AIN SHAMS UNIVERSITY
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EFFECT OF NONLINEAR BEHAVIOR OF SOIL ON THE TWO DIMENSIONAL ANALYSIS OF TUNNELS

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STATEMENT

This dissertation is submitted to Ain Shams University for the degree of Master of Science in Structural Engineering.

The work included in this thesis was carried out by the author in the department of Structural Engineering, Ain Shams University, from June 1992 to April 1994.

No part of this thesis has been submitted for a degree or a qualification at any other University or institution.

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Abstract of the M.Sc. Thesis Submitted by
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ABSTRACT

The main aim of this thesis is to study the behavior of the soil-lining interaction taking into consideration the nonlinear behavior of the soil, and to make a finite element model simulating this actual case.

In this study, the soil is represented by four nodes plain strain elements, and tunnel lining represented by beam elements. Special nonlinear interface finite elements are used to connect the plain strain elements representing the soil around the tunnel with the bending beam elements, representing the tunnel lining.

Several types of soil are used in this study to represent the effect of the linear and nonlinear behavior of each type on the tunnel lining element.

A comparison between the results of the linear and nonlinear analysis is made.

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NOTATIONS

A : Cross-sectional area.

B : Bulk modulus.

C : Cohesion intercept.

E : Young's modulus.

E_B : Young's modulus of the lining.

E_K : Young's modulus of the surrounding soil.

H : Height of soil over the tunnel.

J : Moment of inertia of the tunnel.

K : Modulus number.

[K] : Element stiffness matrix.

K_b : Bulk modulus number.

K_o : Coefficient of subgrade reaction.

K_r : Spring stiffness.

K_{ur} : Modulus number.

M : Bending moment.

m : Bulk modulus exponent.

N : Normal force.

n : Modulus exponent.

P_a : Atmospheric pressure.

{P} : Vector of nodal forces.

$\{Q\}$: Vector of end forces.

$\{q\}$: Vector of end displacement.

R : Radius of the tunnel.

R_f : Failure ratio.

U_o : Strain energy per element.

u : Horizontal displacement.

v : Vertical displacement.

W_e : Work done by external forces.

γ : Unit weight.

σ_H : Horizontal stresses.

σ_v : Vertical stresses.

ν : Poisson's ratio.

ϕ : Angle of internal friction.

CHAPTER (1)

INTRODUCTION

1.1 General

As soon as ***Homo erectus*** some millions years ago invented digging tool, he dug a hole into the ground for the protection of his family. It was thousands of years before ***Homo sapiens*** arrived, who worried about whether the hole was safe structure. Men were successful tunnellers many thousands of years before the invention of numerical methods. Yet very ingenious mathematical tools may have been employed for engineering purpose as early as 600 BC, when the 1036 m long tunnel for the water supply of Samos was designed and excavated by Eupalinos.

Now there is a great need for tunnels in underground excavations, irrigation networks and in mining. Indeed tunnels have been in common use in USA,EUROPE and RUSSIA during the last sixty years. In the mining sector RUSSIA and INDIA have mines reaching a depth of 1200ms and 300ms respectively.

Many lining systems have been used to support tunnels opening, steel segments reinforced concrete segments, composite sections of steel and concrete, shotcrete shells, and steel ribs and timber lagging are examples of the commonly used lining systems. Many shallow depth metro tunnels were constructed by the cut and cover method. The nature of the ground surface and geological conditions, ground stiffness, configuration of tunnel, and in-situ stresses around the tunnel opening are the major factors considered in determining the appropriate lining system.

The construction of tunnels in urban areas is always associated with surface subsidence. The soil displacements due to tunnelling are intimately linked to the construction procedure and the geological conditions.

Many approaches are used in predicting the surface and subsurface displacements due to tunneling, as well as the lining forces and deformations. Most of these methods were developed according to specific theoretical considerations. The analysis must simulate the transfer of loads due to excavation to the soil-lining system.

1.2 Aim of The Thesis

The main aim of this thesis is to study the behavior of the soil-lining interaction taking into consideration the nonlinear behavior of the soil, and to make a finite element model simulating this actual case.

Special nonlinear interface finite elements are used to connect the plane strain elements representing the soil around the tunnel with the bending beam elements, representing the tunnel lining.

Several types of soil are used in this study to represent the effect of the linear and nonlinear behavior of each type on the tunnel lining element.

1.3 Scope of The Thesis

An investigation on design models for tunnels and a comparative review of the progress to date in this field are presented in chapter 2. Also the main differences in the assumptions of the different models are stated. Diagrams for the hoop forces, bending moments, and radial displacements showing the difference in the design values evaluated for three different models are also given.

Chapter 3, describes the hyperbolic stress-strain relationships, and outline the procedure for evaluating the hyperbolic parameters.

In chapter 4, the possible modeling of the structure using the modern design methods is detailed. Also, chapter 4 discusses the different finite elements simulations of the continuum, the lining, and the interface between them.

The numerical results obtained from the computer analyses, a set of curves, tables, and figures for the evaluation of the internal force in the tunnel lining are illustrated in chapter 5. Also, the ground linear and nonlinear behavior is examined.

Finally the summary of the present work, and its conclusions are given in chapter 6.

CHAPTER (2)

REVIEW OF THE PREVIOUS WORK

2.1 General

In planning and bidding for a tunnel structure, engineers must relay-apart from their experience-on a structural model where they may derive criteria to establish whether the design is suitable, safe, and economical. Those items which must be translated from reality into a mechanical-mathematical engineering model are marked in *Fig. (2-1)* by a bar. Soft ground requires immediate support. The stiffness of the lining is rather great compared to the ground stiffness .

Shield-driving *Fig. (2-2)* requires circular cross-sections. In the most cases, a first support of shotcrete in soft ground requires the immediate closing of the invert, which result in an almost circular cross-section *Fig. (2-2)*. Even a plane - strain model may be sufficiently accurate for design purposes.

2.2 Basic Assumptions for Structural Design Models for Tunnels

The simplicity of the circular geometry and the much simpler interaction between a stiff structure and soft ground are the reasons why, internationally, the design models for soft ground tunnelling specially for shield-driven tunnels are fairly well - developed.