under working loads and before failure is reached. For this application a work hardening theory of plasticity is necessary. The application of a work hardening theory to soils was first qualitatively described by Drucker et al. (1957), who suggested an "extended Von Mises" conical yield locus closed by a spherical work hardening cap. Although several later models are qualitatively similar to this prototype, the model was incomplete and did not achieve a full synthesis of soil behavior

At about the same time Roscoe et al. (1958) successfully combined the ideas of a unique surface in (p',q,V) space for normally consolidated clays (introduced by Rendulic (1936)), the normalisation of clay behaviour with respect to preconsolidation pressure (following Hvorslev (1936)) and an extension of the idea of a critical voids.ratio (Casagrande (1936)) to that of a critical state line in (p',q,V) space. (For definitions of p' and q see Schofield and Wroth (1968), V is specific volume.) The intersection of an "elastic wall" (which simply represents a statement of elastic isotropy) with the state boundary surface for normally consolidated clays (the Roscoe surface) was later identified as a yield locus (Calladine (1963)). Quite separately a work equation similar in concept to that of Taylor (1948) may be integrated to give a plastic potential; adoption of Drucker's stability hypothesis allows this to be identified as a yield locus, which happens to be similar in shape to that given by the intersection of the elastic wall and the Roscoe surface.

Finally, expressed conveniently in terms of variables appropriate to the triaxial test, the Cam-Clay model of Schofield and Wroth (1968) achieved a synthesis of the above ideas. The "elastic wall" and work hardening law are specified by the consolidation behaviour (using a simple empirical relation); the work equation is integrated to give a

plastic potential, and normality is assumed to give also the yield locus. The "Critical State" is automatically included and the yield surface is part of the "State Boundary Surface". The model goes far in not only fitting the behaviour of soft clays, but also in explaining that behaviour. The behaviour implied by the model is mainly qualititatively correct, for instance the variation of undrained strength with overconsolidation ratio is quite well describe.d

The slight change in the flow rule to give Modified Cam-Clay (Roscoe and Burland (1968)) and the addition of a shear modulus result in a model which is well suited to computation using the Finite Element Method. Whilst useful for modelling the loading of soft clays the critical state models are less suitable for overconsolidated materials, or for unloading or reversal of loading on soft materials.

The loading of stiff soils shows a work hardening behaviour apparently linked to a yield locus taking approximately the conical form used by Drucker et al. (1957). This has given rise to a series of "cap models" employing a combination of the conical locus and a consolidation"cap". The models are mainly empirical and that by Lade (1977) is a good example of the type. In the case of a sand the conical locus (in this example a distorted cone in stress space) assumes greater importance than the consolidation behaviour. Lade's model is expressed entirely in terms of plasticity theory. In adopting a nonassociated flow rule and non-conservative elastic behaviour it moves far from the simple theories where the uniqueness and bound theorems apply. Although the model may fit test data accurately the validity of any solutions to boundary value problems may therefore be questioned.

The Lade model, like the Cam-Clay models does not fit unloading behaviour well. Soils show hysteresis and nonlinear behaviour below the yield locus, and attempts to include these effects have been made in a variety of ways. Hueckel and Nova (1979) use for example a model related to the cap models, but incorporate a "paraelastic" strain in which the elastic compliance increas-eswith the distance from the last stress reversal point so that hysteresis is introduced. The form of all unloading curves is similar, and no "shakedown" to elastic behavior :ts possible.

The above model introduces hysteresis effects independently from the main plastic behaviour. An alternative is to link these effects specifically to plasticity. This is achieved by the model of Dafalias and Herrmann (1980), and a simplified version of the concepts involved is given here. For every stress point A in Figure 1.2 an image point B on a "Bounding Surface" is determined. The plastic strain in a conventional plasticity model with an associated flow rule and a yield is given by:

$$= \frac{1}{h} \frac{\partial f}{\partial \sigma_{ij}} \frac{\partial f}{\partial \sigma_{k\ell}} \dot{\sigma}_{k\ell} \qquad (1.4.1)$$

where h is a hardening modulus. In the bounding surface mode1 f is interpreted as the bounding surface and O' •• in Equation (1.4.1) as the stress at the image point. The value of h is then given by:

$$h_o + h_1 \frac{\delta}{(p'_c - \delta)} \qquad (1.4.2)$$

Bounding Surface Point

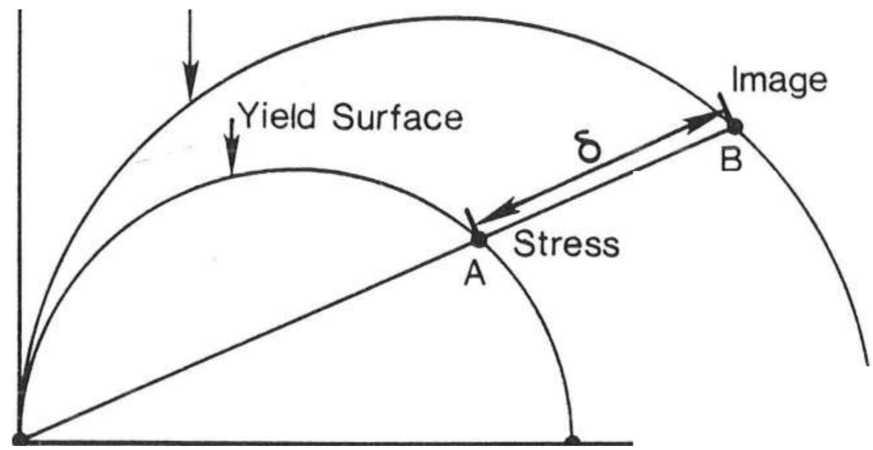


Figure 1.1 Yield and bounding surfaces for simplification of model of Dafalias and Herrmann (1980) where is as shown Figure 1.1 Yield and bounding surfaces for simplification of the model of Dafalias and Herrmann (1980)

The result is that when the stress point is on the bounding surface conventional plastic behaviour is given, inside the surface a reduced plastic strain occurs if the quantity pe' is increasing. (A yield locus through the stress point and similar to the bounding surface may be imagined.) The model has several advantages: it is incrementally bilinear, models hysteresis and has a smooth transition from elastic to plastic behaviour. Whether the development of plasticstrains after many cycles is in fact modelled accurately is as yet unknown.

n alternative arrangement which also produces hysteresis effects involves the use of multiple yield loci. The model of Prevost (1979) uses this technique, with many yield loci of different sizes, all similar in shape to the Modified Cam-Clay yield locus but not fixed in stress space, nested together in stress space. Each locus has a simple linear hardening law associated with it which determines its contribution to the overall plastic strain. The yield loci are each translated independently by the stress point.

These models are characterized principally by many material constants, but this is countered by the fact that they require no complex functions to be chosen. Although capable of fitting test data well their value for the solution of boundary value problems seems questionable.

Finally the "microstructural" model of Calladine (1971) may be mentionde. Although based on theories for the contact behaviour of planes in the material, calculations using the model also involve multiple yield loci, in this case each associated with a different plane. Computationally the problems are similar to those of the last model, although conceptually the models are very different. The distribution of yield loci in stress space is quite different in the two models, and the microstructural model does not require a large number of material constants. The above models give some idea of the ways in which plasticity theory may be modified to accommodate many aspects of soil behaviour. Although some of the latter models are more accurate than the simple models they have the disadvantages of complexity. They are not pursued further here, where the emphasis is rather on the establishment of simple models on a theoretical basis which seems better suited to the description of soils than conventional plasticity theory.

1.7 The Contribution of Particulate Mechanics

An alternative to the continuum mechanics approach is to adopt an analysis paying specific regard to the particulate nature of soils. This work is usually based on assumptions of rounded particles with frictional contacts; the results are therefore more applicable to sands than clays, where the particles are predominantly plate or rod like in form and complex electrical interactions are frequently important. Although the particulate nature of soil is specifically acknowledged, the aim of the theories is to describe macroscopic behavior and so their results may ultimately be very similar to those of continuum mechanics

a) The analysis of regular arrays of rigid frictional particles.
b) The analysis of irregular arrays paying special attention to stresses and strain increments on planes oblique to the principal stress directions.
c) Probabilistic analysis of irregular arrays.
d) (d) Study of the contacts between particles

Topic (b) may not involve an approach specifically taking into account the particulate nature of soil, but derives from the significance of certain planes in the analyses of type (a) and has led to some fruitful results.

The importance of the analysis of regular arrays lies entirely in the expectation that more complex irregular assemblies will behave in an analogous manner to the simple structures which are studied. This expectation may not be realized since regular arrays involve certain highly unrealistic features; for instance the fairly continuous creation and destruction of particle contacts in ili deformation of an irregular array is replaced by the sudden change of whole sets of contacts. In spite of these problems the method has given some useful results, in particular the analysis of a regular array of spheres by Rowe (1962) which led to the development of the stress-dilatancy theory. More recently Thornton and Blackburn (1980) have extended the analysis of assemblies of spheres to demonstrate the importance of an anisotropic structure on the initial yield locus of a soil. Although the study of regular arrays is mainly a theoretical exercise, the results may also be verified experimentally. The tests of Rowe(1962) demonstrate · for instance the development of discrete shear bands in strain softening materials.

The analysis of soil behaviour placing particular emphasis on certain planes oblique to the principal stress directions dates from Coulomb's first contribution to the subject. That analysis was purely concerned wit the strength of the material, but more recent analyses have also made many hypotheses about the flow. The stress-dilatancy theory of Rowe (1962) for instance results in a flow rule by considering sliding on planes for which an energy ratio is minimised (the validity of the energy ratio hypothesis is open to question). The inclusion of this approach amongst particle mechanics is because the planes of interest arise by analogy with certain important planes in the analysis of regular arrays.

More recently Matsuoka (1974) has focussed attention on the deformation of soil in relation to the "Mobilised Plane" (identical to Coulomb's critical plane), and also the "Spatially Mobilised Plane", a concept rather more difficult to interpret physically (Matsuoka (1976)). The analysis makes complex assumptions about particle movements related to the plane, the details of which are open to criticism. Some promising results have, however, been reported. The models are formulated in such a way that strains are calculated in response to stress changes, and may be difficult to use within continuum mechanics.

A deterministic approach to the deformation of irregular arrays of particles is prohibitively complex, but analyses using probabilistic techniques have been attempted. The initial work in the subject wasby Horne (1965) who, assuming no rotation of particles, derived from virtual work principles a complex expression for the ratio of the work. Horne also introduced a measure of anisotropy, the "mean projected solid path" or "mpsp" which is the mean distance a given direction traversed between two random contacts on a particle. The variation of "mpsp" with direction is a measure of the structure of a granular assembly and is related to the distribution of contact directions.

Horne makes use of an arbitrary probability density function for the contact directions to derive the "mpsp" in terms of this function under certain assumptions. Using another probability density function for the proportion of particles sliding at a given velocity, and assuming no particle rotation, he also derives expressions for strain rates. With further simplifying assumptions Horne calculates the stress ratio for initial deformation of an isotropic assembly, the peak stress ratio and the stress ratio for deformation at constant volume (Horne (1969)).

Further work (e.g. Oda (1974)) has been done using other. Fabric indices and assumptions, resulting mainly in slight modifications of the stress dilation flow rules. Although involving rather complex mathematics, all the above calculations are based on several arbitrary, and largely unverifiable, assumption.s Lagoni (1976) for instance questions an assumption by Oda (1974) which has a significant effect on his final result. Some assumptions have, however, been examined experimentally, and Oda has supported his work with experiments on both two-dimensional rod models and also sands. He has shown for instance (Oda (1972)) that in a triaxial test the predominant direction of contact normal is approximately the principal stress direction He also finds the more surprising result that at any stress state there are a small number of contacts near the limiting friction condition, but that the proportion of such contacts increases little with stress ratio. This finding indicates that any change in stress ratio may be expected to cause irreversible strains.

Information about the orientation of the contacts near critical would be relevant to Rowe's hypothesis of a critical angle for sliding contacts. Some aspects of soil behaviour may be inferred from the study of particle contacts using Hertzian contact theory (see for example Mindin and Deresiewicz (1953)). The approach of two contacting rounded elastic bodies may be shown under certain assumptions to be proportional to the two thirds power of the normal force between them. Thus one may expect the elastic volumetric strain to be proportional to the two thirds power of the pressure. In practice a rather lower power law is observed, probably due to the angularity of contacts .

If a shear force is applied between two spherical elastic frictional bodies, then an annulus of the contacting area must slip if the stress ratio increases. So, since a stress ratio change will in general increase the shear stress at some contacts then dissipative (plastic) behavior must be expected for any change of stress ratio (note that this is without Allowing that an elastic stress change at constant stress ratio will slightly alter particle arrangements then any stress change may be expected to cause plastic deformation In the remainder of this dissertation soils will be described entirely in terms of continuum mechanic's The contributions described above must be borne in mind, however, as giving some indication of the type of behavior which a continuum theory must accommodate.

1.8 The contribution of particulate mechanics

An option for using continuous dynamics would be to have an analysis that takes into account the particle structure of soils. This study is often focused on fine aggregates with mechanical connections; as a consequence, the findings are much more relevant to sandy soils than clay minerals, in which the granules are mostly plates or filament in shape and complicated electromagnetic interconnections are common. Despite the fact that the particle character of the soil is explicitly recognized, the concepts' purpose is to explore macroeconomic behavior, and hence their conclusions should be quite identical to those of computational fluid dynamics (Laitinen, and Nikoloski, 2019). The relevance of normal matrix research stems largely from the anticipation that more complicated irregularity assemblages would behave similarly to the basic structures analyzed. This assumption might not even be achieved because normal matrices have several extremely unrealistic aspects; for example, inside the ill distortion of an uneven arrangement, the fairly steady production and demolition of particles connections are substituted by the dramatic development of entire sets of connections. The analysis of particle interactions utilizing "Hertzian contact theory" can predict certain features of properties of the soil. Within certain conditions, the approaching of receptors is activated spherical elastic entities might well be proven to be proportionate to the two-thirds magnitude of the dynamic pressure among them (Al Houri et al. 2020). As a result, the elasticity translational tension should be equivalent to the pressure that comes in two-thirds magnitude. In practice, a reduced power curve is seen, which is most likely owing to interaction rigidity and the development of additional connections.

CHAPTER 2

LITERATURE REVIEW

2.1 Kinematic variables and conjugate forces

According to the reviews from several authors, in this part, plasticity theory is described by means of computational fluid dynamics, wherein the idealized version of mathematics conception of a homogenous continuity replaces the actual non-homogeneous substance. A tension matrix corresponds to these, and therefore must be specified such that the combination of the pressure and the tensile stress equals the quality of the work supplied per unit volume of the sample (Wang et al. 2021). Assuming that perhaps the province under evaluation has enough granules for the theories of average total anxiety, tension, pressure gradients, as well as void space proportion to be impactful, the displacement of the foundation soil can be characterized by the outlined previously strain: model variables to characterize the movements of the pore solution should be tried to introduce. As a result, the synthetic spillage velocity describes the mobility of the pore solution, and the excess pore pressure difference represents the associated stress. An extra kinematics quantity, the mean translational tension in the pore water, is required in this instance.

2.2 Use of internal variables in the plastic theory

In this part, the condition of a substance might be characterized by its movement history, as indicated in the previous article (Hicks et al. 2022). The reaction to changes in patterns of the substance is seen as the pressure on the component. In principle, the reaction to any good changes in status will be determined not just by the present state, but also by the object's complete experience. As a result, tension will be dependent not only on existing pressure but also on the tension histories: pressure is referred to as a derivative of straining antiquity instead of a variable of tension. When only one internal variable gets utilized, the amount of complication of behaviors that can be explained is virtually zero; however, when more variables are introduced, the degree of competition intensifies. In fact, an endless amount may be required to explain a particularly complicated load history.

Figure 2.1: Internal variables in plastic theory As a result, tension will be dependent not only on existing pressure but also on the tension histories: pressure is referred to as a derivative of straining antiquity instead of a variable of tension. When only one internal variable gets utilized, the amount of complication of behaviors that can be explained is virtually zero;

however, when more variables are introduced, the degree of competition intensifies. In fact, an endless amount may be required to explain a particularly complicated load history.

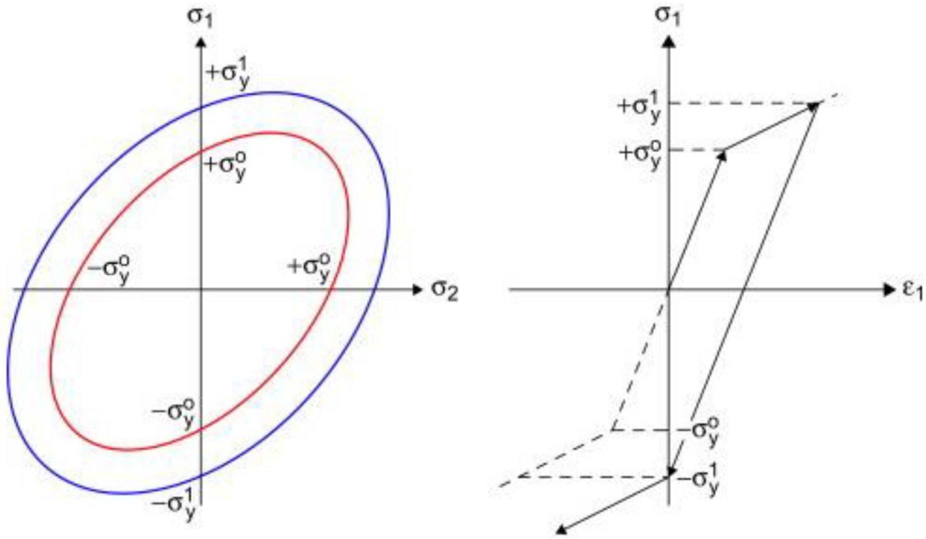


Figure 2.1: Internal variables in plastic theory

(Source: https://www.sciencedirect/topics/materials-science/plasticity-theory)

2.3 A theoretical restriction imposed on plastic theory

In this part, elastic-plastic concepts for unsaturated soils can be merely experimental, depending on parameter estimation of soil testing, or they can be built on more basic presumptions that strive to interpret as well as describe the performance of the soil (Zhang et al. 2021). Several personality circumstances would not be discussed in depth here. For example, a simulation would have to be full and coherent in that it may determine a reaction for every given stress state pathway; simulations are correctly written in terms of computational fluid dynamics typically meet this requirement. A second restriction that is frequently enforced is consistency, which states that infinitely different applied routes result in infinitely different answers. As a result, the rules of combustion, therefore, place significant restrictions on how continuous concepts may be represented. Figure 2.2: Plastic theory of bending shows The easiest example is flexibility; if a "strain energy function" doesn't really exist, i.e. the pressures can indeed be acquired by specialization of a probability density, the tensions can indeed be acquired by differentiating state equations.

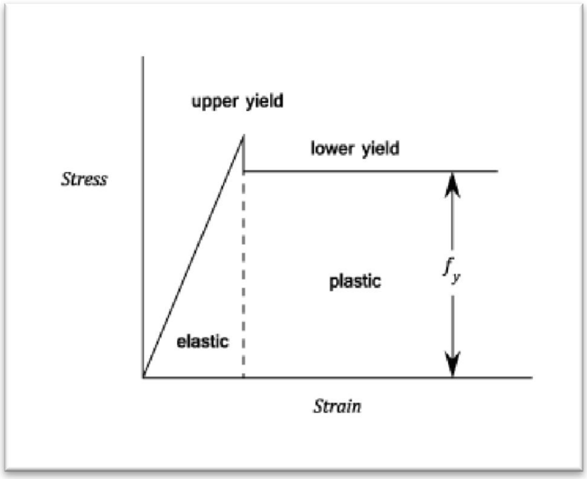


Figure 2.2: Plastic theory of bending

(Source: https://www.codecogs/users/23287/Plastic-Theory-0001.png)

2.4 Need for a less restrictive approach

In this part, the main outcomes postulate the stresses of the yielding locus and even become normal to the increment of the strain of plasticity (Zhao et al. 2019). Even though there is no compelling research showing opposing curvature, certain particles, particularly granular substances, deviate significantly from the normalcy requirement. A stress cycle, for example, does not seem to be a loop within the thermodynamics understanding, but it might entail modifications in the substance's inner core. It is self-evident how important it is for a workable approach to existing for a particular situation. Other metaphorical meanings include the superior and inferior bound theories, which allow easy approaches to nearly surround the precise answer for maximum stress on completely polymeric products. It is envisaged that by basing the formulations on a few basic assumptions, proofs including the originality of progressive responses and altered variants of the bound statements would emerge (Belousova et al. 2021). Several inevitable consequences of the concept, such as the presence of a yielding region, are offered as the first stages in this approach.

2.5 Cam-clay models

"Schofield and Wroth" described the "Cam-Clay" computational foundation for geotechnical properties (1968). The idea is built on simple assumptions for energy production and dispersion, the idea of stabilization as described by Drucker (1959), as well as an experimental connection for the pneumatically volumetric response of clayey soil, as represented in the theories of plasticity. The simulation result integrates the consolidation and shear characteristics of clay particles into a coherent model, however not most of its recommendations are accurate. While Customized Cam-Clay isn't perfect, it does a good job of simulating most of those characteristics of clayey soil performance (Îvchinnikov et al. 2018). Calculations for clay particles containing an over commutated larger than nearly two have become less efficient, with toughness frequently over-predicted and, throughout most circumstances, a too rigid reaction on loading reverse. Figure 2.3: Cam-clay models shows In addition to this, this model can be used successfully for other similar models within the prediction of the behavior of the soil specimens. Thus, this helps in demonstrating the derivation of the models based on thermodynamics. Hence, several modifications could be made to the model under the same concepts.

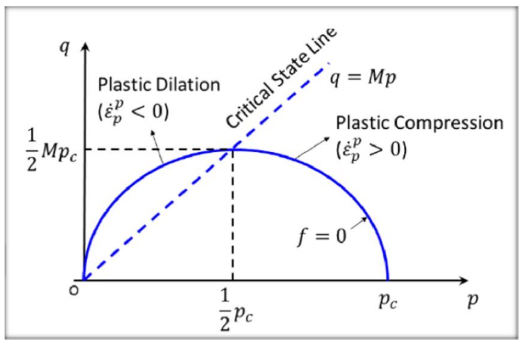


Figure 2.3: Cam-clay models

(Source: http://docs.itascacg/3dec700/common/models/camclay/doc/modelcamclay)

2.6 Derivation of Cam-clay models

The performance of the simulation would not be detailed at this time, in keeping with the thermo-mechanical method, but the two activities necessary (particular energy input and specialized depreciation) would be presented initially (Li et al. 2019). These variables would then be used to generate the response, with the ties to standard theoretical methods underlined. This method must be compared with the traditional method that specifies the model's end functionality from the start. Even though the model would be generalized to more broad pressure states with regard, this was first described in terms of the restricted pressure and stress characteristics used mostly by "Schofield and Wroth (1968)" for the triaxial test specification. The exponential concept of tension is employed for numerical simplicity; it is unrecognizable from the Cauchy strains for small deformations analyses. As a result, it is emphasized that the two technologies entail totally distinct sets of assumptions, there appear to be no advantages in learning the above formulation of the Revised Cam-Clay framework over through the standard approach to ductile materials (Hurley, and Nizzetto, 2018). The advantages of the novel method are highlighted in the following Section by making a few minor adjustments to the simpler models. The model's adjustments also enable certain acquaintance with the importance of specific shapes to be formed.

In this Chapter some ideas from continuum mechanics are introduced as preliminaries to the thermomechanical analysis in the next Chapter. Kinematic variables and their conjugate forces are introduced, and a discussion of internal variables is given. The theoretical restrictions conventionally imposed on plasticity theory are described, and their overrestrictive nature for soils is noted.

2.7 Kinematic Variables and Conjugate Forces

Plasticity theory is expressed in terms of continuum mechanics, in which the real non-homogeneous material is replaced by the idealized mathematical concept of a homogeneous continuum It is usual in continuum mechanics to assume that the current state of a material body may be described entirely by the history of its motion and temperature. Considering an infinitesimal homogeneous element of a material, its motion may be described by a properly defined strain tensor .(measured from some arbitrary reference state) and its history; the temperature is not of interest in this study. Corresponding to the strain tensor is a stress tensor, which must be defined so that the product of the stress with the strain rate gives the rate of work input per unit volume to the material.

For a single phase material, it is straightforward to show that the conventional definitions used in small strain theory of stress as force per unit area and strain as deformation per unit length satisfy Equation (2.1.1). For a two phase material such as a saturated soil the position is, however, more complex. Assuming that the region under consideration consists of sufficient grains for the concepts of an averaged stress, strain, pore pressure and voids ratio to be meaningful, then the deformation of the soil skeleton may be described by the conventionally defined strain: additional parameters must be introduced to describe the motion of the pore fluid. The correct stresses will be the forces which are conjugate to the kinematic variables, i.e. those quantities which when multiplied by the rate of change of the kinematic variables give the rate of work input per unit volume. The word force is used here in the generalised thermodynamic sense, and not in the narrower mechanical sense (the forces here have the dimension of stress, not of mechanical force).

In Appendix A (Houlsby (1979)) it is shown that, under the idealisation of incompressible grains and an incompressible pore fluid, the rate of work input per unit volume to a granular material is given by:

that the stresses conjugate to the strains are the effective stresses defined by Terzaghi (1943). The motion of the pore fluid is described by the artificial seepage velocity, and the corresponding force is the (negative) excess pore pressure gradient. It is suggested in Appendix A that the uncoupling of the work input into two terms as in Equation (2.1.2) is related to the principle of effective stress. This idea is explored in greater detail in Section 3.5, but the above.result is first extended to a more general case.

The idealisations under which Equation (2.1.2) was derived are most appropriate for a saturated soil. A better approximation is achieved if the pore fluid is regarded as compressible. In this case an additional kinematic parameter, the average volumetric strain in the pore fluid v(w) , must be included. Using the definitions of Appendix A the compatibility condition is now written:

$$\int_A (\mathrm{nf.}_J + (1-n)v._J)_J\, v.\,dA + \int_V n\,(w)\;dV = 0 \qquad (2.1.3)$$

in which the first integral is the outflow of material from the element and the second is the new term giving the compression of the porefluid. This equation may be rewritten(cf. Equation(8)of Appendix accounted for the analysis of Appendix A is considerably complicated and it has not been established whether a definition of the form used by Bishop may be used to give the appropriate effective stress which is conjugate to the skeleton strain.

2.8 The Use of Internal Variables in Plasticity Theory

In the preceding Section it was stated that the state of a material could be described by the history of its motion. The forces on the body (which in the case of a continuum are the stresses) are regarded as the response to changes in the state of the material. In general the response to any particular change in state will depend not only on the current state, but on the whole history of the material. Thus the stress will depend not only on the current strain but on the strain history as well: the stress is said to be a functional of the history of strain, rather than a function of strain.

An alternative to the functional approach is the use of "internal variables". The internal variables are not directly observable quantities, but are convenient fictions which in some way summaries the history of the material. A simple example of an internal. variable is the reconsolidation pressure for a clay. The whole of the previous consolidation history is summed up in a single previous maximum consolidation pressure, and the behavior of a soil element depends both on its current stress and on the reconsolidation pressure.

Another useful form of an internal variable is the plastic strain and in the following Chapters internal parameters will all be kinematic (strain like) parameters. In the simple example shown in Figure 2.4

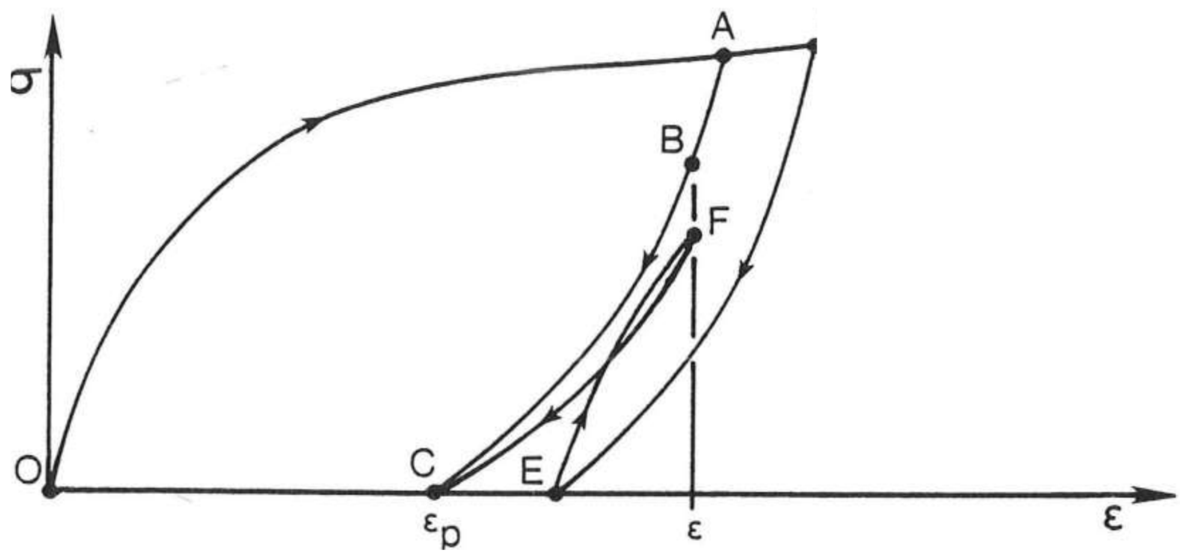


Figure 2.4 Unloading reloading curves and internal variables of an elastic-plastic material with non-linear work hardening the strain £ and the plastic strain £ p at the point B are sufficient to determine both the stress and the response to all subsequent changes in strain. The strain alone would not be sufficient.

A real material will more probably behave as shown in Figure 2.4(b), showing hysteresis on unloadin-g reloading curves. In this case a single plastic strain is inadequate for the complete description of the material. Consider in Figure 2.l(c) samples of a hypothetical material loaded along OABC and OADEFC (D has been chosen so that both samples finally unload to C). At B and F both are at the same strain and plastic strain (since both would end at C on unloading). The samples are, however at different stresses, so a single internal variable is insufficient to describe the material.

Although models using a single internal variable may describe some behaviour of the sort shown in Figure 2.l(b), this is only by requiring the hysteresis curves to take certain restricted forms. If a single internal variable is used the level of complexity of behaviour which can be described is essentially that shown in Figure 2.l(a). For each additional variable a further level of complexity may be added. In order to describe very complex loading histories an infinite number may be necessary in theory (with this leading back to the approach using functionals) but for all practical purposes a small number is adequat.e Figure 2.l(a) reproduces many of the features of behaviour of a typical soil (see Figure l.l(e) and (f)) and a single plastic strain tensor will allow this character of response to be described.

In the following Chapters attention will be restricted entirely to materials with a limited number of internal variables, resulting in distinct yield loci and elastic regions. The study does not include behaviour in which continuous curvature of unloading-reloading curves, and the consequent effects of hysteresis and accumulation of irreversible strains over many cycles are important. The models studied are for a small number of unload-reload cycles and not for the special behaviour after many (e.g. several thousand) cycles.

2.9 Theoretical Restrictions Imposed on Plasticity Theory

Elastic-plastic theories for the behaviour of soils may either be purely empirical, based on the curve fitting of tests on soils (e.g. the non-linear elastic theory of Duncan and Chang (1970)) or may be based on some more fundamental postulates which seek to explain the behaviour of the soil as well as to model it (e.g. the Cam-Clay flow rule, Schofield and Wroth (1968)). The two approaches are often combined, Certain self-evident conditions will not be dealt with in detail here. A model must for instance be complete and consistent in that it should detennine a response for any specified stress or strain path; models properly formulated in terms of continuum mechanics usually satisfy this criterion. A second condition that is usually imposed is that of con.tinu;i.ty : that infinitesimally differing applied paths result in infinitesimally differing responses. (This is not a fundamental law, but a condition imposed on the grounds of an intuitive approach to how materials are expected to behave.) The formulation of plasticity theory by Hill (1950) automatically satisfies continuity, but more elaborate models must be checked for this condition.

The laws of thermodynamics also impose certain limitations on the ways in which continuum theories may be expressed. The simplest example is that of elasticity; if a "strain energy function" does not exist, .e. the stresses cannot be obtained by the differentiation of a potential function (Equation 1.3.2), then it is possible to extract energy continuously from the material over many cycles and the first law of thermodynamics is violated. Various attempts have been made to apply thermodynamics to limit the possible forms of plastic behaviour, with Drucker's stability postulate (Drucker (1951)) being perhaps the best known limitation of this type. Drucker's postulate is not a statement of the second law of thermodynamics, although the two appear to be superficially similar; it is therefore regarded as a "quasi-thermodynamic" classification of materials. The postulate has been stated in a variety of equivalent ways, but represents the idea that if a material is in a given state of stress, and an external agency applies additional stresses, then "The work done by the external agency on the displacements it produces must be positive or zero" (Drucker (1959)). If the external agency applies 1..e . in the one-dimensional case in Figure 2.2(b) the area ABD must be positive. From this fact it can be shown that if the elastic properties do not depend on the plastic deformation, then (making also the conventional assumptions of plasticity theory) the yield locus 1.s convex and identical to the plastic potential for plastic strain. If the elastic behavior does depend on the plastic deformation (elasticplasticcoupling) these results are only slightly modified In this case careful attention must be paid to the precise definition of plastic strain.

An alternative restriction is the "Postulate of Plasticity", of 11'iushin (1961) which states that the work done durinB a cyc'le of strain must be positive or zero. In the one-dimensional case shown in Figure 2.2(c) the area ABE must be positive. This hypothesis is again superficially similar to a statement of the second law of thermodynamics, and has frequently been misinterpreted as such. It is less restrictive than Drucker's postulate, and allows for instance strain softening behaviour. In the absence of elastic-plastic coupling the convexity of the yield surface and normality of the plastic strain increment to the yield surface also follow from this postulate.

2.10 The Need for a Less Restrictive Approach

The main results of either Drucker's or Il'iushin's postulates are convexity of the yield locus and normality of the plastic strain increment. Although there is no strong experimental evidence against convexity, there is a major deviation from the normality condition for some materials, notably coarse granular materials (e .g. Poorooshasb et al. (1966)). The obvious microscopic non-homogeneityof such materials may seem to make a continuum approach to their modelling invalid, but all materials are non-homogeneouswhen viewed on a sufficiently small scale. It should be possible to produce a continuum theory which adequately models granular materials when a sufficiently large region is considered for a continuum approach to be applicabl.e The criteria of both Drucker and Il'iushin are over-restrictive; they are thought to be sufficient conditions to ensure that the second law of thermodynamics is obeyed, but are not necessary. Astrain cycle need not, for instance, be a cycle in the thermodynamic sense, but may involve changes to the internal structure of the material. For certain changes it may be possible for the material to release energy. The usefulness of the postulates lies not, however, in the mere compliance with thermodynamics, but in some important corollaries.

From Drucker's postulate it is possible to prove the uniqueness of incremental response for the stress and strain rates of an elasticplastic material under given changes in applied boundary forces and displacement,s(Drucker (1956)). The importance of a single solution existing for a given problem is obvious. Other corollaries are the upper and lower bound theorems which allow the exact solution for the ultimate loads on pe-rfectly plastic materials to be closely bracketed by simple methods. If a non-associatedflow rule is allowed the theorems are so much weakened as to render them virtually useless in many cases (Drucker (1954)).

The major motivation in seeking a new approach to theoretical restrictions on plasticity theory is to establish a formulation which satisfies the laws of thermodynamics, but also allows the nonassociated flow observed in soils. In the conventional approach plasticity theory is developed from a series of assumptions (e.g. the existence of a yield locus) and the limitations discussed above then applied to the theory.

In the following Chapter an alternative approach is made in that a formulation is derived starting from the laws of thermodynamics and therefore including them as an integral part. In its form for rate independent materials the new formulation gives rise to theories of the elastic-plastic type. The new approach can, however, acconnnodate nonassociated flow.

By founding the formulation on a few simple assumptions it is hoped that it will lead to theorems such as that of uniqueness of incremental response and modified forms of the bound theorems. As first steps in this direction some corollaries of the formulation are presented, e.g. the existence of a yield locus.

2.11 Comparison to alternate energy theory

The initial Cam-Clay approach is founded on a straightforward energy concept for clay movement. The clay's condition was thought to be determinedby its position in space. Through this comparison, the expression that is obtained could not define the substances, and in addition, such assumptions are made with the help of plastic theory. The result of this comparison states that there seems to be a null value of recoverable stress strain. In addition, integration yields a payout region under the condition of normalcy (Bradford et al. 2019). The magnitude of the yielding region is determined by the integrated characteristic, which is equal to maximum compressive stress. The experimentally found relationship that convergence segments are typically horizontal in spatial was subsequently used to relate locus enlargement to proportional plastic strain. To contrast the preceding characteristics to those utilized in the thermal-mechanical technique, the latter should be rewritten in measures of pressures instead of tensions. The fusion power, for example, is a transition wherein the temperatures take the form of thermodynamics as that of the predictor variables. The mechanism investigated is conservative as well as the volatility is indeterminate when elasticity stress intensity potentials are used, therefore the difference between providing and interior potential is superfluous (Johnston, and Sibly, 2018). Yet, in order to apply similar concepts to viscous dissipation systems, this difference must be established. Further, when the power characteristics employed in the traditional plastic and thermal-mechanical techniques are compared to Revised Cam-Clay, the two techniques may be harmonized as long as the potential glycogen in the deformation strategy is not matched with fusion power. Palmer uses an alternate energy storage concept that is quite close to the thermal-mechanical method.

2.12 Extension to large strain theory

The model given thus far is defined on the basis of characteristics that are only appropriate to pressure levels seen in the experiment. All of the preceding concepts are characterized by small labeling theory, whereby the densities assumption is appropriate (Koch et al. 2018). Because the particular capacity only fluctuates by a little amount under this assumption, no differentiation is recognized. This divergence is required in big labeling theory when densities variations are taken into consideration. The explanation that follows will be confined to the experiment, and the expansion to an even more generalized loading condition is not as simple as it does in the small deformations situation. Further, the Euler stresses, as well as the Hencky exponential strains, would be employed. A Lagrangian method employing Green's strains and indeed the Kirchoff primary standard is more suited for an application of the principles to universal pressures since none of these quantities is handy (Cuomo, 2019). Yet, in the words employed herein, the arithmetic of the deformation situation is easier. Thus, the algorithms utilized in big strain analysis were more complicated than those utilized in small deformations assessment. When the assessment is expanded to include generic stress networks, it introduces even more complications. As a result, it's important evaluating the relevance of the switch to huge research and determines if it's required for ordinary soil testing issues.

CHAPTER 3

MATERIALS AND METHODS

3.1 Thermo mechanical methods

The technique utilized in this Section would be that of "generalized" mechanics, which seems predicated on a straightforward expansion of conventional static kinetic theory as both quantum gravity to systems that should not be insignificantly slow, in other words, might have been in preliminary and exploratory (Hodo et al. 2019). The majority of the preceding derivation is unobjectionable; therefore, a review of the accuracy of the thermodynamics techniques is unnecessary. Unfortunately, the strategy relies on an eigen value concept (the conditional independence criterion), whose applicability has indeed been challenged. Figure 3.1: Thermo mechanical principle shows The idea will not be defended; but, because it is a bigger argument than that of the basic lesson of mechanics, it can be seen as a categorization of a limited category of materials instead of natural law in whatsoever event. Thermo chemical acceptable substances are those that meet the stationary criteria. The intrinsic variables do not have to be symmetric higher-order data structures, but comparing them to the stresses makes it easier to think about the circumstances when they are. Intrinsic variables in traditional elastic-plastic concepts include loading condition values, such as "plastic strain" (Surana et al. 2019). The structures constructed can be considered as a documentation of the object's distortion experience

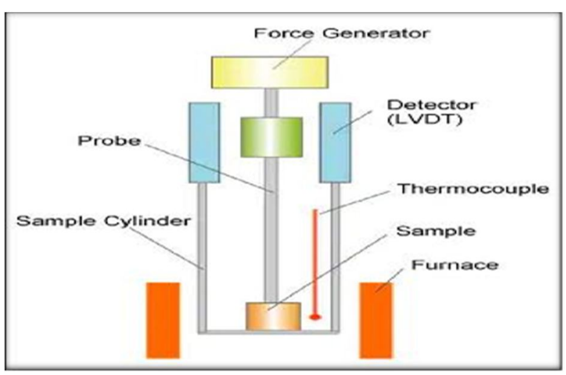


Figure 3.1: Thermo mechanical principle

(Source: https://www.hitachi-hightech/global/products/science/tech/ana/thermal/descriptions)

3.2 Ziegler's thermo mechanical formulation

The preceding chapters' thermal-mechanical technique to plasticity theory offers a potential tool for describing soil characteristics. It has accomplished its main goal of establishing a terminology that ensures thermal acceptability while permitting the characterization of "non-associated" thermoplastic movement. Although the thorough advancement of thermal-mechanical techniques in computational fluid dynamics is not examined herein, a quick remark on the concepts' reliability might well be provided (Masi et al. 2021). At the very minimum, the techniques given in this research reflect a constrained class of compounds, one that is considerably larger than the narrow focus by Il'iushin and Drucker's postulates, as well as the vital issue that seems to be whether grounds resemble this class appropriately. As a consequence, the resultant model contains an adjustable height, yielding a variety of workable alternatives instead of a perfect response for too many issues. This process model, wherein the beginning and border circumstances are more important in generating the future response, differs from the one utilized throughout this whole research, Figure 3.2: Graphical representation of Thermomechanical modeling shows whereby the fundamental connections give a comprehensive framework for deciding the reaction (Trinh et al. 2019). To determine if the approximations produced by the adoption of an eigenvalue concept are warranted, much more research is necessary.

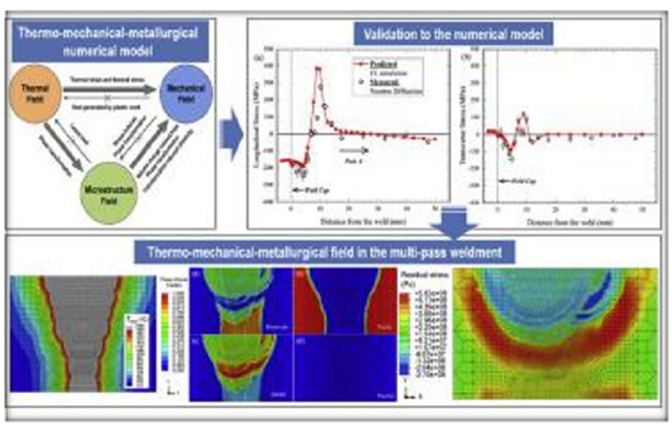


Figure 3.2: Graphical representation of Thermomechanical modeling (Source:

(Source: https://ars.els-cdn/content/image/1-s2.0-S0143974X1931449X-gr4.jpg)

3.3 Implications of Ziegler's formulation for plastic theory

The idea of a yielding point, containing a totally elastic zone, and that of a flowing rule underpins traditional plastic research. The presence of a yielding region in space changes for viscous dissipation rate invariant materials with a fixed amount of input parameters is demonstrated in the following study. The normalization concept links the network protocol to the yielding signifier: while Ziegler (1977) claims that the normalization concept emerges immediately from the orthogonality requirement, this will only be valid for "cohesive" substances wherein the decomposition is independent of the strained condition (Banabic et al. 2020). Although the functional structure of the progressive resolution has still not been determined, this has been experimentally shown that functionalities of the aforementioned form may be adjusted to provide simulations that still include a yielding region for plasticity deformation and then also produce a specified routing protocol.

3.4 Derivation of elastic-plastic models

The application of free power functions to determine elastic properties is well-known. Instead of adopting the precise formalism stated, Ziegler (1977) analyses rigor and is capable of adapting. The calculation demonstrates how a yielding region, flowing rule, compatibility matrices, and the summing of separate elastoplastic strain elements may also be used to generate an elastic-plastic substance from Ziegler's formulations. The assumptions in the traditional and thermal properties models are fundamentally different, despite the fact that the ultimate material behavior follows the same trend (Bryant, and Sun, 2019). This paradigm will have the same elastic characteristics as the cohesion version, and there is no plastics volumes tension during deformations, with the plasticity strain elements in the very same ratios as the pressure proportional limit elements. As a result, there is a lot of scientific proof that this happens in granular soils. The impacts of thermoplastic dilatation, which happens in actual soils, weren't included in the preceding paradigm, although they may be added; this has been proven, meanwhile, that this approach can accept non-associated phenomena.

3.5 Effective stress model for soils

The theories in the prior Chapter have all been single-stage simulations, wherein the tension is simply calculated as the thermodynamics pressure conjugated to the tension. The resulting stress will become exceptionally helpful if the equations are implemented to a two-phase ground and the tension is understood as the skeletal strain (Zhou et al. 2020). The kinematics displaying the pores fluid has no implications in the perpetual energy and disintegration formulas. The pore fluids are equal to suction, and therefore there are no pores pressures or porous pressure differences. Equations can be changed to include a stiffer pour liquid in the elasticity approximation. The utilized framework includes the stress concept, which states that the displacement of the foundation soil is proportional to the Terzaghi applied stress rather than the pressure distribution. This is attributable to the fact that now the words for strain and pores liquid compression are not coupled. It's unusual to think of the pore's pressure difference as a force in almost the same manner that the applied stress or pressure gradients are; yet, this conclusion occurs merely from the kinematics selected variables to express the object's state. This is the same as the traditional thermodynamics concept of the thermal gradient as the pressure related to the thermal expansion.

3.6 The choice of materials for experimental testing

The tests provided in the following Segments are designed to investigate the underlying behaviors of the most basic granular soils (Borja et al. 2020). Because the contact among granules in the sand is believed to be solely mechanically instead of electrical and chemical, as it is in mud, dunes should be close to a perfect crushed stone. Because most grains experienced in structural engineering are thick, all experiments were conducted on a single densely packed soil. The influence of the variation in compression load on the penetrating of the granules into the specimen membranes is a significant contributing factor to the recorded permanent deformation of the specimen in tests including variations in compression force.

3.7 Experimental testing of plastic theory

The testing described previously aren't ones that would be used in ordinary studies to assess the characteristics of individual soils, but rather those that are being used to further thoroughly evaluate if plastic hypotheses are a suitable model that describes topsoil. After a scientific theory's validity has been proved, considerably simplified tests may be used to determine the required parameters (Banaszkiewicz, and Dudda, 2018). Investigations wherein the ground is supplied asymptotic, emptied, and reloaded, and the type of the reaction noted, are perhaps the easiest demonstrations of plasticity theory. Consolidate or shearing tests are examples of such testing.

3.8 Stress probe and stress cycle tests

All of the experiments listed above entail quite substantial stress fluctuations, which can be used to evaluate some aspects of theoretical methods. Figure 3.3: Orientation of stress cycles shows Another option is to look at an object's reaction at a specific stress position in detail, infer the complete progressive stress-strain dynamics at that moment, and contrast it to plastic theory. A sequence of pressure probing experiments on usually cemented clay was used in this inquiry. Stress probing tests have one major drawback: they need the fabrication of numerous similar samples. The intrinsic heterogeneity between samples adds a layer of ambiguity to the data interpretations (Bychkov et al. 2018). If a study of the effects of pressure and anxiety experience is to be conducted, a significant number of observations are also necessary.

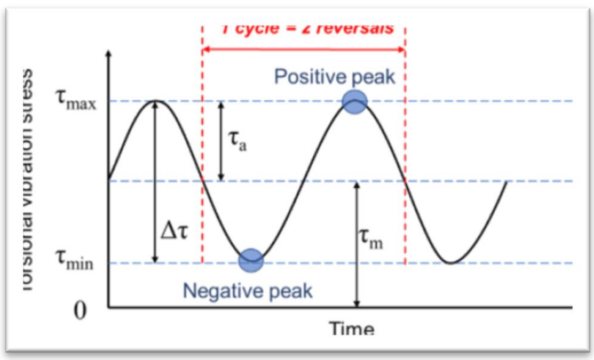


Figure 3.3: Orientation of stress cycle

(Source: https://www.researchgate.net/figure/Comparison-between-stress-cycle-and-reversal_fig2_343695565)

3.9 Effect of stress

Since the performance of the sand changes depending on the tensile stress, pressure cycling experiments were performed under triaxial compressive at a range of strain sites. Because the general strain theory and tension are regarded to become the two most significant impacts, a grid of 9 stress sites at 3 tensions and multiple stress proportions was selected for the study. Stress routes are first divided into distinct sorts to explore the impacts of stress and coping. The most basic scenario is when both the intensity and proportion of stress are growing and reaching their extremely high levels (Golchin et al. 2019). As a result, an apparatus competent for concurrently adjusting cell pressure as well as axial force in an experiment is needed to undertake the stressing cycle testing. The following Chapter describes a machine that uses automated controlling and data logging technology.

3.10 Triaxial apparatus for stress cycle tests

A Leonor deformation cell is fitted on a redesigned bottom plate in a Wykeham Farrance 1 tonne loaded seat to make the axial loads machinery. To reduce the longitudinal frictional resistance on the loaded drive, the cell has a spinning top bearing. A twin arrangement of mercurial pots operating on parallel rails provides cell pressure. To mitigate creep as well as for settling impacts, the maximum load was saturated to about double full-fledged capacity for two weeks before calibrating and cycling many thousand times in an endurance apparatus to a comparable load (Houlsby, 2019). Figure 3.4: Schematic diagram of cyclic triaxial test apparatus shows The largest departure from normality of responses was found in tests utilizing accumulated depreciation loading. The PDP-SE performs mathematical simulations utilizing three-word precision floating-point computation. The measurements were made by striking on a fast speed sticky tape punches at frequencies that could be defined on the controlling tapes for the experiment, in addition to using the transducers measurements, which are predictive control even during the experiment, to compute the present condition of the specimen.

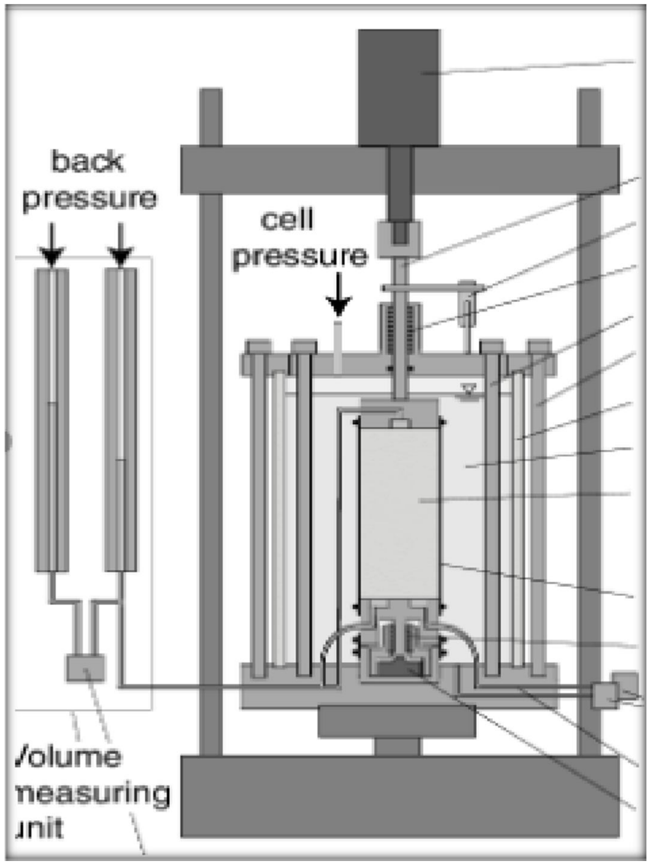


Figure 3.4: Schematic diagram of cyclic triaxial test apparatus

(Source: https://www.researchgate.net/figure/Scheme-of-cyclic-triaxial-test-device_fig1_222418835)

3.11 A triaxial testing control program

Within the limits of the 4 k of 12bit terms of storage device, the control measure for the PDP-BE is designed to give the greatest adaptability and simplicity of use. The usage of these methods, especially the arbitrary point mathematics, made the rest of the program much easier. The primary control software is being used to capture the following details and measure cylinder measurements for the pores fluids, which are input through the keyboards, and to retrieve the objective criteria for the detectors at the beginning of an experiment (Leane et al. 2018). This procedure is done manually, with the application prompting users for the information they need.

As a result, before being used in the testing, the sands were sieved and measured in an air-dry condition, then soaked with the desired freshwater, heated for fifteen minutes, and cooled. A draining aperture in the middle of the bottom platen is sealed with a 15 mm diameter sintering steel disk. A thin coating of silicone lubricant and a 0.35 run thickness vulcanized rubber membranes cover the rest of the polished metal base steel plate. The compressive forces estimated for the specimens were modified to account for the loaded ram's deformation, transmembrane elasticity, and barrier penetrating calculations.

In this Chapter a new formalism for the expression of plasticity theories is given; using a method of description of materials based on thermodynamics. Some implications for rate independent materials are studied; and in particular the existence of a yield locus is examined Specific examples of some elastic plastic models are given, and the inclusion of the effects of a pore fluid are discussed with reference to the principle of effective stress.

3.12 Introduction to Thermomechanical Methods

The method of analysis used in this Chapter is based on a simple extension of classical equilibrium thermodynamics as a field theory to processes which need not be infinitesimally slow, i.e. may be in nonequilibrium, The approach used is that of the so-called "generalized" thermodynamics. Most of the following derivation is uncontroversial and a discussion of the rigour of the thermodynamic methods would be inappropriate here. The method used employs, however, an extremum principle (the orthogonality condition) the validity of which has been questioned. A defense of the principle will not be given; but it may be noted that since it represents a stronger statement than the second law of thermodynamics it may in any case be regarded as a classification of a restricted set of materials rather than a law of nature. Those materials which comply with the orthogonality condition will be thermodynamically admissible.

The first assumption of the thermomechanical method is that the state of a material (in a thermodynamic sense) may be entirely described by a suitable number of kinematic parameters and temperature Although element, the view is taken here that for all practical purposes a limited number may be used discussed in the preceding Chapter.) divided into two sets: The kinematic parameters are The internal parameters need not take the form of synnnetric second order tensors, but by comparison with the strains it is convenient to consider the cases where they do take this form. In conventional elastic-plastic theories the internal parameters are strain-like quantities, for instance the "plastic strain" The internal parameters may be thought of as representing a record of the history of deformation of the material, and some examples of this role of the internal parameters are given later.

Note that the stresses are not included as parameters describing the state of the material, but are regarded as a response to changes in strain; this may be contrasted with the notion that stress 1.s an independently observable property whereas strain is merely a quantity measured from an arbitrary reference state. The method has certain advantages, however, in that it avoids any ambiguity in the consideration of both hardening and softening behaviour (both of which are of engineering importance). Types of behaviour in which certain strain paths are not possible (either locking or sub-critical softening) are less easy to accommodate, but seem of little practical importance. It is also found that although strain 1.s measured from some arbitrary state the mechanical behaviour of a material may still beuch a way that it is independent of the reference state; the problem that strain is not an independently observable property may therefore be resolved.

3.13 Ziegler's Thermomechanical Formulation

The restrictions of hydromechanics on material behavior are now developed. The analysis follows that of Ziegler (1977) and is at first developed for a system and then later specialized for a continuum. It is hypothesized that a state of a system may be entirely described by a set of independent kinematic parameters and the temperature Force corresponding to the kinematic parameters are defined such that the work done on the system is given by:

$$dW = A_k da_k \tag{3.2.1}$$

If dQ is the heat supply then the First Law of Thermodynamics states that there is a property (a function of the state) called the internal energy (U: U(ak,8)) such that:

dU = dW + dQ

Expanding dU - SdS in terms of partial derivatives with respect

to 8 and and considering a process of pure heating only (i.e. dW = d¾ = 0) it follows that for the second equation to be valid for both heating and cooli

$$A_k da_k \left(\frac{\partial U}{\partial a_k} - \theta \frac{\partial S}{\partial a_k}\right) da_k + \theta (dS)^{(i)}$$

The expression 6(dS)(i) therefore has the form of a work term and, ifit is assumed that the irreversible entropy changes depend linearly on the changes of state, may bewritten dissipative forces defined by:

$$A_k - \frac{\partial U}{\partial a_k} + \theta \frac{\partial S}{\partial a_k} \qquad (3.2.11)$$

Similarly $$A_k = A_k^{(d)} + A_k^{(q)} \qquad (3.2.12)$$

Derivation of Specific Elastic-Plastic Models from Hydromechanics

The use of a free energy function to derive elastic behavior is well established (see for example Love(1927))and anisotropic elastic material can for instance be described:

$$\frac{\lambda}{2} \varepsilon_{ii}\varepsilon_{jj} + \mu\varepsilon_{ij}\varepsilon_{ij}$$

(3.4.1)

where A and μ are Lame's constant’s gives:

$$\lambda\varepsilon_{kk}\delta_{ij} + 2\mu\varepsilon_{ij}$$

Ziegler (1977) studies the rigid-cohesive and elastic-cohesive materials, but rather than following the strict formalism outlined inSection 3.2 he presents the familiar results of additive elastic and plastic·strains, a yield locus and an associated flow rule. Although he links these ideas with those outlined above, he does not give a formal derivation of the behavior of an elastic-plastic material from the two functions w and The appropriate functions for an isotropic elastic- perfectly plastic material with a von Mises yield surface and associated flow rule are:

$$(\frac{\lambda}{2}+\frac{\mu}{3}\rho\psi\ \varepsilon_{jj} + \mu(\varepsilon'_{ij}-\varepsilon'^{(p)}_{ij})(\varepsilon'_{ij}-\varepsilon'^{(p)}_{ij})$$

$$\sqrt{2}\ c(\dot{\varepsilon}^{(p)}_{ij}\,\dot{\varepsilon}^{(p)}_{ij})^{\frac{1}{2}}$$

is an internal variable which will be seen to play the role of a conventional plastic strain and a dash notation indicate the deviator of a tensor. Differentiating as in Equations (3.3.14) and(3.3.15)gives:

$$(\lambda+\frac{2\mu}{3})\varepsilon_{kk}\delta_{ij} + 2\mu(\varepsilon'_{ij}-\varepsilon'^{(p)}_{ij}) \qquad (3.4.7)$$

$$-2\mu(\varepsilon'_{ij}-\varepsilon'^{(p)}_{ij}) + \sqrt{2}\ c\dot{\varepsilon}^{(p)}_{ij}/(\dot{\varepsilon}^{(p)}_{k\ell}\,\dot{\varepsilon}^{(p)}_{k\ell})^{\frac{1}{2}} \qquad 3.4.7)$$

The first of these equations yields the value of the mean stress:

$$(\lambda + \frac{2\mu}{3})\,\varepsilon_{kk} \qquad (3.4.8)$$

and combination of the equations then gives:

$$\sqrt{2}\ c\dot{\varepsilon}^{(p)}_{ij}/(\dot{\varepsilon}^{(p)}_{k\ell}\,\dot{\varepsilon}^{(p)}_{k\ell})^{\frac{1}{2}} \qquad (3.4.9)$$

which confirms direct lay the flow rule in which the plastic strain components are proportional to the components of the stress deviator. Equation(3.4.9) also gives the relationship between the stresses which is the von Mises yield condition which must be satisfied by the stresses if El.J). is non-zero. Equation (3.4.9) also confirms the fact that E) = 0, i.e. there is no plastic volumetric strain in this model

$$\lambda\dot{\varepsilon}_{kk}\delta_{ij} + 2\mu\dot{\varepsilon}_{ij}$$

so that the material behaves elastically under these conditions

$$(\lambda + \frac{2}{3}\mu)\dot{\varepsilon}_{kk}\delta_{ij} + 2\mu(\dot{\varepsilon}'_{ij}-\dot{\varepsilon}'^{(p)}_{ij})$$

which may be re-arrangedto give Noting that t! p)= .£ (.. p) this confirms that the change inthe l. J l. J internal variable £) simply represents an additional term to the strain deviator when dissipation occurs, i.e. that to the conventional plastic strain. corresponds

The above derivation shows how an elastic-plastic material may be derived from Ziegler's formulation without introducing in addition the conventional hypotheses of a yield locus, flow rule, compliance matrix and the summation of independent elastic and plastic strain components.It is emphasised that although the final material behaviour derived is identical, the hypotheses in the conventional and thermomechanical formulations are completely different.

As was stated in the last Chapter, one of the main motivations 1.n examining a new approach to plasticity theory is the derivation of plasticity models with non-associated flow rules. Both the stability criterion of Drucker (1951) and the postulate of plasticity of Il'iushin(1961) lead to the normality condition; but it was shown in the last Section that the orthogonality condition leads to normality only in a limited stress space for arigid- plasticmaterial. An example of an elastic-plastic material with a non-associated flow rule will now be given. Consider for instance the following functions:

$$\rho\psi = \left(\frac{\lambda}{2}+\frac{\mu}{3}\right)\varepsilon_{ii}\varepsilon_{jj} + 2\mu(\varepsilon'_{ij}-\varepsilon'^{(p)}_{ij})(\varepsilon'_{ij}-\varepsilon'^{(p)}_{ij}) \qquad (3.4.14)$$

$$\rho\phi = \frac{2}{3}M\left(\lambda + \frac{2\mu}{3}\right)\varepsilon_{kk}\left(\dot{\varepsilon}^{(p)}_{ij}\dot{\varepsilon}^{(p)}_{ij}\right)^{\frac{1}{2}} \qquad (3.4.15)$$

in which the cohesion has been replaced by a term proportional to the mean normal stress. The elastic properties of this model are exactly as for the cohesive one, and during plastic deformation there 1.s againno plastic volumetric strain, with the plastic strain components beingin the same proportions as the components of the stress deviator.

$$\frac{2M^2}{27}\sigma_{ii}\sigma_{jj} \qquad (3.4.16)$$

which is a conical locus in principal stress space sometimes termed the'extended von Mises' locus. The constant M is related to a friction angle, and is equivalent to the same parameter used in critical state soil mechanics. Although there is still association of the yield locusand flow rule in the octahedral plane the plastic strain increment is no longer normal to the yield locus in the isotropic-deviatoric plane. There is ample experimental evidence that such behavior occurs in granular materials. The above model does not include the effects of plastic dilation, which occurs in real soils, but this may also be included; it has been shown, however, that this formulation can accommodate non-associated behavior.

3.14 Effective Stress Models for Soils

The models described in the preceding Section were all single-phase models, in which the stress is simply derived as the thermodynamicforce conjugate to the strain. If the models are

applied to a two-phase soil and the strain interpreted as the skeleton strain, then as shown in Section 2.1 the derived stress will be the effective stress. No terms are present in the free energy and dissipation expressions containing the kinematic parameters describing the pore fluid: and All differentials with respect to these quantities are therefore zero, and so their conjugate forces nu and u'.are zero.

There is no pore pressure or pore pressure gradient: the pore fluid isequivalent a vacuum. A pore fluid of stiffness K(w) may be introduced to the elasticmodel by modifying Equation . The above model obeys the principle of effective stress: the deformation of the soil skeleton is related only to the Terzaghi effective stress and not to the pore pressure. This is due t·othe factt that there is no coupling of terms between the strai .

and the pore fluid compression v(w) in Equation (3.5.1). It was suggested inAppendix A that the principle of effective stress was closely related to an uncoupling of these terms. This may now be clarified by differentiating Equation (3.5.1) for a non-dissipative material, and equating this change of free energy to the work input: where a. represents effective stress (not the deviator of stress) l.J and it has been assumed that pore pressure gradients do not exist. The proof of Section 2.1 shows that there is no coupling between theeffective stress/ skeleton strain and pore pressure/ pore fluid compression terms on the left- hand side of Equation (3.5.3). It1.s only because the free energy has been chosen so that there is similarlyno coupling on the right band side that this model exhibits the principle of effective stress: the skeleton strains depend only onthe Terzaghistress.

This analysis may be extended to an elastic soil with a compressible viscous pore fluid by including a dissipation term inthe artificialseepage velocit:y which simply represents Darcy's law. Note that the factor of 1/2appears in Equation (3.5.5) because the dissipation function is of second order in the velocity w. and so V defined by Equation (3.2.18) is not unity. It is unfamiliar to consider the pore pressure gradientderived as a force in the same way as the effective stress or pore pressure; this result arises, however, simply from the choice of the kinematic variables chosen to represent the state of the material It represents exactly idea as the conventional thermodynamic idea of the temperature gradient being the force corresponding to the heat flow in terms in Equation (3.5.1) would result in a model which did not obey the principle of effective stress, certain forms of coupling between the skeleton and pore fluid behavior are possible without violating the principle. For instance in Equation (3.5,.4) the permeability k could be a function of the skeleton volumetric strain, and there is evidence that this is indeedthe case. In this case the pore fluid ,behavior would depend on the state of the soil skeletonbutsince the dissipation function wou ld still not contain terms in the rate of strain the effective stress expression would be unaltered: the skeleton strains will still dependsolely on the effective stress.

A model in which the principle of effective stress is not obeyed could also be expressed within the thermodynamic framework For instance, if the free energy expression included terms involving products between theskeleton strain and pore fluid compressione.g. of Equation (3.5 .7) means that the effective stress (as defined by Terzaghi) can be altered by a change in pore fluid strain with no accompanying skeleton strain. In conventional terms, the principle of effective stress is notobeyed. The fact that models not exhibiting the effective stress principleinvolvese somewhat unlikely product terms may offer some explanation as to why soils are observed as obeying theprinciple.

The above examples only include cases where the skeleton itself behaves elastically. If dissipation occurs in the skeleton, then the dissipation function may contain both first and second-order terms in velocities; for instance in the case of an extended von Mises materialEquation(3.4.15) would be modified to:

3.15 Clay Models

The "Cam-Clay" theoretical model for soil behavior was describedby Schofield and Wroth (1968). The model is expressed in the theoryof plasticity and is based on simple hypotheses for the storage and dissipation of energy, the concept of"stabilityas defined by Drucker (1959), and an empirical relation for the pressure-specific volume behavior of soft clay. The model successfully combines the consolidation and shearing bbehaviorof clays within a single framework, but it is not entirely satisfactory on all its predictions.One notable defect is the prediction of excessively large shear strains for consolidation at small stress ratios, with this effect being due to the pointed shape of the yield locu·s. This effect was eliminated by the introduction of a.slightly different hypothesis for the dissipation of energy by Roscoe and Burland (1968-), resultingin the "Modified Cam-Clay" rodel.

Although Modified Cam-Clay too is not completely satisfactory, it successfully models many of the features of the behavior of softclays. The predictions for clays with an oover consolidationratio greater than about two are less good, with strength usually over• predicted; and too stiff a response on load reversal is predicted for most cases. Modified Cam-Clay in its original form involved no elastic shear strain; the resulting underprediction of shear strains at low-stress ratios is in part improved by including a constant elastic shear modulus, and this has frequently been done in numericalcompu tations using the model.

Although some comparisons with experimental data will be made,a systematic presentation of evidence to justify the applicability ofthe Modified Cam-Claymodel to soils or to assess the accuracy of its predictions will not be present.d The successful use of the model has beendemonstrated.elsewhere(e.g., the useof avery similar model in the prediction of the behaviorof anembankment by Wroth(1977)). In this chapter, it will be demonstratede. Dhowthe model may be derived froma thermomechanical basis,and in the next Chapter some modifications to the model.will be made within the same framework.

3.16 Derivation of the Modified Cam-Clay Model from Hydromechanics

In the spirit of the thermomechanical approach, the behavior of the model will not be stated.at this stage, but the two functions required (the specific free energy and specific dissipation) will first be introduced. The behavior will then be derived from these functions and the link.With conventional plasticity theory noted.

This approach should be contrasted with the conventional technique in which the final behavior of the model (e.g. the shape of the yield locus)isspecified from the outset.t For a simple model there is no advantage in the new approach, which in fact apberather less direct. However, in more complex cases the new methodoffers certain advantages, which will be illustrated by considering some simple modifications to the two governing functions.

3.17 Comparisons with Alternative Energy Theories for Clays

The original Cam-Clay model is based on a simple energy theory for the behavior of alay. The state of the clay was considered asdefined by its location in (p'a,V) space, and the ststore d and dissipated ene gy per unit volume (W5 and W0) were given by:

These two expressions do not completely define the material, andso additional assumptions from conventional plasticity theory were also made. The first assumption·was that the total strain was made upof additive elastic and plastic strains, the second that the change in stored energy Would beequated to the quantity (p 'I've+qee:). This leads directly to the result that there is zero recoverable shearstrain and that thebulk modulus is equal top'V/K.The dissipated energy is then equal to the remaining quantity (p'v+qe:), and when substituted into Equation(4.3.2) this gives ap flow rule. The assumption of normality allows integration to give yield locus. The value of the integration constant is equivalent to aonsolidation pressure, andgoverns the size of the yield locus. The expansion of the locus was then linked to the volumetric plasticstrain by the empirically observed relation that consolidation lines areapproximately straight in (in px, V) space. This thenprovides the hardening law.

The final assumption in the model, which is not usually statedexplicitly, is that £ > 0 for q > 0 and £ < 0 for q < 0.

Because of the modulus sign in Equation (4.3.2) two families of yieldloci are given according to the sign of e: The final assumption isrequired to select the appropriate yield locus and results in the characteristic bullet shape symmetrical about the p'-axis.

The only change introduced in Modified Cam-Clay was to alterEquation(4.3.2) to

$$W_d = p' (\dot{v}_p^2 + M^2 \dot{\varepsilon}^2)^{\frac{1}{2}} \qquad (4.3.3)$$

with the result that the yield locus becomes an ellipse, and the final assumption is no longer required. To compare the above functions with those used in the thermomechanical method, the latter will first be re-stated in terms of stresses rather than strains. Substitution of the expressions for the stresses and p' into Eupations (4.2.1) and (4.2.2) yields the free energy and dissipation per unit volume as: The first term of Equation (4.3.4) is directly comparable to Equation (4.3.1), the difference simply resulting in a bulk modulus of p'lK* instead of pV/K The second term represents the additional energy stored on shearing, and resu1ts in a constant.t elastic shear modulus G The third term is of a different characte, and represents additional free energy as a result of plastic compression.

The presence of the last term is a result of the different definitions of "stored energy". In the thermomechanical formulation Equation (4.3.4) gives the *free energy,* whereas Equation (4.3.1) gives a more loosely defined recoverable power. The comparison of Equation (4.3.3) and Equation (4.3.5) is also linked to the definitions for the energy expressions. Equation (4.3.5) gives the thermomechanical dissipation as proportional to reconsolidation pressure, and

3.18 Extension of the Modified Cam-Clay Model to the General Stress States

The model so far described is expressed in terms of parameters which apply only to the stress states which occur in the triaxial test. Jt may beItxtended to general stress states by replacing the functions of v, e: ' , and e :by functions of the invariants of the strain and plastic strain tensors. It is convenient to define a quantity, equivalent to the conventional elastic shear strain:

$$\varepsilon_{ij}^{(e)} = \varepsilon_{ij} - \varepsilon_{ij}^{(p)} \qquad (4.4.1)$$

Where will be used as the internal variable?

$$= \frac{\partial x(\varepsilon_{ij}, \varepsilon_{ij}^{(p)})}{\partial \varepsilon} \qquad \frac{\partial x(\varepsilon_{ij}^{(e)}, \varepsilon_{ij}^{(p)})}{} \qquad (4.4.2)$$

$$\frac{\partial x(\varepsilon_{ij}^{(e)}, \varepsilon_{ij}^{(p)})}{\partial \varepsilon_{ij}^{(p)}} \qquad \frac{\partial x(\varepsilon_{ij}^{(e)}, \varepsilon_{ij}^{(p)})}{\partial \varepsilon_{ij}^{(e)}} \qquad (4.4.3)$$

The free energy and dissipation functions for the Modified Cam-Clay model may now be written in terms of invariants as:

l/1 = [pK*exp(E:(e) /K*) + 2GE:' (e)

(1) The contours are illustrated in Figure 3.5 together with the yield locus which is unchanged from the simple model. Note that maximum stress

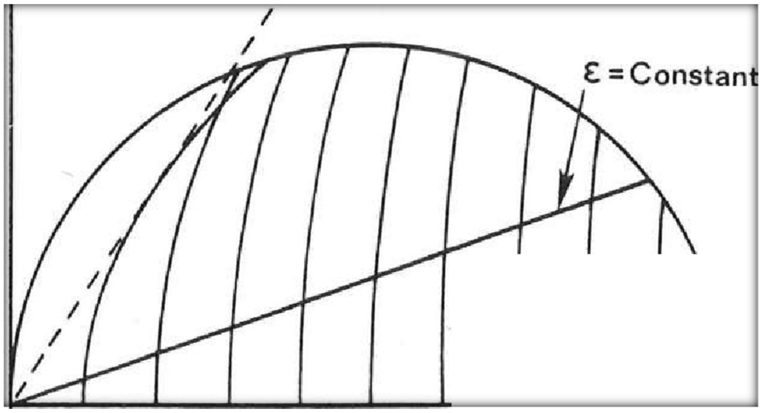


Figure 3.5 Contours of shear and volumetric strain for elastic behavior of the material with shear modulus proportionalthe to pressure

The ratio which can be achieved is $(\frac{3\alpha\kappa^*}{2})^{\frac{1}{2}}$ and that increased shearing then

reduces the stress ratio. Linked to this is the fact that the curvature of the undrained stress paths causes them to cross. These secondary effects, caused by the expected interaction between shear and volumetric behavior, are thought to be unrealistic. Figure 5.7 shows the calculations for the same family of undrained tests as in Figure 5.4,

3.19Elastic-Plastic Coupling

Although the analysis of the previous section could have been achieved using only the simpler thermodynamic concept of an elastic potential, the following results can only be obtained by making use of the new formulation. An alternative to the use of a shear modulus

proportional to pressure is to make the modulus proportional to reconsolidation pressure. This has the advantage of restoring the non-depersonalization of all behavior at a given over consolidation ratio concerning pressure, which is central to both Critical State Soil Mechanics and also the SHANSEP analysis and design procedure (Ladd and Foot (1974)). This scaling does not hold completely for a material with constant shear modulus, and, as shown in the last section, can only be introduced by a pressure-dependent shear modulus at the expense of unrealistic side effects.

The model with shear modulus dependent on pre-consolidation pressure represents an example of elastic-plastic coupling, in which the elastic properties are altered during plastic deformation. Thus the effect of a shear test on a lightly over consolidated sample would show the pattern shown in Figure 3.6 Loading and unloading of material with elastic-plastic coupling on load reversal.

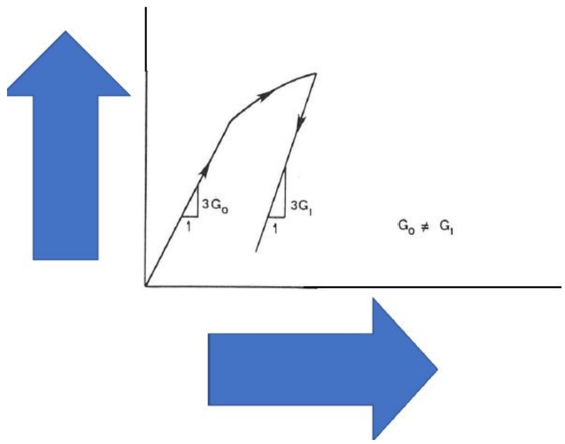


Figure 3.6 Loading and unloading of material with elastic-plastic coupling

Although the analysis of the previous section could have been achieved using only the simpler thermodynamic concept of an elastic potential, the following results can only be obtained by making use of the new formulation. An alternative to the use of a shear modulus proportional to pressure is to make the modulus proportional to reconsolidation pressure. This has the advantage of restoring the non-depersonalization of all behavior at a given over consolidation ratio concerning pressure, which is central to both Critical State Soil Mechanics and also the SHANSEP analysis and design procedure (Ladd and Foot (1974)). This scaling does not hold completely for a material with constant shear modulus, and, as shown in the last section, can only be introduced by a pressure-dependent shear modulus at the expense of unrealistic side effects. second is the development of plastic anisotropy and its dependence on stress history.

3.20 Generalisation of Yield Loci in the Octahedral Plane

The models which have been described in the previous Chapters have all been based on data derived from the triaxial test, and so refer only to the limited stress conditions which may be attained in this test. In Section 4.4 a generalization of Modified Cam-Clay to fully general stress states was given, with this simply being derived by substituting appropriate invariant functions of the strains and internal variables in the isotropic and deviatoric terms in the original triaxial model. This generalization is not, however, unique: several different general models could all reduce to the same model in the triaxial plane. In this Section, some alternativegeneralizationss will be discussed.

One way of representing the generalization of a plasticity model to states other than those in the triaxial test is by the s·hape of a section of the yield locus in principal stress space (o1,o 2,o 3) at constant mean pressure pm

The shape is usually shown projected onto the "octahedral plane", which is the plane in principal stress space perpendicular to the space diagonal cr1 = cr2 = cr3. In this plane, the three principal stress axes are seen as 120° apart (Figure 6.1). The generalization used in Section 3.7 gives a circular section, as does the Von Mises yield locus. The failure points of soils tested at intermediate values of between triaxial compression and extension show a variation that approximates more closely to the Mohr-Coulomb criterion (an irregular hexagon in the octahedral plane) than the circular section (see e.g., Pearce.

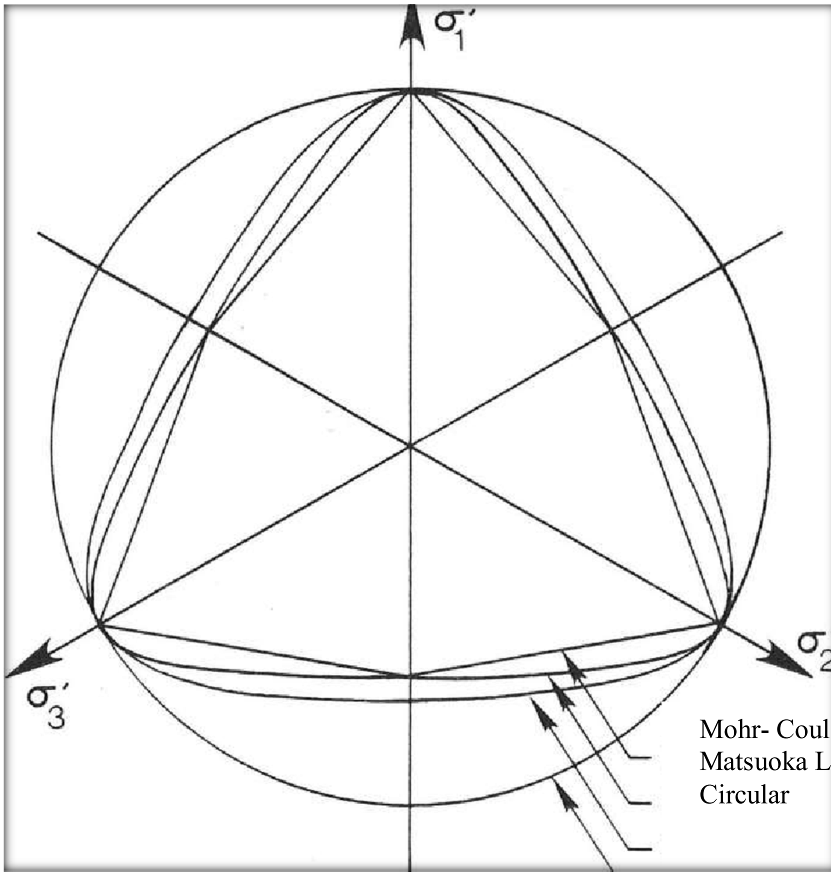


Figure 3.7 Generalization of failure criteria in the octahedral plane for' = 40° in triaxial compression

A curvilinear triangle, approximating the Mohr-Coulomb hexagon, but passing outside it at intermediate CJ'2values if chosen to coincide at triaxial compression would seem to offer the best overall approximation.

It may be expected that the shape of the yield locus will be similar to that of the failure envelope, and so the alternative shapes will first be introduced as failure criteria. The envelope of failure points for a cohesionless granula on an approximately conical or pyramidal surface in principal stress space, the section of the cone specifying the octahedral generalisation. generalization" Vor material plotn Mises criterion for instance gives a circular cone and may be expressed in terms. of stress invariants as:

$$0(I_2)' o(1) = \text{Constant} \qquad (6.1.1)$$

Many authors have suggested different shapes for such a curve, but the simplest and potentially most useful are those due by Lade and Duncan (1975) and Matsuoka and Nakai (1974). Lade's criterion, which he has also used as a yield surface, may be expressed as the function:

$$cr(J)\, o(I)^{,3} = \quad \text{Constant} \qquad (6.1.2)$$

For low equivalent friction angles, the section approximates a circle, and at very high angles it approaches an equilateral triangle. The curve for a given friction angle in triaxial compression passes slightly outside the Mohr-Coulombhexagon in triaxial extension (see Figure 6.1).

The Matsuoka generalization is based on reasoning about the significance of the "Spatially Mobilised Plane", a concept which is not discussed further here. It results in a failure surface of the form:

$$\sigma'_{(3)} / (\sigma'_{(1)} \sigma'_{(2)}) = \text{Constant} \qquad (6.1.3)$$

which is found to bear the same mathematical relationship to the Mohr-Coulombcohesionless criterion as the Von Mises surface to the Tresca; i.e. it may be represented as a curve passing through the apices of the irregular Mohr-Coulomb hexagon (see Figure 6.1).

As a brief excursion from the main theme of this Section, this observation leads to the suggestion which may be compared with the Mohr-Coulomb criterion with friction and

cohesion which may be written for a'_1

$$\frac{((l I_1 - (l I_3)^2}{(c + cr_1 \mathrm{Tan})(c + cr_\beta \mathrm{Tan})} = 4 \qquad (6.1.5)$$

If = 0 is inserted in Equations (6.1.4) and (6.1.5) the Von Mises and Tresca conditions are given; if c = 0 is substituted the Matsuoka and cohesionless Mohr-Coulomb criteria result.

The main difference between the shapes suggested by Lade and Matsuoka is that whilst Matsuoka's gives the same equivalent angle of friction at both triaxial compression and extension, Lade's gives a slightly higher angle in extension. Evidence in favor of both has been obtained, and ineither is likelycapable of modelling tmodelinge of all soils.

Both give a considerably better approximation than the circular generalization and both give a slightly higher angle of friction at intermediate cr2 values (e.g. under plane strain conditions) than at triaxial compression.

Although the non-circular generalizations have not been studied in the context of the thermomechanical method, the Matsuoka criterion may be derived from the thermomechanical approach, and it is worthwhile examining the functions which lead to it. In terms of principal strains the Von Mises criterion results from a dissipation function:

$$= \frac{2\sqrt{2}}{3} c((\dot{\varepsilon}_1^P-\dot{\varepsilon}_2^P)^2 + (\dot{\varepsilon}_2^P-\dot{\varepsilon}_3^P)^2 + (\dot{\varepsilon}_3^P-\dot{\varepsilon}_1^P)^2)^{\frac{1}{2}} \quad (6.1.6)$$

The simplest extension to a frictional type of behavior involves replacing c with a term proportional to pressure, and after substitution of the stresses into the dissipation expression the "extended Von Mises" criterion may be derived from a function of the form:

$$\rho\phi = \frac{\sqrt{2}M}{9} (\sigma_1'+\sigma_2'+\sigma_3')((\dot{\varepsilon}_1^P-\dot{\varepsilon}_2^P)^2 + (\dot{\varepsilon}_2^P-\dot{\varepsilon}_3^P)^2 + (\dot{\varepsilon}_3^P-\dot{\varepsilon}_1^P)^2)^{\frac{1}{2}} \quad (6.\ 1.7)$$

It may be expected, however, that each of the dissipation components

of the form (time) 2 may depend on the stresses in a different way rather than simply a uniform multiplication by the pressure. In particular' the second method above if this problem is to be avoided.d (In the region in triaxial compression where the stress ration is greater than 3.0 the minor stress is tensile). It is therefore convenient first to modify the locus to eliminate a tensile region, this may be achieved by altering the Modified Cam-Clay ellipse so that it becomes tangential to a line of slope 3.0 at the origin in stress space (Figure 3.8

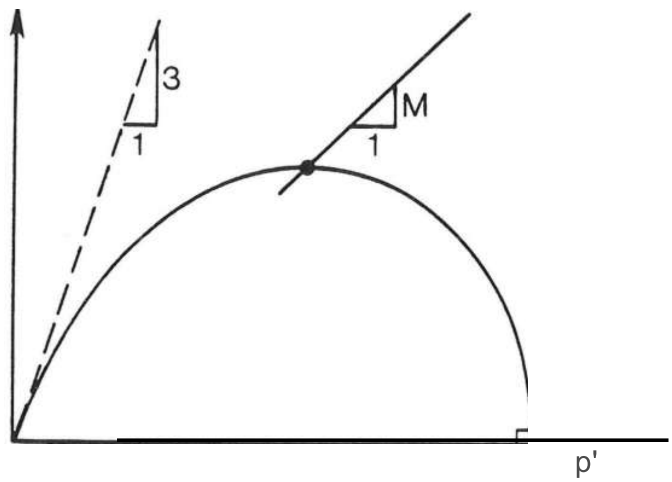


Figure 3.8 Failure points for Champlain Sea Clay, modeled by Modified Cam-Clay

Ellipse and Matsuoka generalisation (using M = 1.4 and p' = 124 kPa); the variation of strength with b value is much better fitted by this model. (The irregular pattern of strength variation arises because the tests were made using large loading increments,s which were alsomodeledd in the theoretical calculations.) Sufficiently accurate momodelingf this variation is important since strengths measured in triaxial compression tests are frequently used in the analysis of problems involving plane strain or other shearing modes.

The second effect of the change of the generalization is to alter the flow rule, giving different ratios between the plastic strain components on shearing at any given b value. A converse effect is that when strain rate ratios are fixed, for instance under plane strain conditions, the flow rule affects the stress ratios. A series of undrained plane strain tests on Boston Blue Clay was reported by Ladd et al. (1971). The samples were one

3.21 The Choice of Material for Experimental Study

The object of the tests described in the following Sections is to study the fundamental behavior of the simplest of granular materials. In sand the interaction between particles is expected to be purely mechanical, rather than electrochemical as in clay, and so sands may be expected to <l>Yfe.Sfllndmos t nearly to an ideal granular material. Most sands encountered in civil engineering practice are relatively dense, so all tests were on sand at a single high density. At the opposite end of soil behavior an investigation of the local state of soft clays has already been made by Lewin (1970). The choice of sand for investigation has the further advantage that the stress cycle tests (which must be drained) may be carried out quite quickly, and that creep becomes of less importance.

In tests involving changes in cell pressure, an import ant contributor to the measured volume change of the sample is the effect of the change of pressure on the penetration of the grains into the sample membrane.

This effect reduces with particle size, so fine sand was used for the tests. Fine sands also have the advantage that by increasing the ratio of saa mple size to particle size a more continuous response is observed, with smaller jumps due to movements of small groups of particles.

The sand chosen was an almost single-sized 0.2 ran quartz grained sand from Leighton Buzzard. The specific gravity of the grains is

2.65 and the grading passing between the British Standard No.60 and No.100 sieves are shown i Figure 3.9. The grains, micrographs of which are given in Figure 3.9, are rounded to sub-angular. A single sized

material was chosen for ease of preparation of a uniform sample. The mean specific volume of the samples was 1.623, giving a saturated bulk unit weight of 19.8 kN/rn3' .

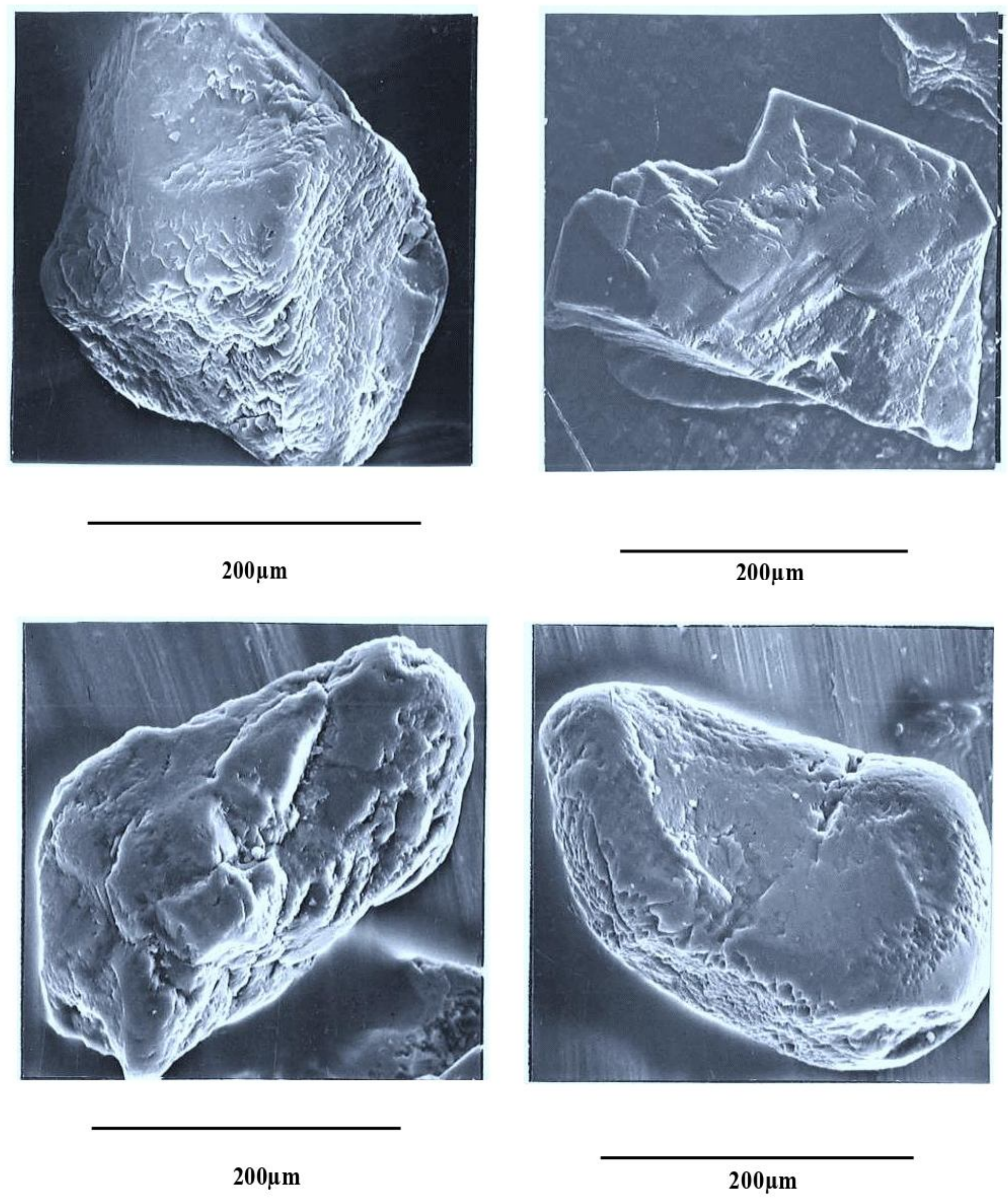


Figure 3.9 Micrographs of Leighton Buzzard sand grains

The results of a conventional drained triaxial compression test at cr3 260 kPa are shown in Figure 7.3, showing a typical response for dense sand with an initially stiff response followed by a fairly flat peak in the stress ratio - shear strain curve. The initial compression are not those which might be carried out as part of routine experiments to determine the properties of specific soils but are those which are used to eestablishmore rigorously whether plasticity theories form an appropriate framework to describe soils. Having established the validity of a particular theory, much simpler tests may then provide the necessary parameters.

Many routine tests concentrate principally on the failure of a material, but the concern here is with the deformation of the material, recoverable and irrecoverable, at working loads below failure.

The first and simplest tests of plasticity theory are experiments in which the soil is loaded monotonically, unloaded, and reloaded, and the character of the response is observed. Such tests might be eithconsolidationino tests or shear tests. Under these conditions, the response of soil is esessentialf the type predicted by plasticity theory, as shown in FiFigures.l(e) and (f). These tests provide, however, only limited information about the more general applicability of the theory. The limitations are:

(a) It must be assumed that the response on the unloading-reloading line (assuming hysteresis is small) is of an elastic rather than plastic character:r the information available in a test restricted to a single line in stress space is insufficient to derive the entire incremental stress-strain matrix, and so the different forms of an elastic rather than a plastic matrix cannot be determined.

(b) In a test restricted to a single line in stress space the previous maximum stress point may be determined as a yield point, but no information is given about the shape of the yield surface.

(c) The strains on unloading may be assumed to be elastic and subtracted from the total strains to determine the plastic strains. The orientation of the plastic potential can be inferred, but there is no indication as to whether this is unique or depends on the stress path.

(d) Only limited information on the hardening of the material is available.

(e) No information is provided about the stiffness of the material on the so-called "loading to the side", i.e. when the stress path has a sharp change in direction.

Despite these limitations, tests of this sort have provided extensive information about plasticity theories for soils, for instance the, good experimental evidence for the stress-dilatancy flow rule for monotonic loading of sands (Rowe (1962)) and the detailed knowledge of the consolidation and swelling of clays.

By carrying out families of similar tests much more information may be obtained, for instance on the variation of elastic properties. Carrying out two or more types of test provides even more detail, e.g. the unique specific volume contours for a normally consolidated clay in triaxial stress space located by Rendulic (1936). More recently the use of simple shear and true triaxial devices has extended this type of information to a much wider variety of stress conditions.

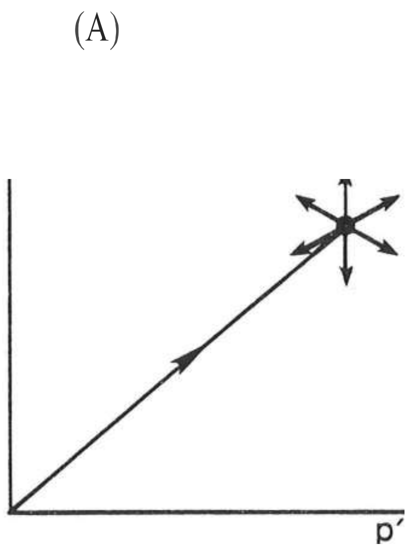
Although sets of te·sts on different samples provide information about plasticity theory, they do not check the form of the yield locus which is established for a single specimen on loading; the yield locus B and F. The investigation is continued with further probes. This sort of investigation gives a more detailed picture in that the yield locus is identified at CTvo points for the same sample, independently of the study of the flow rule. (The tests are, however, complicated by the hardening of the material since the yield locus expands during the path FE .) Since the tests involve crossing the yield locus in approximately the same direction in each case it does not fully explore the effect of loading to the side sands were not constant stress ratio lines but were curved towards lower stress ratios at higher pressures. The curves were not as marked however as in the

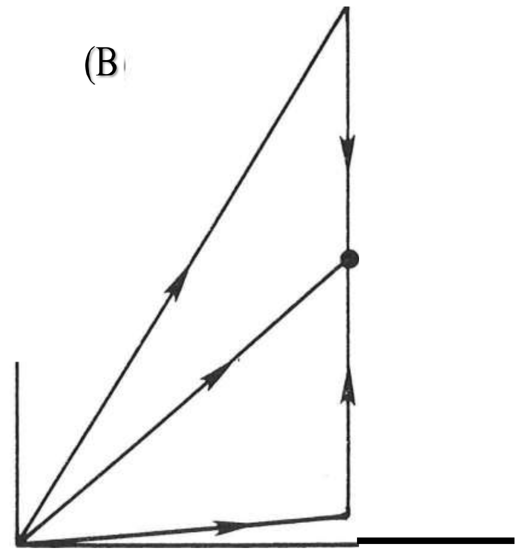
Cam-Clay yield locus. The investigation of the behavior of dense sand is described in the following orientation of the yield locus as well as independent measurements of other elastic and plastic properties. The form of the yield locus found is consistent with Tatsuoka and Ishihara's findings.s

3.22 Stress Probe and Stress Cycle Tests

All the tests described above involve relatively large stress changes from which certain of the ideas of plasticity theory may be checked. An alternative is to investigate in detail the response of a material at a particular stress point, deduce the entire incremental stress-strain behavior at that point, and compare it to plasticity theory. Such an investigation was made by Lewin and Burland (1970), who reported a series of stress probe tests on normally consolidated clay.

In Lewin's tests samples were subjected to identical stress histories, and then subjected to a series of small stress probe tests (Fig.3.10(a)) in which the probe was made in a different direction for each test. The stress changes in each set of probes were small (5%) compared to the total stresses so the investigation was trulytruehe 'local' state of the material. The strain response to the probes.





If the probes are carried out on an elastic-plastic material the response will be of the type shown in Figure 7.8(a). Some of the probes involve a fully elastic response and some involve plastic loading and elastic unloading; the final points OABCD lie on a line-oriented in the direction of the flow rule. It is possible to deduce the location of the original yield locus from the distribution of the final points, but the process is indirect, Clearly all those tests which produce a purely elastic response could be carried out on a single element and would yield the same results; and indeed if all the tests were carried out on the same elastic-plastic sample (in order 1-8) the result would be as shown in Figure 7.8(b) in which much of the information from the original set of eight probes is retained in a single test. Note the break point P on the loading of segment 5 as the new yield locus established by probe 4 is crossed;

and the purely elastic response to probes 6, 7 and 8 after the yield locus has been expanded to its maximum extent. The end points of probes 1, 2, 3, 4 and 5 are the same as in the tests on separate samples.

The test may finally be simplified by omitting the return to the central point O between probes, resulting in the stress cycle test shown in Figure 7.8(c). The end points of all the probes 1-8 are obtained as the same in both Figure 7.8(b). and Figure 7.8(c). In addition, the stress cycle test shows a break at point Q as the yield locus is passed; this point can only be inferred indirectly from the stress probe results. Although the entire elastic-plastic response may be deduced from a single stress cycle test, more detailed information is given if both clockwise and anticlockwise tests are carried out on separate samples.

A real material will probably not behave exactly as the elasticplastic idealization, and in the case for instance of material with two independent yield loci with different flow rules the final points of the stress probe response would not lie on the unique line of Figure 7.8(a). Such a result was in fact obtained by Lewin and Burland (1970) (see Section 6.2). Since the probes provide only a few discrete points on the final curve it is in practice difficult to interpret the data in terms of double yield loci, and the interpretation of tests in any more complex way than a single locus would be unrealistic for stress probe tests with any experimental scatter.

The stress cycle tests, which contain essentially the same information as the probe tests, must similarly be analysed assuming a single smooth yield locus. Several soil models use two loci, either of which may dominate during certain types of stress path. The cycle tests may therefore detect each locus separately.

Comparing the two methods for local investigation of material state, the cycle tests have the advantage that fewer tests are needed. If continuous monitoring is made all round the cycle they contain essentially the same information as many probe tests ending at each data point. The probe tests are more rigorous in that the incremental response of identical samples is found directly, but variation between samples may be a problem. In practice both must be interpreted using only a simple theory, and in this case provide the same information.

3.23 The Effect of Stress and of Stress History

The behavior of the sand varies with the stress state, so stress cycle tests were carried out at a variety of stress points in triaxial compression. The two most important effects are thought to be that of stress ratio and of pressure, so a grid of nine stress points at three pressures (267, 427 and 693 kPa) and three stress ratios (values of 75, 1. 09, and 1. 43) was chosen for investigation. The pressures were chosen to represent realistic stress levels for civil engineering problems (400 kPa represents approximately 40 m of overburden in a saturated material) and the ratios may be compared with the critical state value of 1.03 and the peak at p' 550 kPa of 1.60 . Although a wider range of stress levels would be desirable, it is difficult to achieve using a single apparatus if a consistent accuracy from the rec riding devices is required.

As well as dependence on the current state of stress, it is well known that the plastic behavior of soil produces a response that is strongly dependent on the primary loading history. Thus, the behavior of clay depends on its pre-consolidation pressure, and sands show a distinct change in stiffness at (approximately) the previous maximum stress ratio. Secondary effects do, however, also occur and the behavior may depend on history even for primary loading. For instance Lewin (1973) presented data for a clay on the variation of the flow rule according to stress history, even for samples currently at their maximum stress ratio. This investigation was made by subjecting samples with different histories to identical subsequent stress paths

In order to investigate the effects of stress history, stress paths are first classified into different types. The simplest case is that in which both stress magnitude and ratio are increasing and at their maximum values (AB in Figure Paths with n increasing may also involve p' constant (CD in Figure or decreasing Similarly, n may be decreasing below some maximum previous value whilst p' is increasing (HI in Figure 7.9(d)), constant (KL in Figure 7.9(e)) or decreasing Clearly many considerably more complex stress paths could also be studied, but attention is here restricted to primary loading and In addition to the nine main stress points for investigation further points were defined for the standardisation of previous stress history; all the points are shown on Figure 3.1 Table 3.1 lists the tests with the sequence of stress points as given in Figure 4.1 In the tests with an odd code number the stress cycles were executed clockwise and those with an even number anticlockwi.se The path from the central point for the cycle to the first corner was chosen so that it should be as nearly as possible elastic, i.e. approximately reversing the immediate past stress path.

In order to carry out the stress cycle tests a machine capable of simultaneously varying cell pressure and axial load in a triaxial test is required. Such a machine, using an automatic control and datalogging system, is described.

Table 3.1 datalogging system, is described

Specimen	InitialSpecific Volume	Stress Path (see Figure 7.10)
1002	1. 623	Constant o_3 test, o_3 275kPa
1034	1.623	rGEC
2010	1.627	Special consolidation test, n increasing
2012	1. 622	AE(testdiscontinued)
2013	1.641	AEJvuJtHsGDA
2014	1.634	AEJvuJtHsGDA
2021	1.639	DEFvuJkFgCBA
2022	1.614	DEFvuJkFgCBA
2033	1.617	rGEC
2044	1.616	eCEG
2045	1.607	eCEG
2051	1.614	efABCgjDEFkmGHJ
2052	1.631	ef.ABCgjDEFkmGHJ
2061	1.623	hCBAR.FEDpJHG
2062	1.620	hCBAtFEDpJHG
2071	1.614	Speciai consolidation test, n decreasing
2072	1.623	Constant cr_3 test, o_3 260 kPa
Mean	1.623	
Standard deviation	0.009	

where px = prexp((.£.n(r/V) + Ea)/().*-K*)) has also been substituted.

As in the case of the triaxial variables these may be re-arranged to give the yield locus and flow rule:

3.24 Extension to Large Strain Theory

The above models are all based on small strain theory, for which the approximation that the density is constant is valid. Under this approximation the specific volume only varies by a small quantity, and so no distinction is made between V/V and V/V ; hence the original 0

Modified Cam-Clay and the model described in this paper in which consolidation lines are straight in (tn p', tn V) rather than (tn p', V) space are essentially identical. In large strain theory, where density changes are accounted for, this distinction is necessary. The following discussion will be limited to the case of the triaxial test, and the extension to more general stress states is not as straightforward as for the small strain case. The Hencky logarithmic strain and the Euler stress will be used. Neither of these variables is convenient for an extension of the theory to general stresses, for which a Lagrangian approach using Green's strain and the Kirchoff so that the separation of the normal consolidation and critical state lines is slightly altered from the original model. This is due to the fact that the yield locus is slightly changed from that of the original model, and may be expressed in the form:

$$p'^2 - (2p'_x)^{(1-\kappa')} \; p'^{(1+\kappa')} + \frac{q^2}{M^2} = \qquad (4.5.13)$$

The flow rule 1.s also altered by a small amount.

In the alternative approach 1.n which the expressions forand are interpreted as applying to unit volume (as opposed to unit mass) the substitution of Equation (4.5.4) r p r p p before differentiation results in the stress expressions: p1 = p exp (v-v)/K*) - [p K*exp((v-v)/K* + 3G(e:-e:) 2 / 2

Table 3.2 Values of Modified Cam-Clay Parameters

Parameter	Boston Blue Clay	Speswhite Kaolin	Champlain Sea Clay	Llyn BrianneSlate Dust
References	Randolphet al.(1979)	Unpublished data	Yong and Silvestri (1977)	Lewin andBurland(1970)
M	1.3	0.89	1.26	1.045
A*	0.065	0.127	0.5	0.055
K*	0.025	0.028	0.007	0.008
G/MPa	9.0	13.7	9.07 '	32.15
r	2.5	3.5	5.3	-
a	79.0	85.0	-	-
s	50.05	75.0	-	-

If large strain analysis is taken into account the constant shear strain contours for the model where the functions are considered as referring to unit mass are of the shape shown in Figure 4.1. Clearly the effect of the large strain analysis is very small in that, except at very low pressures, the contour is essentially a line at constant deviator stress.

CHAPTER 4

RESULT AND ANALYSIS

4.1 Numerical calculation using Cam-clay models

The Improved Cam-Clay theory was established from a thermal-mechanical method in the previous Chapter, and in principles of ductile materials, it may give no benefit over a more traditional form (Zhang, and Lu, 2020). The perpetual motion and disintegration terminology will be somewhat changed in this section to provide further insights into how functional structures are connected to mechanical behavior. Elastic-plastic theories also couldn't predict linkages between diverse elements of behavior, but the thermal-mechanical method does. The application enables the progressive computation of a model's reaction to every combination of tensile stress controls, allowing models to be tested and verified for various stress paths. Every model's procedure might then be employed in a Numerical Method. By altering a function in the Single Layer Programme, each concept may be investigated individually.

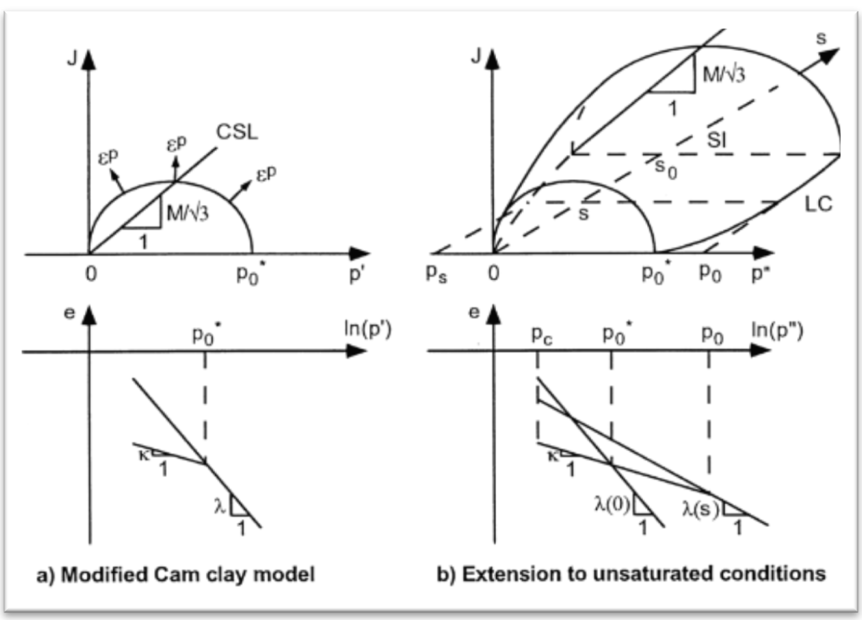


Figure 4.1: Cam clay model Vs BBM model

(Source: https://www.researchgate.net/figure/Cam-clay-model-and-BBM-model_fig1_222257756)

4.2 A change in dissipation function

The notion that the yielding region for Generalized Cam-Clay goes across the origins in space changes appears to be random, and it comes as a result of the term appearing in both the perpetual energy and dissipated equations (Monforte et al. 2018). The yielding region no lengthier crosses through the source when either of these variables is amplified by a variable. The assumption is frequently made in deformation modeling that the frequency of plastic activity should be non-negative. The yielding location should contain the source in space changes as a consequence of the assertion. Because non-negative real deformable work would not be a criterion of the formulations, the modeling approach above obviously violates this criterion.

4.3 A pressure-dependent shear modulus

The elastic strength of actual soils seems to be a product of the average strain rate, and an extended study of the variability shows that it is thermochemical impermissible for the elastic strength to rely on pressures except if the shear density is in turn a factor of the tensile force. Nevertheless, empirical findings suggest that an elastic strength proportionate to stress may be adequate (Mousavi et al. 2019). The supplementary effects, which are regarded to be implausible, are created by the hypothesized interplay among shear and capillary dynamics. With a significant over accumulation percentage, the curving of unconfined tension channels is most visible. The computation should be stopped whenever the highest stress proportion is achieved for tests with greater over concentration proportions than just those given because the following anticipated pressure ratio is larger.

4.4 Elastic-plastic coupling

Even though the preceding segment's research might be done using the simplified thermodynamics idea of an elasticity perspective, the main findings will only be derived from the synthetic form. Making the shearing elasticity proportionate to pre-consolidation temperature is indeed an alternative to using a pressure-dependent modulus and strength (Aingaran et al. 2018). This would have the benefit of reinstating the non-dimensionalization of all behaviors at a particular over commutated concerning pressures, which is important both in Crucial Condition Soil Mechanics as well as the SHANSEP planning and implementation technique. Figure 4.2 shows Deformation of elastic-plastic coupling

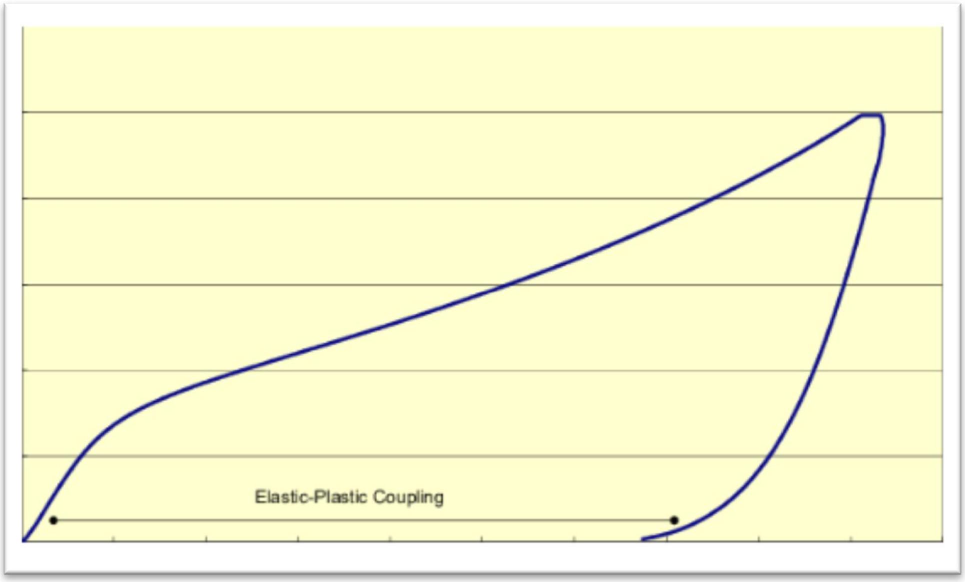


Figure 4.2: Deformation of elastic-plastic coupling

(Source: https://www.researchgate.net/)

4.5 Experimental data on the variation of the shear modulus of clay

In the former, it was common to utilize either a set shear resistance or a constant Poisson's ratios for Generalized Cam-Clay computations, despite the fact that the very first is impractical and the latter is conceptually unsuitable. When a changing elastic strength, proportionate to stress or maximum compressive force, was introduced into a rigorous thermal-mechanical structure, it was discovered that some indirect impacts changed the basic model. These consequences are dependent on the elasticity variation's shape, and their amplitude is proportional to the elasticity intensity (Zeng et al. 2020). It's useful to compare the findings to predictions from the initial Cam-Clay concept, even if it wasn't generated using a thermal-mechanical technique. The over-combined specimens' strength forecasts are substantially better.

4.6 Analysis of stress cycle test

The stress cycle experiments on thick sand were broken down into four phases for study. For something like a typical test, the very first step consisted of simply editing the resulting tape from PDP-8E with the complete adjustments mentioned to produce a sequence of around 1000 stress and tension points. The pressure route was mapped out to ensure that the desired path was matched, and the intake pressure pathway was a predictor of success in each instance during the official test (Kuhn,and Daouadji, 2018). The database frequently had a few solitary instances showing erroneous numbers, possibly due to the influence of the data logging equipment, and these instances were erased for further examination. In almost all of the studies, though, there have been indications of a stage of recovery behaviors, indicating that an elastic-plastic reaction was taking place. Yet, the potential of anisotropy complicates the understanding even of the elasticity portion.

4.7 Optimization of elastic and plastic properties

The identification of an acceptable theoretical model to represent the condition of the specimen is the first step in the calculation of elastic-viscous characteristics. A continuous shear modulus will be used to characterize the elastic characteristics. A perfect continuous yielding region, that stays parallel to its initial position while it is transferred by subsequent ductile materials, will be used to characterize the plastic characteristics; a constant stiffening elasticity and a consistent ratio in between applied stress increases will be maintained (Kang et al. 2018). The final stage of the study, which is detailed in the next Sections, includes applying an optimization technique to automatically adapt elastic-viscous characteristics to each period of testing. The collection and evaluation of the position in terms of every cycle was the final phase of the assessment.

4.8 Representation of stress cycle test result

The controversial aspects reaction for the cycle was calculated using the integrated approach of the nine components, and this was evaluated in terms of response. The mean pressures over the cycle, as well as the cycle histories characterized by the highest previous stress levels, are determined from all of the tests. The graph enables a quick comparison of the overall importance of elasto-plastic displacement. It's reasonable to predict that elastic characteristics will be erroneous in experiments characterized by substantial plastic stresses. The thermoplastic qualities would also be problematic if the reaction is nearly elastic (Cheng et al. 2019). The size of the sum of the squared inaccuracy was rather indifferent to the position of the yielding region in the latter scenario, indicating that the yielding region alignment is inaccurate in this situation, despite the fact that the flowing principle was pretty accurately specified. It is indicated which tests are characterized by elastic deformation properties. characterized by substantial plastic stresses. The thermoplastic qualities would also be problematic if the reaction is nearly elastic (Cheng et al. 2019). The size of the sum of the squared inaccuracy was rather indifferent to the position of the yielding region in the latter scenario Figure 4.3 Shows stress cycle

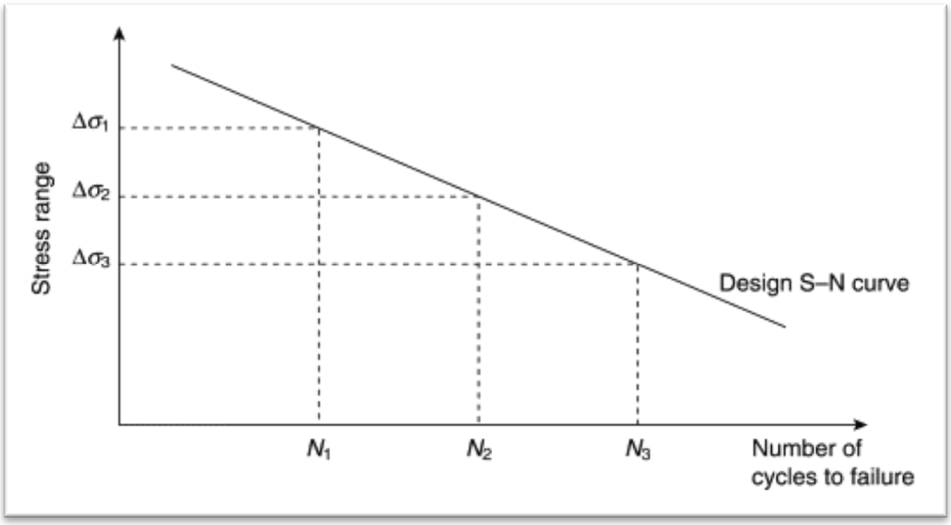


Figure 4.3: Stress cycle result

(Source: https://ars.els-cdn/content/image/3-s2.0-B9781782423706500071-f07-20-9781782423706.gif)

4.9 Variation and interpretation of elastic properties

Variability in present pressure and anxiety histories are taken into account. The tension and its preceding highest are regarded to become the most essential factors in rigidity, while the influence of applied stress on the material will be investigated. The performance is understood in the context of the competing assumptions that elasticity conduct can be generated from a perspective or supplied by Hertzian social penetration theory (Pan et al. 2018). The extraneous variable might have been a significant contributing factor to the determination of extremely tiny elastic stresses in dynamic loading, which requires measures of numbers near the sensitivity of the triaxial equipment. Another issue is that the barrier penetrating adjustment is considerable (about one-third of the modest elasticity volumes stresses); penetration would vary according to different substrates. Due to the difficulties in determining elastic response from tiny dynamic loading, the second series of experiments was conducted to more precisely determine the fluctuation of young's modulus with tension. Because it is expected that discharging sand at a residual stress proportion may result in considerably dynamic loading, experiments were run including loading or unloading at quite a variety of residual stress proportions.figure 4.4 shoes varion of elastic

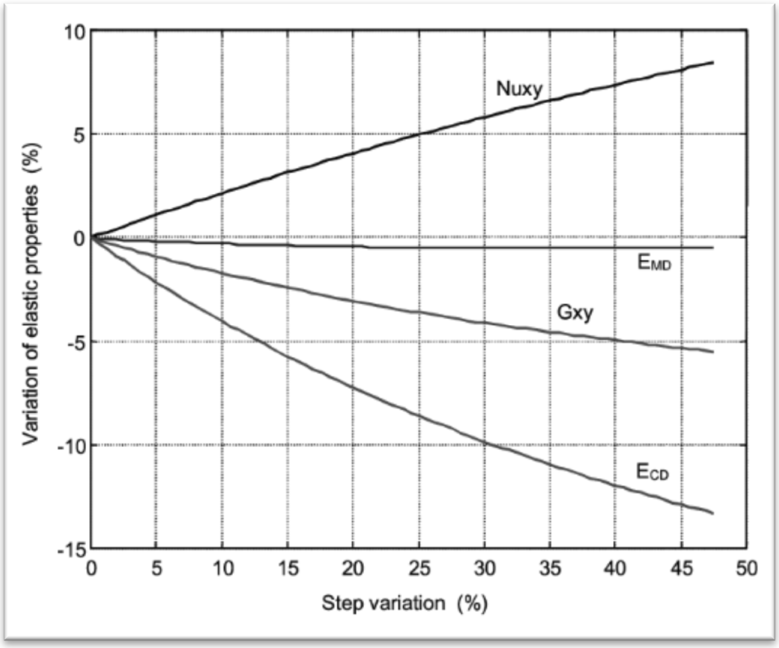


Figure 4.4: variation of elastic properties

(Source: https://www.researchgate.net/figure/Variation-of-elastic-properties-versus-step-variation_fig3_232389896)

4.10 Variation of plastic properties

The plastic characteristics of the material, as one might imagine, are substantially influenced by the sand's previous stress history (Gross et al. 2019). The prior record general strain theory is regarded to be the most essential characteristic; hence those experiments wherein the stress ratios were continually growing will be evaluated first. The pressures were maintained at a constant for 30 minutes before the first pressure has led began, because during that time a minor degree of creep happened, which was strongly reliant on the present applied stress. Because each phase of the cycle took 30 minutes to complete, more creep is predicted during the round. If a pressure condition is achieved during the process that results in substantial thermoplastic strains, most of this tension might well be predicted to manifest as creep after the maximum stress gets gone.

CHAPTER 5

CONCLUSION

5.1 Use of thermodynamics in soil modeling

The application of an approximate solution concept, Ziegler's "orthogonality principle," has been essential to the growth of the thermal-mechanical technique. Even though some consider it problematic, the concept is connected to some well-established theories, including Onsager's reciprocating links. Although many interpretations make more use of approximate solution concepts (explicitly or implicitly), others deliberately ignore them. The emergence of a separate yielding region in space changes was an essential conclusion of the formulations, which was inextricably linked to the choosing of a small number of individual factors. While this supposition may be reasonable for a limited amount of cyclic stress, it is sufficient to result in "shakedown" to elasticity circumstances after several cycles, making this technique undesirable for cyclical behavior analysis. Using the power intake equations developed previously, thermal-mechanical approaches may be utilized to provide the idea of overburden pressure in a simulation. As a result, the stress-strain concept would become an essential element of the approach, and it is no longer necessary to activate it as a particular condition.

5.2 Modified Cam-clay models

The value of the technique rests in how it handles modeling improvements. For several situations, the application of bigs theory provides for an evaluation of the requirement thereof of this complexity, which was considered superfluous in many cases. Mathematical advancements even outside thermo-mechanics might yield some key implications for research, and incorporating these concepts into the thermal-mechanical paradigm is a clear next step. The relevance of homogeneity is understood, as is the requirement or potential of non-circular generalization of yielding locus upon that octahedral surface. The progress of anisotropy assessment will be largely dependent on the presence of more exact and consistent information for a few substances. The presence of directed yield locations and plasticity prospects is still a topic of debate.

5.3 Result of stress cycle tests

The microprocessor managed depending on a computerized feedback mechanism was ultimately successful, with both strengths and weaknesses logged. Stress routes could be properly tracked, allowing studies that would be hard to conduct in a traditional apparatus. The need for a machine for both the recording and reporting technology allows for extremely precise stress path tracking since all design adjustments can be done in real-time. A downside is relying only on electronic measuring techniques, which have concerns of inaccuracy and inconsistency. The pressure cycling tests are a novel way of soil testing that was created to distinguish between the elastic - viscous characteristics of the product. The experiments were then set up to investigate the variations in these features. The tests suggest becoming a helpful and instructional means of investigating soil qualities, and they put the application of ductile materials to the test. The matching of elasto-plastic characteristics to the pressure cycling data required the use of a machine. The attributes' degree of fit revealed that the performance of thick sand might be described in terms of elastic deformation.

5.4 Applicability of plastic theory to soils

This analytical and empirical study has added to the growing body of data supporting the plastic philosophy's application to soils. Elasto-plastic concepts are generated from a fundamental variety of theories in the thermal-mechanical context than in the traditional method. The formulations, to be able to accept concepts with non-associated routing information without breaking any thermodynamics constraints, can also provide several important insights, including quite into processes like elasticity plasticity couplings. Most crucially, the technique is generally relevant to soils since it incorporates elasticity non-linearity, war-hardened, non-associated circulation, and other subsurface characteristics into a single consistent expression. The use of thermal-mechanical principles to construct plastic hypotheses for sediments, meanwhile, is perhaps the most significant issue discussed in this research. Future research on this topic must be divided into two categories. To begin, a thorough examination of the generalized formulation of plastic concepts here in this method is required, particularly in terms of normalcy criteria, and then searching for plausible boundary statements. Second, computational methods for actual soils must be built using particular versions of the theory, incorporating factors like anisotropic and non-associated movement.

REFERENCE LIST

Journals

Yin, Q., Sun, Y., Li, B., Feng, Z. and Wu, G., 2022. The r/K selection theory and its application in biological wastewater treatment processes. Science of the Total Environment, p.153836.

Peñuelas, J., Fernández‐Martínez, M., Ciais, P., Jou, D., Piao, S., Obersteiner, M., Vicca, S., Janssens, I.A. and Sardans, J., 2019. The bioelements, the elementome, and the biogeochemical niche. Ecology, 100(5), p.e02652.

Larson, J.E., Anacker, B.L., Wanous, S. and Funk, J.L., 2020. Ecological strategies begin at germination: Traits, plasticity and survival in the first 4 days of plant life. Functional Ecology, 34(5), pp.968-979.

Piovesan, G. and Biondi, F., 2021. On tree longevity. New Phytologist, 231(4), pp.1318-1337.

Hakro, M.R., Kumar, A., Almani, Z., Ali, M., Aslam, F., Fediuk, R., Klyuev, S., Klyuev, A. and Sabitov, L., 2022. Numerical Analysis of Piled-Raft Foundations on Multi-Layer Soil Considering Settlement and Swelling. Buildings, 12(3), p.356.

Laitinen, R.A. and Nikoloski, Z., 2019. Genetic basis of plasticity in plants. Journal of Experimental Botany, 70(3), pp.739-745.

Al Houri, A., Habib, A., Elzokra, A. and Habib, M., 2020. Tensile testing of soils: History, equipment and methodologies. Civil Engineering Journal, 6(3), pp.591-601.

Wang, Z., Cai, X. and Yin, Z., 2021. Research progress on phenotypic plasticity of invasive plants in response to drought stress. In E3S Web of Conferences (Vol. 245, p. 02020). EDP Sciences.

Hicks, L.C., Frey, B., Kjøller, R., Lukac, M., Moora, M., Weedon, J.T. and Rousk, J., 2022. Toward a function‐first framework to make soil microbial ecology predictive. Ecology, 103(2), p.e03594.

Zhang, J., Huang, W. and Ding, J., 2021. Phenotypic plasticity in resource allocation to sexual trait of alligatorweed in wetland and terrestrial habitats. Science of The Total Environment, 757, p.143819.

Zhao, S., Bui, H.H., Lemiale, V., Nguyen, G.D. and Darve, F., 2019. A generic approach to modelling flexible confined boundary conditions in SPH and its application. International Journal for Numerical and Analytical Methods in Geomechanics, 43(5), pp.1005-1031.

Belousova, M.E., Malovichko, Y.V., Shikov, A.E., Nizhnikov, A.A. and Antonets, K.S., 2021. Dissecting the environmental consequences of Bacillus thuringiensis application for natural ecosystems. Toxins, 13(5), p.355.

Ovchinnikov, A.S., Borodychev, V.V., Lytov, M.N., Bocharnikov, V.S., Fomin, S.D., Bocharnikova, O.V. and Vorontsova, E.S., 2018. Optimum control model of soil water regime under irrigation. Bulgarian journal of agricultural science, 24(5), p.909.

Li, L., Wilson, C.B., He, H., Zhang, X., Zhou, F. and Schaeffer, S.M., 2019. Physical, biochemical, and microbial controls on amino sugar accumulation in soils under long-term cover cropping and no-tillage farming. Soil Biology and Biochemistry, 135, pp.369-378.

Hurley, R.R. and Nizzetto, L., 2018. Fate and occurrence of micro (nano) plastics in soils: Knowledge gaps and possible risks. Current Opinion in Environmental Science & Health, 1, pp.6-11.

Bradford, M.A., McCulley, R.L., Crowther, T., Oldfield, E.E., Wood, S.A. and Fierer, N., 2019. Cross-biome patterns in soil microbial respiration predictable from evolutionary theory on thermal adaptation. Nature Ecology & Evolution, 3(2), pp.223-231.

Johnston, A.S. and Sibly, R.M., 2018. The influence of soil communities on the temperature sensitivity of soil respiration. Nature Ecology & Evolution, 2(10), pp.1597-1602.

Koch, T., Heck, K., Schröder, N., Class, H. and Helmig, R., 2018. A new simulation framework for soil-root interaction, evaporation, root growth, and solute transport.

Cuomo, M., 2019. Continuum damage model for strain gradient materials with applications to 1D examples. Continuum Mechanics and Thermodynamics, 31(4), pp.969-987.

Hodo, W.D., Peters, J.F., Walizer, L.E., McInnis, D.P. and Carrillo, A.R., 2019. Development of the particle-scale definition of stress and strain for the discrete element method: Report 3 in "Discrete nano-scale mechanics and simulations" series.

Surana, K.S., Joy, A.D. and Reddy, J.N., 2019. Ordered rate constitutive theories for non-classical thermoviscoelastic solids with memory incorporating internal and Cosserat rotations. Continuum Mechanics and Thermodynamics, 31(2), pp.427-455.

Masi, F., Stefanou, I., Vannucci, P. and Maffi-Berthier, V., 2021. Thermodynamics-based Artificial Neural Networks for constitutive modeling. Journal of the Mechanics and Physics of Solids, 147, p.104277.

Trinh, A.L., Ber, S., Howitt, A., Valls, P.O., Fries, M.W., Venkitaraman, A.R. and Esposito, A., 2019. Fast single-cell biochemistry: theory, open source microscopy and applications. Methods and applications in fluorescence, 7(4), p.044001.

Banabic, D., Barlat, F., Cazacu, O. and Kuwabara, T., 2020. Advances in anisotropy of plastic behaviour and formability of sheet metals. International Journal of Material Forming, 13(5), pp.749-787.

Bryant, E.C. and Sun, W., 2019. A micromorphically regularized Cam-clay model for capturing size-dependent anisotropy of geomaterials. Computer Methods in Applied Mechanics and Engineering, 354, pp.56-95.

Zhou, X., Lu, D., Zhang, Y., Du, X. and Rabczuk, T., 2022. An open-source unconstrained stress updating algorithm for the modified Cam-clay model. Computer Methods in Applied Mechanics and Engineering, 390, p.114356.

Borja, R.I., Yin, Q. and Zhao, Y., 2020. Cam-Clay plasticity. Part IX: On the anisotropy, heterogeneity, and viscoplasticity of shale. Computer Methods in Applied Mechanics and Engineering, 360, p.112695.

Banaszkiewicz, M. and Dudda, W., 2018. Applicability of notch stress-strain correction methods to low-cycle fatigue life prediction of turbine rotors subjected to thermomechanical loads. Acta Mechanica et Automatica, 12(3).

Bychkov, A.L., Podgorbunskikh, E.M., Ryabchikova, E.I. and Lomovsky, O.I., 2018. The role of mechanical action in the process of the thermomechanical isolation of lignin. Cellulose, 25(1), pp.1-5.

Golchin, A., Vardon, P.J. and Hicks, M.A., 2019. A thermodynamically based thermo-mechanical model for fine-grained soils. In XVII European conference on soil mechanics and geotechnical engineering (ECSMGE-2019), Reykjavik, Iceland.

Houlsby, G.T., 2019. Frictional plasticity in a convex analytical setting. Open Geomechanics, 1, pp.1-10.

Leane, M., Pitt, K., Reynolds, G.K., Dawson, N., Ziegler, I., Szepes, A., Crean, A.M., Dall Agnol, R. and Manufacturing Classification System (MCS) Working Group, 2018. Manufacturing classification system in the real world: factors influencing manufacturing process choices for filed commercial oral solid dosage formulations, case studies from industry and considerations for continuous processing. Pharmaceutical development and technology, 23(10), pp.964-977.

Zhang, C. and Lu, N., 2020. Unified effective stress equation for soil. Journal of Engineering Mechanics, 146(2), p.04019135.

Monforte, L., Arroyo, M., Carbonell, J.M. and Gens, A., 2018. Coupled effective stress analysis of insertion problems in geotechnics with the particle finite element method. Computers and Geotechnics, 101, pp.114-129.

Mousavi, S.Z.S., Tavakoli, H., Moarefvand, P. and Rezaei, M., 2019. Assessing the effect of freezing-thawing cycles on the results of the triaxial compressive strength test for calc-schist rock. International Journal of Rock Mechanics and Mining Sciences, 123, p.104090.

Aingaran, S., Le Pen, L., Zervos, A. and Powrie, W., 2018. Modelling the effects of trafficking and tamping on scaled railway ballast in triaxial tests. Transportation Geotechnics, 15, pp.84-90.

Zeng, Q., Yao, J. and Shao, J., 2020. An extended finite element solution for hydraulic fracturing with thermo-hydro-elastic–plastic coupling. Computer Methods in Applied Mechanics and Engineering, 364, p.112967.

Kuhn, M.R. and Daouadji, A., 2018. Quasi-static incremental behavior of granular materials: Elastic–plastic coupling and micro-scale dissipation. Journal of the Mechanics and Physics of Solids, 114, pp.219-237.

Kang, J.J., Becker, A.A., Wen, W. and Sun, W., 2018. Extracting elastic-plastic properties from experimental loading-unloading indentation curves using different optimization techniques. International Journal of Mechanical Sciences, 144, pp.102-109.

Cheng, L., Bai, J. and To, A.C., 2019. Functionally graded lattice structure topology optimization for the design of additive manufactured components with stress constraints. Computer Methods in Applied Mechanics and Engineering, 344, pp.334-359.

Pan, X., Zhang, G. and Yin, X., 2018. Elastic impedance variation with angle and azimuth inversion for brittleness and fracture parameters in anisotropic elastic media. Surveys in Geophysics, 39(5), pp.965-992.

Gross, A., Pantidis, P., Bertoldi, K. and Gerasimidis, S., 2019. Correlation between topology and elastic properties of imperfect truss-lattice materials. Journal of the Mechanics and Physics of Solids, 124, pp.577-598.

BALASUBRAMANIAM, A.S. (1969) Some Factors Influencing the Stress Strain Behaviour of Clays, Ph.D. Thesis, University of Cambridge

BAZANT, Z.P. and KRIZEK, R.J. (1976) Endochronic Constitutive Law for Liquefaction of Sand, Jour.Eng.Mech.Div., Proc.ASCE, Vol.102, No,EM2, Apr., 225-238

BISHOP, A.W. (1959) The Principle of Effective Stress, Teknisk Ukeblad No.39

BOYCE, J.R. and BROWN, S.F. (1976) Measurement of Elastic Strain in Granular Material, Geotechnique, Vol.26, No.4, Dec., 637-640

BUTTERFIELD, R. (1979) A Natural Compression Law for Soils (an Advance on e-log p'), Geotechnique, Vol.29, No.4, Dec., 469-480

CALLADINE, C.R. (1963) The Yielding of Clay, Correspondence, Geotechnique, Vol.13, No.3, Sept., 250-255

CALLADINE, C.R. (1971) A Microstructural View of the Mechanical Properties of Saturated Clay, Geotechnique, Vol.21, No.4, Dec., 391-415

CALLEN, H.B. (1960) Thermodynamics, John Wiley and Sons, New York
CASAGRANDE,. A. (1936) Characteristics of Cohesionless Soils Affecting the Stability of Slopes and Earth Fills, Jour. Boston Society of Civil Engineers, Jan.

DAFALIAS, Y.F. and HERRMANN, L.R. (1980) A Bounding Surface Soil Plasticity Model, Proc.Int.Symp. on Soils under Cyclic and Transient Loading, Swansea, 7-11 January, 335-345

DAVIDSON, C.S. (1980) The Shear Modulus of Clays, Engineering Tripos, Part II, Group A, Project Report, Cambridge University

DE JOSSELIN DE JONG, G. (1977) Mathematical Elaboration of the Double Sliding, Free Rotating Model, Archives of Mechanics, Vol.29, No.4, 561-591

DRUCKER, D.C. (1951) A More Fundamenta.1 Approach to Plastic Stress Strain Relations, Proc. 1st US National Congress on App.Mech., Pub. ASME, June, 487-491

DRUCKER, D.C. (1954) Coulomb Friction, Plasticity and Limit Loads, Jour.App.Mech., Vol,21, Trans.ASME, Series E, Vol.76, 71-74

DRUCKER, D.C. (1956) On Uniqueness in the Theory of Plasticity, Quat.App.Maths., Vol.14, No.l, Apr., 35-42

DRUCKER, D.C. (1959) A Definition of a Stable Inelastic Materia,l Jour.App.Mec,h.Vol.26, Trans.ASME, Series E, Vol.81, 101-106

DRUCKER, D.C. (1964) On the Postulate of Stability of Material in the Mechanics of Continua, Jour. de Mech., Vol.3, No.2, June, 235-249

DRUCKER, D.C., GIBSON, R.E. and HENKEL, D..J. (1957) Soil Mechanics and Work-Hardening Theories of Plastictiy, Trans.ASCE, Vol.122, 338-346

DUNCAN, J.M. and CHANG, C.-Y. (1970) Nonlinear Analysis of Stress and Strain in Soils, Jour. Soil Mech.Found.Eng.Div., Proc.ASCE, Vol.96, No.SMS, Sept., 1629-1653

GEROGIANNOPOULOS, N. and BROWN, E.T. (1978) The Critical State Concept Applied to Rock, Int.Jour. Rock Mechanics and Mi nt'"-': Science and Geomechanics Abstracts, Vol.15, 1-10

HEYMAN, J. (1972) Coulomb's Memoir on Statics, Cambridge University Press

HILL, R. (1950) The Mathematical Theory of Plasticity, Oxford University Press

HORNE, M.R. (1965) The Behaviour of an Assembly of Rotund, Rigid, Cohesionless Particles, I.and II, Proc.Roy.Soc., Series A, Vol.286, 62-97

HORNE, M.R. (1969) The Behaviour of an Assembly of Rotund, Rigid, Cohesionless Particles, III, Proc,Roy.Soc., Series A, Vol.310, 21-34

HOULSBY, G.T. (1979) The Work Input to a Granular Material, Geotechnique, Vol.29, No.3, Sept., 254-258

HUECKEL, T. and NOVA, R. (1979) Some Hysteresis Effects of the Behaviour of Geologic Media, Int.Jour. Solids and Structures, Vol.15, 625-642

HVORSLEV, J. (1936) Condition of Failure for Remoulded Cohesive Soils, Discussion, Proc.Int.Con.fSoil Mech.Found.Eng., Vol.3, Cambridge, Mass., 51-53

IL'IUSHIN, A.A. (1960) Problems of the General Theory of Plasticity, Jour.Ap.pMaths. and Mech., Vol.24, No.3, 399-411

IL'IUSHIN, A.A. (1961) On the Postulate of Plasticity, Jour.App.Math. and Mech., Vol.25, No.3, 746-752

JOWITT, P.W. and MUNRO, J. (1975) Influence of Void Distribution and Entropy on the Engineering Properties of Granular Media, Proc. 2nd Int.Conf. Applications of Statistics and Probability in Soil and Structural Engineering, Vol.2, Aachen, Germany, Sept., 365-385

KOLYMBAS, D. and GUDEHUS, G. (1980) A Constitutive Law for Sands and Clays - Position, Prediction and Evaluation, Proc.NSF/NSER North American Workshop on Plasticity and Generalised Stress- Strain Modelling of Soils, Montreal, May,28-30

LADD, C.C., BOVEE, R.B., EDGERS, L. and RIXNER, J.J. (1971)

Consolidated-Undrained Plane Strain Shear Tests on Boston Blue Clay, Research in Earth Physics, Phase Report No.15, Research Report R71-13, Soils Publication 273, Massachusetts Institute of Technology, Mar.

LADD, C.C. and FOOTT, R. (1974) New Design Procedure for Stability of Soft Clays, Proc.ASCE, Jour.Geotech.E.Dnigv.,Vol.100, No.GT7, July, 763..:786

LADE, P.V. (1972) The Stress-Strain and Strength Characteristics of Cohesionless Soils, Ph.D. Thesis, University of California, Berkeley

LADE, P.V. (1977) Elasto-PlasticStress-Strain Theory for Cohesionless Soil with Curved Yield Surfaces, Int.Jour. Solids and Structure,s Vol.13, 1019-1035

LADE, P.V. and DUNCAN, J.M. (1975) Elastoplastic Stress-Strain Theory for Cohesionless Soil, Proc.ASCE,Jour.Geotech.Eng.D.i,v Vol.101, GTlO, Oct., 1037-1053, Closure Vol.104, Jan. 1978, 134-141

LADE, P.V. and DUNCAN, J.M. (1976) Stress Path Dependent Behaviour of Cohesionless Soil, Jour.Geotech.Eng.Div., ASCE, Vol.102, GTl, Jan., 51-68

LAGONI, P. (1976) Kornede Materiale·rsMekanik, Thesis, Soil Mechanics Laboratory, 1 TechnicalUniversity of Denmark

LEE, I.K. (1978) End Restraint Effects on Undrained Static Strength of Sand, Proc.ASCE, Jour.Geotech.Eng..D,ivVol.104, No.GT6, June, 687-704

LEWIN, P.I. (1970) Stress Deformation Characteristics of a Saturated Soil, M.Sc. Thesis, University of London

LEWIN, P.I. (1973) The Influence of Stress History on the Plastic Potential, Symp. on the Role of Plasticity in Soil Mech., Ed. Palmer, A.C., Cambridge, 96-106

LEWIN, P.I. and BURLAND, J.B. (1970) Stress Probe Experiments on Saturated Normally Consolidated Clay, Geotechnique, Vol.20, No.l, Mar., 38-56

LOVE, A.E.H. (1927) A Treatise on the Mathematical Theory of Elasticity, Cambridge University Press

MAIER, G. and HUECKEL, T. (1977) Nonassociated and Coupled Flow Rules of Elastoplasticity for Geotechnical Media, Proc. 9th Int.Con£. Soil Mech.Found.Eng.,Session 9, Constitutive Equations for Soils, Tokyo, July

MATSUOKA, H. (1974) Stress Strain Relationships of Sands Based on the Mobilised Plane, Soils and Foundations, Vol.14, No.2, June, 47-62

MATSUOKA, H. (1976) On the Significance of the 'Spatial Mobilised Plane', Soils and Foundations, Vol.16, No.l, Mar., 91-100

MATSUOKA, H. and NAKAI, T. (1974) Stress-Deformation and Strength Characteristics of Soil Under Three Different Principal Stresses, Proc.JSCE, No.232, Dec., 59-70

MINDLIN, R.D. and DERESIEWICZ, H. (1953) Elastic Spheres in Contact Under Varying Oblique Forces, Jour.App.Mech., Vol.20, No.3, Sept., 327-344

MITCHELL,. R.J. (1970) On the Yielding and Mechanical Strength of Leda Clay, Canadian Geotechnical Journal, Vol.7, 297-312

M:>LENKAMP, F. (1980) Some Aspects of Constitutive Equations for Sand, Proc.Int.Symp. on Soils Under Cyclic and Transient Loading, Swansea, Vol.l, 411-420

NAMY, D. (1970) An Investigation into Certain Aspects of Stress-Strain Relationships for Clay Soils, Ph.D. Thesis, Cornell University

NOVA, R. and WOOD, D.M. (1978) Accessibility and Material Stability, Internal Report CUED/C-Soils TR44, University of Cambridge

OHTA, H. and WROTH, C,P. (1976) Anisotropy and Stress Reorientation in Clay Under Load, 2nd Int.,Conf. on Numerical Methods in Geomechanics, Blacksburg, Virginia, USA, Vol.l, Ed. D sai, C.S., Pub.ASCE, June, 319-328

ODA, M. (19 72) The Mechanism of Fabric Changes During Compressional Deformation of Sand, Soils and Foundations, Vol.12, No.2, June, 1-18

ODA, M. (1974) A Mechanical and Statistical Model of Granular Material, Soils and Foundations, Vol.14, No.l, Mar., 13-27

PALMER, A.G. (1967) Stress Strain Relations for Clays: An Energy Theory, Geotechnique, Vol.17, No.4, Dec., 348-358

PAPPIN, J.W. and BROWN, S.F. (1980) Resilient Stress-Strain Behaviour of a Crushed Rock, Proc.Int.Symp. on Soils under Cyclic and Transient Loading, Swansea, 7-11 Jan., 169-177

PARRY, R.H.G. (1965) Shear Strength of Saturated Remoulded Clay, Proc. 6th Int.Con£. Soil Mech.Found.Eng., Montreal, Vol.2, 333-337

PARRY, R.H.G. and AMERASIN , S.F. (1973) Components of Deformationin Clay, Symp. on the Role of Plasticity in Soil Mechanics, Ed. Palmer, A.G., Cambridge, 13-15 Sept., 108-126

PEARCE, J.A. (1970) The Behaviour of Soft Clay in a New True Triaxial Apparatus, Ph.D. Thesis, University of Cambridge

POOROOSHASB, H.B., HOLUBEC, I. and SHERBOURNE, A.N. (1966) Yielding

and Flow of Sand in Triaxial Compression, Part I, Canadian Geotechnical Journal, Vol.3, No.4, Nov., 179-190

PRAGER, W. and HODGE, P.G. (1951) Theory of Perfectly Plastic Solids, John Wiley and Sons, New York

PREVOST, J.H. (1979) Mathematical Modelling of-Soil Stress-Strain- Strength Behaviour, Proc. 3rd Int.Con£. Numerical Methods in Geomechanics, Aachen, Vol.l, 347-361

RANDOLPH, M.F., CARTER, J.P. and WROTH, C.P. (1979) Driven Piles in

Clay - The' Effectsof Installation and Subsequent Consolidation, Geotechnique, Vol.29, No.4, Dec., 361-393

RENDULIC, L. (1936) Relation Between Void Ratio and Effective Principal Stresses for a Remoulded Silty Clay, Discussion, Proc.Itn.Conf. Soil Mech.Found.Eng., Vol.3, Cambridge, Mass., 48-51

ROSCOE, K.H. and BURLAND, J.B. (1968) On the Generalised Stress-Strain Behaviour of 'Wet' Clay, Engineering Plasticity, Ed. Heyman, J. and Leckie, F.A., Cambridge University Press, 535-609

ROSCOE, K.H., SCHOFIELD, A.N. and WROTH, C.P. (1958) On the Yielding of Soils, Geotechnique, Vol.8, No.l, Mar., 22-53

ROWE, P.W. (1962) The Stress Dilatancy Relation for Static Equilibrium of an Assembly of Particles in Contact, Proc,Roy.Soc., Series A, Vol.269, 500-527

ROWE, P.W. and BARDEN, L. (1964) The Importance of Free Ends in Triaxial Testing, Proc.ASCE, Jour. Soil Mech.Found.Eng.Div., Vol.90, No.SMl, 1-27

SARSBY, R.W. (1978) The Deformation Behaviour of Particulate Media Subjected to Constant Stress Ratio Paths, Ph.D. Thesis, University of Manchester

SCHOFIELD, A.N. and WROTH, C.P. (1968) Critical State Soil Mechanics, McGraw Hill, London

SOKOLOVSKII, V.V. (1965) Statics of Granular Media, Pergamon, Oxford TATSUOKA, F. and ISHIHARA, K. (1974) Yielding of Sand in Triaxial

Compression, Soils and Foundations, Vol.14, No.2, June, 63-74

TAYLOR, D.W. (1948) Fundamentals of Soil Mechanics, Wiley, New York

TERZAGHI, K. (1943) Theoretical Soil Mechanics, Wiley, New York TIIORNTON, C. and BLACKBURN, D.J. (1980) Yield Conditions for Body

Centered Tetragonal Arrays, Internal Report, SM1080, Dept. of Civil Eng., University of Aston, Birmingham

TIIURAIRAJAH, A. (1961) Some Shear Properties of Kaolin and of Sand, Ph.D. Thesis, University of Cambridge

VALANIS, K.C. (1971) A Theory of Viscoplasticity Without a Yield Surface, I and II, Archives of Mechanics, Vol.23, No.4, 517-551

VANEEKELEN, H.A.M. and POTTS, D.M. (1978) The Behaviour of Drammen Clay Under Cyclic Loading, Geotechnique, Vol,28, No.l, Mar,, 173-196

WOOD, D.M. (1974) The Mechanical Behaviour of Kaolin, Ph.D. Thesis, University of Cambridge

WROTH, C.P. (1977) The Predicted Performance of a Soft Clay Under a Trial Embankment Loading Based on the Cam-Clay Model, Finite Elements in Geomechanics, ed. G. Gudehus, John Wiley and Sons, London, 191-208

WROTH, C.P. and HOULSBY, G.T. (1980) A Critical State Model for Predicting the Behaviour of Clays, Proc.NSF/NSERCNorth AmericanWorkshop on Plasticity and Generalised Stress-Strai·n Modelling of Soils, Montrea,1 May 28-30

WROTH, C.P., RANDOLPH, M.F., HOULSBY, G.T. and FAHEY, M. (1979)

A Review of the Engineering Properties of Soils with Particular Reference to the Shear Modulus, CUED/D-Soils TR75, Cambridge University

WROTH, C.P. and ZYTYNSKI, M. (1977) Finite Element Computations Using an Elasto-PlasticSoil Model for Geotechnical Problems of Soft Clay, Proc. 9th Int.Con£. Soil Mech.Found.E.n,gComputers in Soil Mechanics: Present and Future, Tokyo, July, 193-243

YONG, R.N. and SILVESTRI, V. (1977) Plastic Yielding of a Sensitive Clay in True Triaxial Testin,g Proc. 9th Int.Con£. Soil Mech. Found.Eng., Constitutive Equations for Soils, Session 9 , Tokyo, 271-277

ZIEGLER, H. (1975) Non-Linearityin Thermomechanic,s Int.Jour. of Non-Linear Mechanics, Vol,10, 145.154

ZIEGLER, H. (1977) An Introduction to Thermomechanics, North-Holland, Amsterdam zyTYNSKI, M., RANDOLPH, M.F., NOVA, R. and WROTH, C.P. (1978) On

Modelling the Unloading-Reloading Behaviour of Soils, Int.Jour. Numerical and Analytical Methods in Geomechanics, Vol,2, No.1, Jan., 87-93

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24	H. S. Yu, S. M. Tan, F. Schnaid. "A critical state framework for modelling bonded geomaterials", Geomechanics and Geoengineering, 2007	CROSSREF	<1%
25	Poul V. Lade. "Rotational kinematic hardening model for three-dimensional stress reversals in sand", International Journal for Numerical and Analytical Methods in Geomechanics, 2008	CROSSREF	<1%
26	University of Hong Kong on 2017-06-25	SUBMITTED WORKS	<1%

27	Yuanxue Liu, Yingren Zheng. "Plastic Mechanics of Geomaterial", Springer Science and Business Media LLC, 2019 CROSSREF	<1%
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32	www.roseschool.it INTERNET	<1%
33	Behaviour of Granular Materials, 1998. CROSSREF	<1%
34	Collins, I.F.. "A systematic procedure for constructing critical state models in three dimensions", International Journal of Solids and Structures, 200308 CROSSREF	<1%
35	Engineering Computations, Volume 18, Issue 1 (2006-09-19) PUBLICATION	<1%
36	Georgetown University on 2019-04-16 SUBMITTED WORKS	<1%
37	Gerd Gudehus. "Physical Soil Mechanics", Springer Science and Business Media LLC, 2011 CROSSREF	<1%
38	Hashiguchi, K.. "Extended yield condition of soils with tensile yield strength and rotational hardening", International Journal of Plasticity, 200712 CROSSREF	<1%
39	Mohammad M. Eslami, Scott J. Brandenberg, Daniel Pradel, Maria Esteva. "Yield Surface Mapping and Triaxial Compression Test Data Curation", IFCEE 2018, 2018 CROSSREF	<1%
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A study of theories of plasticity and their applicability to soil under environmental factors.

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Abstract:

In addition to a general overview of soil rate autonomy hypotheses, a more in-depth look of soil pliancy speculations is provided. Particle mechanics' obligations are summarized in a few paragraphs. Sections 2 and 3 of the study are broken up into hypothetical and trial investigations of the pliancy hypothesis' application to soils. Addendums contain further information. Various types of tests are described to determine whether or not the hypothesis of generalizability is supported by the data available for trial. A programme of pressure cycle tests and an LS plot were used to examine the effects of pressure and stress history on a thick sand in triaxle pressure. Additionally, a PC-controlled triaxle test machine is depicted with details on the data logging and control framework, as well as the example preparation system. The examination strategy for the exams is described, including a method for fitting versatile and plastic qualities to the data. The outcomes of the experiments are explained. Pressure and stress history influence the anisotropy of flexible characteristics. When emptying, the plastic qualities were carefully monitored to ensure that they did not override the historical significance of their historical subordination. Finally, a few loose ends from the hypothetical and trial work are tied together, and a few ideas for further research are recommended. An emphasis is placed on the thermo mechanical technique to depicting soil.

Keywords: Soil, Behavioral Study, Environmental Effects on Soil

INTRODUCTION

The breadth of this explanation plot and the topic of hypothetical soil models are both introduced at the outset. This is followed by a more detailed examination of the various rate-free hypotheses for soils, which is then followed by a final clarification of the terminology to be used. There are some antecedents to the thermo mechanical study in the next chapter, which sums up the possible commitments of particle mechanics. Internal variables are discussed, as well as kinematic variables as well as associated conjugate forces. New formalism for expressing plasticity theories is presented in this work, employing a thermodynamics-based method for the description of materials. The theoretical constraints typically imposed upon plasticity theory is explained, and their extremely restrictive character for soils is noted. The existence of a yield locus is investigated in relation to rate-independent materials. Examples of elastic plastic models are given, and the incorporation of the effects of pore fluid is examined in relation to the idea of effective stress.

METHODOLOGY

Theoretical Models for Soils: The investigation of hypothetical models for soils is currently more than 200 a long time old, dating from the examination of the disappointment of a dirt mass by Coulomb in 1773 (see Heyman (1972». The mechanical conduct of soils is still, notwithstanding, a long way from being appropriately seen, in any event, for the most straightforward of lab arranged materials. The use of versatility hypothesis to soils, a subject which has been concentrated broadly during the last quarter of a century, is still consequently a theme which must be analyzed basically. The subject of hypothetical soil mechanics might be around separated into two fields, the characterization of the dirt (the investigation of constitutive relations) and the arrangement of limit esteem issues; this exposition is altogether worried about

the previously the subject of constitutive relations it is first important to recognize cautiously bovine three locales of study. The first is the investigation of the conduct and properties of the genuine material: for instance, the exploratory estimation of the variety of the shear modulus of a sand. The subsequent field is the investigation of the materialness of a specific hypothesis to a dirt in the above model the inquiry wouldemerge with respect to whether a flexible shear modulus sensibly spoke to the conduct of the soil inside the scope of intrigue. The third subject is the investigation of the hypothesis itself: it might be the situation forexample that any appropriately communicated hypothesis utilizing a variable shear modulus must conformto certain basic hypothetical conditions. The three subjects have been presented backward request from theconsistent methodology by and by a hypothesis must be appropriately figured first, its materialness to soilssurveyed lastly the properties for singular soils decided. The subjects concentrated in this thesis identify with the best possible definition of pliancy speculations, and the evaluation of the reasonableness of these speculations for soils. The investigation of the hypothesis itself is essential on the grounds that tragically numerous models for soils are either deficient or conflicting with the standards of continuum mechanics. Different hypothetical standards must be fulfilled before any investigation of the value of a hypothesis in its application to soils. The convenience of a model is accentuated since in picking a hypothetical romanticizing of a dirt one isn't in every case principally concerned with exactness: the best model for tackling a designing issue isn't essentially that which most intently fits the pressure strain bend for the picked research center or field tests. Soil is an exceptionally intricate material, and any model which accomplishes a serious extent of exactness is likely likewise to be complex. A more straightforward model may have preferences which may exceed any misfortune in exactness; for example, the utilization of directversatility permits the use of numerous standard answers for stresses and relocations. Complex models additionally have the disservice that they may include numerous boundaries and capacities which are hard to decide, and might be of obscure centrality if the conditions in the genuine issue withdraw in any route from those from which the model was determined.

Plasticity Theories for Soils: As of late the quantity of hypothetical models for soils either utilizing thorough pliancy hypothesis or put together more freely with respect to the ideas of versatility has expanded massively. Any survey should essentially be profoundly specific, and in the accompanying most accentuation is set on the advancements identified with the basic state models, on which consideration at Cambridge has been chiefly focused. Pliancy hypothesis was grown at first for the investigation of malleable metals, and first included the utilization of immaculate versatility (for example Prager what's more, Hodge (1951)) in which the yield locus is fixed in pressure space and is along these lines indistinguishable from the disappointment locus. Immaculate versatility has found much application to the issue of the disappointment of soils, mainly through the utilization of the upper and lower bound hypotheses. The hypothesis is especially valuable in contemplating the undrained conduct of dirt (which might be treated as an absolutely strong material). Despite the fact that the bound hypotheses are extensively debilitated for a frictional material with a no associated stream rule (Drucker (1954», versatility hypothesis has additionally been applied with progress to frictional materials (for example the pressure field arrangements created. by Sokolovskii (1965». While valuable in the investigation of the disappointment ofa dirt, great versatility isn't so appropriate for the investigation of the advancement of displacements under working burdens and before disappointment is reached. For this application a work solidifying hypothesis of pliancy is fundamental. An "extended Von Mises" cone-like yield locus was first subjectively depicted by Drucker et al. (1957), who advised a round work solidifying top for soils. Despite the fact that a few following models appear to be equivalent to this model, the model was weak and did not achieve a complete combination of soil conduct. A similar time, Roscoe and his colleagues (1958) effectively consolidated the opinions of a remarkable surface for typically united dirt in (p',q, V) space, the standardisation of earth behaviour as for reactivating pressure (following Hvorslev (1936»), and an expansion of the possibility for a basic state line in (p,q,V) space to that of the basic state line in (p,q,V), all at the same time. V u explicit volume by Schofield and Wroth (1968) provides definitions of p' and q. When a "flexible partition" (which is basically a declaration of flexible isotropy) crosses over a "state limit surface" for generally solidified soil (the

It was eventually discovered that the Roscoe surface (Calladine (1963)». Using Drucker's solidity theory, it is possible to recognise this as a yield locus, which is similarly well-suited to that provided by the crossing point of the flexible divider and, moreover, the Roscoe surface. Separately, one may coordinate a working condition similar to that of Taylor (1948). Finally, the Cam-Clay model of Schofield and Wroth (1968) was able to combine all of the foregoing ideas into a single model that was adequate for the triaxle test. Work conditions are coordinated to provide a plastic potential, and ordinariness is accepted to provide more yield. locus. The "versatile divider" and work solidifying law are defined by the combination conduct (using an obvious exact connection). The "State Boundary Surface" naturally includes the "Critical S ta te" and the yield surface. To a great extent, it not only fits but also clarifies the behaviour of fine dirt. The model's conduct is primarily correct in terms of quality, such as the depiction of the variety of un - drained quality with an over-consolidation proportion. In this model, a small change in the flow rule and an increase of the shear modulus result in a well-suited model for calculation using the Finite Element Method.

While valuable for demonstrating the stacking of delicate muds the basic state models are less reasonable for over consolidated materials, or then again for emptying or inversion of stacking on delicate materials. The stacking of firm soils shows a work solidifying conduct clearly connected to a yield locus taking around the cone shaped structure utilized by Drucker et al. (1957). This has offered ascend toa progression of "top models" utilizing a blend of the funnel shaped locus and a solidification "top". The models are chiefly experimental and that by Lade (1977) is a genuine case of the sort. On account of a sandthe funnel shaped locus (in this model a misshaped cone in pressure space) expect gr eater significance thanthe combination conduct. Replenish's model is communicated totally regarding pliancy hypothesis. In receiving a non-associated stream rule and non-moderate flexible conduct it moves a long way from the basic hypotheses where the uniqueness and bound hypotheses apply. Despite the fact that the model may fit test information precisely the legitimacy of any answers for limit esteem issues may consequently be addressed. The Lade model, similar to the Cam-Clay models doesn't fit emptying conduct well. Soils showhysteresis and nonlinear conduct beneath the yield locus, and endeavors to incorporate these impacts have been made Ln assortment of ways. Hueckel and Nova (1979) use for instance a model identified with the top models, yet join a "Para elastic" strain in which the versatile consistence increments with the good waysfrom the last stress inversion point so hysteresis is presented. The type of all emptying bends is comparative,and no "investigation" to versatile conduct I:S conceivable.

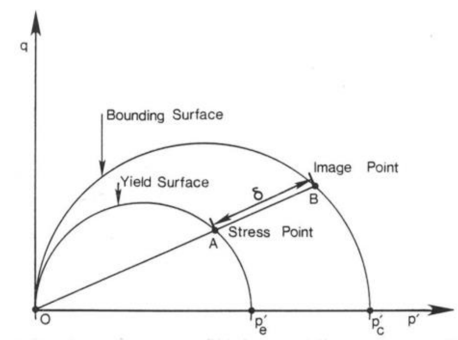

Figure: Yield and bounding surfaces for simplification of model of Dafalias and Herrmann (1980)

The Use of Internal Variables in Plasticity Theory: In the previous Section it was expressed that the condition of a material could be depicted by the historical backdrop of its movement. The powers on the body (which on account of a continuum are the burdens) are viewed as the reaction to changes in the condition of the material. When all is said in done the reaction to a specific change in state will depend not just on the present status, yet in general history of the material. In this manner the stress will depend on thecurrent strain as well as on the strain history too: the pressure is supposed to be a utilitarian of the historicalbackdrop of strain, as opposed to a component of strain. An option in contrast to the useful methodology

~s the utilization of "inside factors". The inward factors are not straightforwardly detectable amounts, yet are advantageous fictions which somehow or another sum up his conservative of the material. A straightforward case of an internal variable is the pre consolidation pressure for an earth. The entire of the past combination history is summarized in a solitary past greatest combination pressure, and the conduct of a dirt component depends both on its present pressure and on the pre consolidation pressure. Another helpful type of an interior variable is the plastic strain, furthermore, in the accompanying Chapters inner boundarieswill all be kinematic (strain like) boundaries. In the basic model appeared in Figure:

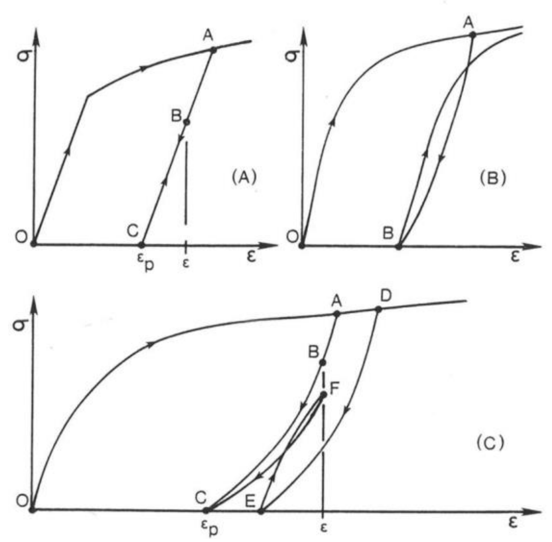

Figure: Unloading-reloading curves and internal variables of an elastic-plastic material with non-linear work hardening the strain E and the plastic strain EP at the point B are sufficient to determine both the stress and the response to all subsequent changes n strain. The strain alone would not be sufficient.

REVIEW OF LITRATURE

Theoretical Restrictions Imposed on Plasticity Theory: Elastic-plastic theories for the behavior of soilsmay either be purely empirical, based on the curve fitting of tests on soils (e.g. the non-linear elastic theoryof Duncan and Chang (1970» or may be based on some mere fundamental postulates which seek to explainthe behavior of the soil as well as to model it (e.g. the Cam-Clay flow rule, Schofield and Wroth (1968».

The two approaches are often combined, and the theory of elastic-plastic materials is able to accommodate an almost limitless variety of models. Questions must arise, however, as to whether a model is internally consistent or whether additional limitations must be imposed on plasticity theory.

Certain plainly obvious conditions won't be managed ~n detail here. A model should for example be finished and steady ~n that it ought to decide a reaction for any predetermined pressure or strain way; models appropriately defined regarding continuum mechanics normally fulfill this standard. A second condition that is normally forced ~s that of congruity: that imperceptibly contrasting applied ways result inimperceptibly varying reactions. (This is definitely not an essential law, however, a condition forced on the grounds of a natural way to deal with how materials are required to act.) The definition of pliancy hypothesisby Hill (1950) consequently fulfills progression, yet more expand models must be checked for this condition. The laws of thermodynamics additionally force certain impediments on the manners by which continuum speculations might be communicated. The least difficult model is that of versatility; if a "strain vitality work" doesn't exist, for example the anxieties can't be acquired by the separation of a likely capacity(Equation 1.3. 2), at that point it is conceivable to extricate vitality constantly from the material over numerous cycles and the first law of thermodynamics is abused. Different endeavors have been made to apply thermodynamics to restrict the potential types of plastic conduct, with Drucker's steadiness hypothesize (Drucker (1951)) being maybe the most popular restriction of this sort. Drucker's propose isn'tan announcement of the second law of thermodynamics, in spite of the fact that the two give off an impression of being hastily comparative; it is in this manner viewed as a "semi thermodynamic" order of materials. The hypothesize has been expressed in an assortment of comparable ways, yet speaks to the possibility that if a material is in a given condition of stress, and an external agency applies additional stresses, then "The work done by the external agency on the displacements it produces must

be positive or zero" (Drucker (1959».

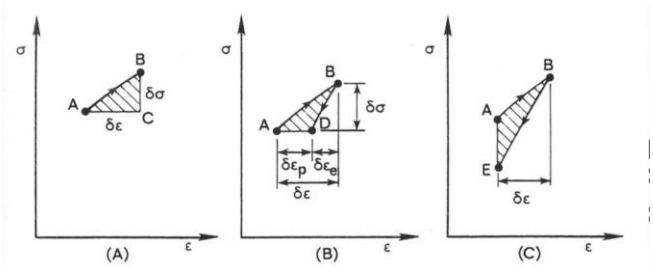

Figure: Stress and strain cycles for the postulates of Drucker

The Need for a Less Restrictive Approach: From Drucker's postulate it is possible to prove the uniqueness of incremental response for the stress and strain rates of an elastic plastic material under givenchanges in applied boundary forces and displacements (Drucker (1956)). The importance of a single solution existing for a given problem is obvious. Other corollaries are the upper and lower bound theorems which allow the exact solution for the ultimate loads on perfectly plastic materials to be closely bracketed by simple methods. If a non-associated flow rule is allowed the theorems are so much weakened as to renderthem virtually useless in many cases (Drucker (1954)).

The major motivation in seeking a new approach to theoretical restrictions on plasticity theory is to establish a formulation which satisfies the laws of thermodynamics, but also allows the non-associated flow observed in soils. In the conventional approach plasticity theory is developed from a series of assumptions (e.g. the existence of a yield locus) and the limitations discussed above then applied to the theory. In the following Chapter an alternative approach is made in that a formulation is derived starting from the laws of thermodynamics and therefore includi.ng them as an integral part. In its form for rate independent materials the new formulation gives rise to herioes of the elastic-plastic type. The new approach can, however, accommodate non-associated flow. By founding the formulation on a few simple assumptions it is hoped that it will lead to theorems such as that of uniqueness of incremental response and modified forms of the bound theorems. As first steps in this direction some corollaries of the formulation are presented, e.g. the existence of a yield locus.

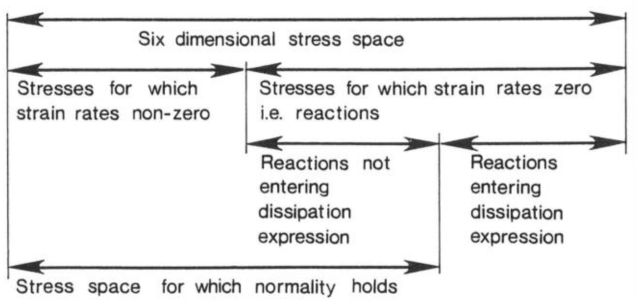

Figure: Schematic diagram showing the stress space for which the normality rule for a rigid-plastic material will apply

The CamrC1ay Models: The "Cam-Clay" hypothetical model for soil conduct was portrayed bySchofie1d and Wroth (1968). The model is communicated in the hypothesis of pliancy and depends on straightforward theories for the capacity and dissemination of vitality, the idea of "dependability" as characterized by Drucker (1959) and an exact connection for the weight explicit volume conduct of a delicate earth. The model effectively consolidates the combination and shearing behavior of muds inside asolitary system, however it isn't ent ~ re1y acceptable in the entirety of its forecasts. One eminent imperfection is the forecast of unreasonably enormous shear strains for solidification at little pressure proportions, with this impact being because of the sharp state of the yield locus-. This impact was wiped out by the presentation of a-somewhat unique theory for the dispersal of vitality by Roscoe and Burland (1968), coming about in the "Adjusted Cam-Clay" model.

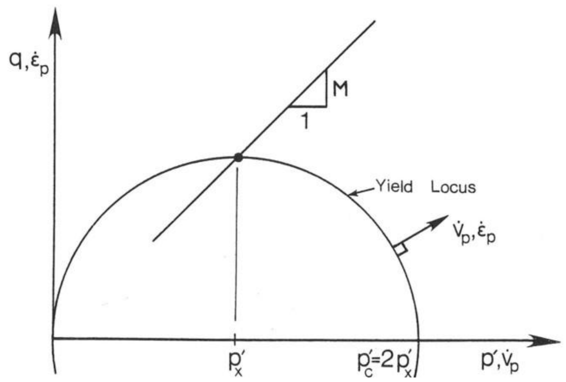

Figure1: Modified Cam-Clay yield locus triaxial stress space, flow rule

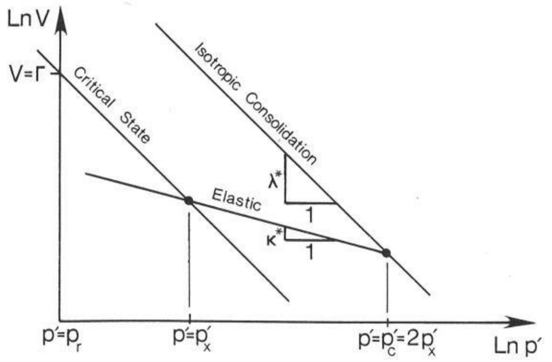

Figure2: Consolidation and swelling lines for Modified Cam-Clay

METHODOLOGY OF IMPLEMENTATION

The force input articulation has been shown to contain only the two terms mentioned above. As a result of the successful worry with the strain rate and the (negative) excess pore pressure angle with the fake drainage speed, a straightforward articulation for force input per unit volume continues to apply in the case of limited distortion rate and leakage. (The negative sign is mostly the result of the sign showing the inclination of abundant pore pressure.) An alternative translation of the standard of compelling pressure can be obtained from this result. If the Terzaghi definition of high pressure is taken into consideration, it is clear that the total rate of work input per unit volume of dirt is given by the terms "(1ij's ij) and "(- U,/IVJ)". They can be decoded as two different cycles, one for dirt and one for pore liquid, and there is no linkage between these two cycles of twisting of the dirt skeleton, as well as leaking. If there is no coupling between the work contribution to the dirt skeleton and to the pore liquid, then the force input per unit volume to the soil skeleton is supplied consistently by the result of the viable worry with the strain rate, as shown in the figure. When Terzaghi's description of the mechanical conduct is taken into account and the cycles for twisting and leakage are uncoupled, the mechanical conduct of the skeleton will be determined by the viable worry as defined by Terzaghi. The guideline of inciting worry in phrasing of continuum mechanics is given an elective understanding here, but no statement is provided as to whether soil would be required to comply with the rule and subsequently show the. Uncoupling of work terms. Particulate mechanics (especially Bishop, 1959) and a wide collection of trial evidence support any avocation of this guideline of successful soil concern. A new translation of continuum mechanics, however, is that the standard of successful pressure serves as a guideline for the contribution of mechanical labour to the dirt skeleton as well as to the pore fluid.

HOMOGENEITY OF RESPONSE

It is usually assumed without question in plasticity theory that the response of a continuum will remain homogeneous; and this assumption has been made throughout all other parts of this dissertation. A criterionfor the homogeneity of response can, however, be established within the thermodynamic framework, and is examined briefly in this The equilibrium state of a system in thermal contact with a heat reservoir at constant temperature is such that the free energy a minimum. The use of a minimum free energy criterion is not appropriate to other conditions (e.g. adiabatic or isentropic) and so the following analysis is appropriate only to the isothermal case, which represents a reasonable approximation to the conditions in soil mechanics problems. Ziegler's formulation requires an explicit statement of the free energy expressionsfor either internal energy extend the minimum energy criterion to other conditions. The minimum free energy condition is used into establish the criterion for plastic loading or unloading. It is here adapted as acriterion for homogeneity of response: if a non-homogeneous mode of deformation can result in a lower free energy than homogeneous deformation, then this non-homogeneous mode will occur. The mode of bifurcation into non-homogeneous deformation which is studied is the case where a homogeneous materialsplits into a series of infinitesimally thin layers of material undergoing alternatively elastic and plastic deformation; the filming discussion is therefore only relevant to a material in which the stress point is on the yield locus. Only bifurcation from an initially homogeneous state is considered. The proportion of the material which behaves elastically is an and that Hitch behaves p1astically is (l-a) (see Figure B.1).

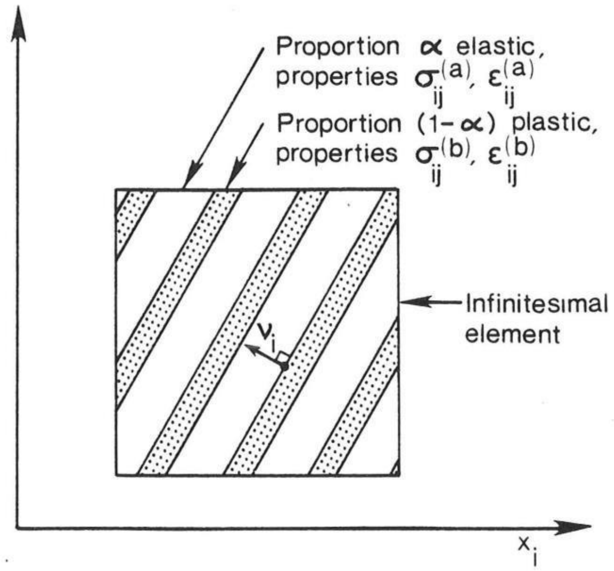

Figure B.1 Mode of bifurcation into non-homogeneous deformation

CONCLUSION

Some general conclusions are drawn from the evidence presented in the preceding Chapters. The mostimportant points are reemphasized and some suggestions for future developments made.

The Use of Thermomechanics in Soil Hodelling: The thermomechanica1 approach to plasticity theorydeveloped in a promising method for the description of soil behavior. In particular, it has achieved the primary objective of developing a formulation which guarantees thermodynamic admissibility, whilst allowing the description of "non-associated" plastic flow. The rigorous development of thermomechanicalmethods in continuum mechanics is not under scrutiny here, but a brief comment may be made on thevalidity of the theories. At the very least the methods described in this dissertation represent a restrictedclass of materials, somewhat wider than those classes 1imi ted by the postu1ates of Il'iushin and Drucker,and the relevant question becomes whether soils approximately reasonably to materials in this class. Theuse of an extremum principle, Zieg1er's "orthogona1ity principle" is central to the development of thethermomechanica1 approach. Although regarded by some as controversial, the principle is linked to certain well established ideas, for instance the reciprocity relations of Onsager (Zieg1er (1975)). Whilst manyformulations make use (directly or indirectly) of extremum principles, some specifically exclude them. The rigid-plastic model of de Josse1in de Jong (1977) for instance makes use only of a weaker dissipationinequality. The resulting model therefore has an additional degree of freedom, and for many problems yieldsa range of possible solutions rather than a single solution. This sort of model in which the initial and boundary conditions play a greater role in determining the subsequent response, represents a differentphilosophy from that used throughout this dissertation in which the constitutive relations provide a completeframework for determining the response. Much further investigation is required to establish whether the simplifications introduced by the use of an extremum principle are just tidied. An important result of the formulation, related directly to the choice of a limited number of internal variables, was the existence of adistinct yield locus in stress space. Whilst acceptable for a small number of loading cycles this assumptionis expected to lead always to "shakedown" to elastic conditions after many cycles, and so this approachmay be inappropriate for the analysis of cyclic behavior. A limited normality relationship was proven for rigid-plastic materials, and normality conditions also noted for some specific plasticity models. The proofof normality and convexity conditions is an essential preliminary to the establishment of any bound theorems, and seen as an important subject for future study. If sufficient generality is to be achieved this will involve work mainly in applied mathematics rather than soil mechanics.

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Anoop Narain Singh of Rajkiya Engineering College in Azamgarh and **Late Dr. Syed Tabin Rushad** of Birla Institute of Technology in Patna Mesra who passed away due to Covid19 in the year 2021 are two of my mentors and I would like to show my sincere gratitude to them. This project would not have been possible without their constant interest in, support, and advise. Their insightful advice and timely feedback on my work gave me the push I needed to finish my Ph.D. with flying colours..

REFRENCES

1. WROTH, C.P. (1977) The Predicted Performance of a Soft Clay Under a Trial Embankment Loading Based on the Cam-Clay Model, Finite Elements in Geomechanics, ed. G. Gudehus, JohnWiley and Sons, London, 191-208

2. WROTH, C.P. and HOULSBY, G.T. (1980) A Critical State Model for Predicting the Behaviour of Clays, Proc.NSF/NSERC North American Workshop on Plastici ty and Generalised S tress-S train

3. Modelling of Soils, Montreal, May 28-30

4. WROTH, C.P., RANDOLPH, M.F., HOULSBY, G.T. and FAHEY, M. (1979) A Review of the Engineering Properties of Soils with Particular Reference to the Shear Modulus, CUED/D-Soils TR75 , Cambridge University

5. WROTH, C.P. and ZYTYNSKI, M. (1977) Finite Element Computations Using an Elasto-Plastic Soil Model for Geotechnical Problems of Soft Clay, Proc. 9th Int.Conf. Soil Mech.Found.Eng., Computers Ln Soil Mechanics: Present and Future, Tokyo, July, 193-243

6. YONG, R.N. and SILVESTRI, V. (1977) Plastic Yielding of a Sensitive Clay in True Triaxial Testing, Proc . . 9th Int.Conf. Soil Mech. Found.Eng., Constitutive Equations for Soils, Session 9,

7. Tokyo, 271-277

8. ZIEGLER, H. (1975) Non-Linearity in Thermomechanics, Int . Jour. Of Non-Linear Mechanics, Vol.10, 145 . 154

9. ZIEGLER, H. (1977) An Introduction to Thermomechanics, North-Holland, Amsterdam

10. ZYTYNSKI, *M.*, RANDOLPH, M.F., NOVA, R. and WROTH, C.P. (1978) On Modelling the Unloading-Reloading Behaviour of Soils, Int.Jour. Numerical and

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COASTLINE CHANGES ANALYSIS IN SIR CREEK REGION, GUJARAT COASTLINE BORDERING PAKISTAN

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KEY WORDS: Coastline extraction, TM & ETM+ sensors, reclassification, band ratios, Sir creek region, coastline changes.

ABSTRACT:

96 kilometres of the Run of Kutch swamplands are claimed by India and Pakistan as the "Sir Creek" waterway. As time went by, Sir Creek's path changed dramatically. It has been argued that Sir Creek's location has been shifted by water erosion by 1.5 kilometres eastward. Sir Creek, which separates India and Pakistan, acts as a natural border. Oil and gas reserves in the area could be significant, thereby improving the country's overall energy security. A total of 20 Landsat-5 pictures spanning the years 1988 to 2017 have been used in this investigation. Before processing these Landsat images, they were radio metrically as well as geometrically corrected to cover the whole study area. Between 1988 and 2017, coastal alterations were evaluated, and the results showed that the shoreline has degraded. Band-5 pictures were classed and a second set of binary images was generated using the band ratio method to analyse the shoreline alterations. Finally, the total land and water area, as well as the changes in the shoreline, were determined. 30.70 percent of the land area has degraded and 28.40 percent of the water area has expanded in the previous 20 years, according to the findings of this study. However, it continues to deteriorate. When contrasted to ground survey as well as many remote sensing approaches, the known pattern of coastline alteration returned by reclassification was almost congruent with these studies.

1. INRODUCTION

In the coastal zone, land and sea, as well as lithosphere, hydrosphere, atmosphere and biotic spheres interact. The meeting point of coastline as well as coastal waters is referred to as the coastline. The coastline is influenced by waves, tides, winds, storms, sea level rise, erosion as well as deposition processes, and human activities. When you look out to sea, you can see the most recent changes to the coastline. Because the loose granular sediments are continually responding to the ever-changing waves and currents, they can alter the coastline's morphology and develop various coastal landforms [3].

From 1927 until 1980, aerial pictures were the only resource of coastal mapping. In order to map the shorelines of a region, a large number of aerial photographs are needed (Lillesand, et al., 2004). As a result of this labor-intensive process, creating a map from pictures is both time-consuming and expensive. Additionally, there are a myriad of other drawbacks of using black and white photos, such as: The difference among land and water in panchromatic pictures is low, especially in murky or muddy water. In order to use them, you'll need to have them digitally converted from their original format.

The low cost and great precision of remote sensing data could be used to monitor changes in the coastal zone, along with the coastline. It has been over 40 years since Landsat and other remote sensing satellites began producing digital imagery in infrared spectral bands with clearly defined land-water interfaces. It is thus possible to utilise remote sensing images and image processing techniques that can help with land and water segmentation and some of the difficulties associated with producing and updating shoreline maps. Images from different bands of Landsat-5 TM and Landsat-7 ETM+ are used to get the coastline changes and present them in this study. A variety of ArcGIS 10.2 software tools were employed in the process of analysing imagery.

2. STUDY AREA

The Sir creek region, Gujarat coast, India, is the focus of this investigation. India and Pakistan are separated by Sir stream, a natural border. At 23°56'45.48"N and 23°40'21.49"N, longitudes of 68° 9'41.69"E and 68°21'3.38"E, the Sir Creek region is located. Located in the Rann of Kutch, Sir Creek is a 96-kilometer tract of water claimed by India and Pakistan. Formerly known as Ban Ganga, the village of Sir Creek was given its current name in honour of a British representative. Near the mouth of the Creek, which roughly divides Gujarat's Kutch region from Pakistan's Sindh Province, the Arabian Sea opens up to the world's largest ocean. Until it reaches India's land borders, Pakistan claims the entire water stream, while India claims half of the channel with a division in the middle, stating that the subject should be addressed in accordance with international riverine system regulations. After numerous discussions, the problem has still to be resolved since neither one is willing to give ground on their viewpoint. As a result of the potential for large quantities of oil and gas to be found in the area, the issue has taken on greater importance. A further breakdown in negotiations is now inevitable. For India's defence, India employs the Thalweg legislation. River boundaries across two states can be divided by the mid-channel when both states agree. The theory that Sir Creek is a tidal estuary does not apply in this circumstance, says Pakistan, notwithstanding its acceptance of the 1925 map [8]. Refuting Pakistan's claims are the fact that Sir Creek is navigable at high waves, that the Thalweg principle is used to delineate some international maritime boundaries, and that fishing boats use Sir Creek to reach the open sea. Additionally, Pakistan is concerned that Sir Creek's trajectory has changed dramatically. Water erosion may have shifted Sir Creek by 1.5 kilometres eastward, according to some estimates. If the present channel is used to determine the boundary line, Pakistan and India will both lose small swaths of wetlands topography that were once part of their respective countries.

Figure 1. Location of Study Area on Google image

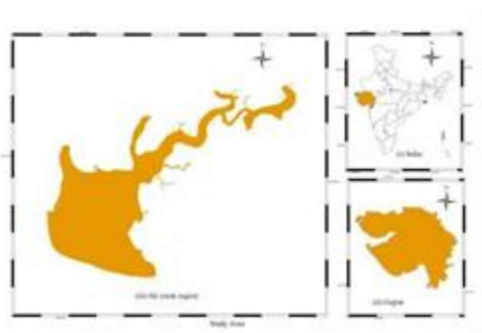

Figure 2. Location map for the Sir creek area

3. MATERIALS USED AND METHODOLOGY

3.1 Data Used

Three Landsat-5 TM images and five Landsat-7 ETM+ images from the years 1988, 1995, 1998, 2004, 2007, 2010, 2014, and 2017 were used in this study's analysis. The pictures containing path-152 row-43 and path-151 row-44 were geometrically corrected and blended using the capability in ArcGIS 10.2 programme to create a final workable image for the study area. Using photos taken at the same time each year (as mentioned above) and under similar tide circumstances, researchers at Sir Creek Regional Center examined the shoreline alterations. Analysis of the data was done using ArcGIS 10.2 software, which was used throughout. Excel was used to create a table and graph to show the findings.

3.2 Methodology

There are a variety of methods for extracting the coastline from optical symbols. Even if you just have a photo of one band, you can still eliminate the coastline. While water's reflectance is nearly identical to that of land's infrared group focus, land's reflectance is more notable than water's. If you change the name of the picture to "land and water divided double picture" on the band-5 of the TM or ETM+ symbolism, this can be done. Of the six intelligent TM groups, band 5 in the mid-infrared is the most effective in separating land and water (Kelley, et al., 1998[2]). As turbid water absorbs mid-infrared radiation, Band 5 is the optimum band for land and water division because the solid reflectance of mid-infrared by flora, soil, rocks and other normal characteristics in this range makes Band 5 ideal for this purpose. The beachfront's remarkable land-water link Sir brook area complicates the separation of land and water, especially since it is not an estuary. The transition zone between land and ocean is where the pinnacles live. When pixels and moisture systems from land and water are merged together, the result is an area of change. Reflectance values can be divided into water (poor quality) and land (high quality) if they are broken into two distinct areas (higher qualities). Since land and water can be divided, the renaming process can produce parallel images. Renaming band-5 qualities with an infrared reflectance of zero to one was done to account for the fact that water has very little infrared reflectance. Another approach is to make use of the ratio of bands 4 and 2, as well as bands 5 and 2. Each percentage may be seen in two ways with this method, which makes it easy to separate water from land. For water, there is no reflection from the TM sensors band-5, which has a frequency range of 1.55 nm-1.75 nm (even sloppy water). Soil is addressed by NIR/R > 1, and water is addressed by NIR/R 1. Renaming and band proportion are just two examples of methods used to get a higher degree of precision with the final double image. Pictures obtained by multiplying band-2 by band-5 (band2/band>1) yield a binary1 image, but pictures obtained by multiplying band-2 by band-4 (band2/band4>1) yield a binary2. Additionally, binary1 picture and binary2 picture are multiplied to generate binary3 image. Last picture from and proportionality strategy is Binary3. [5] After that, each year's renamed image is reproduced using a binary3 image from the same year, which was obtained using band proportions. The final images are used to find out what happened. To begin, a region is selected for each field, such as land or water, and the results are then arranged in a dominant sheet to produce a graphical representation. As a result, the final images of each year are converted to vector (polygon) design, allowing the viewer to see how the land has evolved and grown over the course of the year.

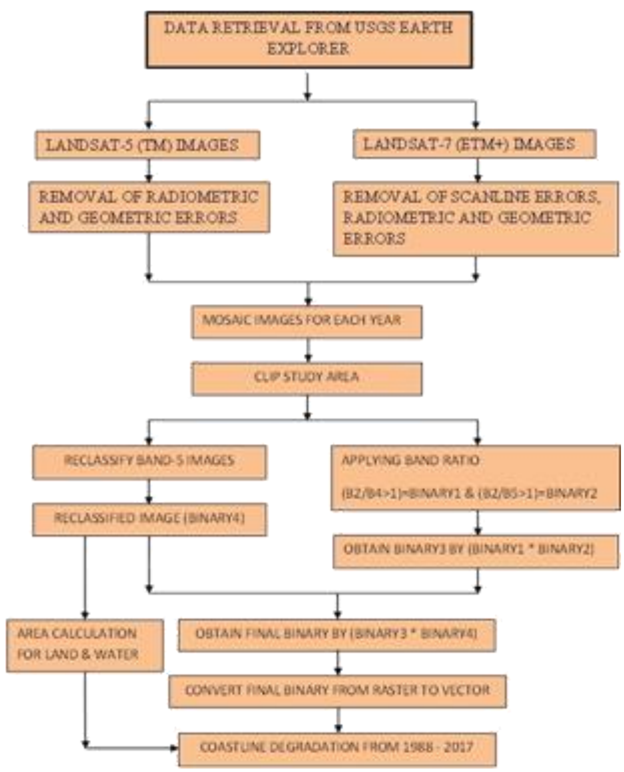

Figure 3. Flowchart for extracting coastline changes from satellite imagery

4. RESULTS

From 1988 to 2017, the coastline saw significant modifications. In the years leading up to and following the year 2014, the deterioration of the coastline was clearly visible and unavoidable.

A modest increase in coastal population in 2014 is possible. In 1988, the land area was found to be approximately 233 km2, which decreased to approximately 181 km2 in 2004 and to approximately 161 km2 in 2017. The results demonstrated that coastal debasement was discovered in the chosen research area. The issue is illustrated in fig (7). Also shown in vector (polygon) design are the results of this study's coastal modifications in fig. (4), fig. (5), and fig (6). Band-2, band-4, and band-5 Landsat images The target of 30m*30m provided clear data concerning land and water when paired structure was implemented. It was easy to distinguish between land and sea. Based on pixel checks, land and sea areas were estimated. A field was added to the property table for each quality, for example, land and water, which gave the region for each. Table 1 shows the calculating method and the resulting data (1). A single pixel with a 30m*30m goal will cover a 900m2 area.For calculation of area:

Land area = (land pixel count * 0.0009) km²:

Year	Land Area km²	Water Area km²	Land Erosion Area	Accretion Area
1988	233.2	319.6	-	-
1995	225.5	327.3	7.7	-
1998	198.4	354.4	27.1	-
2004	181.9	370.9	16.6	-
2007	182.1	370.7	0.3	-
2010	162.8	391.0	19.2	-
2014	182.0	370.8	-	20.4
2017	161.6	391.2	19.3	-

Table 1. Land & water statistics for Sir creek region

5. DISCUSSION AND CONCLUSION

India and Pakistan share a border along the Sir rivulet in Gujarat, which serves as a dividing line between the countries. Imagery acquired by Landsat 5 and 7 throughout the course of 20 years, from 1998 to 2017, for the same season each year, from 1988 to 1995 to 2004 to 2007 to 2010 to 2017. Mathematics and radiometrics were used to correct this data. During the past 20 years, 30.70 percent of the land area was demolished and 22.40 percent of the water area grew. Two different methods were used to examine the coastline's position changes between 1988 and 2017. Renaming band 5 is one option, while mixing renaming with band proportion is another. All the land and water limits for each year were converted from raster data to vector data. According to the results, the Sir Brook district's coastline has shifted closer to the land. Between 1995 and 1998, the land area decreased by around 27 km2 and increased by by 20 km2 between 2010 and 2014. Further studies are clearly needed to identify the progressions in shoreline modifications of this challenged regular border, which is crucial from an economical and business point of view for both domains. However,

REFERENCES

1. Alesheikh A.A., Ghorbanali A., Nouri N. (2007) Coastline change detection using remote sensing of Urmia Lake. *Int. J. Environ. Sci. Tech*., 4 (1): 61-66, 2007.

2. N. Baghdadi, R. Pedreros, N. Lenotre, T. Dewez, M. Paganini. "Impact of polarization and incidence of the ASAR sensor on coastline mapping: example of Gabon", International Journal of Remote Sensing, 2007.

3. Z. Umar, W. A. A. W. M. Akib, A. Ahmad. "Monitoring shoreline change using Remote sensing and GIS: A case study of padang coastal area, Indonesia", 2013 IEEE 9th

4. International Colloquium on Signal Processing and its Applications, 2013.

5. Elkoushy A.A. and Tolba R.A. (2004). Prediction of shoreline change by using satellite aerial imagery.

6. *Proceeding of the XX ISPRS Congress. Istanbul*, Turkey.

7. Kumaravel S., Ramkumar.T, Gurunanam.B, Suresh.M (2012), Quantitative estimation of shoreline changes using remote sensing and GIS A case study in the parts

of Cuddalore district, East coast of Tamil Nadu, India. *International journal of environmental sciences*, Volume 2, No 4, 2012.

8. Masria A., Nadaoka K., Negm A. and Iskander M. (2015) Detection of Shoreline and Land Cover Changes around Rosetta Promontory, Egypt, Based on Remote Sensing Analysis. *Land 2015*, 4, 216-230.

9. Misra A. et al. Department of Civil Engineering, IIT Bombay, Powai,Mumbai 400076 India. A study on the shoreline changes and Land-use/ land-cover along the South Gujarat coastline. *Procedia Engineering* 116 (2015) 381 – 389.

10. Mostafa M.M. and Soussa H.K. (2006), Monitoring of LakeNasser using remote sensing and GIS techniques.

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ORIGINAL ARTICLE **OPEN ACCESS**

Industrial Waste (Brackish Sludge) Utilization inNon-Traffic Block Paving

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ABSTRACT

In the present work, brackish water muck is blended in M30 Solid blend of paver squares. A paver is a clearing stone, tile, block or block like bit of solid which is usually utilized as outside deck, pathways and as non-traffic developments. In the processing plants, concrete paver squares are made by pouring a blend of concrete and some extraordinary kind of shading operators into molds of some shape and permitting to set. Various extents of saline solution slop is blended in solid blend and after that tried for designing properties. The Brine slime was gathered from Grasim Industry Nagda. By utilizing inductively coupled plasma nuclear discharge spectroscopy in IIT Powai, components present in muck was resolved. The proposal shows these outcomes that the muck can be used up to 35% in paver squares which have been utilized in non-traffic zones. In the event that over 35% of ooze is added to the paver square blend, at that point it neglects to fulfill compulsory necessity of the IS-15658 code.

Note:*Brackish sludge is an industrial waste generated in chloral alkali industry. ... The present invention thus aims to achieve total utilization of this brine sludge for making functionalized brine sludge material useful for a broad application spectrum.*

Keywords: *Brackish Sludge, Concrete Mix, Non-Traffic, Paver squares*

INTRODUCTION

The fast development of industrialization in India in the ongoing years is the essential element of country's financial advancement. In any case, the opposite side of industrialization has been the genuine harm to the encompassing condition because of the squanders and toxins produced from the ventures. A gigantic measure of squanders has been created through different substance, mining, steel, manure, paper, and mash businesses, out of their generation forms. The inappropriate and uncontrolled dumping of these squanders makes perilous and hopeless harm the surface and ground water, air, and soil and has turned into a matter of genuine worry for the security of condition [4, 5]. Accordingly, the use/reusing of these squanders are very alluring for the maintainable improvement of the economy and for guaranteeing a perfect and safe condition. As increasingly waste makes natural worries of dangerous risk. A conservative practical answer for this issue ought to incorporate usage/reusing of waste materials for new items which thus limit the overwhelming weight on the country's landfills. Reusing of waste development materials spares characteristic assets, spares vitality, lessens strong waste, diminishes water and contaminations and decreases ozone depleting substances [1-3]. The development business can begin monitoring and exploit the advantages of utilizing waste and reused materials. Studies have examined the utilization of adequate waste, reused and reusable materials and strategies. The utilization of swine compost, creature fat, silica smolder, material shingles, void palm organic product bundle, citrus strips, bond furnace dust, fly fiery debris, foundry sand, slag, glass, plastic, cover, tire scraps, black-top asphalt and solid total in development is getting to be well known because of the lack and expanding cost of crude materials.

The examination goes for the usage of saline solution muck in throwing of non-traffic paver squares. The accompanying goals are underscored for this exploration work and are abridged beneath:

- Accumulation of mechanical ooze from Nagda.
- Throwing of paver hinders by blending muck into solid blend in various extents.
- Testing of paver hinders for various building properties

MATERIAL AND METHODS

A-Binding Material (Cement)

Restricting material that sets and solidifies and utilized as a cover for different materials is known as bond. Concrete which is utilized for development purposes can be delegated water powered and non-pressure driven. The most ordinarily utilized bond for development reasons for existing is normal Portland cement.53 grade customary Portland concrete is utilized for the throwing of paver squares. The common Portland concrete is made by completely combining calcareous and argillaceous and additionally other silica alumina or iron oxide bearing materials, consuming them at a clinkering temperature and granulating the clinker to create a cement.(IS 12269).

B-Fine Aggregates

90-100 % of complete totals goes through 4.75 mm strainer is known as fine total.

- Natural sand: Aggregate framed because of common crumbling of shake and stored by streams or ice sheet.
- Crushed stone sand: Aggregate shaped because of pulverizing of hard stones.
- Crushed rock sand: Aggregate shaped because of pulverizing of common rock
- Natural sand is utilized for throwing of paver squares. Reviewing zone for sand is Narmada zone
- Specific gravity of sand going through 4.75 mm strainer is 2.68

C-Coarse Aggregate

90-100% of absolute total held on 4.75 mm strainer is known as coarse total.

As indicated by IS 383 coarse total are:

- Uncrushed rock or stone coming about because of normal deterioration of shake.
- Crushed rock or stone which is consequence of squashing of rock or hard stone.
- Partially squashed rock or stone when it is result of the blending of (An) and (B)

Coarse total which is utilized for paver squares is 10mm total.

D-Water

Water fit for drinking designs is reasonable for making concrete. Water which is utilized for paver squares ought to be free from acids, alkalis or any kind of natural impurities.PH estimation of water ought not be under 6.water which is utilized for blending cement is appropriate for restoring. Anyway water which is utilized for relieving ought not to create any offensive stain or unattractive stores on paver squares.

Water has two capacities in solid blend utilized for paver squares

- Cement and water responds artificially and structure a glue where inactive total are suspended until bond glue is solidified
- It is an oil in the blend of concrete and total

E-Sludge

Thick staple fiber (VSF),a man-made biodegradable fiber with qualities like cotton. VSF regularly utilized in attire, home materials, dress material, weaved wear and non-woven applications. Rayon grade burning soft drink is a significant crude material in VSF generation to accomplish great supply of this substance Grasim set up a rayon grade acidic soft drink unit at Nagda in 1972 with an underlying limit of 33,000 TPa. This has since developed to 452 Ktpa, making it the nation's biggest harsh soft drink unit.

The slop test is secured from Nagda Grasim industry and utilized in paver hinders in various rates. Fundamental constituent of the Brine muck are AL, B, Ba, Ca, Co, Cr, Cu, Fe ,K ,Li ,Mg ,Mn ,Na ,Ni ,P ,S ,Sc ,Si ,Sr ,Ti ,V,Y, Yb ,Zn ,Zr.

These components are resolved utilizing inductively coupled plasma nuclear emanation spectroscopy in IIT Powai.

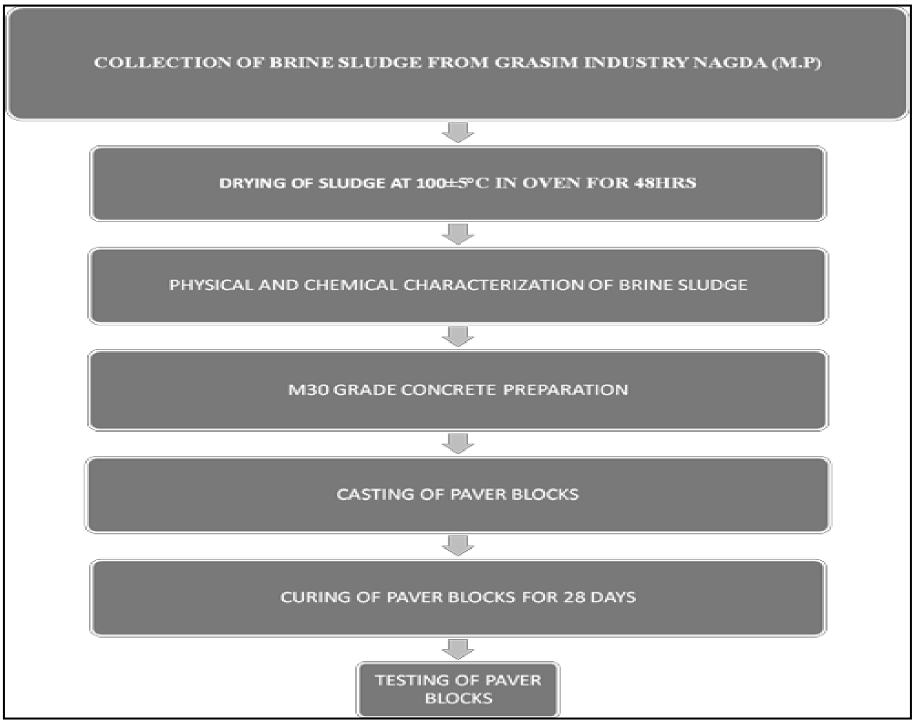

Fig 1: Methodology steps

RESULTS AND DISCUSSION

Table 1: Composition of Paver Blocks (By weight %) &Table 2: Mean thickness of the samples

Sample	Mean Thickness (mm)
Sample-1(S-1)	58
Sample-2(S-2)	59
Sample-3(S-3)	49.00
Sample-4(S-4)	58.00

Sample	Cement	Sludge	Coarse Aggregate	Fine Aggregate
S-1	35	-	50	45
S-2	35	37.5	32.5	35
S-3	35	45	30	30
S-4	35	50	25.5	29.5

Table 3: Comparison between compressive strengths of sample S-1, S-2, S-3 & S-4

Sr. No.	Sample	Average Compressive Strength (N/mm^2)	Percentage decrease in Compressive strength(%)
1	Sample 1(S-1)	49.8	
2	Sample 2(S-2)	35.00	12.95
3	Sample 3(S-3)	36.26	14.4
4	Sample 4(S-4)	30.54	31.24

From above outcomes we can see that compressible quality reductions with increment in the level of ooze. The rate decline from S-1 to S-2 and S-1 to S-3 is less when contrasted with rate decline in S-1 to S-4.Strength of cement relies on a few variables like Ratio of concrete to blending water, Ratio of concrete to totals, the quality of the mortar, the security between the mortar and the coarse total, Grading, surface, shape, quality, and solidness of total particles and Maximum size of total. After expansion of slime in solid, blend proportion of concrete to total reductions just as solidness of total declines. This prompts decline in compressive quality.

Water retention increments with increment in level of ooze . The rate increment from S-1 to S-2 and S-1 to S-3 is less when contrasted with rate increment in S-1 to S-4. It is ordinarily acknowledged that water request and bond content in a solid blend increments as the most extreme coarse total size reductions. The required volume of glue in a solid blend must increment, because of the expanded surface territory of littler total sizes, to coat the majority of the total particles. Comparable Trend of decline in compressive quality and increment in water ingestion were contemplated by MRIDUL GARG and AAKANKSHA PUNDIR "Use of Brine Sludge in Non-basic Building Components: A Sustainable Approach".

In this test examination the compressive quality and water ingestion of paver squares are determined. Four arrangements of paver squares are casted with various level of slop. From the exploratory outcomes and determined estimations of solidarity, the accompanying ends are drawn:

A-Sample-1 (S-1)

In test S-1 muck isn't blended and M30 evaluation cement is readied .M-30 grade paver squares are commonly utilized for non-traffic territories.

- Compressive quality of paver square is 39.8 N/mm^2
- Water retention of paver square is 4.62%

B-Sample-2 (S-2)

In test S-2 27.5% of slop is included. coarse totals and fine totals are supplanted by slime

- Compressive quality of paver square is 35.05N/mm^2. Despite the fact that compressive quality of test S-2 diminishes after expansion of slime yet it fits in with the base furthest reaches of M30 grade paver squares.
- Water retention of paver square is 5.26% which fulfills as far as possible referenced in IS-15658.

C-Sample-3 (S-3)

In test S-3 35% of ooze is included. Regular totals and fine totals are supplanted by muck .

- Compressive quality of paver square is 34.26N/mm^2. Despite the fact that compressive quality of test S-3 diminishes after expansion of ooze yet it adjusts to the base furthest reaches of M30 grade paver squares.
- Water ingestion of paver square is 6.09% which fulfills as far as possible referenced in IS-15658.

D-Sample-4 (S-4)

In test S-4 40% of slime is included. Normal totals and fine totals are supplanted by ooze

- Compressive quality of paver square is 28.54N/mm^2.compressive quality of test S-4 diminishes after expansion of slime and it doesn't fits in with the base furthest reaches of M30 grade paver squares.
- Water retention of paver square is 8.7% which does not fulfills as far as possible referenced in IS-15658.

The 28 days restored bond concrete paver squares of M30 evaluation were tried for fundamental properties which are required for non-traffic paver squares. It was seen that compressive quality declines and water assimilation increments from S-2 to S-4 when contrasted with S-1.However, the properties of S-2 and S-4 fulfills as far as possible referenced in IS-15658 . On other hand test S-4 neglected to pass the base quality paradigm for M30 grade paver squares.

Based on properties of squares and considering the utilization of brackish water slop test S-3 is enhanced i.e 35% of slop can be utilized in blend structure of non-traffic (M30) paver squares. This rate trade may give elective answer for transfer of salt water ooze.

REFERENCES

1. Balasubramanian, J., Sabumon, P.C., Lazar., U, JOHN., Ilangovan, R.,(2005)," Reuse of textile effluent treatment plant sludge in building materials" Waste Management, Vol.26,pp 22–28.
2. Bolden, Johnny.,Lebdeh, Abu. Taher., and Fini, Ellie.,(2013), "Utilization of recycled and waste materials in various construction applications". American Journal of Environmental Science, Vol. 9 (1), pp 14-24, ISSN: 1553-345X, SciencePublication
3. Nguyen, Hanh. Dang.,Boutouil, Mohamed., Sebaibi, Nassim., Leleyter, Lydia., Baraud, Fabienne.,(2013), "Valorization of seashell by-products in pervious concrete pavers". Construction and Building Materials Vol.49,pp151–160
4. Soutsos, N. Marios., Tang, Kangkang., Millard, G. Stephen., (2010) ," Use of recycled demolition aggregate in precast products, phase II: Concrete paving blocks". Construction and Building Material, Vol.25, pp 3131–3143.
5. Xue, Yongjie., Wu, Shaopeng., Hou, Haobo., Zha, Jin., (2006)," Experimental investigation of basic oxygen furnace slag used as aggregate in asphalt mixture" Journal of Hazardous Materials ,Vol.B138,pp261–268.

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Strength and Durability Investigation of Concrete by Partial Replacement of GGBS in Cement

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Abstract— The advancement of concrete technology can reduce the consumption of natural resource & energy source and lesson the burden of pollutants on the enviroment. Currently, Industrial inevitably creates sludge, irrespective of the enhancement introduced in manufacturing processes. In the industries, about 15%-30% production goes as waste. These wastes create a problem in present-day culture. So, it is most essential to develop eco- friendly concrete from these wastes. This project reports the results of an experimental study on the partial replacement of (OPC) cement with GGBS waste powder of 0%, 10%, 20%, 30% and 40% by weight of cement. Concrete mixture were created, tested of compressive strength to the tradionatal concrete. This tests were caried out to calculate the properties for seven, fourteen & twenty-eight days. The moulds prepared are as follows 150.0mm X 150.0mm X 150.0mm cubes and 300.0 X 150.0 mm cylinders for each concrete mix. The aim of the investigation is to study the behaviour of concrete while replacing the GGBS waste with different proportions in concrete. The results of this work have been presented in this dissertation. These tests were carried out to evaluate the properties for the test results of 7, 14, 28days for compressive strength and tensile strength in normal water and in HCL solution of 1%, 3% and 5%. Also, the durability aspect of GGBS with cement for HCL solution was tested.

Keywords: GGBS, M35 Design, Compressive Test, Split Tensile Test and Durability in HCL Solution

I. INTRODUCTION

Ground Granulated Blast Furnace Slag (GGBS) which is a by-product formed from the production of cast iron, also called pig iron, if the slag is cooled slowly in air, the chemical components of slag are usually present in the form of crystalline melilite (C2AS-C2MS2, solid solution), which does not react with water at ordinary temperature.

If it ground to very fine particles, the material will be weak cementitious and pozzolanic. However, when the liquid slag is rapidly quenched from high temperature by either water or a combination of air and water most of the lime, magnesia, silica and alumina are held in non-crystalline or glassy state. The water-quenched product is called granulated slag due to the sand-sized particles, while the slag quenched by air and a limited amount of water which is in the form of pellets is called palletized slag. It can develop satisfactory cementitious properties. Keeping the above in mind, an attempt has been made in the present study to investigate into potentialities of using GGBS admixture in cement concretes and compared to similar characteristics of concretes made with ordinary Portland cement alone without replacement.

II. MATERIALS AND METHODS

A. Cement

Cement is a material that has cohesive and adhesive properties in the presence of water. Such cements are called hydraulic cements. These consist of primarily silicates and aluminates of lime obtained from limestone and clay. There are different types of cements, out of which OPC is used. Ordinary Portland Cement (OPC) is the basic Portland cement and is best combination for use in general concrete used in construction, there are 3 types 33 grade, 43 grade, and 53 grade. One of the important benefits is the faster rate of development of strength.

Ordinary Portland Cement (OPC) available in the market crosscheck to IS 12269-1987 was used for casting the specimens. The cement using is 43 Grade.

1) Main Compounds of Portland Cement:

Name of the Compound	Oxide Composition	Abbreviation
Tri calcium silicate	$3CaOSiO_2$	C_3S
Di calcium silicate	$2CaOSiO_2$	C_2S
Tri calcium aluminate	$3CaO,Al_2O_3$	C_3A
Tetra calcium alumina ferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF

2) Chemical Composition of Ordinary Portland Cement:

Chemicals	Compositions
Lime (CaO)	60 - 68 %
Silica (Sio_2)	17 – 24 %
Alumina (Al_2O_3)	3 – 9 %
Iron oxide (Fe_2O_3)	0.5 – 7 %
Magnesia (MgO)	0.1 – 5 %
Sulphor trioxide (So_3)	1 – 4 %
Soda and /or potash ($Na_2O + k_2O$)	0.5 – 1.4 %

3) Physical Properties of Cement

S.NO	PROPERTY	VALUE
1	Normal Consistency	0
2	Initial Setting	31mnts
3	Final Setting	11hrs
4	Specific Gravity	3.14
5	Fineness of cement	

B. Aggregates

Aggregate properties greatly influence the behavior of concrete, since they occupy about 80% of the total volume of concrete. The aggregate is classified as

- Fine aggregate
- Coarse aggregate

1) Fine aggregate

Fine aggregate are materials passing through an IS sieve that is less than 4.85mm gauge beyond which they are called

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coarse aggregate. From the main matrix of the concrete whereas fine aggregate form the filler matrix between the coarse aggregate. The most important function of the fine aggregate is to provide workability and uniformity in the mixture. The fine aggregate also helps the cement paste to hold the coarse-aggregate particles in suspension.

According to IS 383-1970 the fine aggregate is being classified in to four different zones, that is Zone-1, Zone-2, Zone-3 and Zone-4. The sand obtained from river beds or quarries is used as fine aggregate.

2) Coarse aggregate

The coarse aggregate are granular materials obtained from rocks and crushed stones. They may be also obtained from synthetic material like slag, shale, fly ash and clay for use in light weight concrete. Also, in case of coarse aggregate maximum 20mm sized coarse aggregate is suitable for concrete work. But where there is no restriction, 40mm or large size may be permitted.

3) Sand

Locally available river sand in dry condition is used for the preparation of concrete. The grading of sand confined to Zone II As per IS 383-1970, the specific gravity of sand is 2.67.

C. GGBS

Ground Granulated Blast Furnace Slag (GGBS) which is a by Product formed from the production of cast iron, also called pig iron, if the slag is cooled slowly in air, the chemical components of slag are usually present in the form of crystalline melilite (C2AS-C2MS2, solid solution), which does not react with water at ordinary temperature. If it ground to very fine particles, the material will be weak cementitious and pozzolanic. However, when the liquid slag is rapidly quenched from high temperature by either water or a combination of air and water most of the lime, magnesia, silica and alumina are held in non-crystalline or glassy state. The water-quenched product is called granulated slag due to the sand-sized particles, while the slag quenched by air and a limited amount of water which is in the form of pellets is called palletized slag. It develops satisfactory cementitious properties.

1) Physical Properties of GGBS

S.no	Property	Value
1	Normal Consistency	31%
2	Initial Setting	54mnts
3	Final Setting	9.1hrs
4	Specific Gravity	2.96
5	Fineness of GGBS	9%

2) Chemical Properties of GGBS

Chemicals	Percentage in GGBS
CaO	35 – 50 %
SiO_2	27 – 38 %
Al_2O_3	8.1 – 24 %
MgO	1.0 – 18 %
MnO	0.67 %
TiO_2	0.59 %
K_2O	0.36 %
N_2O	0.26 %

3) Water

Clean potable water is used for mixing concrete. Water used for mixing and curing should be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete and steel.

III. EXPERIMENT

Weigh is the correct method of measuring the material. Use of weight system is batching, facilities accuracy, flexibility and simplicity. Different types of weigh batches are available. In smaller works, the weighing arrangement consists of two weighing buckets, each connected through a system of levers to spring loaded dials which indicate the load. The weighing buckets are mounted on a central spindle about which they rotate. Thus, one can be loaded while the other is being discharged into the mixer skip. A simple spring and electronic balance or the common platform weighing machines also can be used for small job.

On large work sites, the weigh bucket types of weighing equipment are used. This is fed from a large overhead storage hopper and it discharges by gravity, straight in to mixer. The weighing is done through a lever arm system and two inter linked beam and jockey weights. The required quantity of say coarse aggregate is weighted, having only the lower beam in operation. After balancing, by turning the smaller lever, to left of the beam, the two beams are inter-linked and the fine aggregate is added until they both are balanced. The pointer indicates the final balance on the scale to the right of the beams. Discharge is through the swivel gate at the bottom.

A. Measurement of Water

When weigh batching is adopted, the measurement of water must be done accurately. Addition of water by graduated bucket in terms of liters will not be accurate enough for the reason of spillage of water etc. It is usual to have the water measured in a horizontal tank or a vertical tank fitted to the mixer. These tanks are filled up after every batch. The filling is so designed to have control so as to admit any desired quantity of water. Sometimes, water – meters are fitted in the main water supply to the mixer from which the exact quantity of water can be into the mixer.

B. Mixing

Thorough mixing of the material is essential for the production of uniform concrete. The mixing should ensure that the mass becomes homogenous, uniform in colour and consistency. Initially the coarse aggregates and fine aggregates are weighed. Later required quantities of cement and GGBS separately are mixed dry to a uniform colour. As per the mix design water is measured. All the ingredients are added to the concrete mixture and mixed for the required time period to achieve a homogeneous mix of uniform colour.

C. Hand Mixing

Hand mixing should be done over impervious concrete or brick floor of sufficiently large size to take one bag of cement. Spread out the measured quantity of coarse aggregate, fine aggregate in alternate layers. Pour the required quantities of cement and GGBS mixture on the top of it, and mix them dry by a shovel, turning the mixture over and over again until uniformity of colour is achieved. This uniform mixture is spread out in the thickness of about 20cm. Water is taken in required quantity is taken and sprinkled over the mixture and simultaneously turned over. This operation is continued till such a time that good uniform homogenous concrete is obtained. It's a particular importance to see to that the water is not poured but it is only sprinkled. Water in small quantity should be added towards the end of the mixing to get the required consistency.

D. Compressive Strength Test

Compression test is the most common test conducted on hardened concrete, partly because it's an easy test to perform, and partly because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength.

Test for compressive strength was conducted as the specimens of 150mm cubes are exposed to a specific temperature and duration were released from the furnace and tested for compressive strength after cooling down the specimens to normal room temperature condition. The specimen cubes were placed in compression testing machine such that the load was applied on the opposite sides of the cube the axis of the cube was aligned with the Centre of steel plate of the testing machine.

The load was gradually applied without any shock and increased continuously until the resistance of the specimen to the increasing load broke down and no greater load was sustained. The compressive strength of the specimen was computed by dividing the maximum load received by the specimen with the Cross-Sectional area. Average of three test results of the specimen was considered as the compressive strength by ensuring the individual variation is not more than 15% of the average value. A total of 45 conventional cubes was cast for strength testing to account for different ages of curing 7, 14 and 28 days.

E. Split Tensile Test

The split tensile strength is one of the basic and important properties of the concrete. The concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature. However, the determination of tensile strength of concrete is necessary to determine the load at which the concrete members may crack. The cracking is a form of tension failure. The test consists of applying a compressive live load along the opposite generators of a concrete cylinder placed with its axis horizontal between the compressive plates. Due to the compression loading a fairly uniform tensile stress is developed over nearly 2/3 of the loaded diameter as obtained from an elastic analysis. Cylinder specimens of different percentages of GGBS waste were tested under compression testing machine in accordance with after a curing period of 7,14 & 28 days.

After required curing period the cylinder specimens are removed from the curing tubs and cleaned to wipe off the surface water. Draw diametrical lines on each end of the specimen using a suitable device that will ensure that they are in the same axial plane. Determine the diameter of the test specimen by averaging three diameters, Determine the length of the specimen by averaging at least two length measurements. Position the bearing strips, test cylinder, and supplementary bearing bar by means of the aligning jig and centre the jig so that the supplementary bearing bar and the center of the specimen are directly beneath the center of the thrust of the spherical bearing block. Apply the load continuously and without shock, splitting tensile stress until failure of the specimen, record the maximum applied load indicated by the testing machine at failure, note the type of failure and the appearance of the concrete.

The humiliating character of cement concrete begins on the surface of the concrete, slowly penetrating into the inner mass of the concrete and gets a reduction of strength. In order to make the durable structure with usage of GGBS, it is necessary to take all precautions which will be taken in normal weight concrete. There are different degradation agents available like soft water and some acid in solution containing soluble HCL. To evaluate the durability behaviour of concrete (cement replacement with GGBS), test has been performed in this study of concrete strength

The main objective of the present experimental investigations is to obtain specific experimental data, which helps to understand the Bacterial concrete and its characteristics (Strength and Durability)

Effect of HCl acid on pore structure Based on the previous research, damage impact of various de-icing chemicals and exposure conditions on concrete materials was studied and resulted that various de-icing chemicals penetrated at different rates into given paste and concrete, resulting different degree of damage. In present study, the percentage concentration of HCl is 1%,3%,5% concentration and its effect on GGBS is not so significant. As consider the strength of concrete specimens after 7, 14, 28 days' variation was low even for replacement. The range of variation is 0% to 40% with respect to the reference concrete after 7, 14,28 days' exposure to the HCl.

IV. Results and Discussion

Above Tables shows the experimental results of the test samples made from partial replacement of cement using GGBFS. In the Table 3 the result of Slump values of various mix proportions of GGBFS concretes increased when replacement of GGBFS with cement increase 10-40%. Slump value Control mix concrete has Obtain less value than the 40% replacement GGBFS. Test result of Compressive strength (Table 4) of the mix lower with 10%, 20%, 30%, 40% GGBFS replacing with cement as compared to control mix at

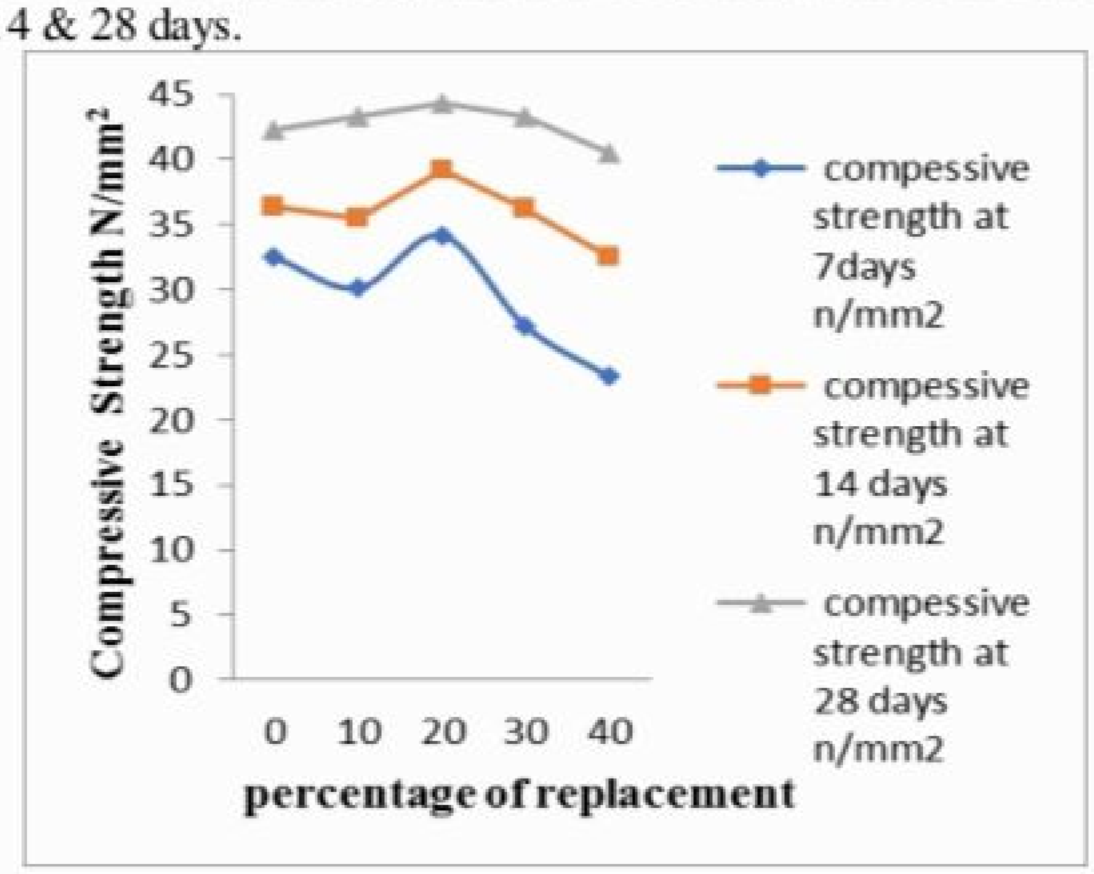
7 days and 28 days due to slower rate of reaction. The compressive strength of the mix with 10%, 20%, 30% cement replacement increased at 56 days whereas the mix 40% cement replacement showed a decrease in strength at 56 days as compared to control mix. The result shown in Table 5 the result of Flexural strength of mix with different cement replacement 10%, 20%, 30%, 40%, showed in decrease for all replacement at 7 & 28 days due to slower rate of reaction. The flexural strength of the mix with 10%, 20%, 30% cement replacement increased after at 56 days where as the mix 40% cement replaced showed a decrease in strength by at 56 days as compared to control mix. It is shown in Table 6 the result of Spilt tensile strength of mix with different cement replacement 10%, 20%, 30%, 40%, showed in decrease for all replacement at 7 days and 28 days due to slower rate of reaction. The Spilt tensile strength of the mix with 20%, 30% cement replacement better performed than control mix at 56

days where as the mix 40% cement replaced showed a decrease in strength by at 56 days as compared to control mix.

A. Compressive Strength for M_{35} grade of Concrete:

% of replacement of GGBS	Compressive strength at 7days N/mm^2	Compressive strength at 14 days N/mm^2	Compressive strength at 28 days N/mm^2
0	32.5	36.32	42.3
10	30.14	35.53	43.25
20	34.2	39.14	44.42
30	27.2	36.23	43.25
40	23.35	32.5	40.56

Compressive strength of cubes made with GGBS powder with partial replacement of cement with GGBS at 7, 14 & 28 days.



B. Compressive strength for Durability of 1% HCL

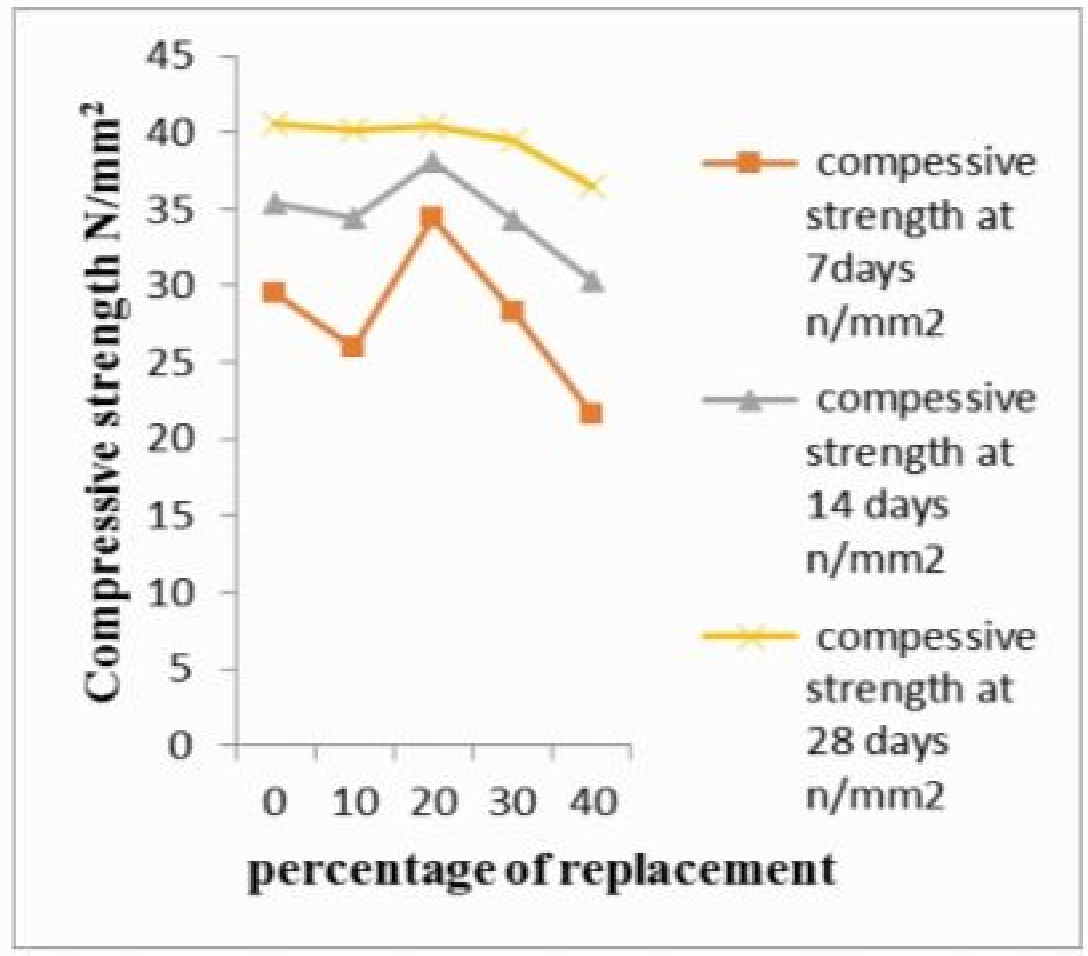
% of replacement of GGBS	Compressive strength at 7daysN/mm^2	compressive strength at 14 days N/mm^2	compressive strength at 28 days N/mm^2
0	34.5	36.34	40.32
10	32.13	36.53	40.25
20	36.2	40.13	42.43
30	41.82	37.23	41.2
40	26.45	32.54	38.5

Effect of HCL by 1% concentration on cubes made with GGBS waste at 7,14 & 28 days

C. Compressive strength for Durability of 3% HCL

% of replacement of GGBS	Compressive strength at 7days N/mm^2	Compressive strength at 14 days N/mm^2	Compressive strength at 28 days N/mm^2
0	29.5	35.4	40.53
10	25.98	34.43	40.22
20	34.5	38.1	40.42
30	28.28	34.24	39.43
40	21.61	30.32	36.44

Effect of HCL by 3% concentration on cubes made with GGBS waste at 7,14 & 28 days



D. Compressive strength for Durability of 5% HCL

% of replacement of GGBS	Compressive strength at 7days N/mm^2	Compressive strength at 14 days N/mm^2	Compressive strength at 28 days N/mm^2
0	34.43	34.02	34.53
10	29.92	33.4	45.23
20	34.53	36.23	35.42
30	30.29	34.02	37.22
40	23.6	30.33	36.4

Effect of HCL by 5% concentration on cubes made with GGBS waste at 7, 14 & 28 days

E. Split Tensile for M_{35} grade of Concrete:

% of replacement of GGBS	split tensile strength at 7days N/mm^2	split tensile strength at 14 days N/mm^2	split tensile strength at 28 days N/mm^2
0	2.9	3.2	4.25
10	2.86	3.08	4.04
20	2.81	3.04	4.2
30	2.72	3.95	4.24
40	2.66	3.99	4.18

Split tensile strength of cylinders made with GGBS powder with partial replacement of cement with GGBS

V. Conclusions

- The compressive properties of concrete have increased, when cement is replaced by 20% of GGBS.
- The split tensile properties of concrete have increased, when cement is replaced by 20% of GGBS.
- The durability of concrete has increased when the specimen is treated with 1% HCL.
- Increase in percentage of HCL the strength has decreases.

References

[1] D.G. Mantel, Investigation into the hydraulic activity of five granulated blast furnace slag with eight different Portland cements, ACI Mater. J. 91 (5) (1994) 471 – 477.

[2] K. Ganesh Babu, V. Sree Rama Kumar, Efficiency of GGBS in concrete, Res. 30 (2000) 1031 – 1036.

[3] Arivalagan.S (2014). "Sustainable Studies on Concrete with GGBS as a Replacement Material in Cement", JordanJournal of Civil Engineering, Volume 8, No. 3.

[4] Sujata D. Nandagawali and Dr. N. R. Dhamge (2014). "Study of Blast Furnace Slag for Improving Mechanical Property of Concrete", International Journal of EngineeringScience and Innovative Technology (IJESIT) Volume 3, Issue 4.

[5] Li Q., Li Z. and Yuan G. (2012). "Effect of Elevated Temperatures on Properties of Concrete Containing Ground Granulated Blast Furnace Slag as Cementitious Material, "Construction and Building Materials, Vol. 35, Pages 687-692.

[6] Elahi, P.A.M. Basher, S.V. Nanukuttan and Q.U.Z.Khan (2010). "Mechanical and Durability Properties of High-Performance Concretes Containing Supplementary Cementitious Materials," Construction and Building Materials.

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(57) Abstract :

Modeling, Optimizing and diagnosis of Chiller Systems using Machine Learning The invention aims to create an energy use model for a chiller in heating, ventilation, and air conditioning system using the artificial neural network learning method. Input layers that included several input variables, quantity (percentage) of training data and number of neurons were measured for accuracy by the suggested chiller energy consumption model. A standard reference structure was also designed to provide operating data for the chiller system during long refrigeration periods (warm weather months). By increasing the number of input variables and changing the percentage of training data, the prediction precision in the energy consumption of the chiller was increased. In contrast, the prediction accuracy was not affected by the number of neurons. Dated this 4 th day of August, 2021

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(57) Abstract :

In recent years, multi fold improvement is viewed in the field of Artificial Intelligence hence plays a significant role in image classification especially classification of medical images. In specific Convolutional Neural Networks (CNN) belonging to Artificial Intelligence performs well in detection of several diseases such as heart disease, Dental diseases, Malaria and Parkinson's disease. CNN has significant vision in detection of lung disease utilizing the medical images of the patient such as X-rays. Lung disease is the basic symptom of the global pandemic disease COVID-19. This invention proposes a CNN model for the detection of lung disease where the model involves four layers namely input layers, convolutional layers, fully connected layers and output layers. The three layered two dimensional convolutional layers involves ReLu activation function along with Max pooling making the detection process easier by training the model using dataset. The proposed CNN model provides 97.4% of accuracy and 94.5% of precision. F1 score of the model is achieved as 97.60 and the curve area of Receiver Operating Characteristic (ROC) is obtained as 0.975.

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