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On the principles of calculation for reinforced concrete.

Zu „Berechnungsgrundlagen des Eisenbetons".

Les principes de calcul du béton armé.

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On the question of "n" — which has been so much discussed and mainly on quite erroneous grounds — it is to be remarked that within certain limits this factor has no influence if the permissible stresses are chosen in relation to the value of n selected (n = 10, 15 or 20). The very latest tendency to do away with the n figure altogether is to be regarded as a mistake, leading not to simplification and clarity but rather to trouble and confusion. It is possible to hold different opinions on the value of n, but as a basis for the calculation of reinforced concrete it is impossible to dispense with this figure, and for practical purposes it lies at the basis of reinforced concrete theory.

The classsical theory of reinforced concrete, which relies on the *Navier-Hooke* law as regards compression, tension and bending and on the generalised *Euler* formula as regards buckling, has been extended in the last few years by knowledge won in the testing of materials — particularly as regards plastic strain — and these extensions are of great value for the more accurate estimation of the degree of safety possessed by reinforced concrete structures.

They cover the following aspects of the problem of deciding what stresses are to be regarded as permissible:

The stress-strain law of the concrete and reinforcing steel.[1]

The modular ratio $n = \frac{E_e}{E_b}$ within the elastic region.[2]

The relationship between the prism compressive strength ${}_p\beta_d$ and elastic modulus of the concrete ${}_bE_e$.[1]

The danger of breakage in concrete stressed along more than one axis. (Experiments at the Swiss Federal Institute for Testing Materials in the light of *Mohr*'s theory of fracture.)[3]

The fatigue resistance to a pulsating load in the concrete and in the reinforcing steel,[4] and

The laws governing stability against buckling in columns loaded centrally and eccentrically. (Experiments and theory developed at the Swiss Federal Institute for Testing Materials.)[5], and by maintaining the closest possible contact between the drawing office, the laboratory and the job itself *it is justifiable to proceed by calculating reinforced concrete structures in accordance with the classical theory of elasticity,* and at the same time to plan the organisation in such a way, and take such constructional measures as

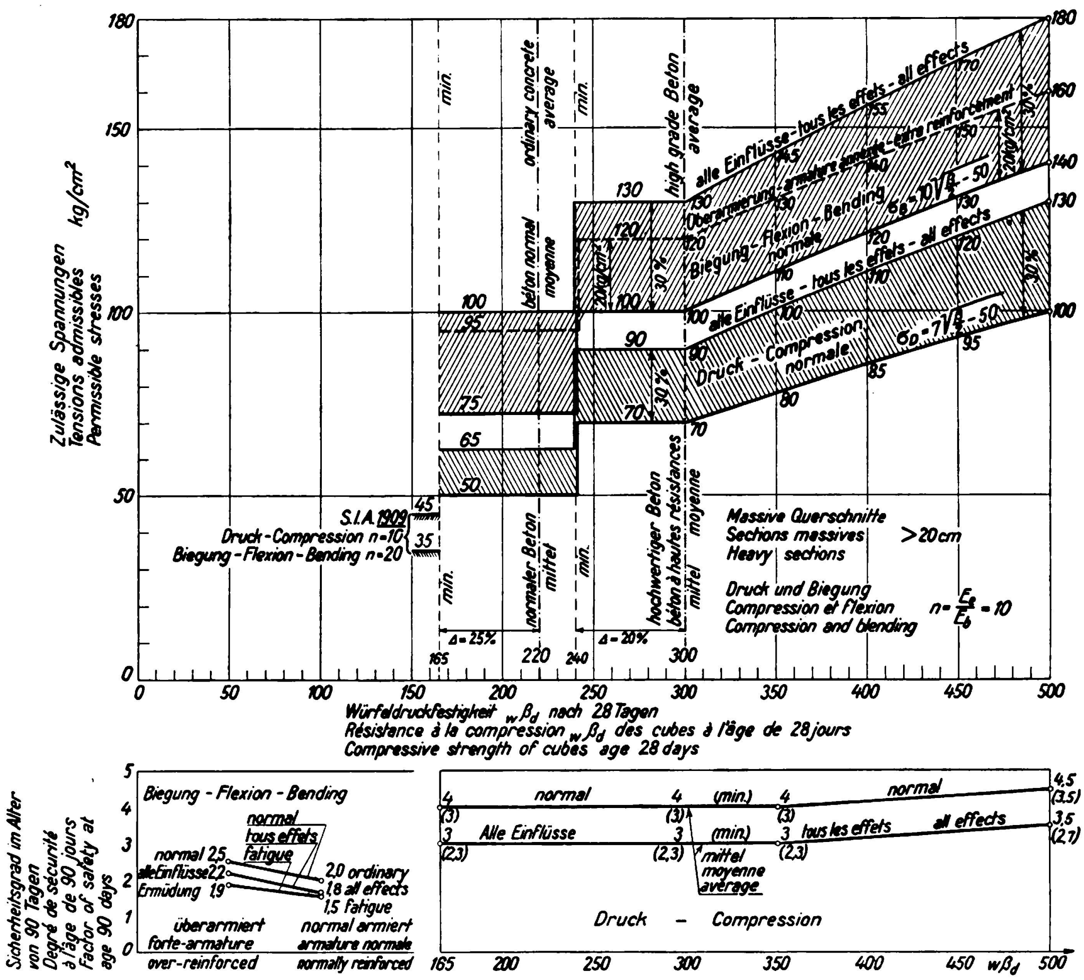


Fig. 1.

Swiss regulations for reinforced concrete of May 14 th, 1935: permissible stresses in the concrete and reinforcing steel in relation to the compressive stress of the concrete and yield point of the steel.

Oblique principal stresses.

Ordinary concrete $\tau_{zul} = 4$ kg/cm² High grade concrete 5 kg/cm²

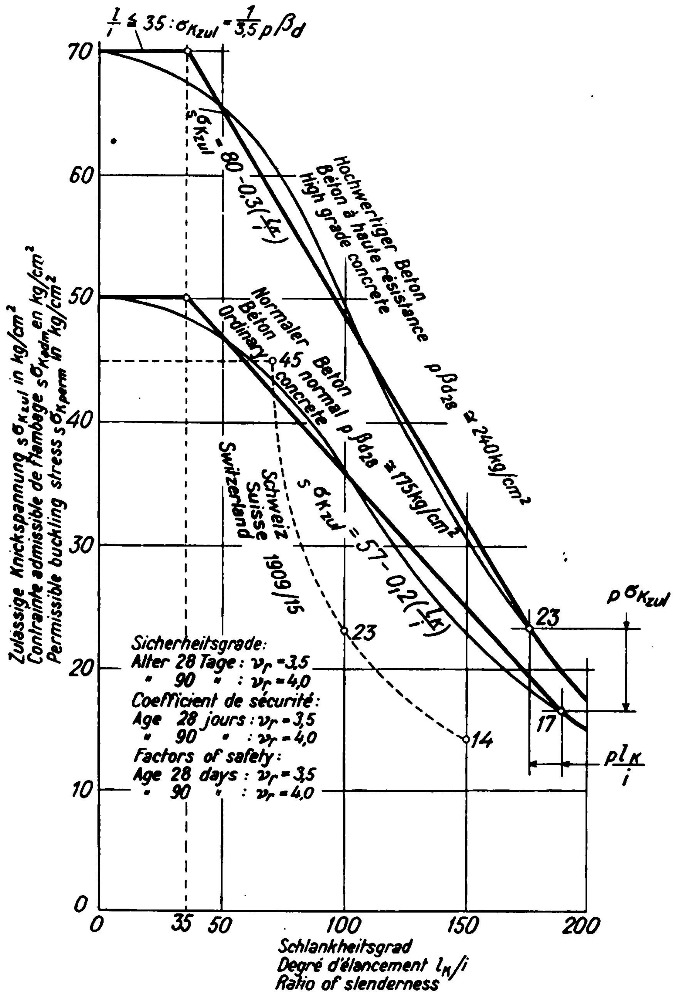
Reinforcing steel: Permissible stresses $_{perm}\sigma_e$.

All effects:

	ordinary	high grade
Excluding temperature and shrinkage stresses	1400 kg/cm²,	1700 kg/cm²
Including temperature and shrinkage stresses	1500 „	1900 „

regards both general arrangement and details, that certainty may be won as to the conditions and effects of stress, which, in its turn, will yield exact indications as to the true factor of safety.

Exhaustive experiments on completed reinforced concrete structures go to show that they behave in accordance with the elastic representation.[6] Despite all that is being argued to the contrary, the theory of elasticity will continue in the future to serve as the basis for dimensioning and estimating the safety of reinforced concrete structures — due account being taken of the effect of plasticity of the concrete on the carrying capacity,[7] but without encroaching on



$_p\beta_d$ Prism compressive strength of concrete

σ_q Yield point of reinforcing steel

F_b Cross section of concrete

F_e Cross section of steel

μ Percentage of reinforcement $F_e : F_b$

Buckling load:

$$P_K \cong {}_s\sigma_K F_b \left(1 + \frac{\sigma_q}{_p\beta_d}\mu\right)$$

$$_{perm}P_K = {}_s\sigma_{K_{perm}} \cdot F_b (1 + n\mu)$$

Limit of proportionality:

$$\sigma_P \cong 0.33\ {}_p\beta_d$$

$$_p\sigma_{K_{perm}} \cong \frac{1}{3.5} \cdot 0.33\ {}_p\beta_d$$

$$\frac{_pl_K}{i} = \pi \sqrt{\frac{E'\min}{0.33\ {}_p\beta_d}}$$

$$E'_{min} \cong 0.75 \cdot 550000 \frac{_p\beta_d}{_p\beta_d + 150}$$

Fig. 2.

Concrete columns without hoop reinforcement, with longitudinal reinforcement $\mu \cong 1\,\%$.

Permissible concentric buckling stresses ${}_s\sigma_{K_{perm}}$ for $m = 0$.

Ordinary and high grade concrete.

the final reserves possessed in this way by the material.[8] It may be said that the axial and shear forces and bending moment which result from the imposition of external loads are now determined in all countries by fundamentally the same rules, so that if definite principles for estimating of the conditions of breaking, fatigue and buckling can be agreed upon on an international basis, the international regulation of calculated factors of safety will be a matter only of careful and wellfounded understandig.

The *unification of principles* would have to be based on characteristics of materials which, while not yet expressed quantitatively in all countries, are nevertheless understood in the same sense. Such characteristics, as regards reinforced concrete, include the following:

The modular ratio $n = \frac{E_e}{E_b}$.

The yield point of the reinforcing steel σ_f

The yield point σ_s under tension.

The breaking point σ_q under compression.

The fatigue resistance to a pulsating non-alternating stress in the reinforcing steel $\sigma_u \cong 0.85\ \sigma_f$.

The prism compressive strength of the concrete ${}_p\beta_d \cong 0.8\ {}_v\beta_d$, ${}_w\beta_d$ = cube compressive strength.

The limit of proportionality of the concrete $0.33\ {}_p\beta_d \cong {}_b\sigma_{zul} \cong \sigma_p$ = *Euler*'s buckling stress.

The fatigue strength of the concrete $\sigma_u \cong 0.6\ {}_p\beta_d$ = resistance to pulsating stresses without change of sign.

The buckling modulus T_K.

The percentage of reinforcement $\mu = \frac{F_e}{F_b}$.

It would appear desirable to observe a calculated factor of safety of beetween ∼ 1.8 and ∼ 2.5 as regards static failure, a factor of safety of ∼ 1.5 to ∼ 2.0 against fatigue, and one between ∼ 3 and ∼ 4 against buckling, having reference in each case to the total load. The following permissible stresses might then be adopted as a basis:

	All Effects Excluding shrinkage and heat	*All Effects* Including shrinkage and heat
	σ_{zul}-values	σ_{zul}-values
Concrete: normally reinforced .	$\sim 0.4\ {}_p\beta_d$	$\sim 0.5\ {}_p\beta_d$
Concrete: over-reinforced ${}_{eff}\sigma_e < {}_{zul}\sigma_e$	$\sim 0.4\ {}_p\beta_d + 0.05\ ({}_{zul}\sigma_e - {}_{eff}\sigma_e)$	$\sim 0.5\ {}_p\beta_d + 0.065\ ({}_{zul}\sigma_e - {}_{eff}\sigma_e)$
Reinforcing steel: normal quality $\sigma_s \cong 2400$ kg/cm²	~ 0.5 to $0.6 \cdot \sigma_s$	$\sim 0.65\ \sigma_s$
Reinforcing steel: high-tensile $\sigma_s \cong 3500$ kg/cm²	~ 0.45 to $0.5 \cdot \sigma_s$	$\sim 0.55\ \sigma_s$

The higher values as here proposed for the permissible stresses in the concrete in over-reinforced sections (wherein the permissible stresses of the steel reinforcement is not fully utilised) are based on the results of a great many breaking tests, and are also supported by theoretical considerations such as the greater depth of the neutral axis in such cases, and the plasticity of the concrete. The same "n" figure is retained as in normally reinforced sections, as it is more correct to adopt this method than to increase "n".

In view of the smaller risk of breakage the permissible extreme fibre stress of the concrete under bending may be fixed 40 % higher than the stress under direct compression.

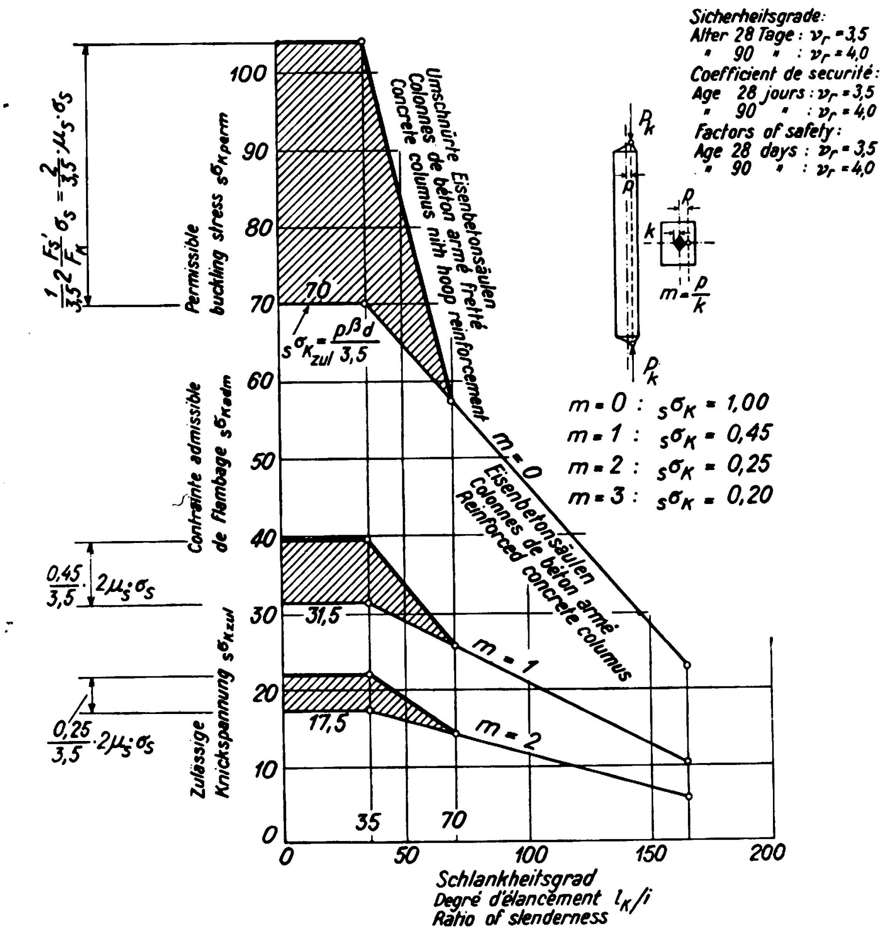


Fig. 3.

Concrete columns with hoop reinforcement and longitudinal reinforcement.

Permissible concentric buckling stresses $_s\sigma_{K_{perm}}$.

For m = 0, m = 1 and m = 2. High grade concrete.

Concrete columns with longitudinal reinforcement:

$$\text{Buckling load:} \quad P_K \cong {_s\sigma_K} F_b \left(1 + \frac{\sigma_q}{_p\beta_d} \cdot \mu\right); \quad \left(\frac{l_K}{i}\right) \geqq 70$$

Concrete columns with longitudinal and hoop reinforcement:

$$\text{Breaking load:} \quad P_{failure} = {_b F_K} \left({_p\beta_d} + 2\,\mu_s \cdot \sigma_s\right) \left(1 + \frac{\sigma_q}{_p\beta_d}\,\mu\right); \quad \left(\frac{l}{i}\right) \leqq 35$$

$$\text{Buckling load:} \quad P_K \cong {_s\sigma_K} \left({_b F_K} + \frac{\sigma_q}{_p\beta_d} F_e + 2\,\frac{\sigma_s}{_s\sigma_K}\,F'_s\,\frac{70 - \frac{l_K}{i}}{35}\right);$$

$$35 \leqq \left(\frac{l_K}{i}\right) \leqq 70.$$

The effect of the principles explained in the preceding paragraph on the new Swiss regulations for reinforced concrete, dated 14^{th} of May 1935, is represented in Fig. 1, showing graphically:

The permissible stresses in the concrete ${}_{zul}\sigma_b$ under compression and bending,[9] in relation to the quality of the concrete (cube strength), and

the factor of safety referred to an age of 90 days.

The permissible stresses in resistance to buckling, for columns with and without hoop reinforcement in normal and high grade concrete, may be taken from Figs. 2 and 3. The contents of Figs. 1, 2 and 3 may serve as an indication of the great advances made in reinforced concrete construction in the last few years, and of the new possibilities of design.

The knowledge now available, based on theoretical and technical conceptions drawn from the field of testing materials — such as strength and deformation — and also on experience gained in practice,[10] offers a starting point for international cooperation to aim at *unification of the interpretation of the laws governing the strength of materials* and at *the establishment of definite factors of safety in reinforced concrete construction.*

Bibliography.

1 *M. Roš:* „Die Druckelastizität des Mörtels und des Betons." Report No. 8 of Swiss Federal Institute for Testing Materials, Zürich, 1925.

2 *M. Roš:* «Coefficient d'équivalence $n = \frac{E_{acier}}{E_{béton}}$ et tensions admissible du béton et de l'acier.» First International Congress on Concrete and Reinforced Concrete, Liége, 1930.

3 *M. Roš* and *A. Eichinger:* „Versuche zur Klärung der Frage der Bruchgefahr — II. Nichtmetallische Stoffe." Report No. 28 of Swiss Federal Institute for Testing Materials, Zürich, 1928.

4 *S. A. Mortada:* „Beitrag zur Untersuchung der Fachwerke aus geschweißtem Stahl und Eisenbeton unter statischen und Dauerbeanspruchungen." Report No. 103 of the Swiss Federal Institute for Testing Materials, Zürich, 1936.

5 *M. Roš:* «La stabilité des barres comprimées par des forces excentrées.» I.A.B.S.E. Congress Paris, 1932, Preliminary Report. — *O. Baumann:* „Die Knickung der Eisenbetonsäulen." Report No. 89 of the Swiss Federal Institute for Testing Materials, Zürich, 1934.

6 *F. Campus:* «Influence des propriétés physiques des matériaux sur la statique du béton armé.» I.A.B.S.E. Congress, Final Report, Paris 1932.

7 *M. Roš:* «La stabilité des barres comprimées par des forces excentrées.» I.A.B.S.E. Congress, Paris 1932, Preliminary Report. — *O. Baumann:* „Die Knickung der Eisenbetonsäulen." Report N° 89 of the Swiss Federal Institute for Testing Materials, Zürich 1934.

8 *M. Roš:* „Aktuelle Probleme der Materialprüfung." Technische Rundschau, Berne 1932.

9 The permissible oblique concrete stresses should not exceed one-twelfth to one-fourteenth of the permissible compressive stresses and the whole of any excess is to be taken up by inclined reinforcing bars.

10 *M. Roš:* „Erfahrungen mit ausgeführten Eisenbeton-Bauwerken in der Schweiz und deren Lehren für die Portlandzementindustrie." Separate reprint from the 24th Annual Report, 1934, of the Swiss Association of Manufacturers of Cement, Lime and Gypsum.

11 *M. Roš:* „Vereinheitlichung der material-technischen Erkenntnisse und des Sicherheitsgrades im Stahlbetonbau." Monatsnachrichten des Österreichischen Betonvereins. Vol. IV, Vienna 1937.