Physikalisch-Technische Bundesanstalt

DECKBLATT

	Projekt	PSP-Element	Obj. Kenn.	Aufgabe	UA	Lfd. Nr.	Rev.
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EU 093.3	9K	324.34	-	EG	RB	0007	00

Titel der Unterlage:

SWIFT - Simulator for Waste Injection Flow and Transport

Seite: I.

Stand: 27.01.87

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Rev.	Revisionsst. Datum	verant. Stelle	Gegenzeichn. Name	rev. Seite	Kat. *)	Erläuterung der Revision

*) Kategorie R = redaktionelle Korrektur
Kategorie V = verdeutlichende Verbesserung
Kategorie S = substantielle Änderung
Mindestens bei der Kategorie S müssen Erläuterungen angegeben werden.

SWIFT

SIMULATOR FOR WASTE INJECTION FLOW AND TRANSPORT

Supplement: Freewater Surface
Version TUB/PTC

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Freewater Surface

1. Mathematical background

In the simulation of shallow aquifer systems, it is often desirable to include the effects of the freewater surface, also referred to as water table conditions. This may be accomplished by allowing finite-difference blocks to drain (dewater), resulting in reduced block-to-block transmissibilities and release of water in accordance with the drainage capacity of the block.

In the code, pressures are evaluated at block centers. The position of the freewater surface is determined by the pressure. The block saturation is the fractional amount of the block below the water table. For a particular block, the position is calculated relative to reference pressure as:

$$s_{fw} = \frac{p^n - p_0}{\rho \Delta z g / g_c} + 0.5 \quad . \tag{S-1}$$

In other words, for the water table to be at the top of the block,

$$s_{fw} = 1 \tag{S-2a}$$

or

$$p^n = p_0 + 1/2 \rho \Delta z g / g_c \quad . \tag{S-2b}$$

and for the water table to be at the bottom of the block

$$s_{fw} = 0 \tag{S-3a}$$

or

$$p^n = p_0 - 1/2\rho\Delta z g/g_c \quad . \tag{S-3b}$$

The amount of water contained by storage in a partially saturated freewater block is:

$$V_{fw} = \Delta x\Delta y\Delta z\Theta_o \tag{S-4a}$$

or

$$V_{fw} = s_{fw}V \quad . \tag{S-4b}$$

Otherwise for blocks that are fully saturated

$$V = \Delta x\Delta y\Delta z\Theta \left| 1 + c_r(p - p_0) \right| \tag{S-5}$$

The approach is consistent with other codes such as the modular U.S. Geological Survey code [McDonald and Harbaugh, 1984].

2. Implementation

The freewater surface option impacts the accumulation and transmissibilities of the pressure equation. In this section the implementation of transient and steady-state flow solutions is presented.

Equations (S-1) and (S-4) are used to modify the expansion of the accumulation terms (INTERCOMP, 1976) as follows

$$(S\rho V) = S\delta(\rho V) + \rho V\delta S \qquad \text{(S-6)}$$

$$= S(V^n\delta p + \rho^{n+1}\delta V) + \rho V\delta S \quad . \qquad \text{(S-7)}$$

Here the first term is the same as for saturated flow, as multiplied by the block saturation. This represents compressible fluid accumulation or confined aquifer storage. The second term is the release of water from drainage or an unconfined yield. The latter term dominates in typical application, thus allowing transient, as well as steady-state, phreatic conditions.

To account for the reduced cross-sectional area available for flow in a partially saturated block, the fluid transmissibilities are modified as follows:

$$T_{Wxx} = T_{Wxx}S \qquad \text{(S-8a)}$$

$$T_{Wyy} = T_{Wyy}S \qquad \text{(S-8b)}$$

$$T_{Wzz} = T_{Wzz} \qquad \text{(S-8c)}$$

where the saturation is allowed to vary between 0.001 and 1.0. Only the horizontal components are modified to reflect the reduced area available for flow. A minimum saturation is maintained such that blocks that fully desaturate may be resaturated in subsequent time steps.

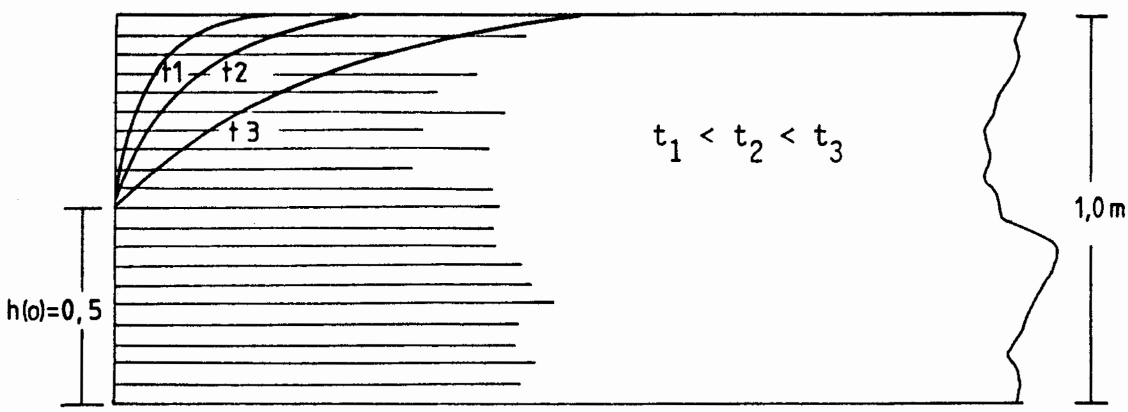
Within the model special consideration has been given to the accumulation terms in Equation (S-7). According to numerical investigations it is necessary to separate the implicit and explicit components. Depending upon whether the freewater surface is above, within, or below a grid block before and after a time step (before or after an iteration for steady-state), special handling of the terms is required. The logic is detailed in subroutine SCOEF.

3. Verification

The following figures are showing a verification example for the implemented freewater surface option. The example is based on an analytical solution by Polubarinova-Kochina (Bear, 1972; page 384). It is showing the desaturation and the resaturation procedure for a multilayer system. The accordance between the numerical and the analytical solution is quite good.

A. Multilayer desaturation

20 layers: $\Delta z = 0{,}05$ m

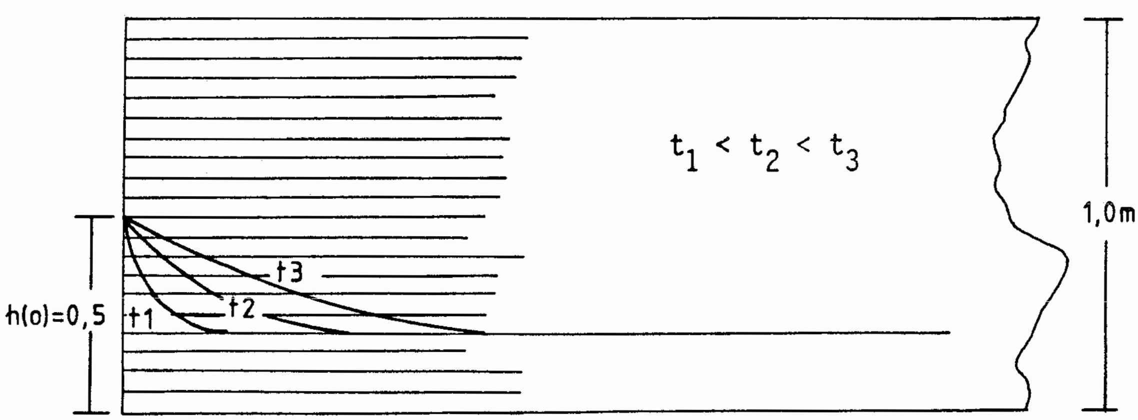


Initial condition : h (x,t=0) = 1,0

Boundary conditions: h (0,t>0) = 0,5

h (α,t>0) = 1,0

B. Multilayer resaturation

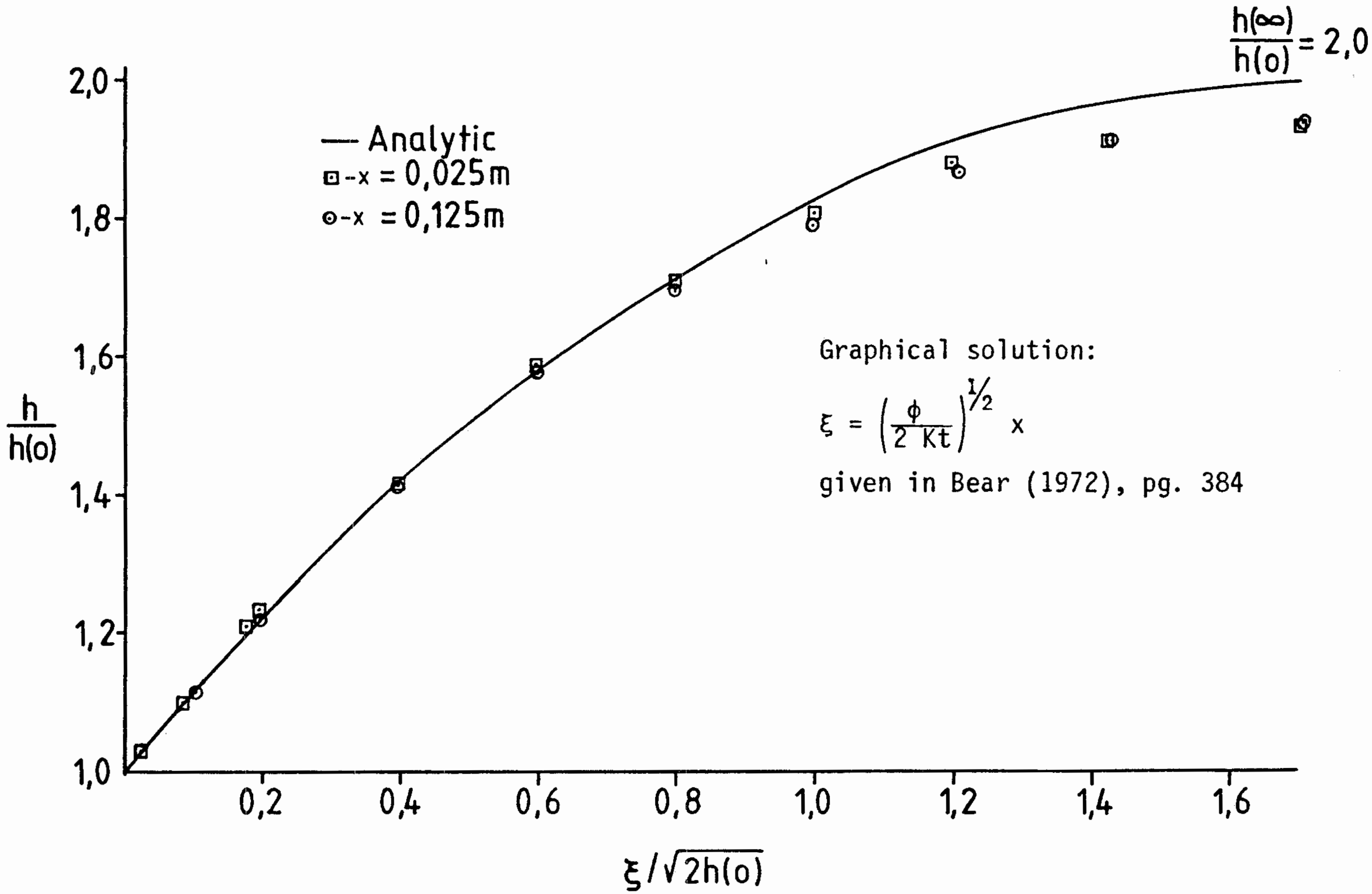


Initial condition : h (x,t=0) = 0,2

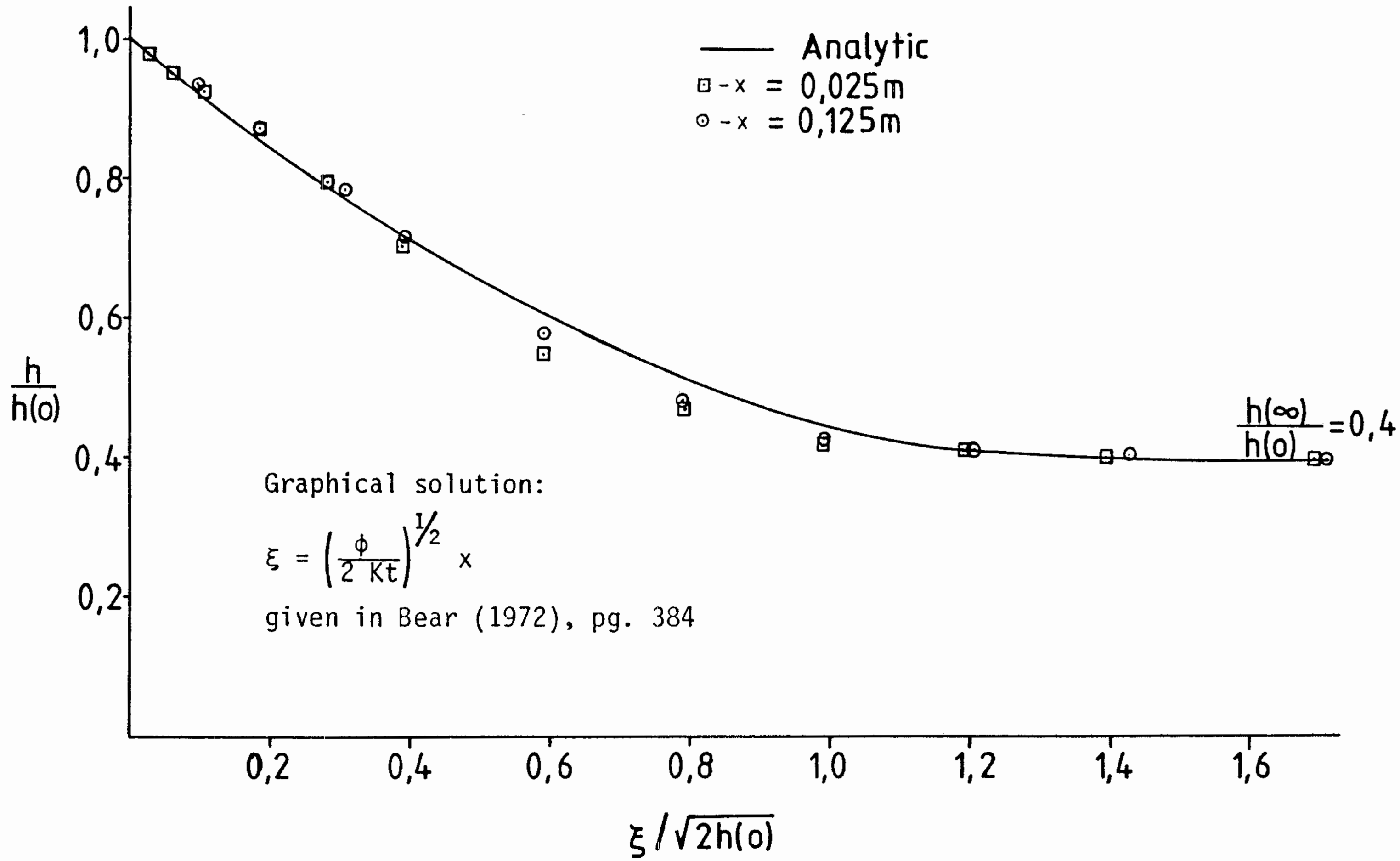
Boundary conditions: h (o,t>0) = 0,5

h (α,t>0) = 0,2

SWIFT FREE-WATER SURFACE : MULTILAYER DESATURATION



SWIFT FREE-WATER SURFACE: MULTILAYER RESATURATION



4. References

Bear, J.: Dynamics of fluids in porous media, American Elsevier, 1972

INTERCOMP: Development of model for calculating disposal in deep saline aquifers, parts I and II, PB-256903, NTIS, 1976

McDonald, M.G.; Harbaugh, A.W.: A modular three dimensional finite-difference ground-water flow model, USGS 1984