DESIGN OF ANCHORS USING NOMOGRAMMS

BEMESSUNG VON VERANKERUNG ANHAND VON NOMOGRAMMEN

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SUMMARY

The following article explains the principle of nomograms. Nomograms assist in graphically representing complicated calculations, allowing for quick and calculation even without software. Only a brief overview of the basic principles and construction of nomograms is provided here, with a fundamental example shown for volume calculation.

The following sections exclusively present nomograms that have been specifically developed for the design of anchor channels, metal anchors, headed studs and bonded anchors regarding different failure modes in accordance with EN 1992-4. These representations enable efficient and software-independent design.

ZUSAMMENFASSUNG

Im folgenden Artikel wird das Prinzip der Nomogramme erklärt. Nomogramme helfen dabei, komplizierte Berechnungen grafisch darzustellen, sodass schnelle Bestimmung auch ohne Software möglich ist. Dabei wird nur kurz auf das Grundprinzip und die Konstruktion von Nomogrammen eingegangen und das Grundlegende Prinzip an einem Beispiel für die Volumenberechnung gezeigt.

Im Folgenden werden ausschließlich die Nomogramme präsentiert, die eigens für die Bemessung von Ankerschienen, Metalldübeln, Kopfbolzen und Verbunddübeln im Hinblick auf unterschiedliche Versagensarten gemäß EN 1992-4 entwickelt wurden. Diese Darstellungen ermöglichen eine effiziente und softwareunabhängige Bemessung.

1. INTRODUCTION

The design of anchorages using nomograms has been an established method in the construction industry for decades. Nomograms, graphical aids for the quick and clear calculation of complex relationships, have been used since the early 20th century and are used in areas where simple and time-saving solutions for engineering tasks are required – for example, in the design of reinforced concrete structures or in the solution of equations in physics. Their advantage is that they simplify computational processes, minimize sources of error and enable design without time-consuming calculations. This makes nomograms a valuable tool both in planning and on the construction site, which is characterized by clarity, efficiency and practical applicability.

2. CREATION OF NOMOGRAMS

A nomogram (from the Greek νόμος "nomos" = law and γραμμή "grammē" = line) is a graphical calculation tool that visually represents complex mathematical relationships between several variables and enables quick approximate calculations. These work like analog computers and were a common tool in engineering offices and science before computers were introduced. Nomography as a study for the creation of nomograms was founded in 1850 by Léon Lalanne and Maurice d'Ocagne, with d'Ocagne coining the term "nomogram" and promoting the systematic development of this calculation method [2].

The application of nomograms is very broad and established in the following areas:

- Electrical engineering: calculation of resistance, capacitances and impedances, ...
- Civil Engineering: Static calculations, material determination, ...
- Mechanical engineering: strength calculations, dimensioning, ...
- Medicine: Body surface area determination for drug dosage, kidney function and dose adjustment, poisoning diagnostics, ...

The following shows how the design of anchorages according to EN 1992-4 can be carried out with the help of nomograms. This has never been implemented before and thus represented the first attempt to make an approximate design of anchorages possible without software.

2.1 Basic working principle

Nomograms consist of several axes that represent different parameters or variables of a function. The basic principle of operation is based on the graphical solution of mathematical equations by connecting points with a straight line and reading the result. The following steps are to be carried out [3]:

1. Two known values are marked on the corresponding scales
2. These dots are connected by a straight line
3. The intersection of this line with the third scale indicates the result you are looking for.

Nomograms can always be constructed if an initial formula can be converted into d'Ocagne's so-called key equation:

$$F(x) \cdot f_1(z) + F(y) + f_2(z) = 0 \qquad (1)$$

2.2 Construction of Nomograms

The construction of nomograms follows a systematic procedure that can be described as follows [3]:

1. Conversion of the initial equation into the key equation, see equation (1)
2. Determination of the scale ranges for all variables x, y, and z
3. Calculation of scale positions based on function values
4. Drawing of the scales with corresponding labelling
5. Verification through test calculations

Parallel scales are the most common arrangement, in which three vertical or horizontal scales are arranged parallel to each other. However, inclined scales, orthogonal scales or curved scales as well as mesh grids can also be used. However, their construction is very complex.

2.3 General example of a nomogram

As an example of a nomogram, the simple calculation of a cylinder volume is described here. The cylinder volume is calculated as follows:

$$V = \pi \cdot r^2 \cdot h \qquad (2)$$

This relationship can be converted into a grand form, in which the equation is transformed via logarithmization. This then leads to the following equation:

$$\log(V) = \log(\pi) \cdot 2 \cdot \log(r) \cdot \log(h) \quad (3)$$

This equation can be constructed as a nomogram and thus calculate the volume if the two variables r and h are known. To do this, the two values on the axis r and h must be marked and connected with a straight line. The intersection of the straight line with the axis V gives the result. Of course, the equation can also be solved accordingly if h and V are known and r is the variable you are looking for.

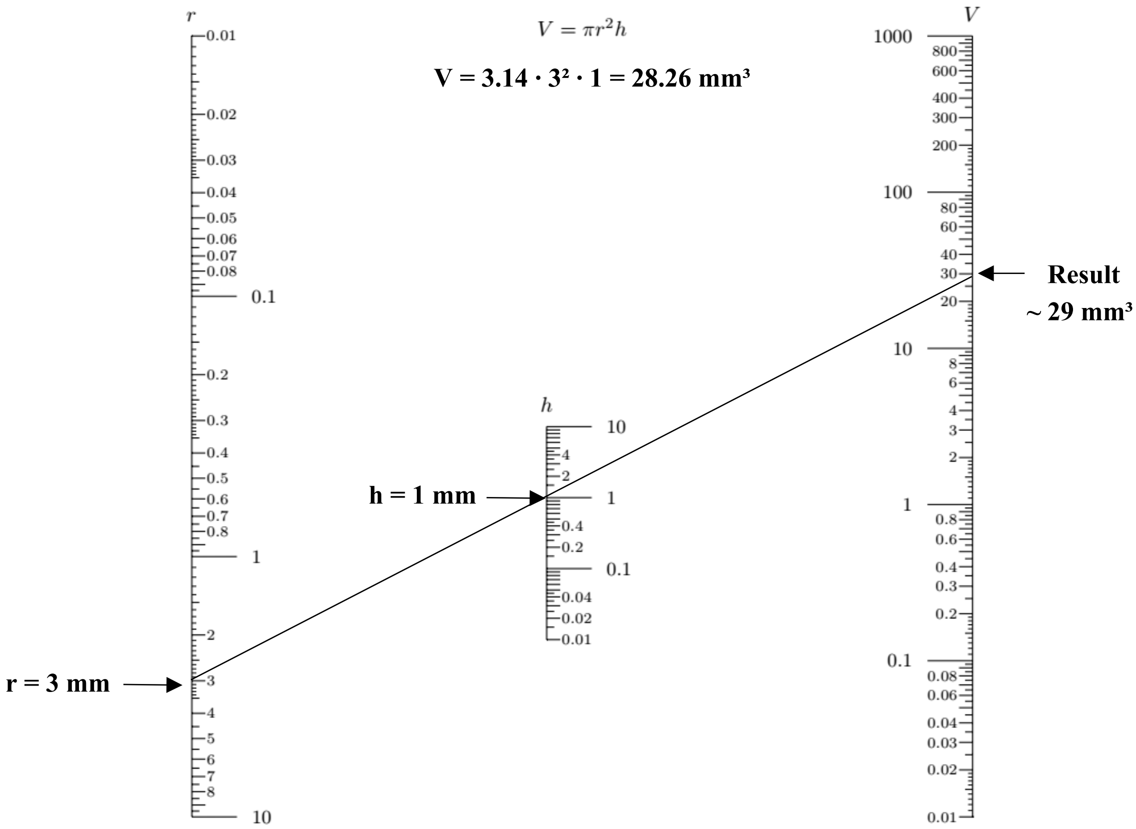

Fig. 1: Nomogram for calculating cylinder volume [1]

3. NOMOGRAMS FOR FASTENING TECHNOLOGY

3.1 General information on nomograms for fastening technology

The nomograms shown below include the design according to EN 1992-4. In some cases, simplifications have been made or special factors have not been considered that may be applied under certain conditions. In addition, the design under transverse load with a lever arm has not been designed as a nomogram so far. However, the following nomograms are available for design:

1. Anchor channels for concrete cone failure mode
2. Metal dowels and head bolts for blow-out failure mode
3. Metal dowels and head bolts for concrete cone failure type
4. Metal dowels for failure type splitting
5. Metal dowels and head bolts for concrete edge fracture failure type
6. Composite anchors for the failure type Composite failure

It must be noted that copying out and enlarging the nomograms is not possible, as they are usually slightly distorted. As a result, the results are no longer correct, as a nomogram only works if the scales and spacing of the scales are preserved exactly as constructed.

The nomograms were created with the Phyton script [1], as the creation is usually relatively complex. To simplify the creation, the equations from fastening technology were also divided into different blocks and the individual factors were implemented as nomograms. Looking at the following equation for concrete cone failure according to EN 1992-4, each factor was (except for the factor $\psi_{M,N}$) implemented as a nomogram (see 3.5).

$$N_{Rk,c} = \boxed{N^0_{Rk,c}} \cdot \boxed{\frac{A_{c,N}}{A^0_{c,N}}} \cdot \boxed{\psi_{s,N}} \cdot \boxed{\psi_{re,N}} \cdot \boxed{\psi_{ec,N}} \cdot \boxed{\psi_{M,N}} \tag{4}$$

This means that the individual factors still must be multiplied together for the final result. In the following nomograms the red dotted lines show how the nomograms are used for a specific parameter r set.

3.2 Design of anchor channels (concrete cone failure)

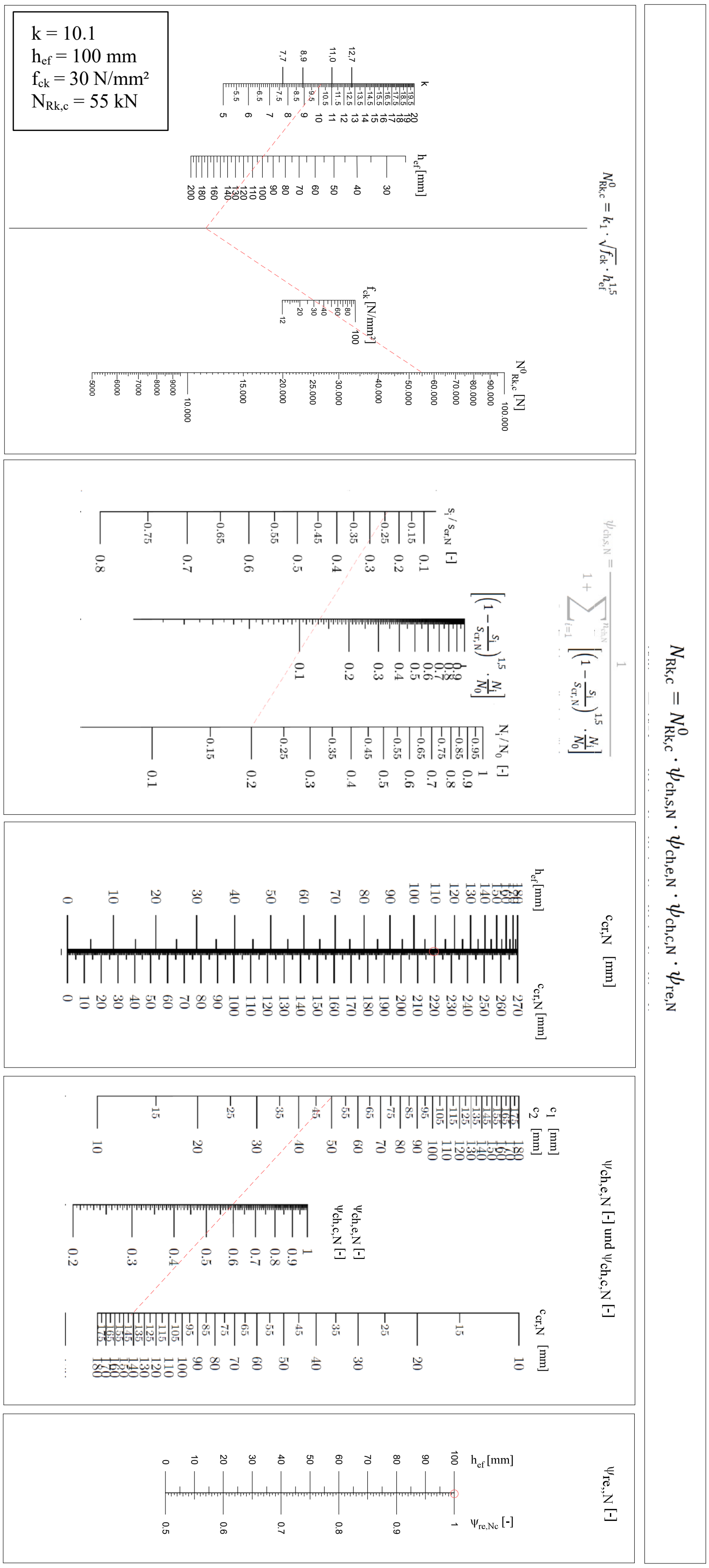

Fig. 2: Load-bearing capacity for concrete cone failure (anchor channels)

3.3 Design of metal anchors and head bolts (Blowout-failure)

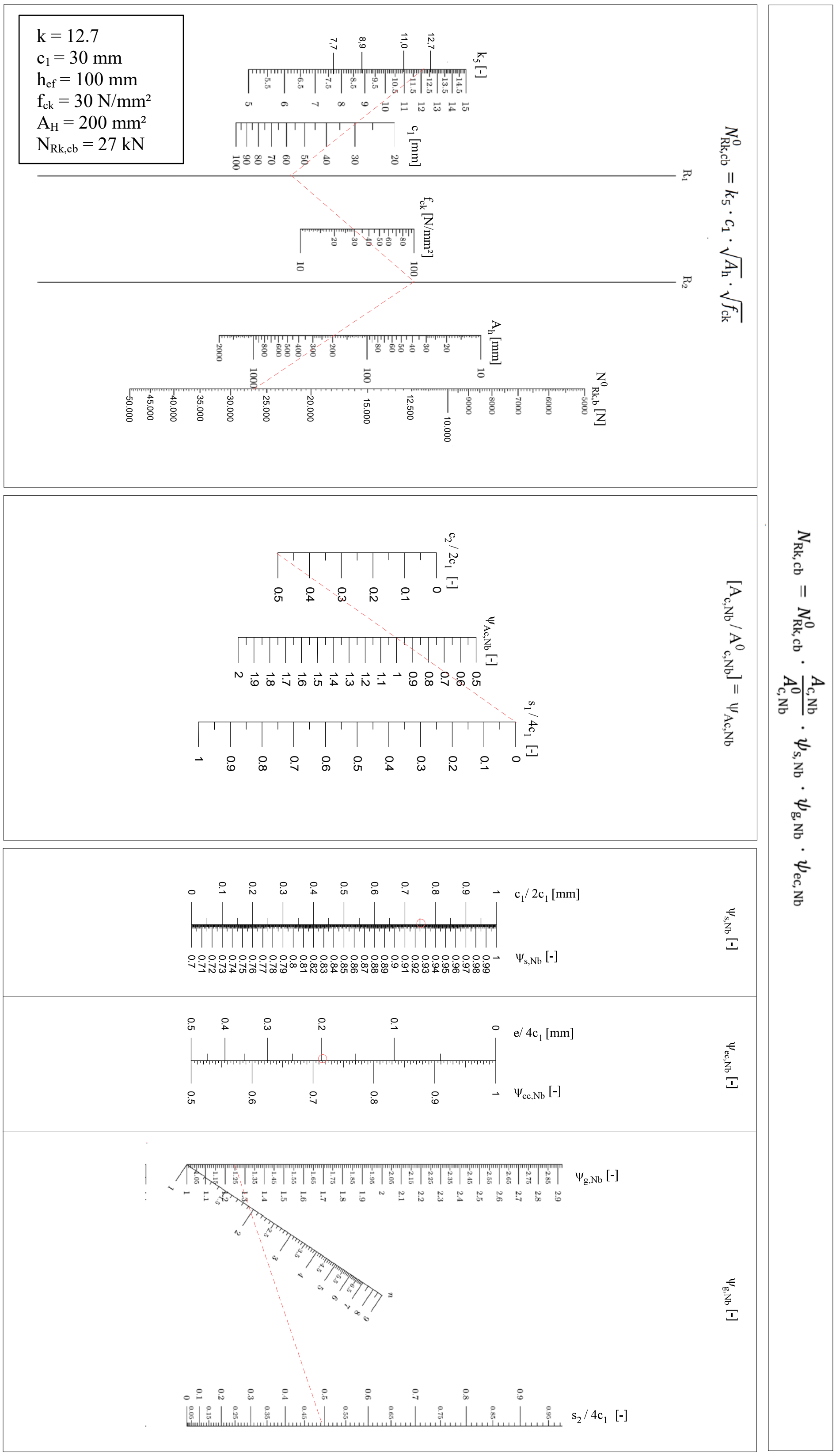

Fig. 3: Load-bearing capacity for Blow-Out failure

3.4 Design of metal anchors and head bolts (Splitting failure)

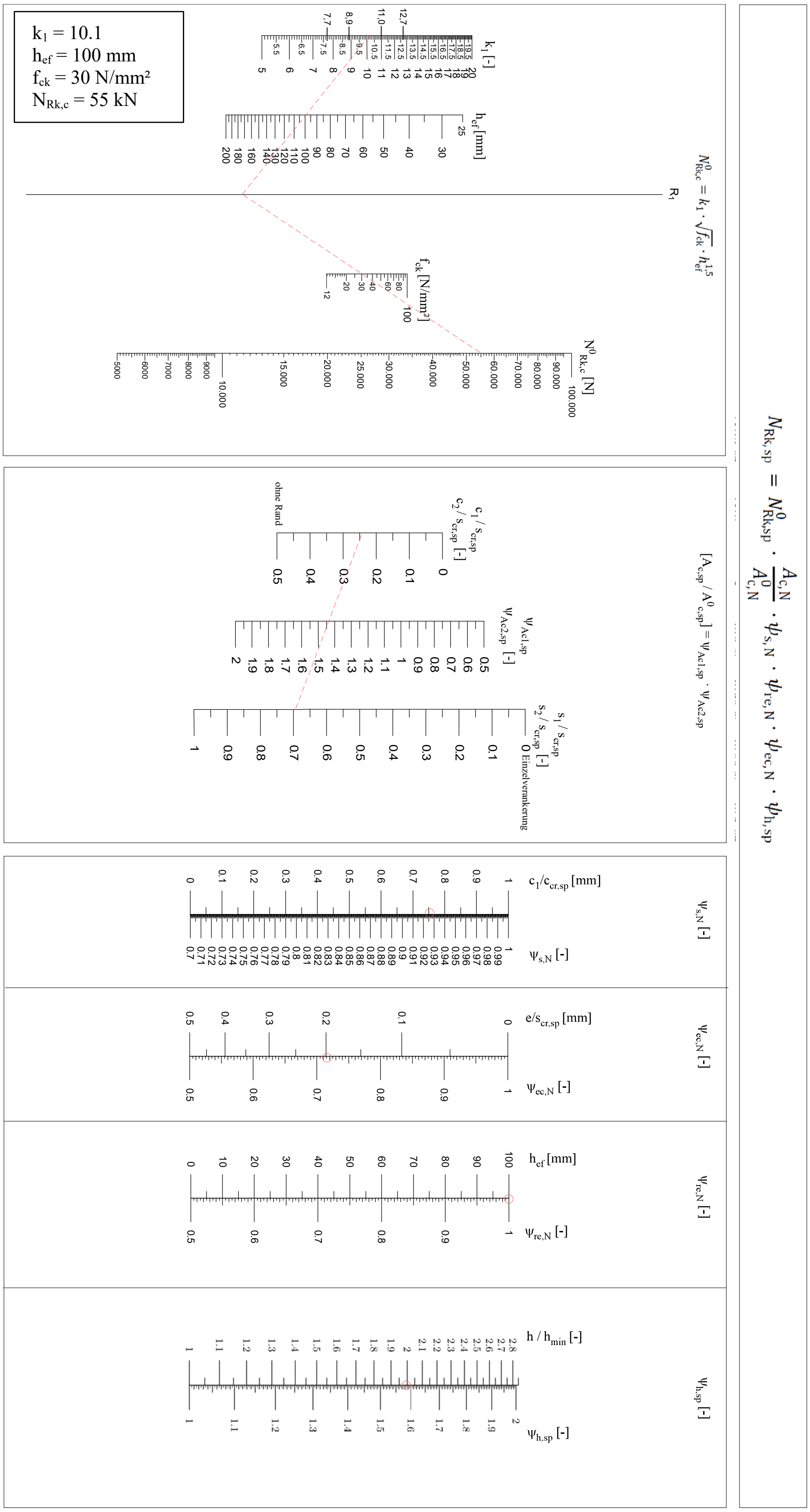

Fig. 4: Load-bearing capacity for splitting failure

3.5 Design of metal anchors and head bolts (Concrete cone failure)

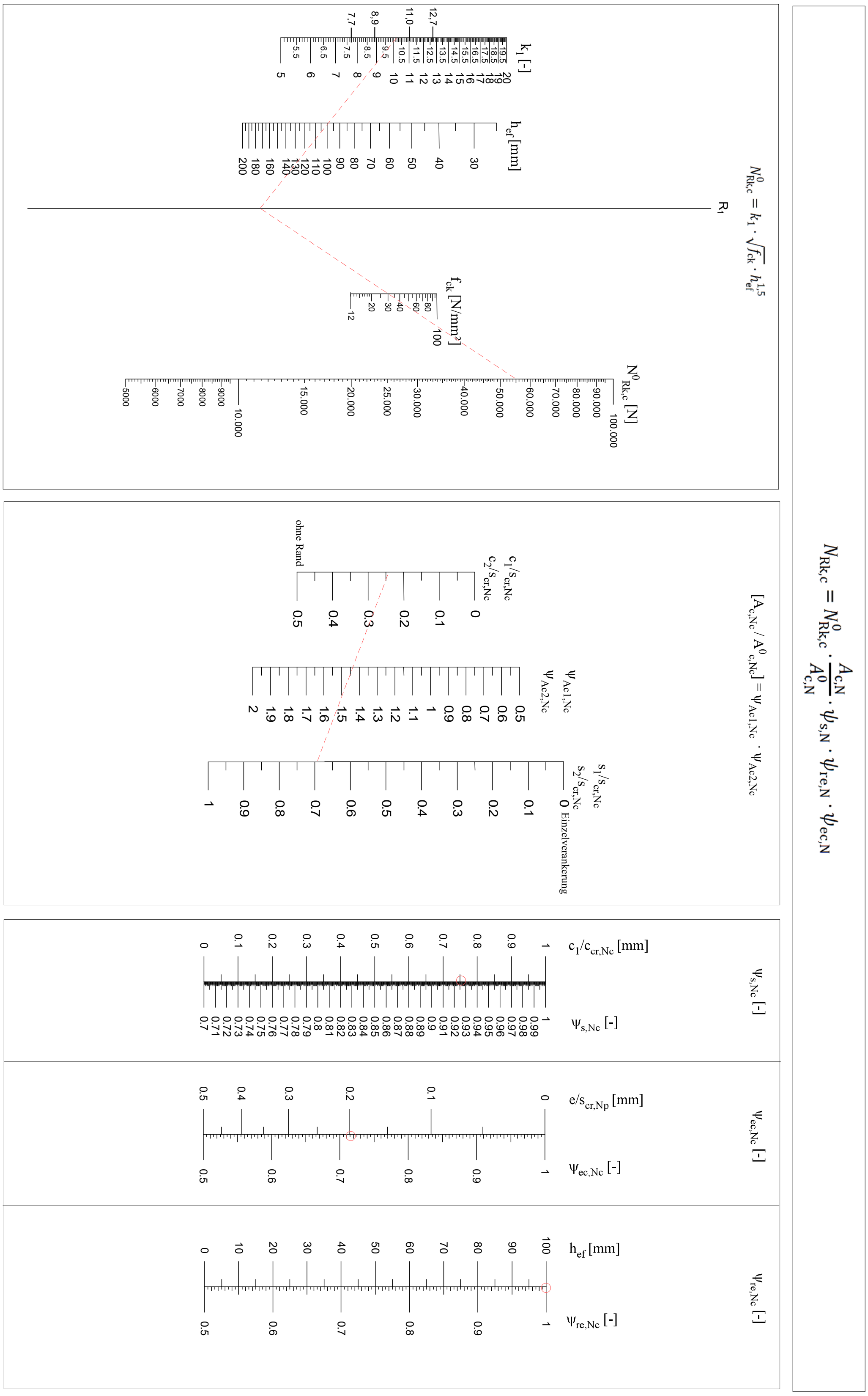

Fig. 5: Load-bearing capacity for concrete cone failure

3.6 Design of metal anchors, bonded and head bolts (Concrete edge failure)

$k = 2.4$
$f_{ck} = 30$ N/mm²
$c_1 = 80$ mm
$h_{ef} = 70$ mm
$d = 10$ mm²
$N_{Rk,cb} \sim 16$ kN

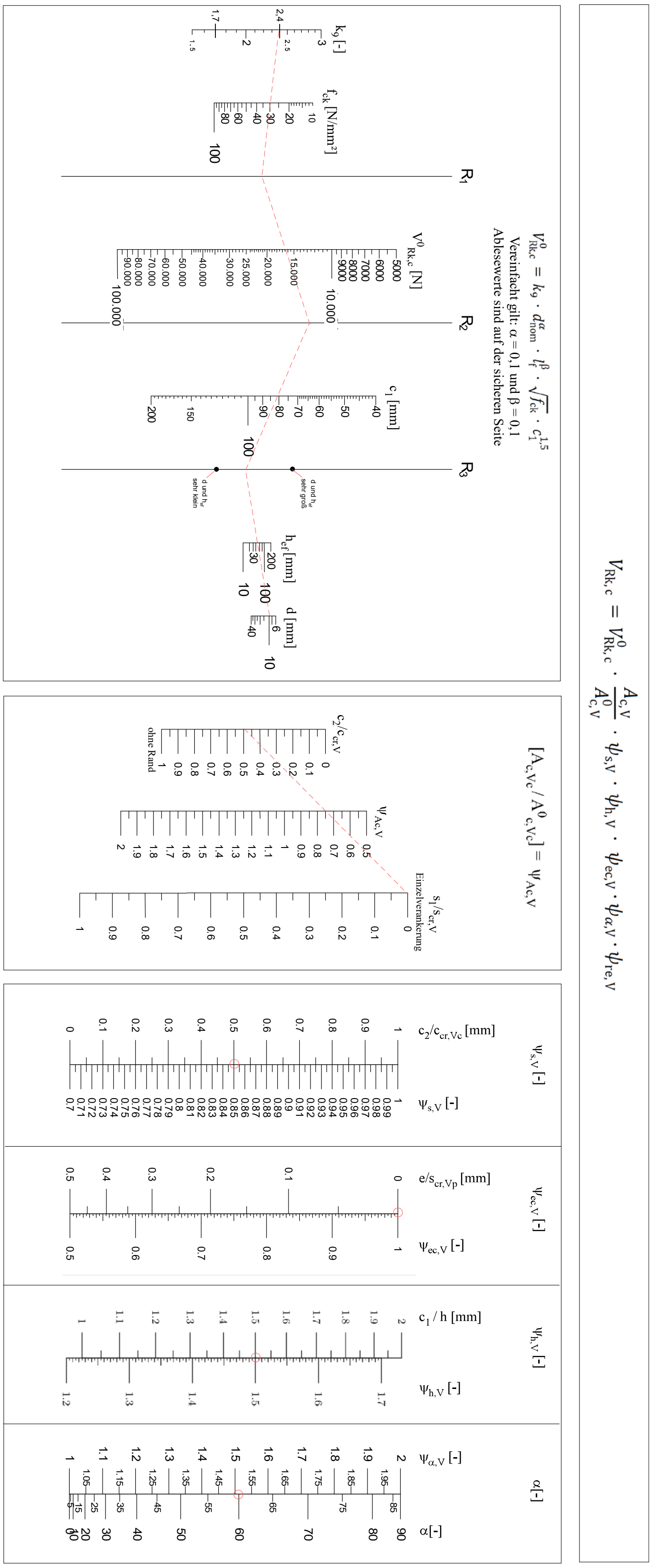

Fig. 6: Load-bearing capacity for concrete edge failure

3.7 Design of bonded anchors (Bond failure)

τ_{Rk} = 7.5 N/mm²
f_{ck} = 30 N/mm²
h_{ef} = 100 mm
d = 12 mm²
$N^0_{Rk,p}$ ~ 29 kN

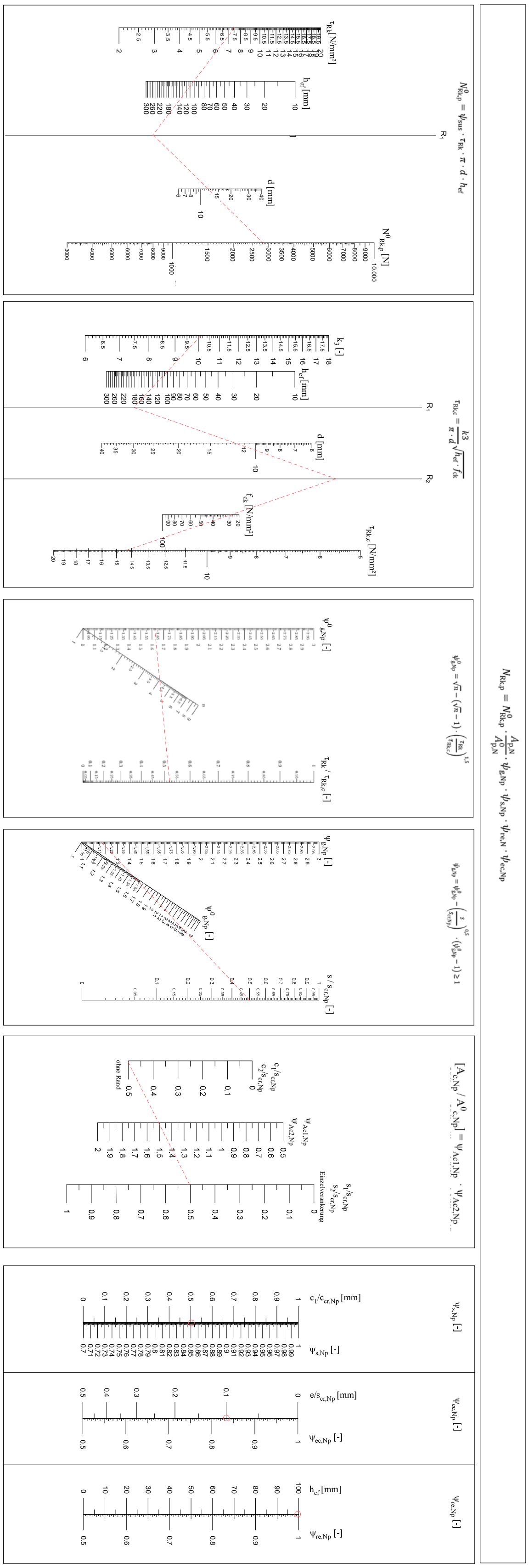

Fig. 7: Load-bearing capacity for bond failure

4. ZUSAMMENFASSUNG

The following sections exclusively present nomograms that have been specifically developed for the design of anchor channels, metal anchors, headed studs and bonded anchors regarding different failure modes in accordance with EN 1992-4.

The nomograms can be used to solve the equations according to EN 1992-4 without using a calculator, software or other resource.

REFERENCES

[1] DOERFLER, R.: *Creating Nomograms with the PyNomo Software*, Online, 19. Oktober 2009

[2] WIKIMEDIA FOUNDATION INC: *Nomogramm*, Online, 20. Juli 2025

[3] HALLER, K.: Programmierte Anleitung zum Erstellen von Nomogrammen, Online, 10. Oktober 2025