Int J Civ Eng (2017) 15:391–400
DOI 10.1007/s40999-016-0058-6

RESEARCH PAPER

Static Analysis of Flexible Pavements over Expansive Soils

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Received: 22 March 2016 / Revised: 14 July 2016 / Accepted: 15 July 2016 / Published online: 26 July 2016

Abstract To study and predict the behavior of flexible pavement over expansive soils, a pavement structure was subjected to different laboratory and fieldwork experiments. The existing pavement was replaced and designed based on California Bearing Ratio (CBR) method, with a new one, and subjected to the traffic from various number of load cycles from 12.1 up to 155.52 kcycles of standard axle load (80 kN) through dual wheel assembly over a 6-month period. As the preliminary step, the deflection measurements were taken at the asphalt surface layer, using a Total station at different distances as function of truck-load applications. The numerical analysis is carried out with the Finite Element software package PLAXIS version 2012. In the new model, the calculation of the transferred pressure to the pavement through contact area of tires is 3D it was turned into a 2D problem, and the pavement was subjected to a static loading using a ratio factor of dynamic additional charge. The materials' behavior was simulated with nonlinear models: Mohr–Coulomb (MC) for pavement layers and soft-soil model (SSM) for the expansive subgrade, in saturated drained and undrained conditions. The results indicate that displacements under static loading in saturated drained conditions and when non-linear materials are present are the closest to field measured deflections.

Keywords Flexible pavements · Expansive subgrades · Soil behavior · Finite element method · PLAXIS

Electronic supplementary material The online version of this article (doi:10.1007/s40999-016-0058-6) contains supplementary material, which is available to authorized users.

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1 Introduction

Pavements on expansive soils are globally frequent geotechnical problems. Such soils are usually unsaturated and contain large amounts of clay. Expansion of the clayey soils is a source of great damage to the infrastructures and buildings. Expansive soils can cause heavy economic losses, as well as being a source of risk to the population. In presence of water after a dry state, expansive soils undergo a significant volume change. It is well known that volume change of a material creates large stresses. The resulting stresses reflect in the form of cracking, heaving and settlement of the highway pavements. The annual cost of damage is estimated at £150 million in the UK, $1 billion in the USA and many billions of pounds worldwide [1]. Even if the pavement is correctly designed, the swelling character of the subgrade tends to distort all the

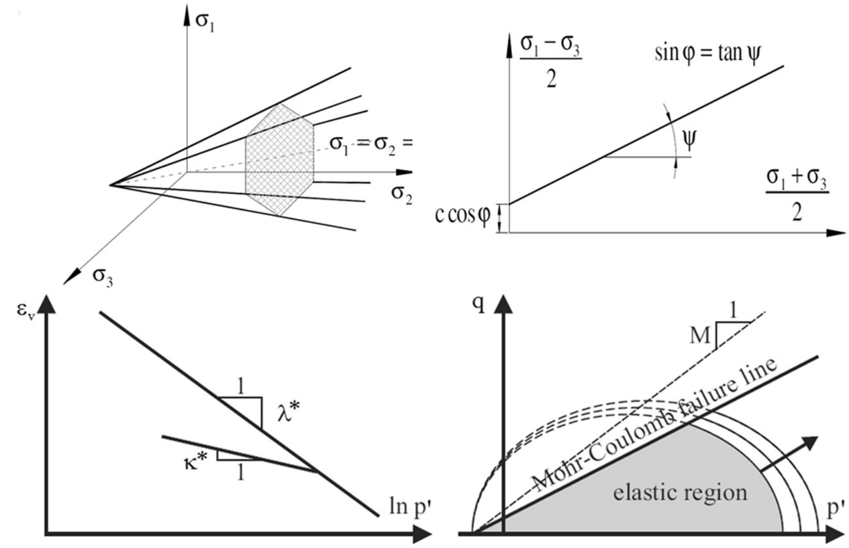

Fig. 4 Basic ideas of the MC (in *top*), the SSM (in *bottom*); $p' = 1/3(\sigma'_1 + \sigma'_2 + \sigma'_3)$

where ψ is the dilatancy angle. The elasticity associated to the MC criterion is a linear isotropic Hooke type one. The criterion contains five mechanical parameters: E, elasticity modulus and, v, Poisson's coefficient are the elastic parameters; and c, φ and ψ are plastic parameters [27].

2.5.2 *Soft-Soil Model (SSM)*

The SSM model is capable to simulate soil behavior under general states of stress, but is limited to the situations that are dominated primarily by compression. It is certainly not recommended for use in excavation problems. In case of triaxial loading conditions under which $\sigma'_2 = \sigma'_3$, the yield function of the model is defined as:

$$f = f' - p_p \tag{7}$$

where f' is a function of the stress state (p', q) and pp, the pre-consolidation stress, is a function of plastic strain such that:

$$f' = \frac{q^2}{M^2(p' + c\ \cot\ \varphi)} + p' \tag{8}$$

$$P_p = P_p^0 \exp\left(\frac{-\varepsilon_v^p}{\lambda^* - \kappa^*}\right) \tag{9}$$

Where λ^* and κ^* are, respectively, the compression and swelling modified index, P_p^0 is initial value of pre-consolidation stress and ε_v^p is the plastic volumetric strain.

In contrast to the MC model, a cap-type yield surface is introduced in SSM to model irreversible strains due to primary isotropic compression; this yield cap describes an ellipse in the p'-q plane as illustrated in Fig. 4. The parameter M in Eq. (8) determines the height of the ellipse. The height of the ellipse is responsible for the ratio of horizontal to vertical stresses in primary one dimensional compression. As a result, the parameter M determines largely the coefficient of lateral earth pressure, K_0.

Since swell behavior of the soil is the main focus in this research, the SSM model is used to simulate the plastic clay layer. This constitutive model appreciates linear stress dependency. When plotting a stress-stiffness curve from a load/unload oedometer test, a line in the form of $E_{\mathrm{oed}} = \sigma/\lambda^*$ is obtained. This leads to the logarithmic relationship between the volumetric strain, ε_v, and the mean effective stress, p', where the virgin compression can be formulated as:

$$\varepsilon_v - \varepsilon_v^0 = -\lambda^* \ln\left(\frac{p'}{p^0}\right) \tag{10}$$

where ε_V^0 is the initial volumetric strain and P^0 is the initial mean stress.

Since of the usage of the volumetric strain, ε_v, instead of the void ratio, Eq. (10) involves the modified compression index, λ^*, instead of the compression index, λ [28]. As the modified swelling index, κ^*, determines the elastic behavior during unloading and reloading [29], hence:

$$\varepsilon_v^e - \varepsilon_v^{e0} = -\kappa * \ln\left(\frac{p'}{p^0}\right) \tag{11}$$

3 Results and Discussion

For a validation of results, it is, therefore, important to compare the results of numerical analyses with actual measurements in full scale pavement structures to assure that the models are similar to the structural behavior.

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