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On the Theoretical Assumption for Stress Measurement in Concrete

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Abstract

Providing creep and shrinkage in concrete, it is often difficult to derive the concrete stresses from measured strains in concrete. Therefore it seems in some load cases e.g. in stressfields without strains more reasonable to measure the stresses directly. Due to this fact, the paper deals with the theoretical assumptions of stress measurement in concrete as well as with practical tests of stress meters in order to get basic knowledge about the advantages and the disadvantages of stress measurement.

First, the state-of-the-art in form of a two-dimensional stress meter/concrete model is illustrated. In order to check this model, the development of a three-dimensional finite element model for the stress meter/concrete system is respresented. Because of the third dimension, this model shows strongly different results as the two-dimensional one and allows more extensive studies on geometrical and material parameters of the stress meter/concrete system as well as some estimations on stress measurements concerning creep and shrinkage in concrete. With regard to the same but concentrated load, the influence of the height to diameter ratio on the normal stress distribution in the middle plane of the loaded prism is investigated by means of this model, too.

Furthermore, the paper deals with a dynamic model for an analog computer, especially of the Glötzl stress meter in concrete, in order to get more insight in its special functions as well as to improve single parts of the stress meter. In particular, this dynamic model gives some ideas in how to reduce the temperature dependence of the stress meter.

The last part of the paper describes the short and long time tests of commercial stress meters and BAM-made stress meters in concrete prisms. The tests were carried out over a time period of two years in the BAM-Berlin and show especially measured stresses as a function of load and time. Some prospects on stress measurement in concrete concerning long time stress measurement in connection with creep and shrinkage in concrete finish this work.

1. Introduction

With regard to the stress measurement in concrete, the common axiom says that the stress meter has to have a small height to diameter ratio while the modulus of elasticity of the stress meter has to be nearly the same as that of the concrete.

In order to get a mathematical basis for this axiom, Y. Loh [1] developed a simple two-dimensional mechanical model of the stress meter/concrete system. This model enables the calculation of the ratio s of theoretically measured stress to exact concrete stress as a function of

- the modulus of elasticity of the stress meter, E_A
- the modulus of elasticity of the concrete, E_B
- the height of the stress meter, $h_A = 2 \cdot z_A$
- the diameter of the stress meter, $d_A = 2 \cdot y_A$, providing a circular stress meter.

That means:

$$s = f\left(\frac{E_A}{E_B}, \frac{z_A}{y_A}\right) = \frac{\sigma_{measured}}{\sigma_{concrete}}$$

Regarding Loh's model, the results of this model are shown in fig. 1-1: In order to limit the relative stress measurement error $f = (1 - s)$ up to $\pm$ 5 %, Loh's diagramm allows a maximum height to diameter ratio of a stress meter, z_A/y_A, up to 0.4.

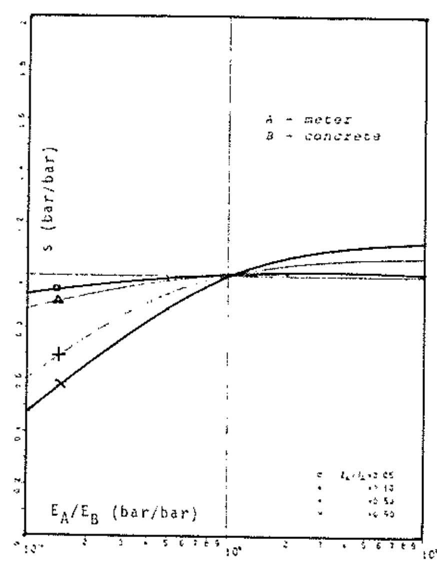


Fig. 1-1 *Loh's model:*

The well-known measured stress to the exact concrete stress ratio s after Loh as a function of the ratio of the moduli of elasticity, E_A/E_B; parameter is the height to the diameter ratio z_A/y_A of a circular stress meter

Magiera,Czaika [2] extended Loh's equations to stressfields without strains and strainfields without stresses; from that follows for creep and shrinkage assuming the same measurement error limit of 5 %, that z_A/y_A has to be smaller than 0.2.

2. Theoretical assumption

Because of some simplification of Loh's model a three-dimensional cylindrical model of this system is made, see fig. 2-1a. In order to minimize the calculation procedure with the computer code SAP 4, only a quarter of the model is discretized into finite elements, see fig. 2-1b. With regard to the area representing the stress meter, the area itself and the surrounding area are discretized very finely since two different materials e.g. two different modulus of elasticity come together. First the model is loaded with a uniform normal load $p_{B,Z}$ and in a second step with a uniform shear load $p_{B,Y}$, see fig. 2-1a. The results referring to the load $p_{B,Z}$ are shown in fig. 2-2.

The main different result in contrast to Loh's one is a clearly greater limitation of the geometrical values in order to limit the measurement error up to 5 %: The height to diameter ratio of the stress meter, z_A/y_A, has to be smaller than 0.1 while the ratio of the moduli of elasticity, E_A/E_B, ranges from about 0.8 to 2.0.

Due to the constant shear load $p_{B,Y}$, fig. 2-3 represents the measured error stress $\sigma_{A,Z}$ limited to $\pm$ 4 bar ($\pm$ 0.4 N/mm^2) assuming that the ratio of Poisson's ratios is smaller than 1.0 and E_A/E_B is smaller than 3.0. Referring to the extension of Loh's equations [2], the same extension - applied to the finite element model - leads to measurement error stresses $\sigma > 30$ bar assuming geometrical and material values of available stress meters. Fig. 2-3 shows the variation of the test specimen dimensions z_B/y_B providing the concentrated load $\overline{p}_{B,Z} = p_{B,Z} \cdot 4$ with the area $\overline{A} = A/4$: If the height to diameter ratio of the test specimen is larger than 1.0, the stress ratio s is smaller than 1.3.

Because of the dynamic behaviour of the stress meter operating on the compensation method (Glötzl meter), a dynamic model as well as its analog computer synonym is developed (s. fig. 2-5) to improve the stress meter in some details especially with regard to its high temperature dependence in concrete. In fig. 2-5d the error stress are shown as a function of the oil stream Q(cm^3/s). The minimum and maximum error stresses represented by the two plots in figure 2-5d, are a result of the Glötzl valve membran vibration observed in the computer model as well as in concrete test specimen during operation.

3. Concrete prism test results

Fig. 3-1 to 3-4 show test results with concrete prism carried out in BAM Berlin over a time period of two years. The prisms include Glötzl stress meters as well as BAM-made circular stress meters loaded with stress and temperature in a special test chamber.

4. Conclusion

The theoretical and practical investigations carried out show special difficulties with stress measurement in concrete over long time periods. The zero drift as well as the temperature dependence increase is very high over long time periods. Because of other tests performed in BAM dealing with maximum ratio of concrete aggregate diameter to stress meter diameter, the BAM-made stress meter can be reduced in its size in order to be the smallest stress disturbances in concrete structures.

References:

1. Y. Loh "Internal Stress Gauges for Cementitious Materials" Proc. Soc. Exp. Stress Analysis XI (1954), pp. 13/28

2. Magiera, Czaika "Zur Meßtechnik für die Sicherheitsbeurteilung und -überwachung von Spannbeton-Reaktordruckbehältern" Heft 293, Deutscher Ausschuß für Stahlbeton, Berlin 1978

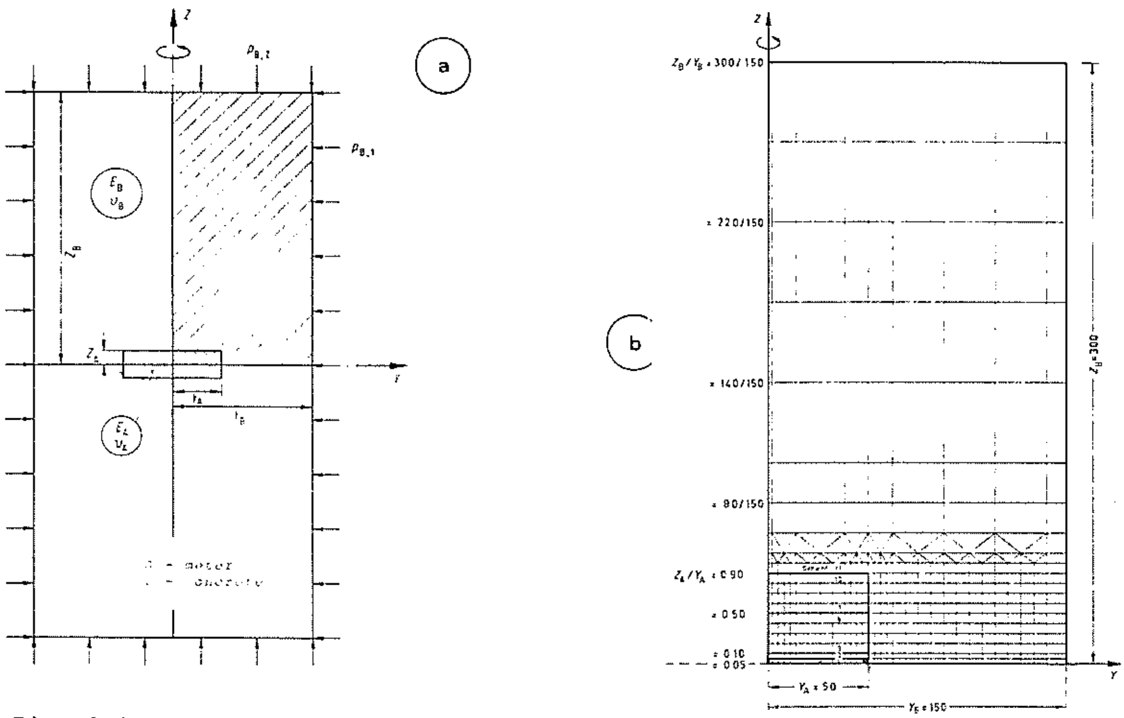


Fig. 2-1

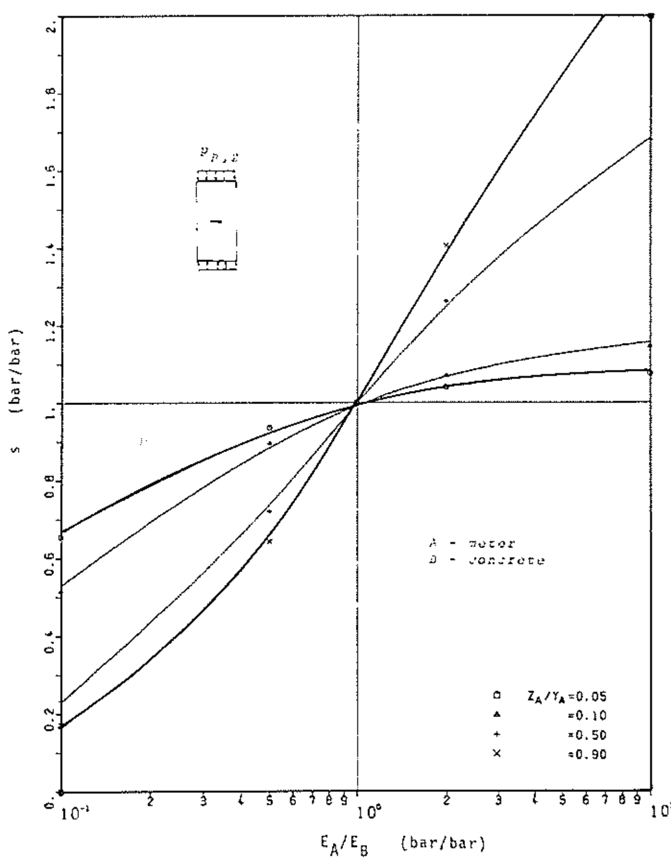
Finite element model:

a - stress meter/concrete system in form of a cylindrical prism

b - finite element mesh of a quarter of the above prism for the calculation with the computer code SAP 4

Fig. 2-2

Finite element model under uniform normal load $p_{B,Z}$: the ratio s of theoretically measured stress to exact concrete stress as a function of the ratio of elasticities, E_A/E_B; parameter is the height to diameter ratio z_A/y_A of a circular stress meter.



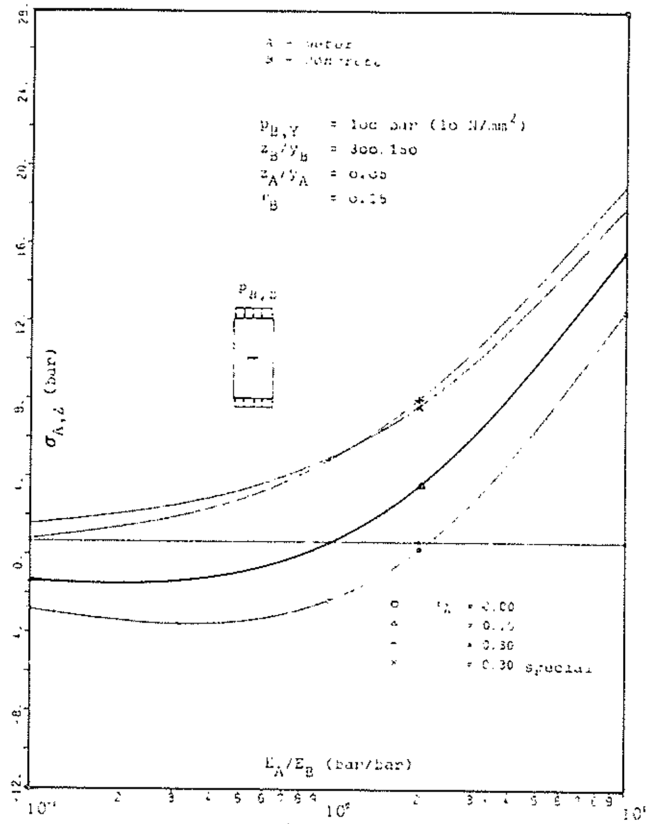


Fig. 2-3

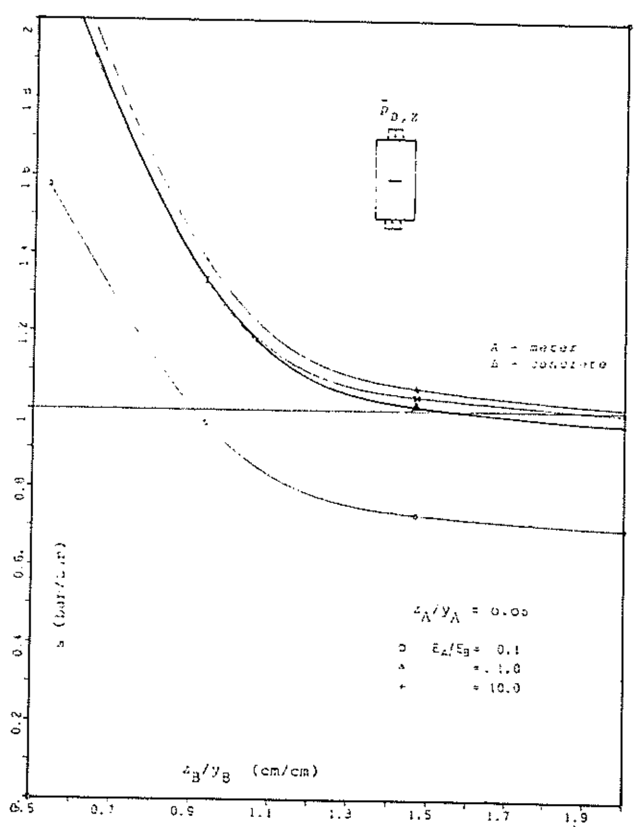
Finite element model under uniform shear load $p_{B,Y}$:

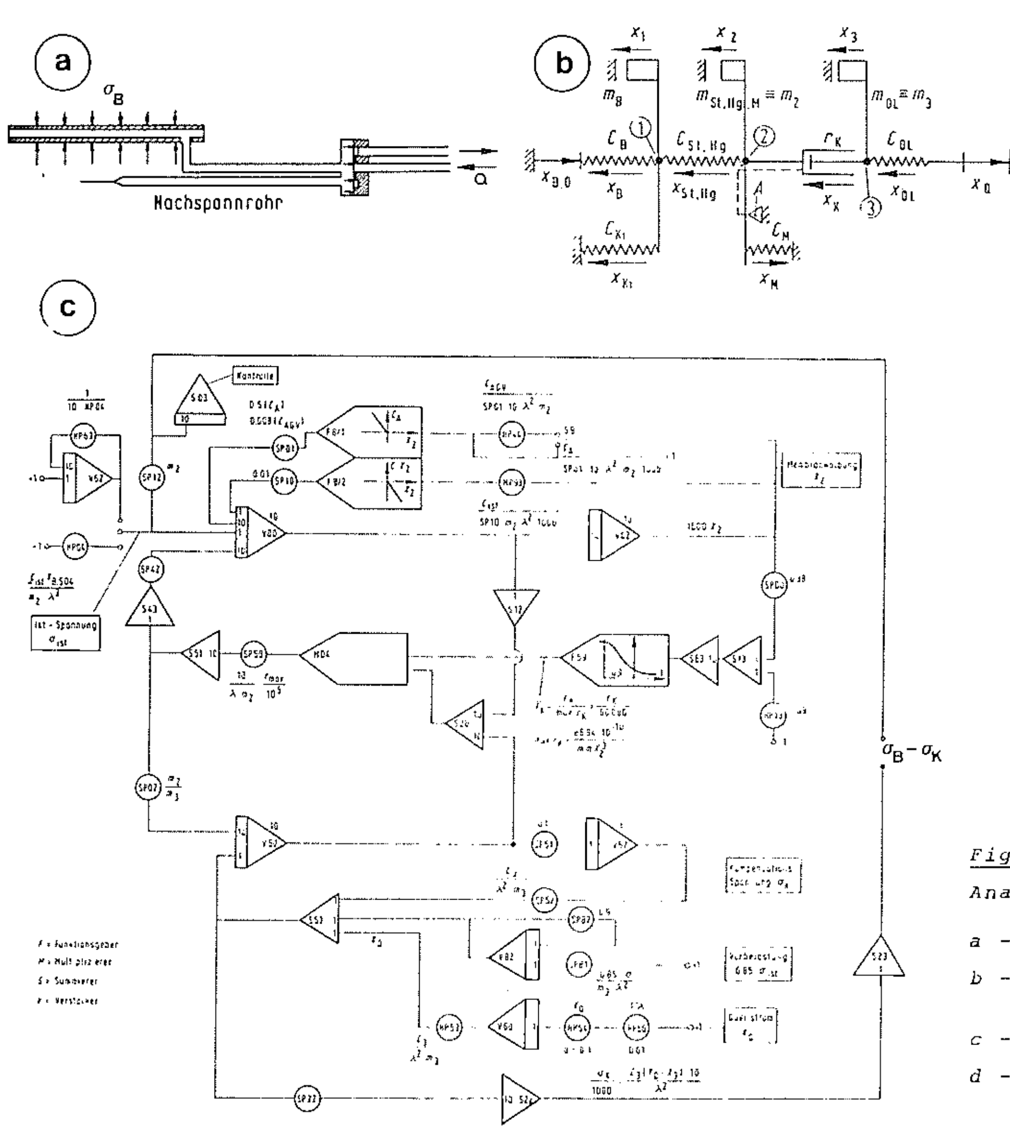
The error stress $\sigma_{A,Z}$ as a function of the ratio of moduli of elasticity, E_A/E_B; parameter is the Poisson's ratio of a stress meter, ν_A, while the Poisson's ratio of concrete is $\nu_B = 0.15$.

Fig. 2-4

Finite element model under concentrated normal load $\bar{p}_{B,Z}$:

The ratio s of theoretically measured stress to exact concrete stress as a function of the dimensions of a cylindrical concrete test prism, z_B/y_B; parameter is the ratio of elasticities E_A/E_B.





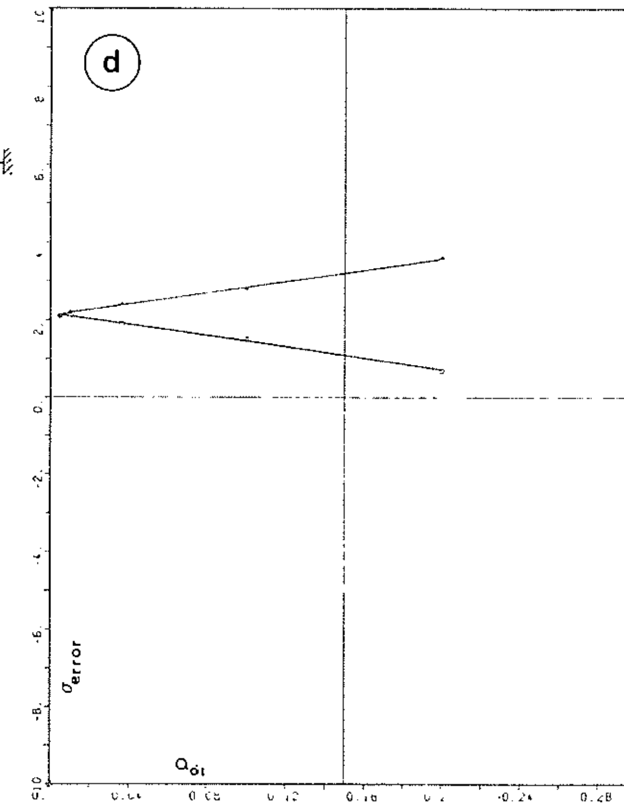


Fig. 2-5

Analog computer model:

a - schematic view of the Glötzl stress meter

b - dynamic model of the Glötzl stress meter concrete system

c - analog computer model of the given system

d - error stress σ_{error} as a function of the oil stream $Q_{\ddot{o}l}$

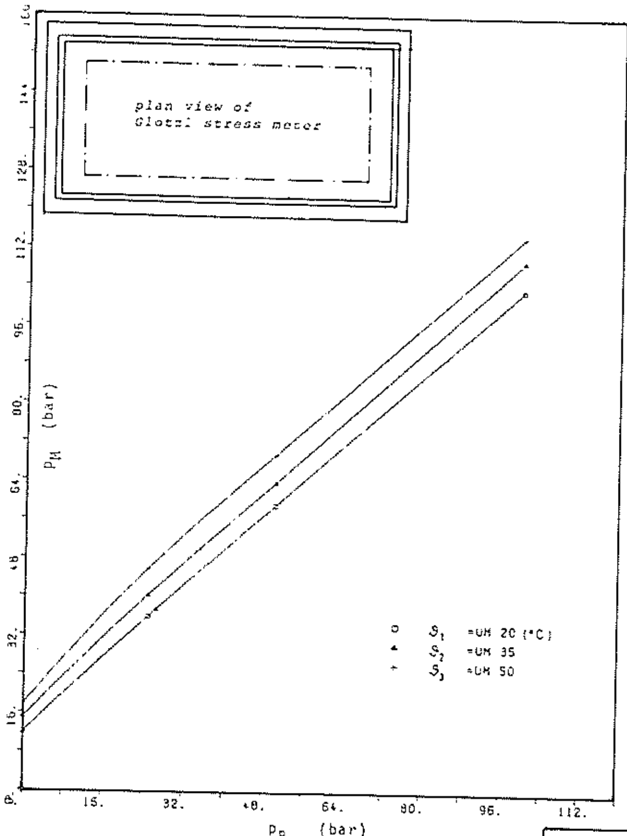


Fig. 3-1

Concrete test prism under uniform normal load p_B:

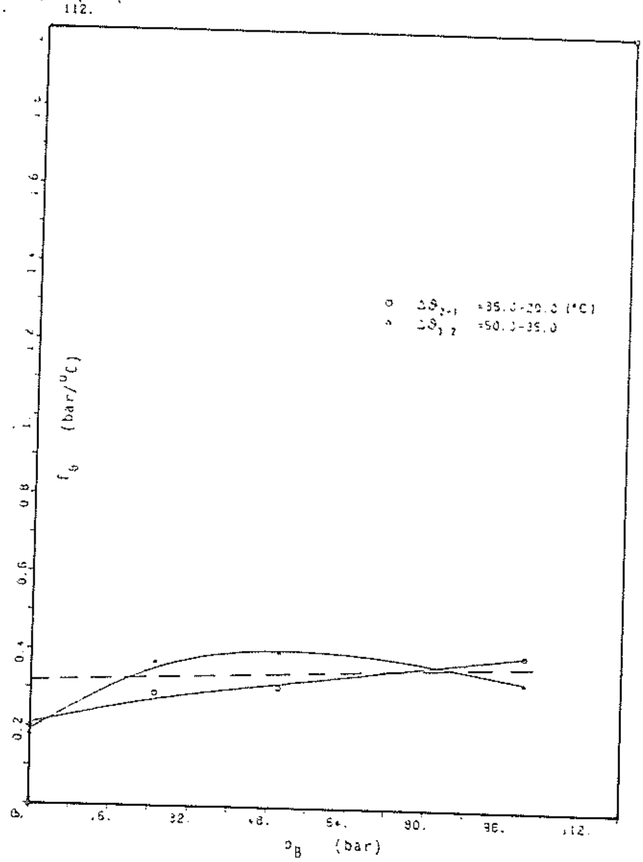
The measured stress p_M of Glötzl stress meter in concrete as a function of constant normal load p_B; parameter is the temperature υ.

The tests were carried out in a temperature chamber including specimen loading.

Fig. 3-2

Concrete test prism under uniform normal load p_B:

The temperature error f_υ of the Glötzl meter in concrete as a function of uniform normal load p_B.



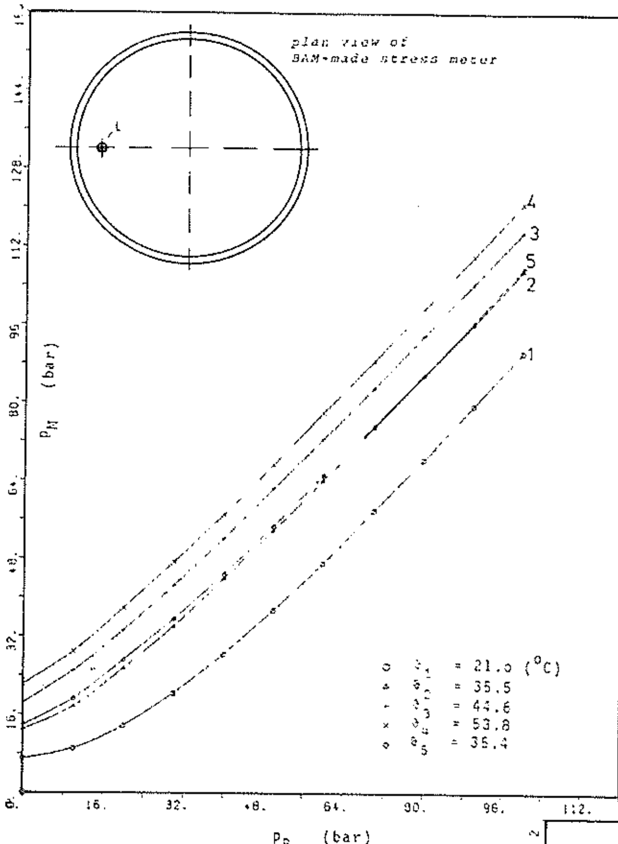


Fig. 3-3

Concrete test prism under uniform normal load p_B:

The measured stress p_M of a BAM-made circular stress meter in concrete as a function of uniform normal load p_B; parameter is the temperature ϑ.
Referring to tests performed in BAM-Berlin which deal with the maximum ratio of concrete aggregate diameter to stress meter diameter, this circular stress meter is a special construction in order to reduce the disturbances in concrete structures.
The meter includes not mercury but another fluid to avoid the manifold dangers with mercury handling.

Fig. 3-4

Concrete test prism under uniform normal load p_B:

The temperature error f_ϑ of the BAM-made stress meter as a function of uniform normal load p_M.
The average value of f_ϑ is about 0.5 bar/°C (= 0.05 N/mm²/°C) assuming a concrete age of about 28 days. As a consequence of creep and shrinkage, the temperature error f_ϑ increases up to 1.1 bar/°C after a time period of about two years.
This test result includes a zero drift of more than 30 bar.