The Influence of Selected Parameters on the Borehole Stability of the Continental Deep Drilling (KTB) Main Borehole

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Introduction and Assumptions

The analysis results presented in this paper were derived during extensive investigations into the stability of the continental deep drilling (KTB) main borehole, which are currently carried out at the Institute for Foundation Engineering, Soil Mechanics, Rock Mechanics and Waterways Construction of Aachen Technical University. The analyses are performed with the finite element program FEST03 (WITTKE 1990). The purpose of the calculations summarized in this abstract was to estimate the influence of the drilling mud and of the thermal stresses. To this end, analyses were carried out with varying assumptions concerning the density and the infiltration mode of the mud, the temperature profile determining the thermal stress distribution, and Poisson's ratio. The parameters used in the numerical investigations are listed in Table 1.

Rock:			
	young's modulus	E_R	= 55000 MPa
	Poisson's ratio	ν_R	= 0.25 / 0.1
	friction angle	φ_R	= 25°
	cohesion	C_R	= 50 MPa
	density	γ_R	= 28.3 kN/m3
Mud weight density:		γ_M	= 10.0 kN/m3 / 12.5 kN/m3
Stress Field:			
		S_V	= 227 MPa
		S_H	= 300 MPa
		S_h	= 150 MPa
Temperature:			
	in-situ temperature	T_i	= 230 °C
	borehole temperature	T_B	= 130 °C
	borehole standing time	t_S	= 1 h / 30 h

Table 1: Parameters

In all cases a borehole section without borehole bottom, located at a depth of 8000 m was simulated. The borehole diameter is 31 cm. The in-situ-stress data were taken from (RUMMEL 1993). The characteristic feature of the stress state is that the major horizontal principal stress is twice the minor horizontal principal stress. The vertical principal stress equals the gravity load. Strength and deformability of the rock are assumed to be isotropic. The difference between borehole and in-situ temperature amounts to 100 °C. The mud weight density equals 10 kN/m^3 for the unweighted mud and 12.5 kN/m^3 for the loaded one. For all calculations the rock was assumed to be initially dry. This assumption is unfavourable with regard to the destabilizing effect of the infiltrating mud since in the model used in these analyses the total stresses in the infiltrated rock mass were reduced by the total amount of mud pressure.

Results

First the influence of different depths of mud infiltration on the borehole stability was investigated (see Fig. 1). An impermeable borehole wall was used as reference case. In the next step, it was assumed that mud infiltrates into all regions where failure occurs in the rock mass. Furthermore, several specified depths of mud infiltration were simulated ranging from 2 to 60 cm. Fig. 1 shows that the plastified zones grow larger with increasing depth of mud infiltration. At an infiltration depth greater than 25 cm, however, the extent of the plastified zones remains unchanged, which indicates that the borehole has reached a stable state.

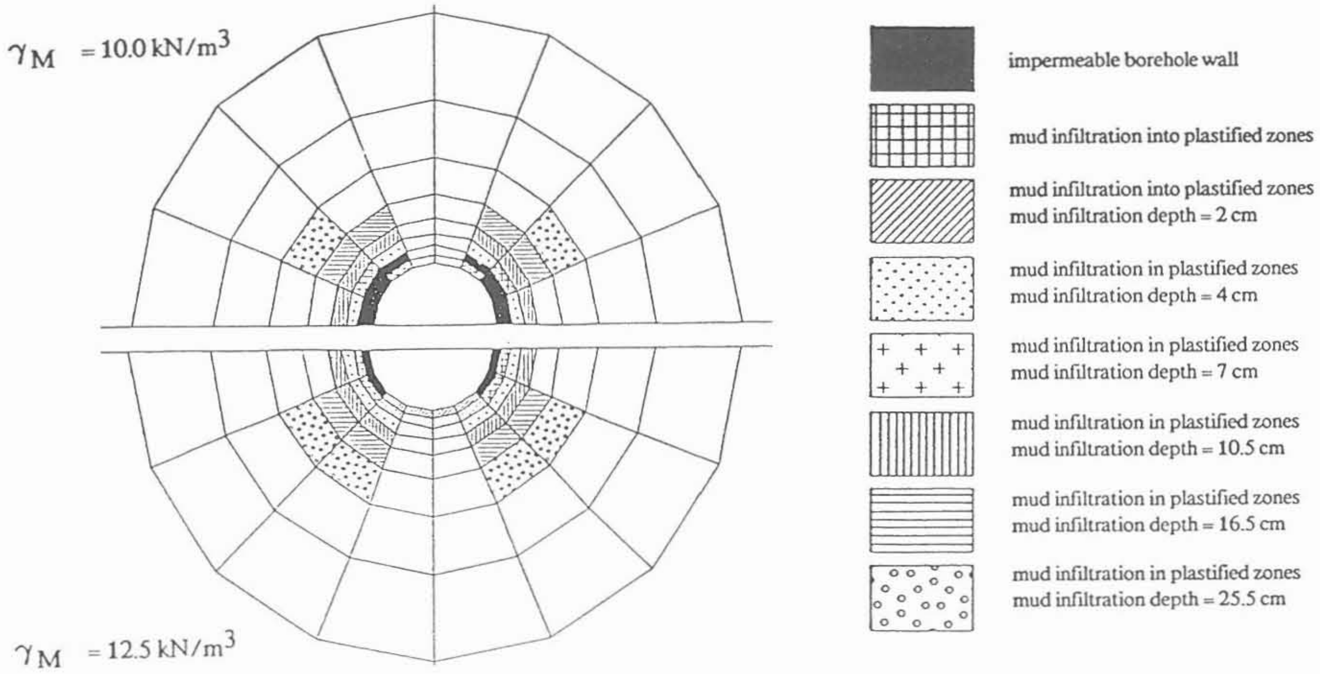
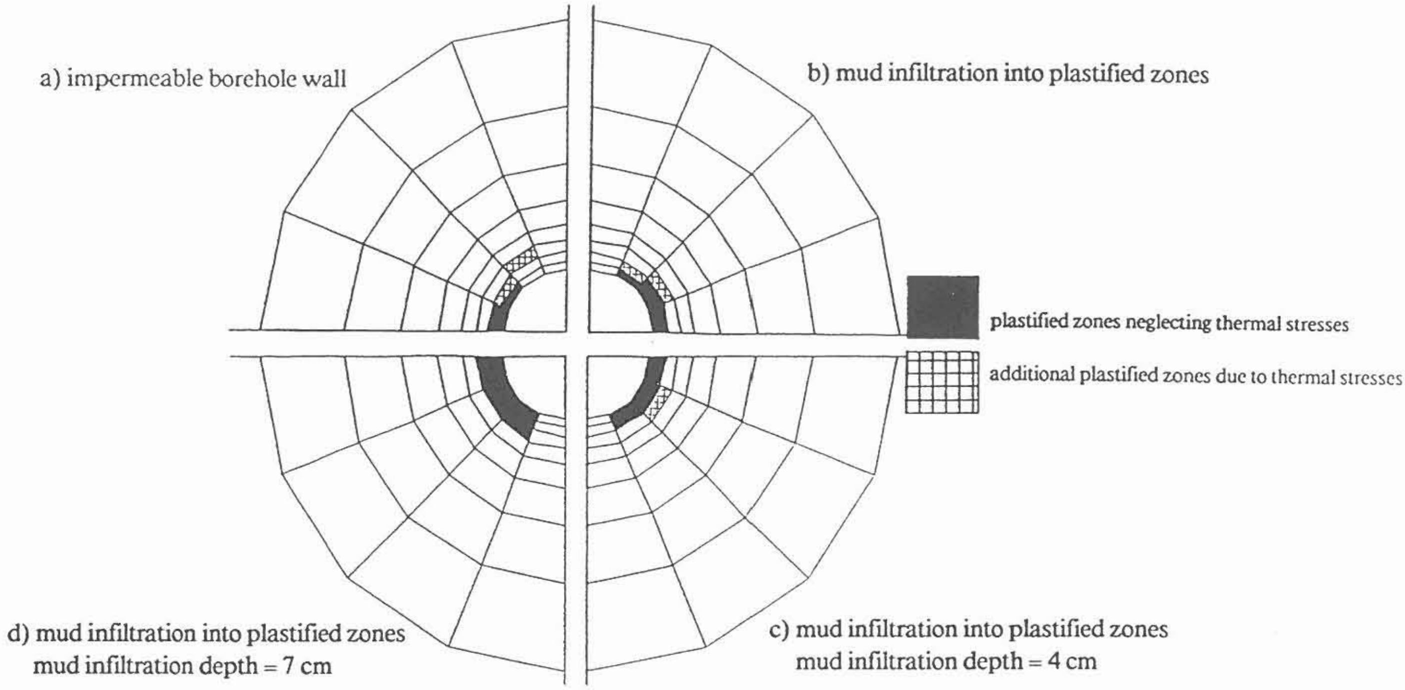


Fig. 1: Development of plastified zones due to different mud infiltration depth

Increasing the mud weight has only a minor effect on borehole stability. If the borehole wall is assumed impermeable or the mud is assumed to infiltrate only into plastified zones, the borehole stability increases with the use of weighted mud. Again, the increase in size of the plastified zones stops when the infiltration depth becomes 25 cm or more. The small differences in borehole stability for loaded and unloaded mud can be explained by the fact that an increase of mud weight increases both destabilization in the rock and the stabilizing forces acting on the borehole wall. Based on these results it can be concluded that loading the mud will at least not reduce the borehole stability, provided the above mentioned assumptions are appropriate. Loading of the mud however becomes increasingly effective for smaller depths of mud infiltration.

In order to evaluate the influence of thermal stresses on borehole stability, thermal stress distributions were calculated for two different temperature profiles corresponding to borehole standing times of 1 h and 30 h respectively (HOFFERS 1993). These stresses were superimposed on the stresses calculated neglecting the temperature profile. The influence of temperature on strength and deformabilty was not considered.

The investigations show that the influence of thermal stresses decreases with increasing borehole standing time and with increasing depth of mud infiltration. For mud infiltration depths exceeding 7 cm, the computations indicate no influence of the thermal stresses on the development of plastified zones (see Figs. 2 and 3). It can therefore be concluded that thermal stresses have an influence on the borehole stability mainly in the area of the borehole bottom.



Development of plastified zones due to superimposed thermal stresses (1 h standing time)

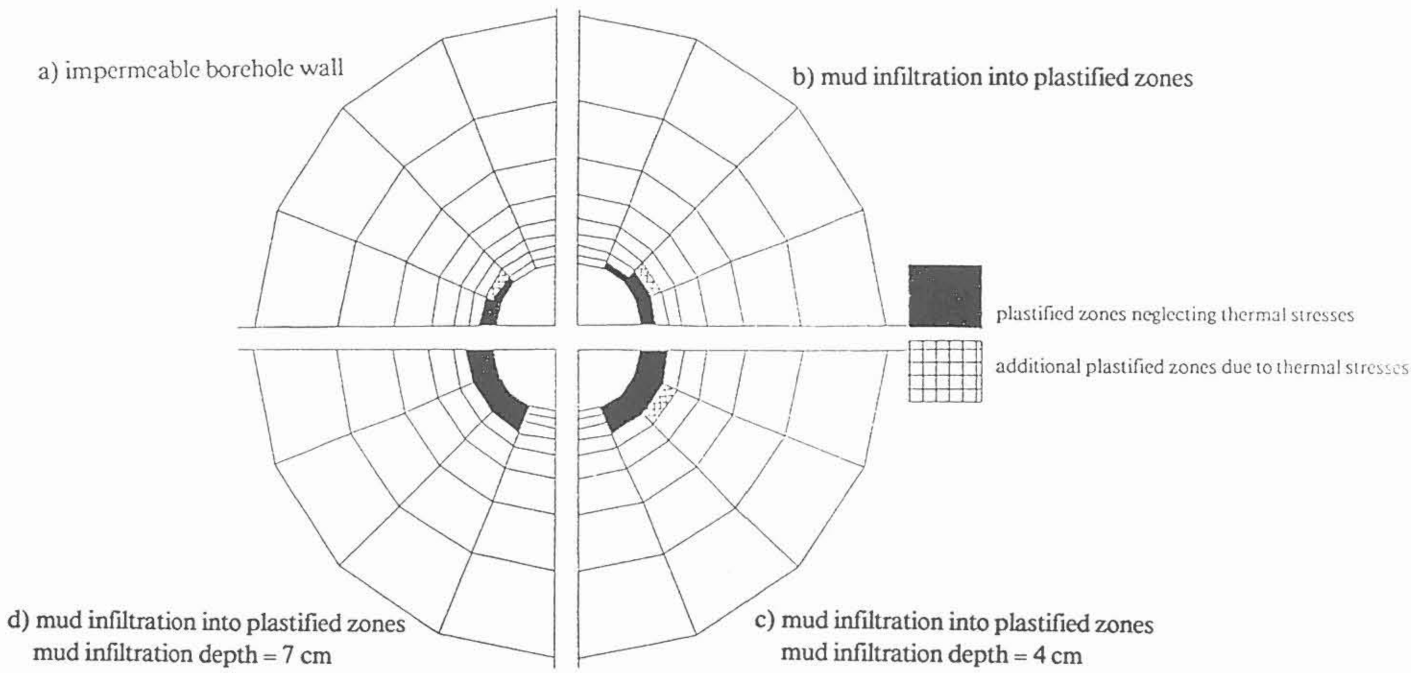


Fig. 3: Development of plastified zones due to superimposed thermal stresses (30 h standing time)

Since cooling of the borehole wall induces tensile stresses and the development of tensile stress areas is strongly influenced by the Poisson's ratio of the rock, calculations were performed with Poisson's ratios $\nu = 0.25$ and $\nu = 0.1$. The results obtained were quite surprising at first sight, with the development of plastified zones hardly affected by the Poisson's ratio. Only for the case of loaded mud and a temperature profile corresponding to a standing time of 30 hours slightly differing results were obtained for the assumptions of an impermeable borehole wall and for mud infiltrating into the plastified zones, respectively (see Fig. 4). The reason for only small differences to occur is that in all cases the applied far field stresses are equal. Therefore the minor horizontal principal stress is independent of Poisson's ratio, which would not be the case under at-rest conditions with no applied far field stresses.

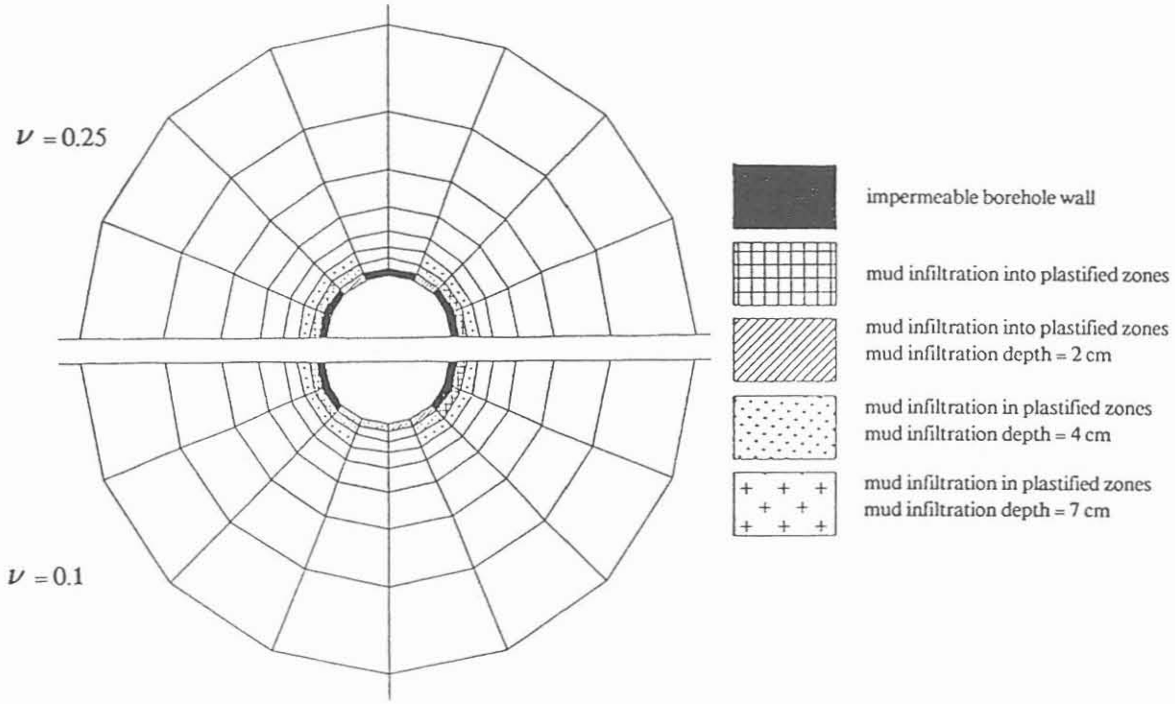


__Fig. 4:__ Development of plastified zones for different Poisson's ratios

On the basis of the results from the above mentioned investigations a three dimensional finite element model including the borehole bottom was created. This model is now used for extensive calculations at the Institute for Foundation Engineering, Soil Mechanics, Rock Mechanics and Waterways Construction.

References

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