XVI Int. Conference on Soil Mechanics and Geotechnical Engineering, Osaka (Japan), September 2005

AN APPLICATION OF THE MECHANICS OF UNSATURATED SOILS TO THE COMPACTION OF OIL RESERVOIR ROCKS DUE TO WATERFLOODING

V. De Gennaro[1]*, P. Delage[1], G. Priol[1], F. Collin[2] and Y.J. Cui[1]

(1) Ecole Nationale des Ponts et Chaussées (CERMES, Inst. Navier), Paris, France
(2) Université de Liège (Dpt GéomaC), Liège, Belgium

ABSTRACT:

A 10 m seabed subsidence has developed in the last ten years in the Ekofisk oilfield in the North Sea, due to enhanced oil recovery by seawater injection (waterflooding). This subsidence imposed an important structural rehabilitation of the operating offshore platforms (Hermansen *et al.*, 2000).

Although it is now widely accepted that the main cause of the seabed settlement is the compaction of the layer of reservoir chalk (300 m thick at 3000 m, porosity n ~ 45-50%), the origin of the compaction is still an open issue. Due to the presence of two fluids in the chalk pores where oil and water interact each other and together with the chalk skeleton, attempts to apply standard saturated geomechanics approaches based on the effective stress principle revealed serious shortcomings.

It was then proposed to adopt a coupled hydro-mechanical framework taken from the mechanics of unsaturated soils (containing water and air as a non wetting fluid) and to adapt it to reservoir chalks (containing water and oil as a non wetting fluid). The oil-water suction s_o was defined by $s_o = u_o - u_w$ (u_o and u_w being the oil and water pressures respectively) and two independent stress variables were considered (the oil-water suction s_o and the mean net stress $p - u_o$). Within this framework, the compaction induced by waterflooding could easily be described referring to the typical collapse phenomenon occurring in loose and low plastic unsaturated soils when wetted under a constant load.

An extended experimental program including suction controlled oedometric and triaxial tests was then carried out from 1997 to 2003 within the framework of two European funded collaborative research projects (Pasachalk1, 2001; Pasachalk2, 2004) carried out together with the Total oil company. The main results gained during these project are presented :

- the Barcelona framework (Alonso, Gens et al. 1987) was able to satisfactorily describe the geological history of the oil reservoir (Delage et al. 1996)
- the experimental hydro-mechanical response of the chalk under combined changes of stress and suction obeyed to the general framework of unsaturated soils mechanics as accounted for in the Barcelona approach
- an adaptation of the Barcelona basic model (Alonso, Gens et al. 1990) with suction hardening could successfully allow for modelling the softening behaviour of the reservoir chalk during water flooding
- time effects as a function of oil-water suction also had to be accounted for so as to properly account for all the phenomena involved in soil subsidence

As a conclusion, a new efficient tool for better understanding and modelling the coupled hydro-mechanical behaviour of multiphase porous oil reservoir rocks during enhanced oil recovery was developed.

Alonso E.E., Gens A. & Hight D.W. 1987. General Report : Special Problem Soils. *Proc. 9th Eur. Conf. on soil Mechanics and Foundations Engineering* 3, 1087-1146. Dublin, Balkema, Rotterdam.

Alonso E.E., Gens A. & Josa A. 1990. A constitutive model for partially saturated soils. *Géotechnique* 40, 405-430.

Delage P., Schroeder C.& Cui Y.J. 1996. Subsidence and capillary effects in chalks. *EUROCK '96, Prediction and performance on rock mechanics and rock engineering,* Vol. 2, 1291-1298, Turin, Italie, 2-5 Sept.

Hermansen, H., Landa, G.H., Sylte, J.E. & Thomas, L.K. 2000. Experiences after 10 years of waterflooding the Ekofisk Field, Norway. *J. of Petroleum Science and Eng.*, 26: 11-18.

* Corresponding author