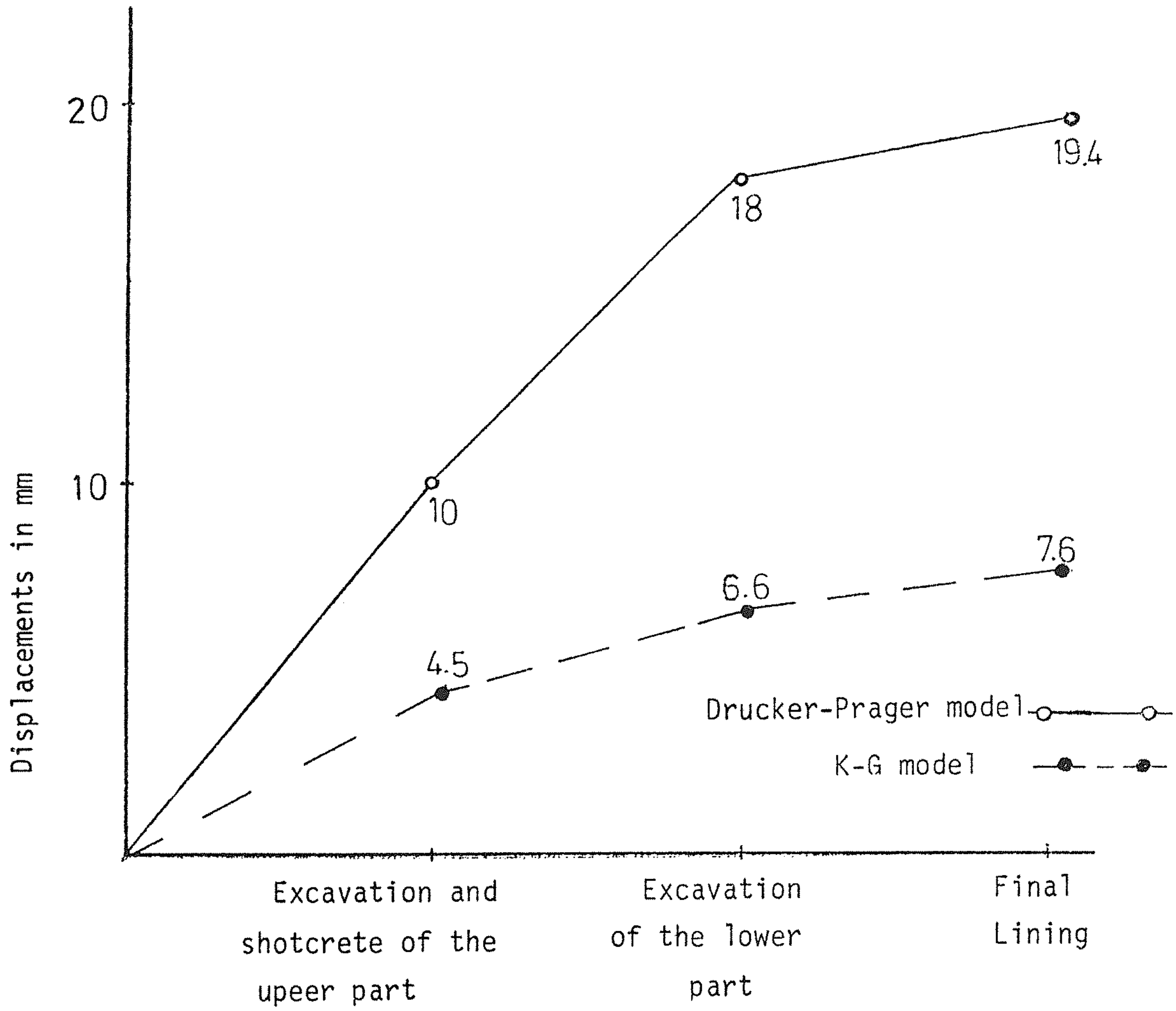

Figure 6. Displacements of the Crown of the Tunnel at Different Stages.

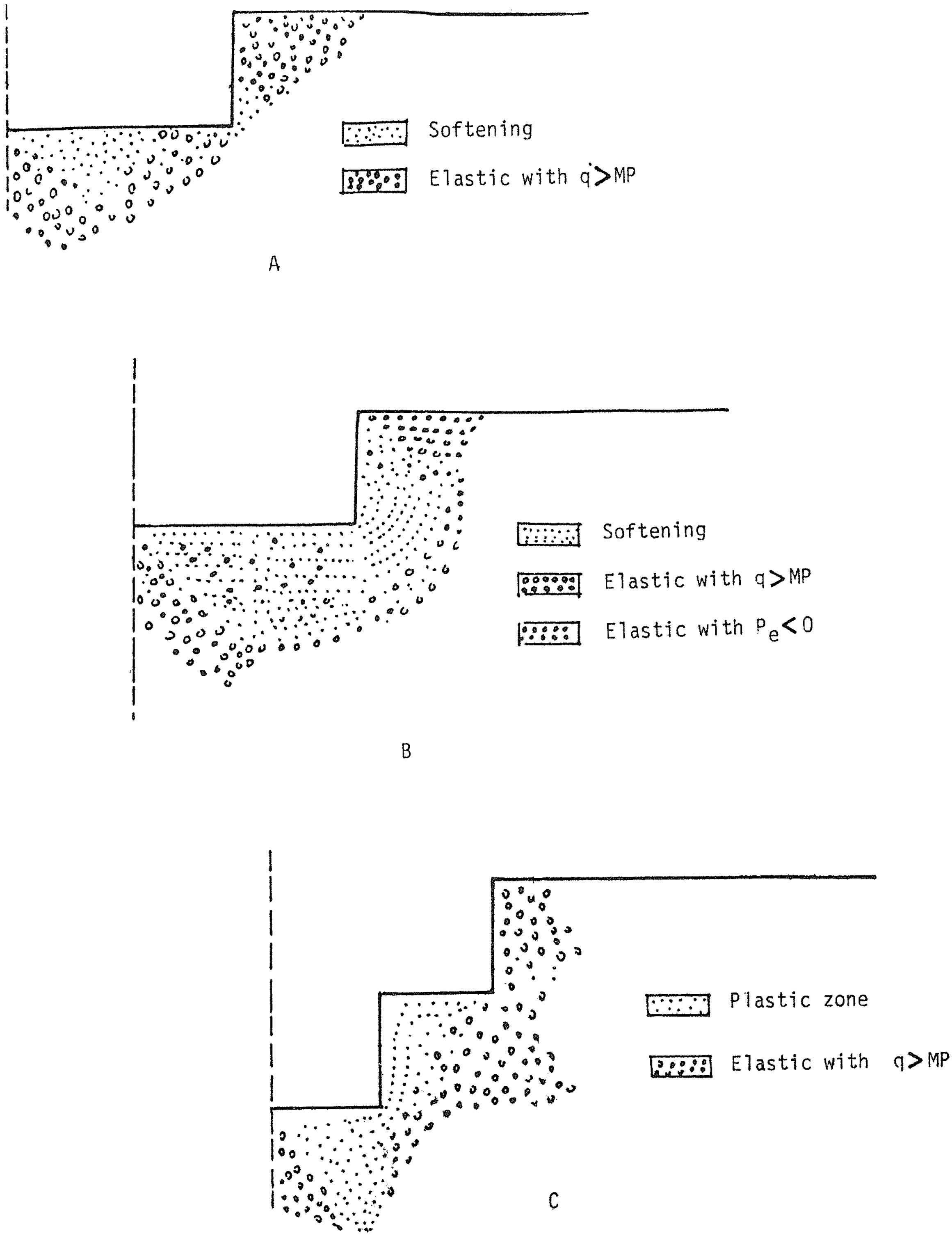

Figure 5. Elastic and Plastic Zones Due to Excavation.
A. For the 10th incremental load-drained condition.
B. For the last incremental load-drained condition.
C. For the last incremental load-undrained condition.

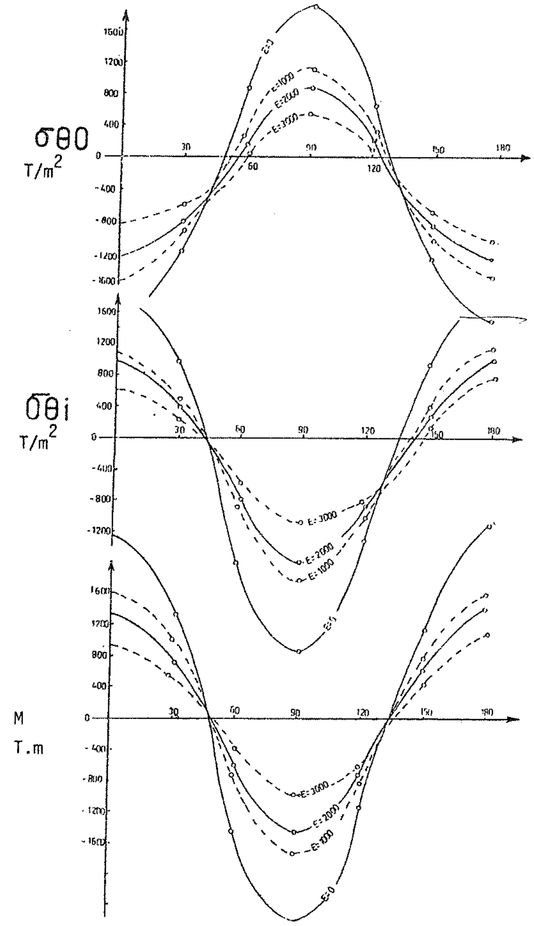

Figure 3. The Effect of Ground Strength on Stresses in Tunnel's Lining.

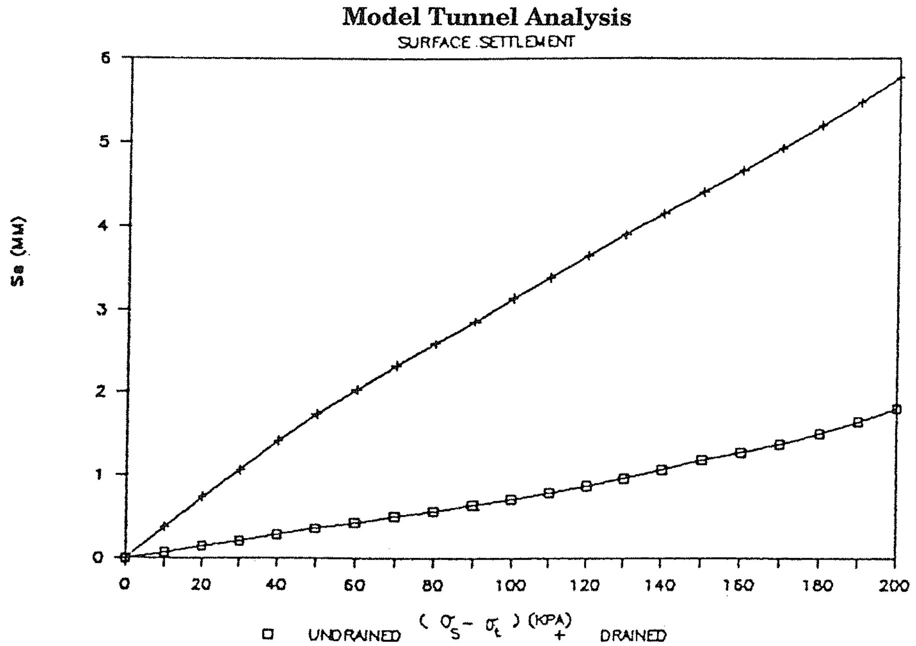

Figure 4. Surface Settlements Due to Excavation of the Tunnel for Drained and Undraine conditions.

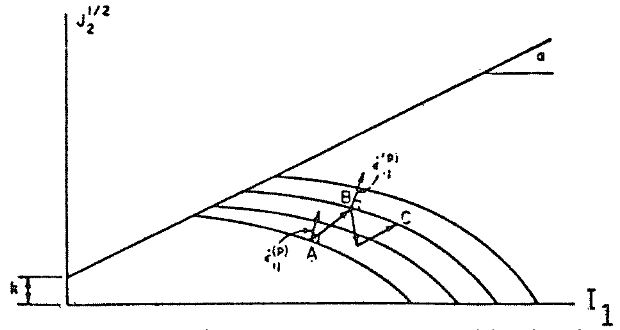

Figure 1. Strain hardening capped yield criterion.

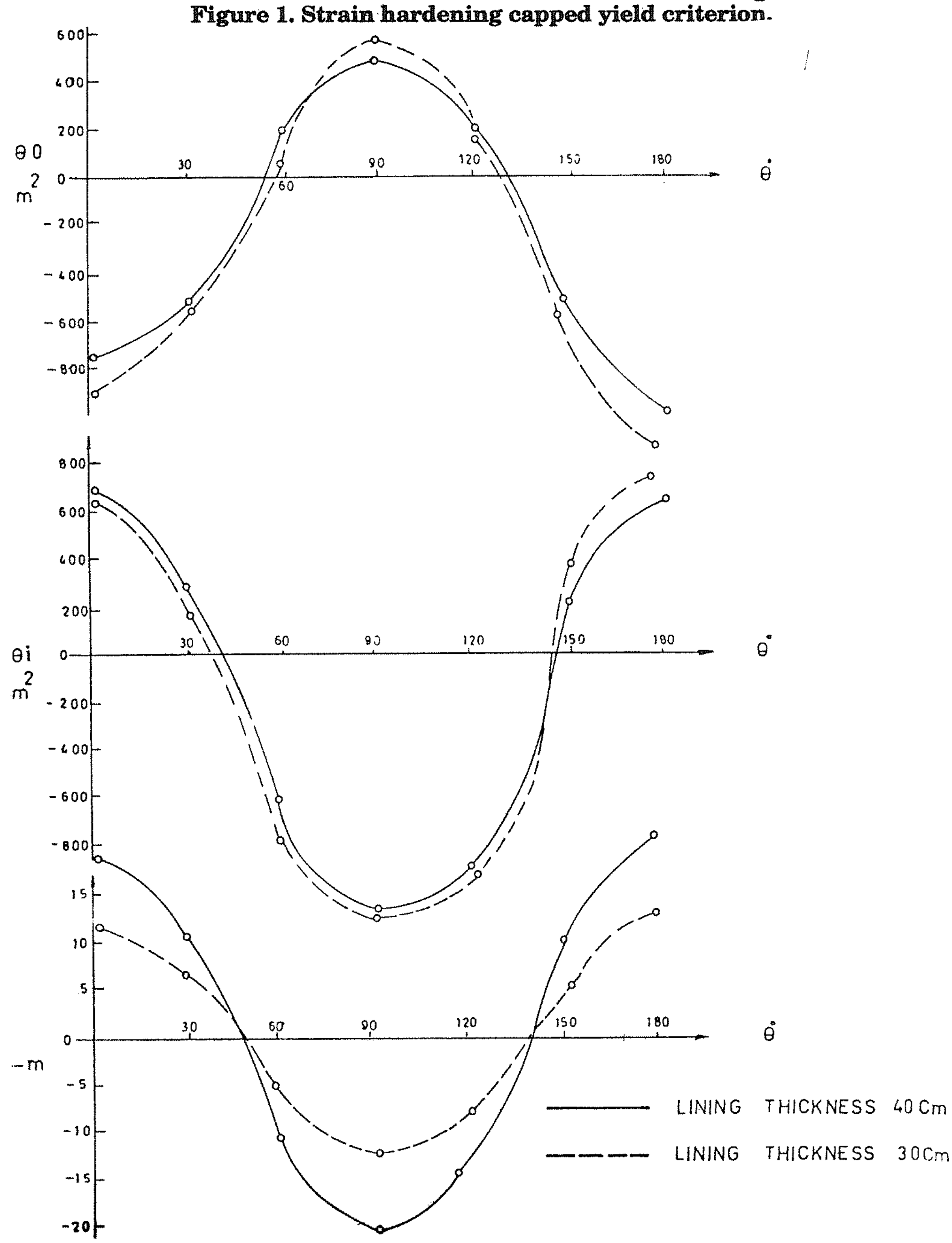

Figure 2. Hoop Stresses And Moments Along the Lining.

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imental ones.

Many tunnelling problems have been tested and based on the results, it has been concluded:

a. To reduce surface settlements and maintain stability of excavation, drainage should be stopped at the early stages of excavation (Figure 4).

b. It has been found that the overconsolidation ratio has a great effect on displacements.

c. It has been found that the modified Cam-Clay model can easily handle any sequence of work operations and show softening effects due to large displacements (Figure 5).

6. New Austrian Tunnelling Method [26]

In the New Austrian Tunnelling Method (NATM), the excavation and supporting are carried out in many stages. Accordingly, the assumption of loading in one-stage according to the linear elastic model seems far from reality. To choose a proper structural design model, two models have been suggested for tunnelling in silty-sand ground and they are:

i. The curve description model based on the K-G relations.

ii. The Drucker-Prager elasto-plastic model with hardening cap and tension cut-off (Figure 1).

Both models are included in the general finite element program ADINA [27] and the parameters of each of them have been obtained from triaxial test results. Samples have been taken from the metro station of Imam Khomeini Square and remoulded in laboratory. Accroding to the results obtained, It has been concluded that:

a. Since NATM is an excavation method which allows the relaxation of structure after each stage (large displacements with small Stresses), it is advisable to use a finite element model which allows the representation of these stages accurately. The results obtained have shown considerable reductions in stresses compared to those taken from linear elastic analyses.

b. By comparing the finite element results with the site measurements available, it has been found that the Drucker-Prager model gives better displacement predictions than the K-G model (Figure 6). Moreover, the Drucker-Prager model is more suitable since it requires less number of parameters which can be extracted easily from tests.

7. Conclusion

In this paper, a simple model has been used for a parametric study. On the other hand, many constitutive models have been used to represent the essential feature of soil behaviour, and tunnelling activities. It has been concluded that the Drucker-Prager and the modified Cam-Clay can be used to predict tunnelling behaviours in silty sand and clay soils with high accuracy. Based on these results, it can be concluded that a thin lining should be used for the tunnels, drainage should be prevented in soils with high water level and work should be carried out in stages to allow for the maximum displacements with the minimum stresses.

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teria. Due to some limitations in these criteria, Drucker and Prager have used a generalized form of the Mohr-Coulomb law with "friction" effects. The Drucker-Prager yield surface with an associated flow rule, however, cannot predict the plastic volumetric strain observed in experiments. This difficulty has been overcomed by using a family of yield criteria forming "caps" as shown in Figure 1. Later, the research group at Cambridge has used the strain hardening plasticity models (models with caps) to develop the Cam-Clay model which since then becomes the basis of many models proposed later. A general discussion on these models can be found in [14-16]. Applications of the elasto-plastic models in tunnelling problems can be found in References [17-20].

d. Time-dependent models: In certain problems of soil mechanics the time effects, other than those due to consolidation, have to be included. Accordingly, some elasto-visco-plastic models with time-dependent plastic strains have been developed. The applications of such models in tunnelling problems can be found in References [21-23].

3. The Choice of Design Models

In dealing with some structural aspects of design in Tehran's metro project, a series of studies has been carried out in Amir Kabir University of Technology, Tehran. Reflecting on the available models for tunnelling, it has been concluded that two kinds of structural design models are needed. The first one must be able to describe the complexity of the tunnel problem as close as possible. However, the parameters used in such models need to be extracted from standard soil tests and they should have definite physical significants. The second type must be simple enough for immediate practical design and can be used easily for parametric study. This type of models does not need the accurate and detailed input information that is required by the first one and which not be available at the design stage. Accordingly, a parametric study has been made to understand the relative importance of each of the design variables on the lining [24]. For more realistic and detailed analyses, the modified Cam-Clay model has been used for clay soils [25], and the K-G (curve description) and Drucker-Prager models have been tested for tunnels in silty-sand soils [26]. These are described in more details in the following sections.

4. Parametric Studies [24]

The requirement for a simple model to be used in a parametric study has led to the adoption of the linear elastic model as the most suitable one for this purpose. It has an advantage over the bedded-beam (Winkler-type) model, since it represents the soil-structure interaction in a more realistic way. Using this model, the range of ground parameters expected along the tunnel route is employed with different loading conditions. The influence of different support elements, to the overall behaviour and stability of the compound structure consisting of ground mass and support elements, has been studied, as well and it has been concluded that:

a. The use of a thin concrete lining is more economical than using a thicker one, since the magnitude of bending stresses produced is smaller for the thin one (Figure 2).

b. The proper presentation of soil-structure interaction is an important factor. The role of ground in reducing the forces in the lining is considerable, even for weak soils (Figure 3).

5. The Modified Cam-Clay Model [25]

In dealing with soft clay soils, as those found in the southern suburbs of Tehran, the modified Cam-Clay model has been adopted. This model is suitable for the analysis of normally consolidated and highly overconsolidated clays. Samples have been taken from Shush-Khayam metro station site and remoulded in laboratory. Laboratory tests, mainly one dimensional consolidation tests and isotropic consolidation tests, have been carried out. These tests have been idealized numerically and the behaviours of soils are reproduced using axisymmetric solid LST elements. The numerical results were found within 10% of the exper-

On The Implementation Of Finite Element For Tunnelling In Soft Ground

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Abstract:

past experience has shown that empirical and analytical methods of design are inadequate. The finite element method has been used to model different tunnelling problems with complicated material, load, geometry and boundary conditions. In this paper, the most important constitutive models have been reviewed and some of them have been tested for tunnelling problems. It has been concluded that elasto-plastic models like the DRUCKER-PRAGER and the modified CAM-CLAY can be used to represent the complicated behaviour of soils during tunnelling with high accuracy.

1. Introduction

In 1978, The International Tunnelling Association (ITA) established a working committee on the general approaches to the design of tunnels. It started its work by making a survey on the different methods used in different countries [1]. The final findings of the working group have been published in 1988 [2]. It has been concluded that the choice of appropriate design method is heavily dependent on results of other activities like geotechnical investigations, excavation methods, supporting methods and field measurements. To have a suitable design method, that can describe the tunnelling excavation and supporting process accurately and reflects the complexity of ground conditions, a sophisticated numerical method is needed [3].

Only by applying the finite element method to the design model we may reflect the complexity of the tunnelling problem. The finite element can cope with general shapes of tunnels, starta of different ground, fissure zones, faults and complicated constitutive behaviour. The simulation of excavation and construction stages can be modelled easily and reflection on the best excavation procedure can be made.

2. Alternative Finite Element Models

Since the introduction of the finite element method, much research effort has been directed to employing the different constitutive models in the finite element analysis. The most important of them are the followings:

a. Linear elastic models: design models based on isotropic elastic, and anistropic elastic relations have been used widely for tunnels [4-6]. Elastic theory for a soil which the modulus increases linearly with depth has been also suggested. By adopting the bulk module and shear moduli, the linear elastic behaviour of the soil can be described in more realistic ways.

b. Non linear elastic models: Many bilinear and multilinear models have been used for tunnelling problems [7,8]. Moreover, based on the observations made by konder [9], the hyperbolic model [10] has been developed and has been considered as the most powerful non-linear model since then. For tunnel problems, applications of the hyperbolic model can be sited in References [11-13].

c. Elasto-Plastic Models: The early elasto-plastic models have been based on Mohr-Columb, Von-Mises and Tresca yield cri-