2.4. ANALYSIS OF CRACK-FORMATION IN THE SHIELDING CONCRETE OF A TRIGA MARK II REACTOR, H. Linsbauer, P. Maydl (Vienna, Austria)

1. General:

In 1962 the TRIGA Mark II research reactor Vienna was put into operation. Within a short time several cracks appeared at the concrete surface and the number and width of the cracks had grown till now. Therefore the origin of this cracks had to be investigated and a solution had to be outlined to avoid further crack increase.

2. Experimental analysis:

First of all a survey of all cracks was made. Fig. 1a shows a typical crack-formation of the lower part of the shielding, which consists of baryte concrete. Crack No. 1 is the one with the maximum width of 1,7 mm. It circles around the whole shielding in the same level.

At four points of this crack~~s~~ as well as at two vertical cracks the crack movement was measured by inductive gages. Simultaneously the temperature of the cooling water in the reactor tank at the top and at the bottom as well as the air and the concrete temperature were recorded. The results of these measurements are shown in Fig. 1b where the crack movement as a function of the air and concrete temperature is demonstrated. A two weeks experiment did not show any correlation between primary water temperature and crack movement.

Four drill cores were taken out of the concrete piercing the cracks under an angle of 45°. The concrete texture was undisturbed; with the drill cores the compressive and tensile strength as well as the static modulus of elasticity were determined by test.
The compressive strength was at about 65 N/mm^2, the tensile strength at 3 N/mm^2 and the modulus of elasticity at an average of 36 000 N/mm^2. These characteristic values were used for the following calculations.

3. Theoretical analysis:

The calcultaion of the thermal stresses was made in two independent ways:

1. analytically, simulating the shielding concrete as an infinite hollow cylinder of constant thickness
2. by the Finite Element method, for a better description of the geometry

The following assumptions were made:

1. Stationary temperature conditions
2. Reference temperature of 18° C
3. Shielding concrete without cracks.

For the build up-factor, which must taken into consideration, two approximations were used:

1. the exponential approximation of Taylor for the analytical calculation with values for normal concrete, being more convenient for further use.

2. the polynome approximation for the Finite Element - calculation, with values for baryte concrete.

The geometric system for the Finite Element calculation is shown in Fig. 2

For both methods the pool water temperature was assumed with 38° C, the air temperature with 18° C. Analytically the three-dimensional state of stress was calculated for 3 thermal insulations, glass or slag wool with a thickness of 5, 10 and 15 cm, and for the bare shielding concrete.

Finite Element calculations were made:

1. without insulation and primary water temperature 38° C
2. with 10 cm insulation and primary water temperature 38° C
3. without insulation and primary water temperature 28° C

The results are shown in the following Figs.:

1. The analytical calculation:

Fig.3 shows the temperature distribution in radial direction for the three various dimensions of the thermal insulation and that for the bare concrete;

Fig.4 to 6 show the radial-axial-and tangential stress distributions for the four cases.

Fig.7 and 8 show the influence of the γ-radiation on temperature and axial stress distribution.

Fig. 9 shows the effect of various dimensions of the thermal insulation on the axial stresses at the concrete surface at different γ-dose rates.

2. The Finite Element Method:

Fig. 10 shows the temperature distribution for the three calculations mentioned above.

Figs. 11 to 13 show the corresponding stress distribution of radial, axial and tangential stresses.

Fig. 14 shows a plotter drawing of the iso-lines of axial stresses without thermal insulation for the baryte concrete part of the shielding. In this part the maximum tensile stress is located very close to the actual crack situation.

Fig.15 shows the principal stresses.

Comparing the two calculation methods very similar results are obtained with one exception,concerning the influence of the thermal insulation.

- according to the analytical calculation 10 cm insulation yield an axial stress decrease of about 50%,

- using the Finite Element Method only 15% are obtained.

This can be explained as follows: The insulation reduces the temperature gradient in radial (horizontal) direction as the concrete surface temperature increases. At the same time an additional temperature gradient in vertical direction results which also causes tensile stresses beyond the tensile strength.

4. Conclusions:

1. The cracks of the shielding concrete are exclusively caused by the thermal stresses.

2. A temperature gradient of 20°Cproduces tensile stresses beyond the tensile strength.

3. A thermal insulation at the lower part of the shielding is not effective. For a stress decrease it is necessary to reduce the temperature gradient from 20 ° C to 10°C which requires a maximum primary water temperature of 28°C. This gradient causes maximum tensile stresses of 3 N/mm^2, near the tensile strength.

4. The structural system of the shielding concrete as a monolithical block without joints produces automatically tensile stresses. Together with an unsufficient reinforcement-assuming a temperature gradient of 20°C - it causes cracks at the outer concrete surface. Baryte concrete has an unfavourable influence on the thermal stresses too, because the temperature expansion coefficient has nearly the double value of normal concrete. In consequence of his numerous cleavage planes the tensile strength of the investigated concrete is very low compared with the high compressive strength and rigidity.

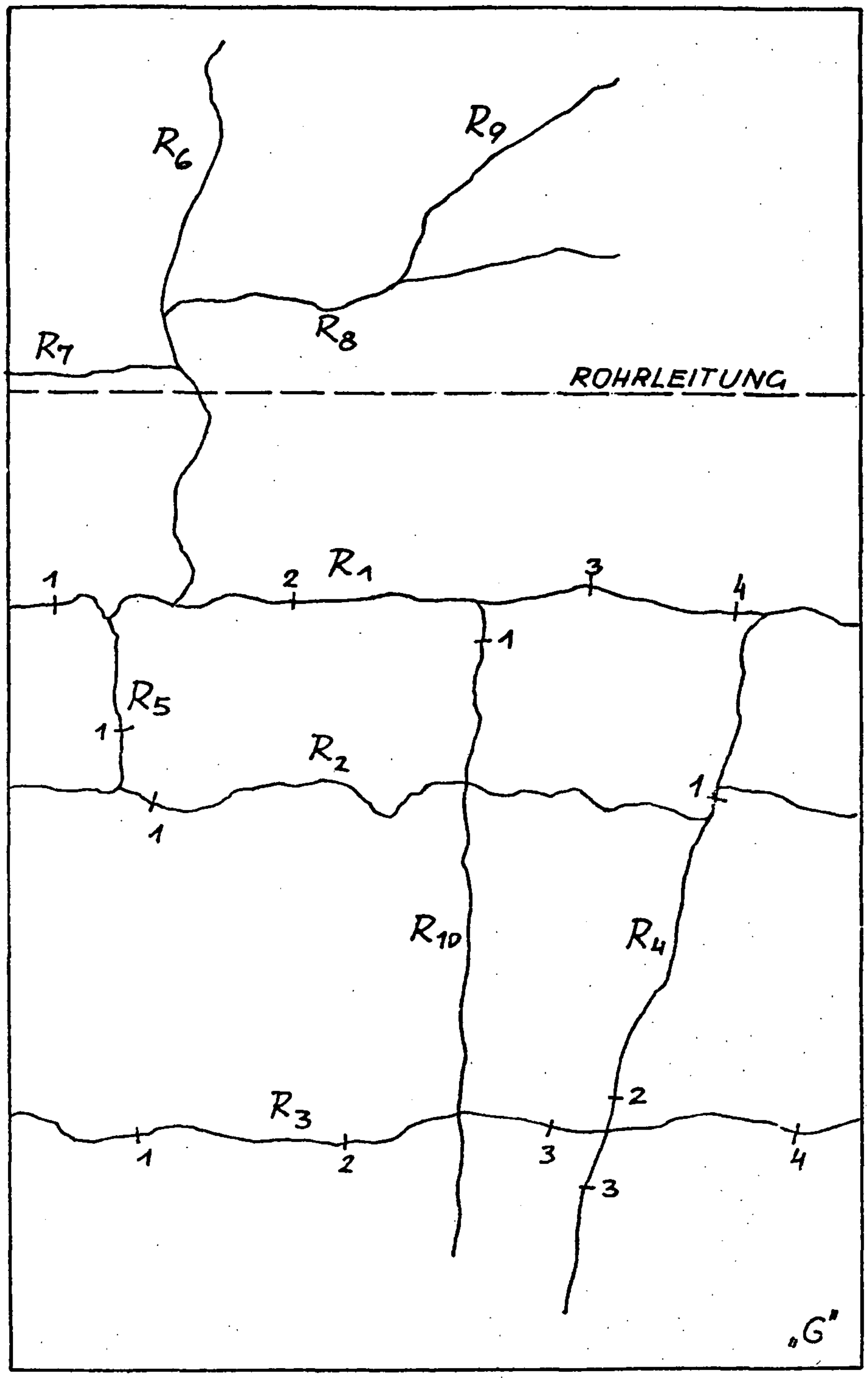

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Bild 1a: Rißbild der Seitenfläche 7

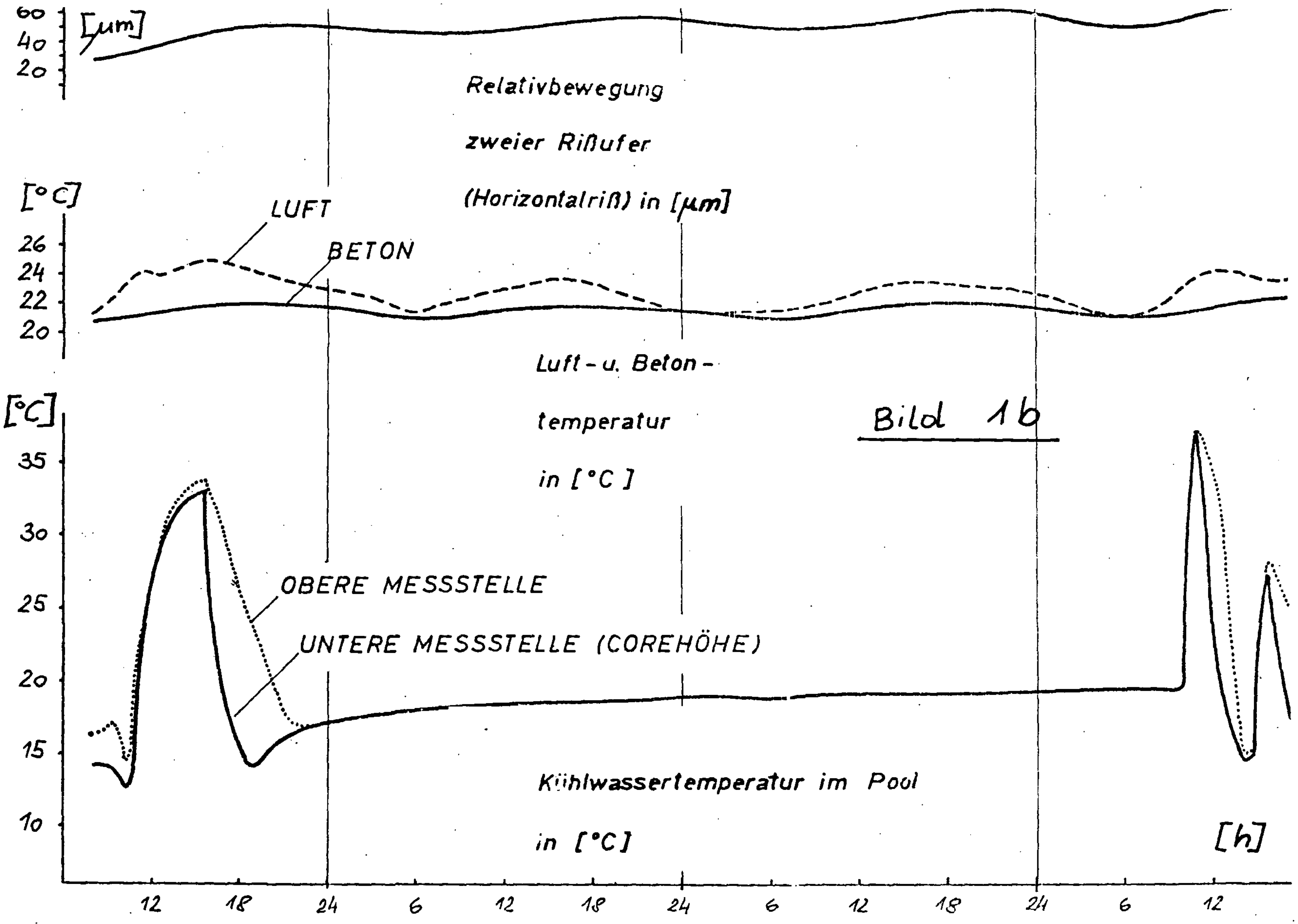

Bild 1b

[µm]
60
40
20
Relativbewegung
zweier Rißufer
(Horizontalriß) in [µm]
[°C]
26
24
22
20
LUFT
BETON
Luft- u. Beton-
temperatur
in [°C]
[°C]
35
30
25
20
15
10
OBERE MESSSTELLE
UNTERE MESSSTELLE (COREHÖHE)
Kühlwassertemperatur im Pool
in [°C]
[h]
12
18
24
6
12
18
24
6
12
18
24
6
12

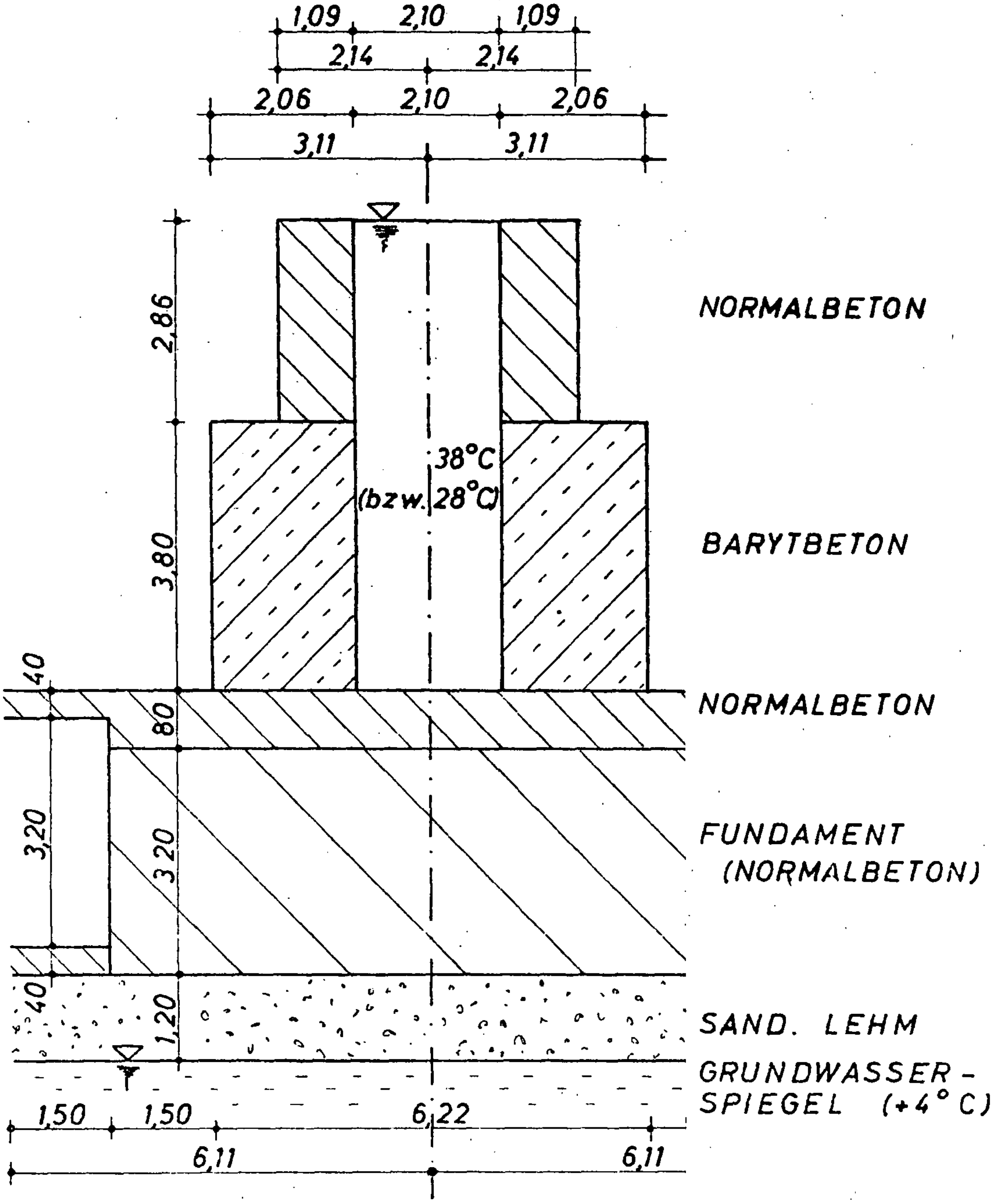

Bild 2:

Geometrie und Randbedingungen für die Berechnung nach der Methode der Finiten Elemente: Schnitt durch die Zylinderachse (Symmetrieachse).

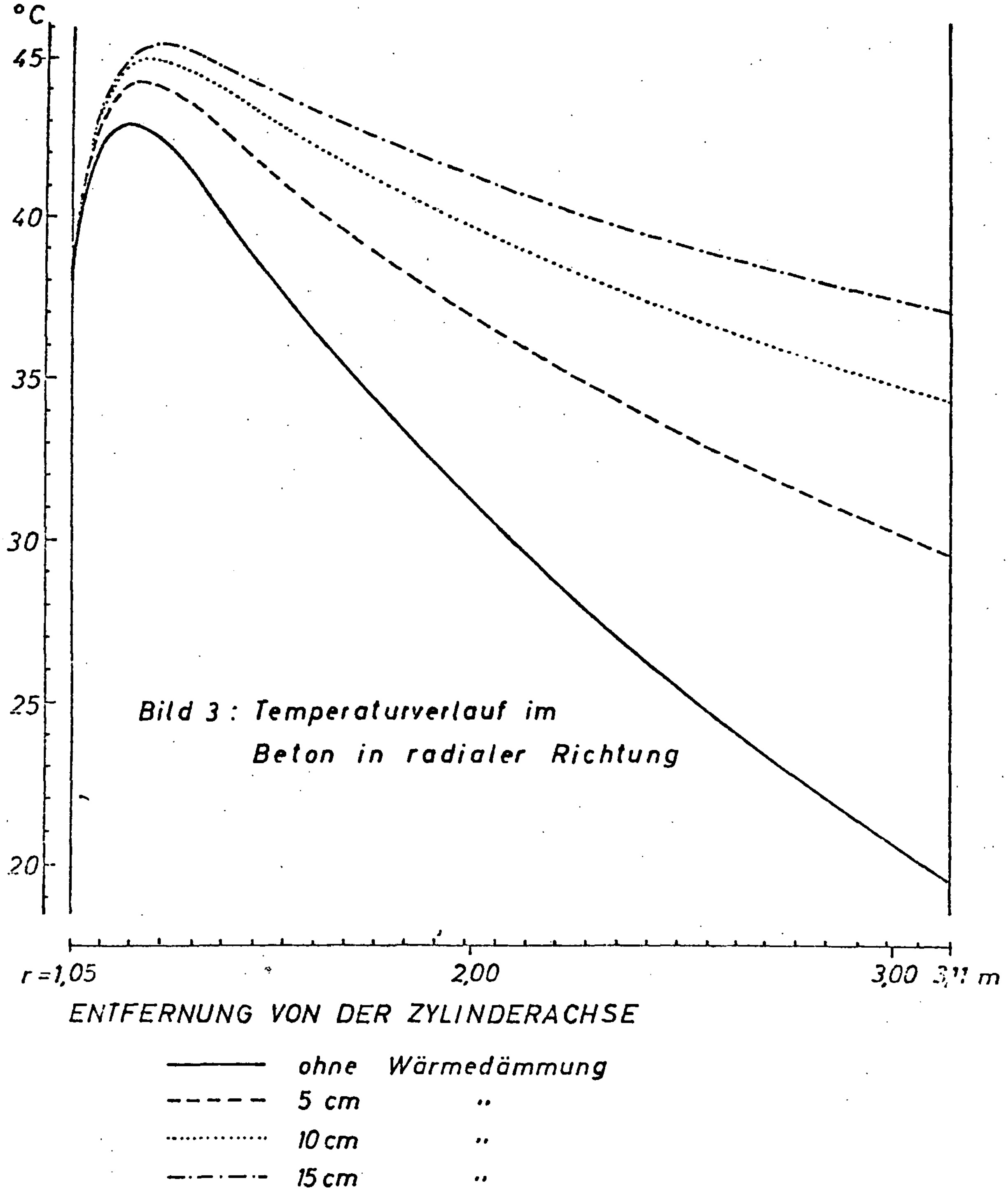

Bild 3 : Temperaturverlauf im Beton in radialer Richtung

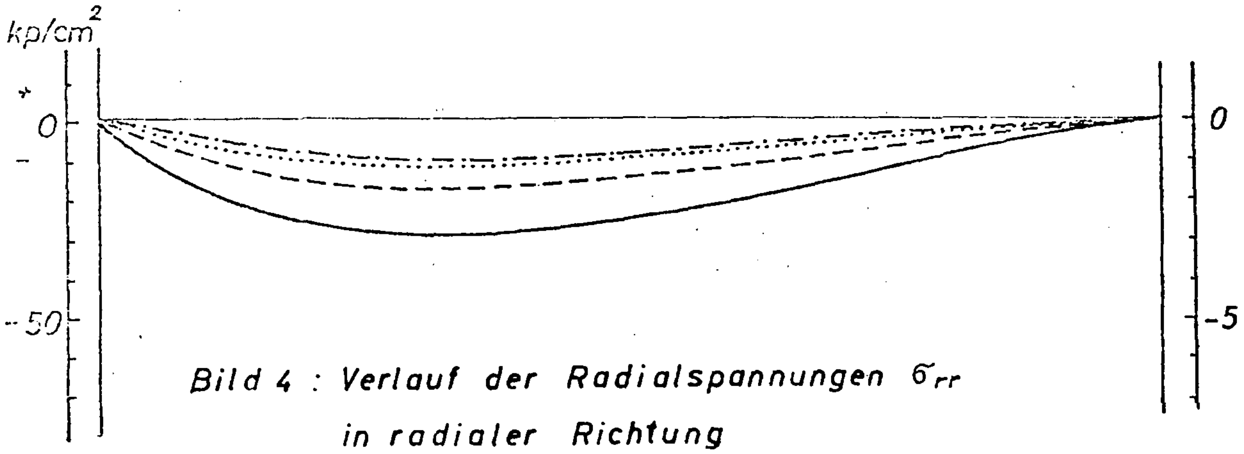

Bild 4 : Verlauf der Radialspannungen σ_{rr} in radialer Richtung

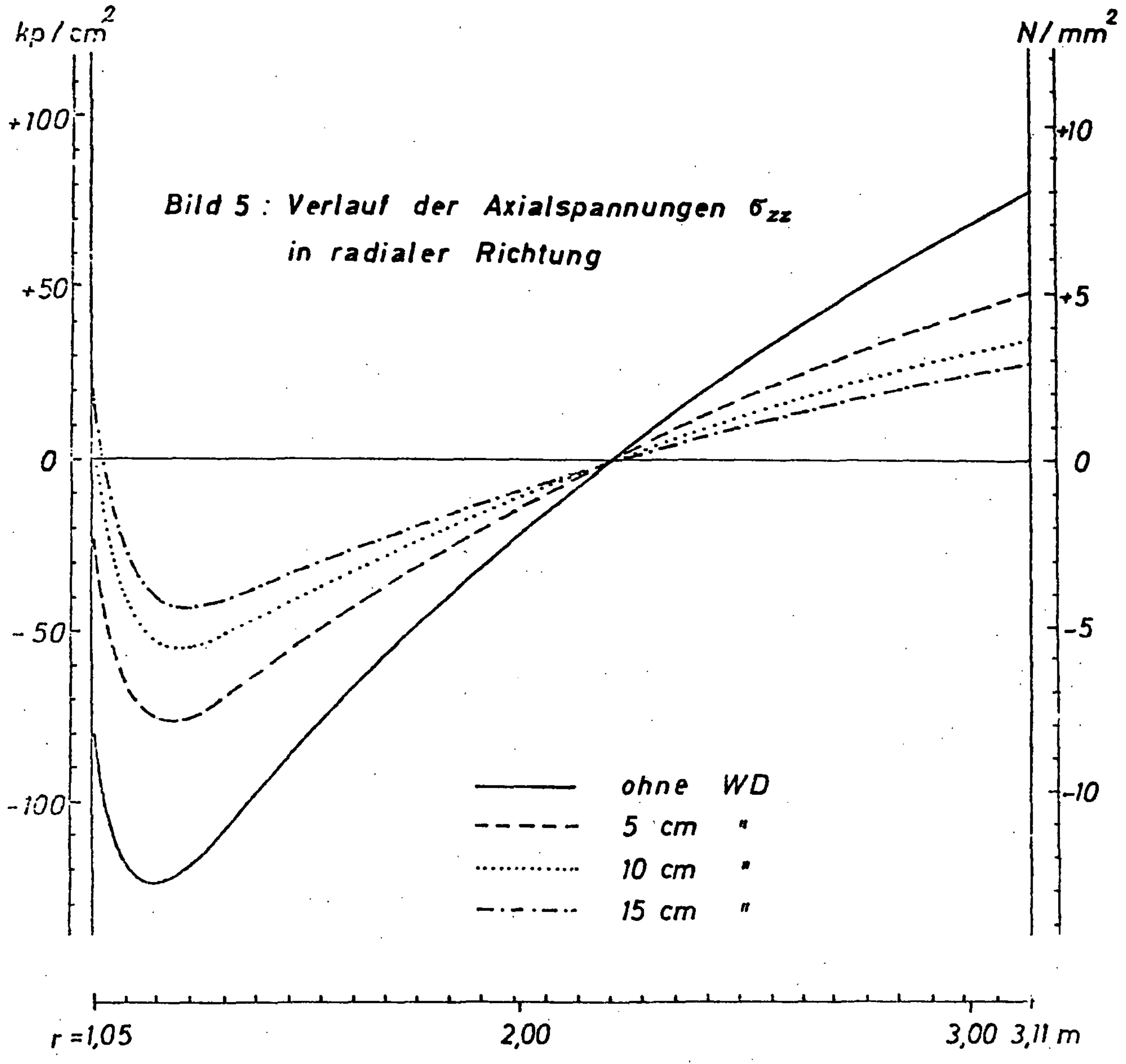

Bild 5 : Verlauf der Axialspannungen σ_{zz} in radialer Richtung

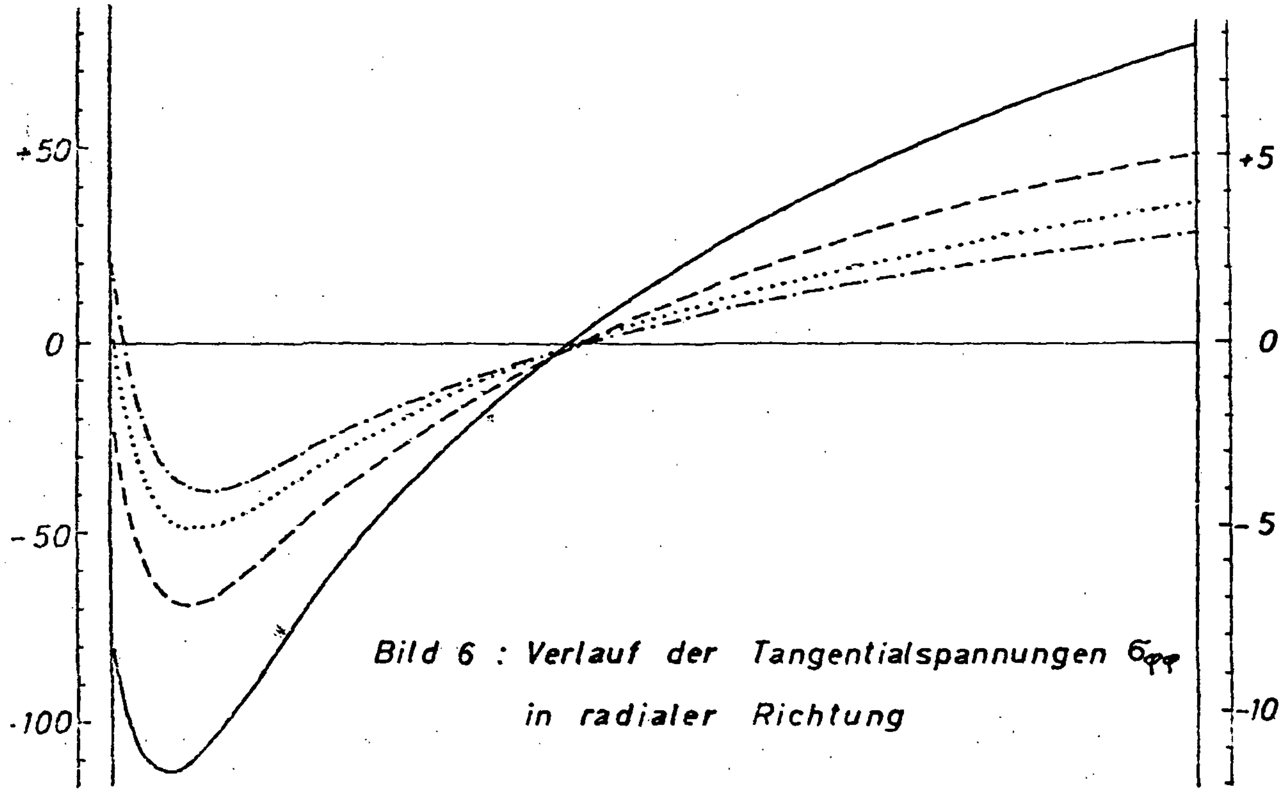

Bild 6 : Verlauf der Tangentialspannungen $\sigma_{\varphi\varphi}$ in radialer Richtung

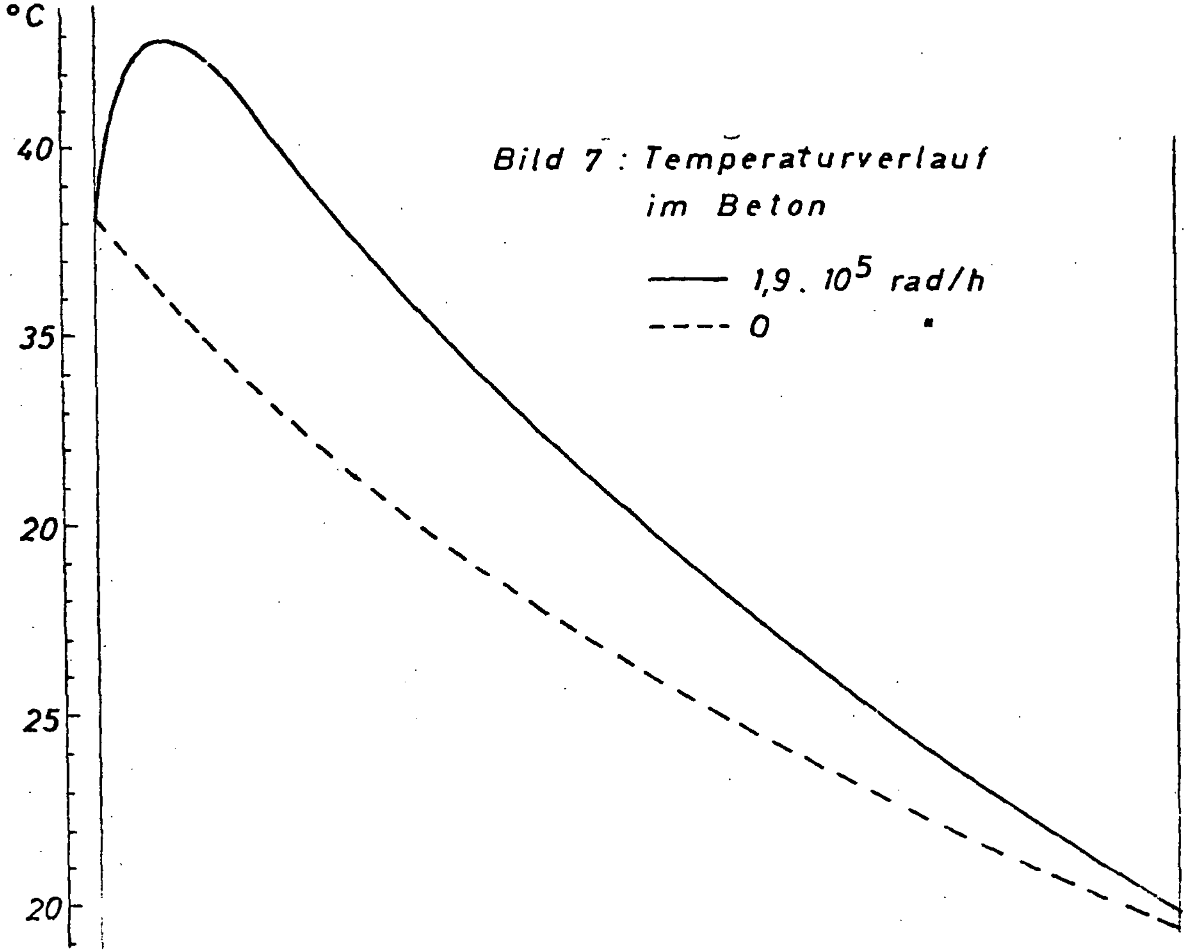

Bild 7 : Temperaturverlauf im Beton

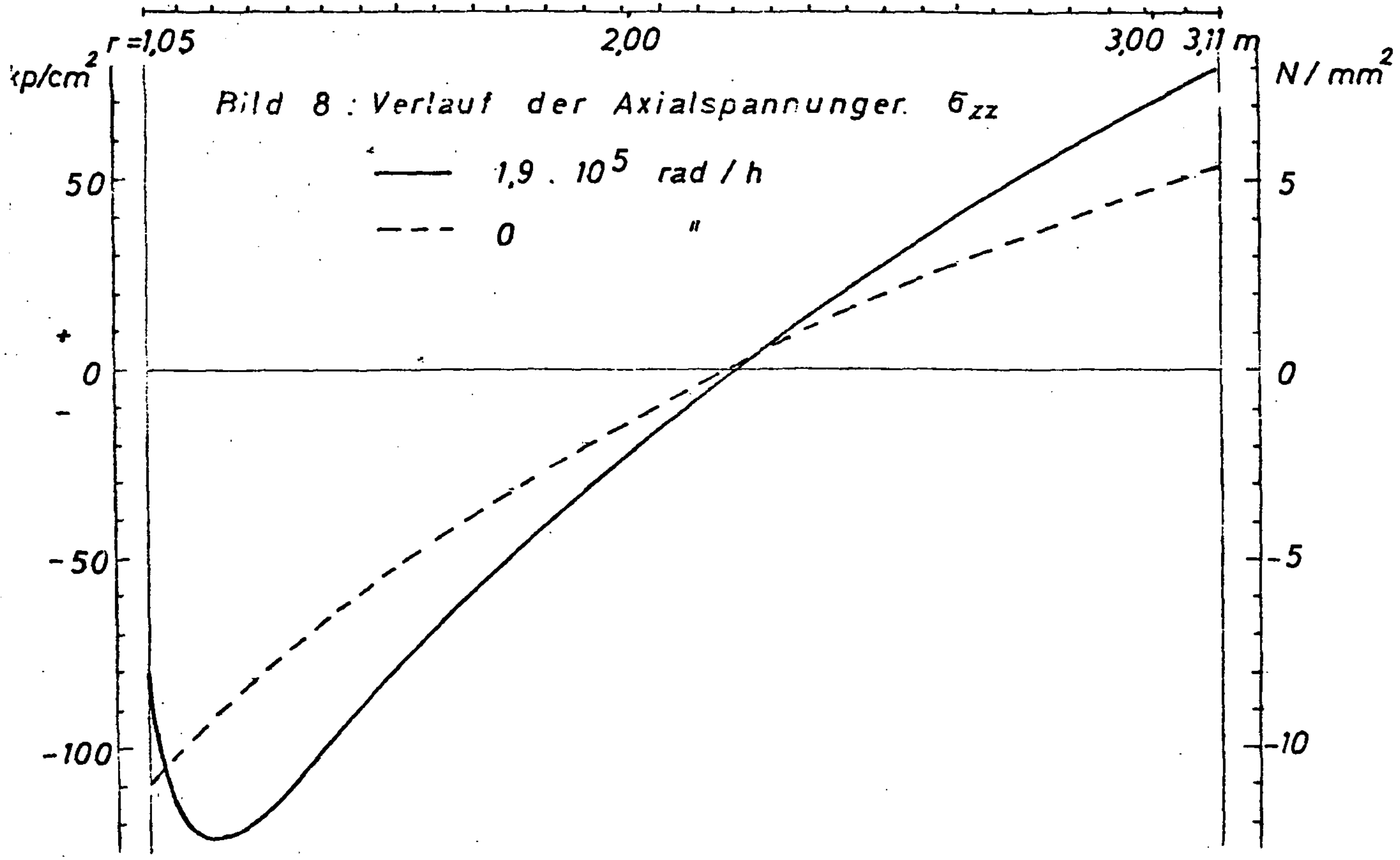

Bild 8 : Verlauf der Axialspannungen σ_{zz}

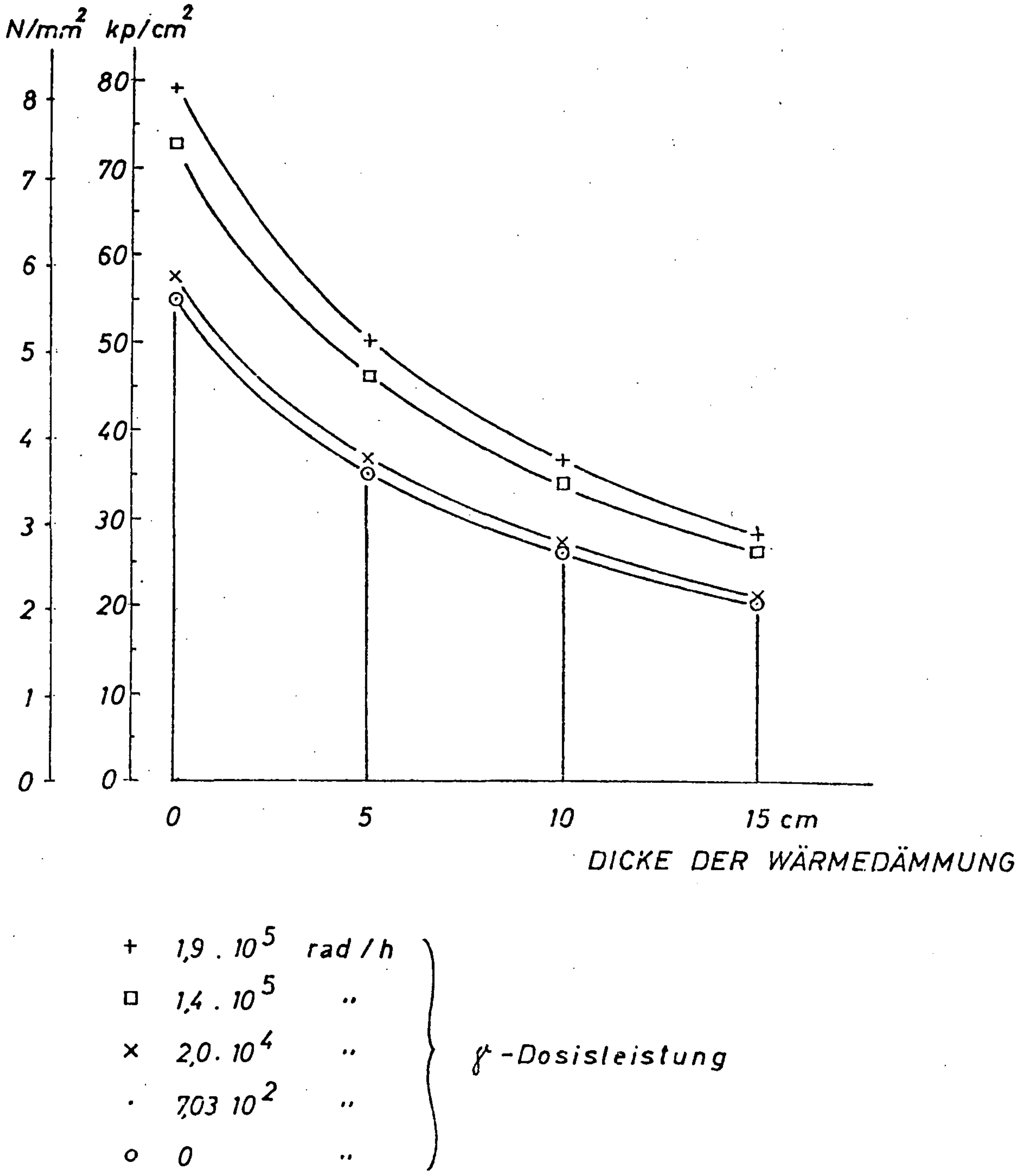

Bild 9: Einfluß der Dicke der Wärmedämmschicht auf die Axialspannung an der Betonaußenseite (r = 3,11 m) bei verschiedenen γ-Dosisleistungen (analyt. Berechnung).

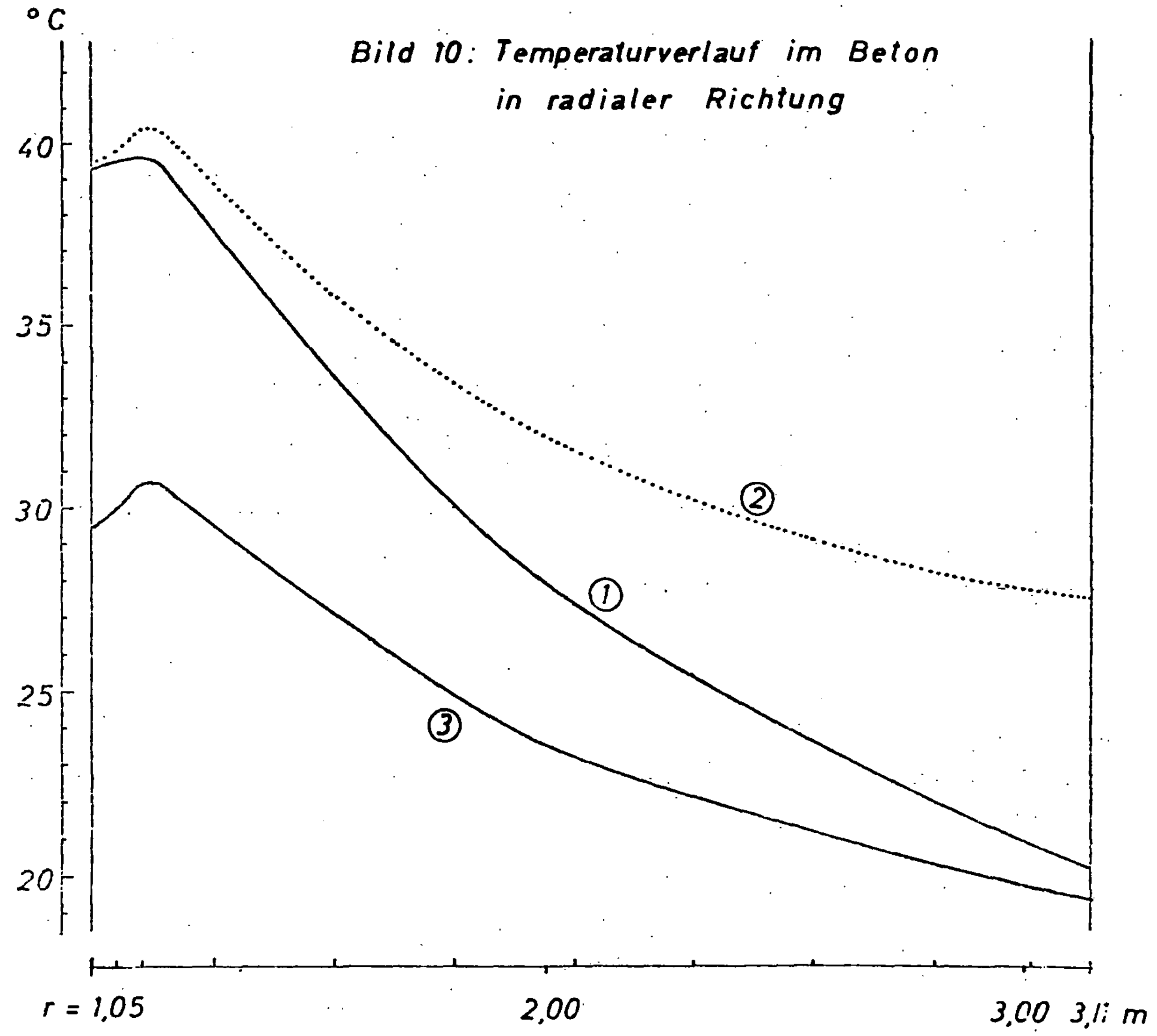

Bild 10: Temperaturverlauf im Beton in radialer Richtung

① $T_1 = 38$ °C, ohne WD

② $T = 38$ °C, 10 cm WD

③ $T = 28$ °C, ohne WD

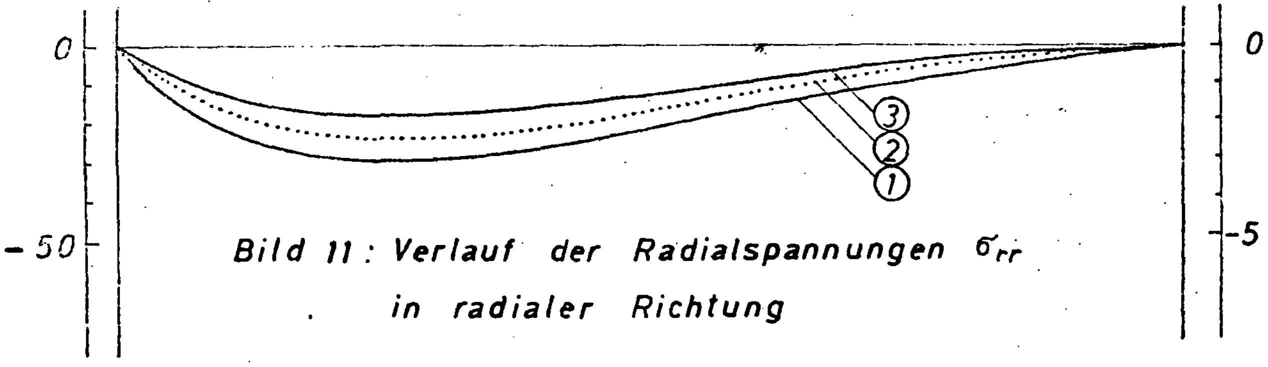

Bild 11: Verlauf der Radialspannungen σ_{rr} in radialer Richtung

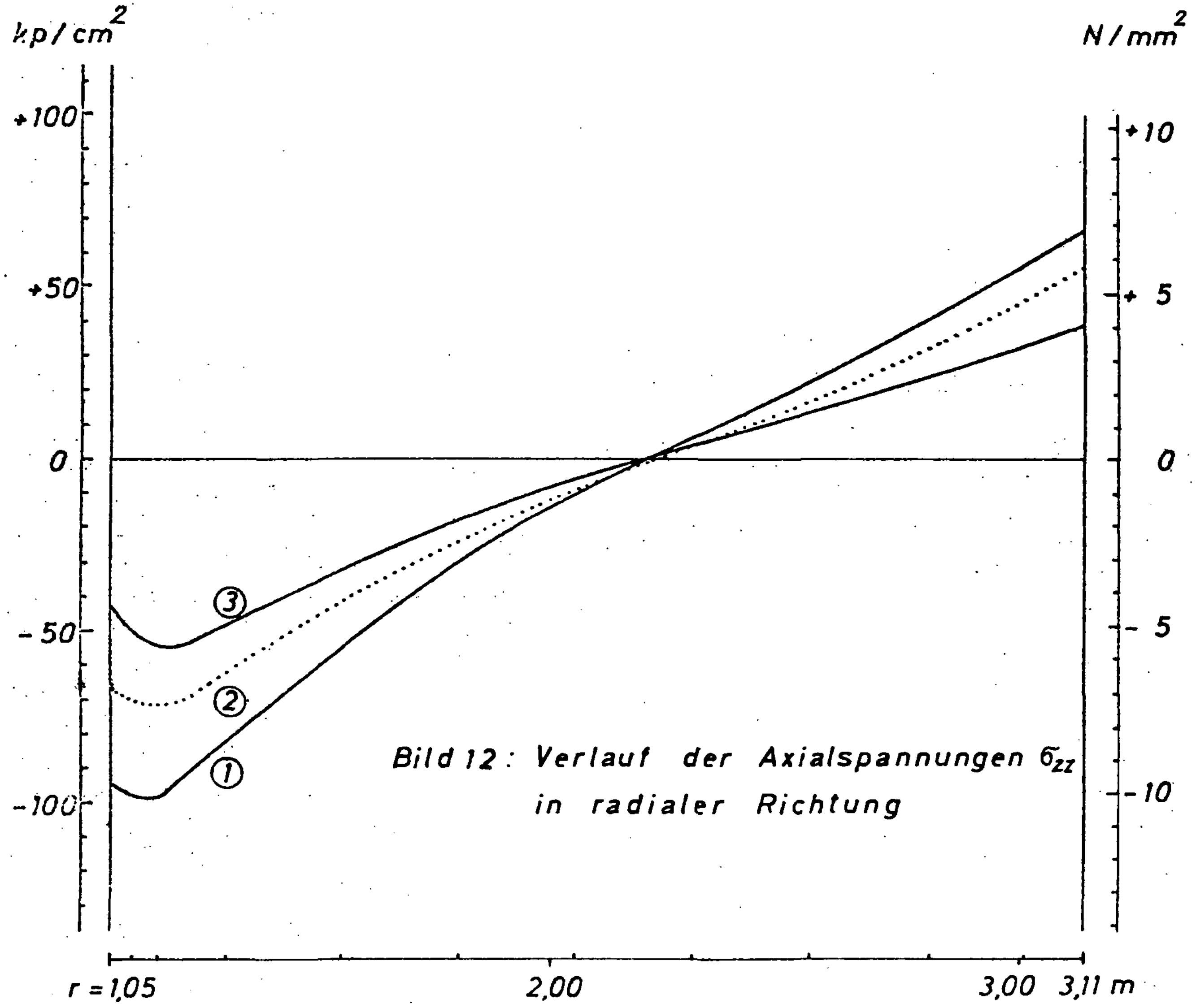

Bild 12: Verlauf der Axialspannungen σ_{zz} in radialer Richtung

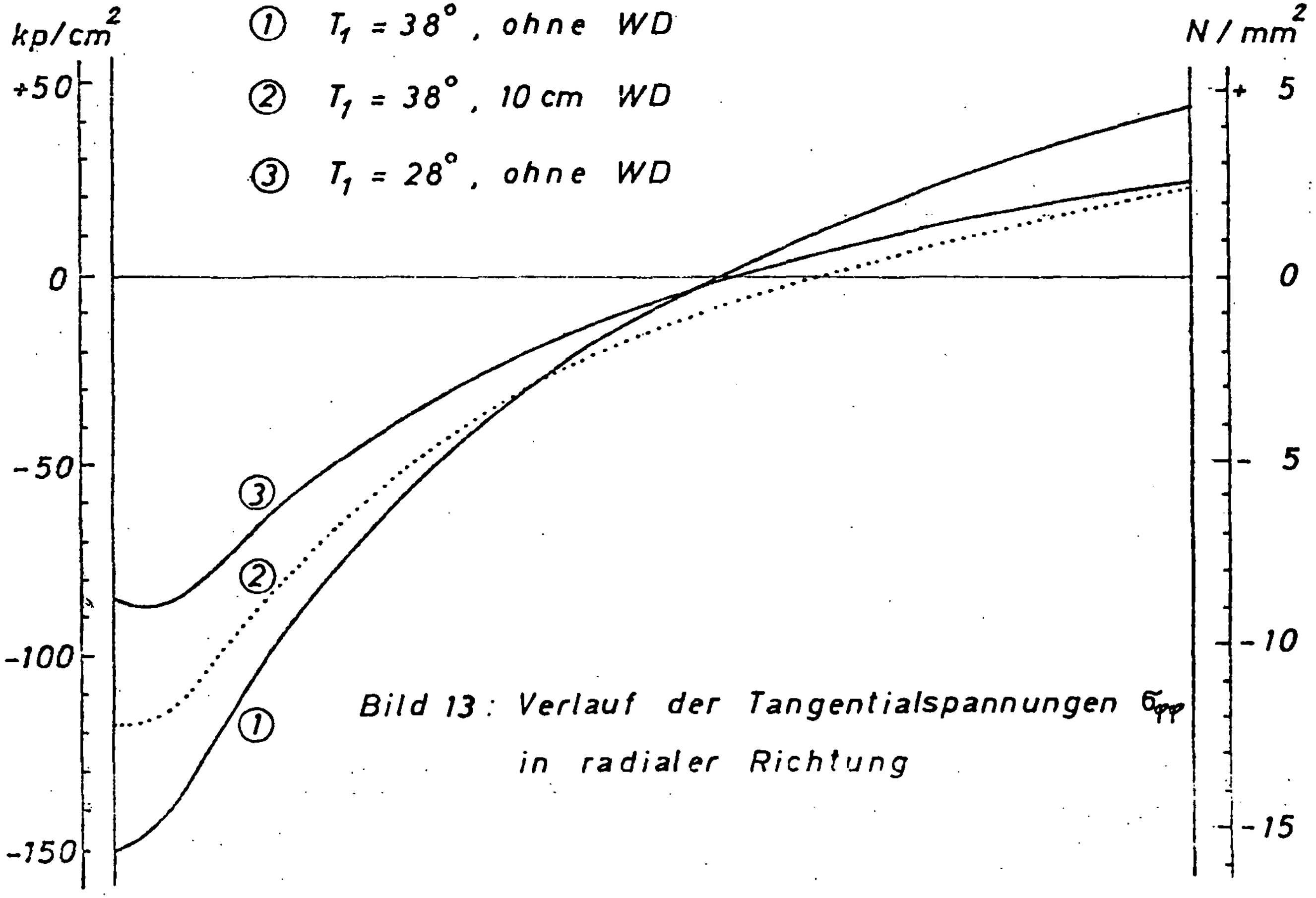

Bild 13 : Verlauf der Tangentialspannungen $\sigma_{\varphi\varphi}$ in radialer Richtung

Bild 14

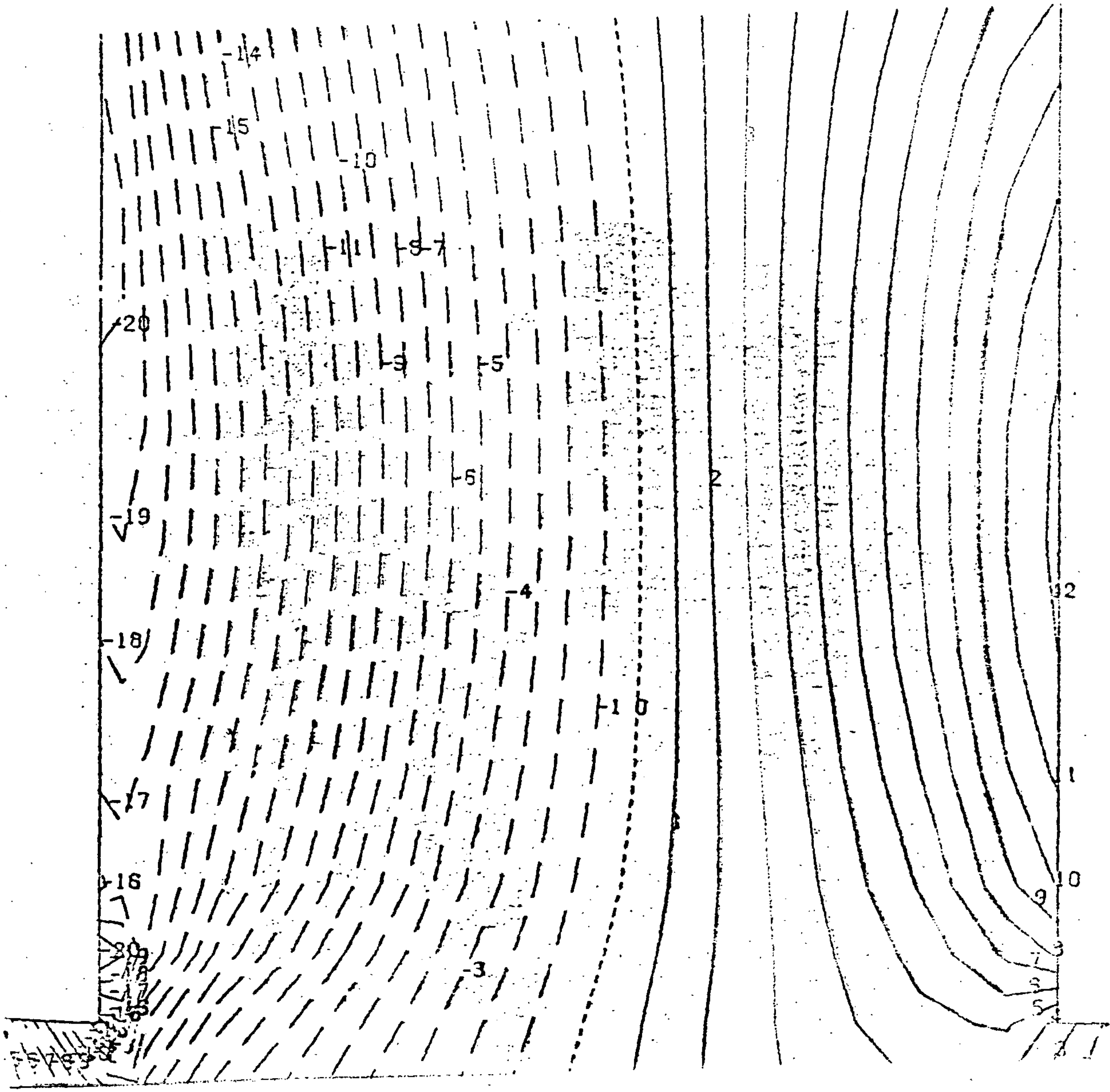

Bild 15