fischer

Spring models for the realistic design of anchorages in concrete.

A White paper for Structural Engineers, Construction Engineers and Planners.

Contents.

White paper “Spring models for the realistic design of anchorages in concrete”

Publisher: fischerwerke GmbH & Co. KG, Klaus-Fischer-Straße 1, 72178 Waldachtal, Germany, Telephone +49744312-0, info@fischer.de **Design, Production & Layout:** Kresse & Discher GmbH, Content Marketing, Offenburg; Marcus Stradinger (Director), Astrid Paz (Graphic Design). Text (original in Gerrman language): Dr. Thilo Pregartner, Boglárka Bokor (fischer), Dennis Müller and Marcus Stradinger (Kresse & Discher). **Photographs & technical drawings:** fischer (13), Lewis Tse Pui Lung/Adobe Stock (p.14), Jakob Studnar (p.3 (1), p.18 (1)), Johannes Zrenner (p.5), Benjamin Gaukler (p.16), Adobe Stock (p.4), Boglárka Bokor (p.6 (3), p.9 (1), p.11 (1)), Akanshu Sharma (p.15), ty /Adobe Stock (p.18). **Year of publication: 2021**

CC Method
A global success model.

The concrete capacity method (CC method) was published by the CEB (Comité Européen du Béton) in 1995 for the purpose of designing anchorages in concrete. The CC method allows planners and structural engineers to design anchorages against concrete breakout failure modes safely and economically.

International Standard

The CC method is a semi-empirical method that was developed and verified on the basis of numerous tests. In 1997, EOTA (known as the European Organisation for Technical Approvals at the time) adopted the CC method into Annex C of the ETAG 001 guideline. The method has undergone constant development ever since and is now accepted internationally. In principle, the established CC method takes into account various factors such as concrete condition (cracked or non-cracked), loading direction (tension, shear and interaction) and different failure modes. The method is recognised as the most popular design method and has been included in various standards and guidelines internationally. Two examples of international standards on designing anchorages in concrete include the European standard **EN 1992-4** and its American equivalent, ACI 318 (Chapter 17).

European standard: EN 1992-4

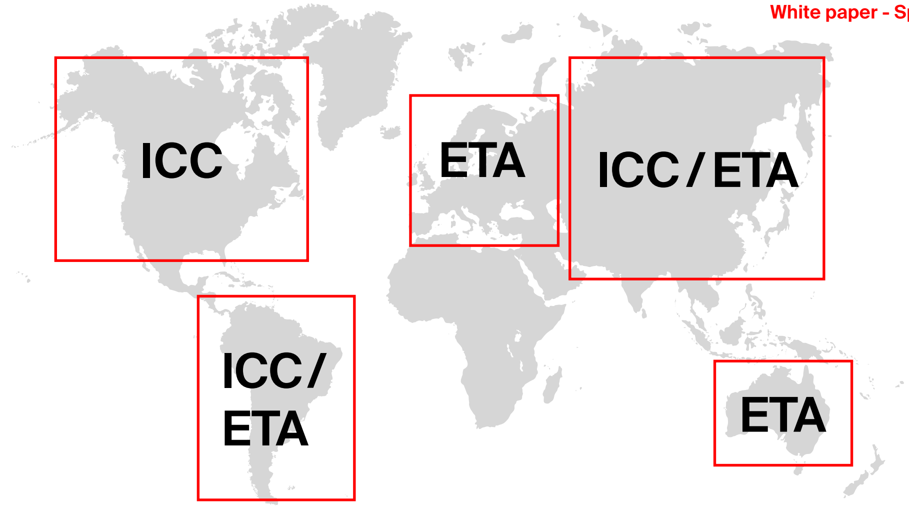
Published in early 2019, EN 1992-4 (**see also the "EN 1992-4" white paper**) is a uniform standard that defined the design standards of anchorages in concrete across Europe for the very first time. As a key document, EN 1992-4 is expected to replace all previous design guidelines for fastenings in concrete in Europe.
The standard is applicable to the design of cast-in anchorages (anchor channels and headed anchors) as

A success model accepted across the globe

The University of Stuttgart, Germany, led the way to develop the CC method. The method has been established across the world as the standard method for design of anchorages in concrete. In Europe, the method was introduced as early on as 1997.

Further Reading:

EN 1992-4, Eurocode 2: Design of concrete structures – Part 4, Brussels, Edition 2018



An overview of the prevalence of ETA (EN 1992-4) and ICC (ACI 318), the internationally recognised verification and qualification methods for anchorages in concrete.

well as the design of post-installed anchorages (metal expansion anchors, undercut anchors, concrete screws, bonded anchors and bonded expansion anchors). In general, design of anchorages according to EN 1992-4 is based on a three-part system consisting of the design standard, **European Technical Assessments (ETA)** and the corresponding European Assessment Documents (EAD).

The American standard: ACI 318

The equivalent standard to Eurocode 2 (EN 1992) in the North American region is the ACI 318 **Building Code Requirement for Reinforced Concrete**, which is published by the American Concrete Institute (ACI). The latest edition, the ACI 318-19, was published in 2019. Anchorage design is addressed in chapter 17: "Anchoring to Concrete". Anchorage design that follows the CC method was adopted into the ACI 318 regulations for the first time in 2002, which can be seen as a real design milestone.

The limitations of current standards

The new standards undoubtedly increase the level of safety and transparency when designing anchorages. At the same time, the design of anchorages, in particular under tension loading that adhere to current standards and guidelines entails several fundamental restrictions in respect to the application of the design provisions. In terms of base plate geometry, this is restricted to rectangular groups of up to nine anchors with a 3x3 configuration, for instance. The second significant limitation in the provisions for the design of anchorages using the CC method concerns the requirement of using a sufficiently stiff base plate. However, quantified definitions and regulations to determine sufficiently stiff base plates are not included in the current regulations.

The first step of anchorage design involves determining the actions (forces) on the anchors and the internal eccentricity of the anchor group. This step is necessary because in the CC method the determination of actions and resistances is combined. Furthermore, due to the technical, functional or structural requirements, anchor group configurations that are not covered by the current regulations are also designed according to these design provisions assuming a stiff base plate in practical construction under more realistic conditions. In general, the examination of the base plate stiffness is often overlooked during the design process.

What do the abbreviations "ETA" and "ICC" stand for?

ETA stands for European Technical Assessment and serves as proof of product performance for construction projects, which leads to CE marking. ICC is the abbreviation for the International Code Council. The American association has been publishing qualification guidelines and approvals under ICC-ESR (ICC Evaluation Service Reports) since 1994.

Further Reading:

ACI 318-19: Building Code Requirements for Structural Concrete and Commentary. ACI Committee 318-19, American Concrete Institute, 2019 Edition

i Look into **fischer's "EN 1992-4" white paper** for further details on the design of anchorages according to EN 1992-4.

» When it comes to the geometry of base plates in particular, standards such as EN 1992-4 have their limitations. Spring models will therefore play a major role in the future fastening technology.«

Dr. Thilo Pregartner

Head of Technology Transfer and International Standardisation at fischer

Base plate stiffness
Examining various methods.

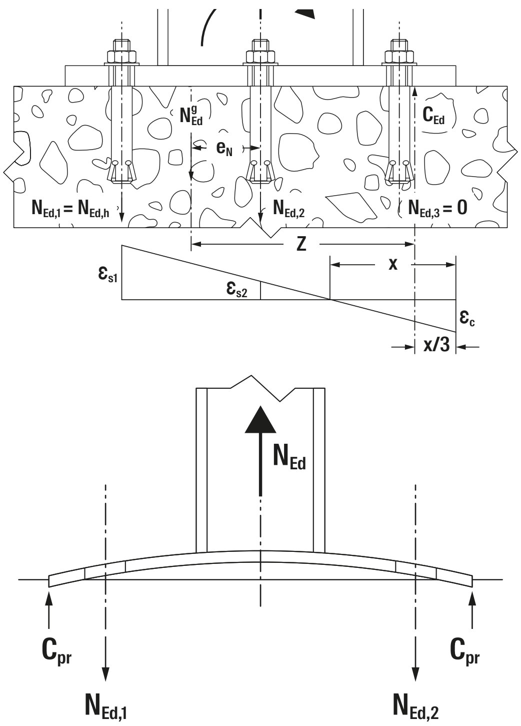
Experts have been working to develop practical methods to verify sufficient base plate stiffness for many years. As mentioned previously, EN 1992-4 requires a sufficiently stiff base plate without specifying the approach to verify the stiffness of the base plate. This requirement is necessary because linear strain distribution is assumed for calculating forces on individual anchors in anchor group (see figure below right).
Furthermore, prying forces on flexible base plates significantly influence the internal force distribution and must be taken into account during the design process in accordance with EN 1992-4 (see figure below right).

In the words of science

A few approaches can be found in literature or engineering practice to verify that a base plate is sufficiently stiff, such as the method according to Mallée/Burkhardt (1999) which checks the yielding of the base plate. However, the application of this method is restricted to anchor groups of 4 with a maximum layout of 2x2 and uni-axial bending. Fichtner (2011) in his PhD thesis proposes a deformation criterion. Spring models are described in recent publications and included in a few anchor design software. In current scenario, for design of anchorages with flexible base plates, such models offer the best solution to the engineers.

Further Reading:

- Mallée R., Burkhardt F.: “Base Plate Fixing with Anchors – Concerning Relevant Base Plate Thickness”, Beton- und Stahlbetonbau 94 (1999), Issue 12, pp. 502 - 509, Berlin, in German.
- Fichtner S.: “Investigations on the load behaviour of group fastenings considering the base plate thickness and a grout layer”, Dissertation, University of Stuttgart, 2011



Source: EN 1992-4

Planners and Structural engineers often are required to design anchor groups with anchor layouts beyond the scope of EN 1992-4.

The forces among the individual anchors of an anchor group are determined assuming a stiff base plate and corresponding linear strain distribution.

Spring models in fastening technology

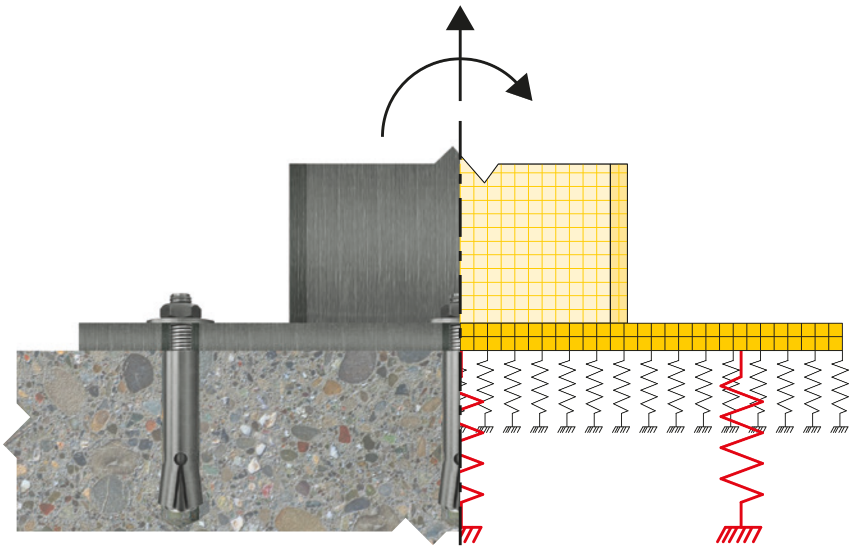
An introduction.

Spring models have been used in structural analyses for several years, in particular for the design of steel and composite structures. However, the application of spring models for design of anchorages in concrete has been highlighted only through recent publications (Bokor et al., 2019). base plate and the connecting profile are modelled using finite elements. The model of the anchorage comprising of the finite element mesh of the baseplate and profile, tension only anchor springs and compression only contact springs is solved utilizing the finite element method (FEM).

Spring model based approach

Spring models can realistically assess the behaviour of tension loaded anchor groups in case of concrete cone failure, eliminating significant limitations of existing approaches (see p.4. “The limitations of current standards”).

In the calculation of anchorages, the spring model concept is based on the assumption that within an anchor group, the anchors resist the tension forces, while the compression forces are transferred directly to the concrete by the base plate. The anchors are replaced by tension-only springs, while the contact between the base plate and the concrete is modelled using compression-only springs. The



The purpose of an FE model is to subdivide a system into many smaller parts of finite size (finite elements). In this example, the base plate and the connecting profile are modeled using finite elements, the anchor springs and contact springs are modelled and the system is solved through FE calculation.

Prof. Akanshu Sharma (University of Stuttgart): *“Improved safety and reliability”*

„One of the most significant advancements in structural engineering over the past decades is the paradigm shift from the traditional force-based concepts to performance-based concepts. Focusing on the complete performance of the structure instead of just strength results in much better understanding of structural behavior and significantly improves the safety and reliability. Nevertheless, the design of anchorages is still performed using empirical force-based methods that significantly limit their scope of application and does not offer the designer freedom of innovation in design. A displacement-based approach is essential to remove the limitations and extend the scope for the design of anchorages and for enhanced safety and reliability through a performance-based concept”.

This results in determination of deformations and stresses in the base plate under the influence of the applied force combination while simultaneously determining the forces in the individual anchors within a group. This allows a realistic simulation of the entire system. In principle, the spring model can be used for realistic assessment of the stiffness of base plates and its influence on the load distribution and potential load re-distribution among anchors of the anchor groups.

Spring characteristics

Depending on the approach and the objective of the calculation, linear or non-linear anchor springs can be used within the framework of the spring model. The load-displacement behaviour of the overall system can be obtained by using nonlinear anchor springs. However, the force distribution within anchor groups can also be obtained using linear spring characteristics.

Modelling of the anchor behaviour realistically is one of the most important aspects to be considered within the framework of the spring models.

Load-displacement curves

Anchors failing by concrete cone failure exhibit non-linear load-displacement behaviour under tension loading (see lower right diagram). This behaviour is characterised by the initial linear ascending branch of the load-displacement curve, a peak load and a post-peak descending branch. In principle, load-displacement curves obtained through the tests on single anchors are used to determine the anchor spring characteristics.

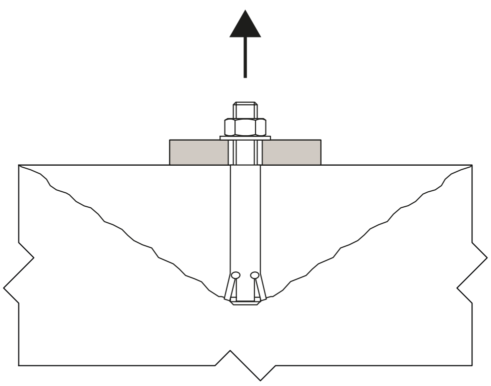
The load-displacement curves obtained from the tests are idealised in order to determine the anchor stiffness values. In the following, the two spring modelling approaches and corresponding details are presented. The aim is to determine the resistance of anchor groups while considering the respective anchor characteristics.

i The load-displacement behaviour of an anchor depends on both the type of anchor and the failure mode.

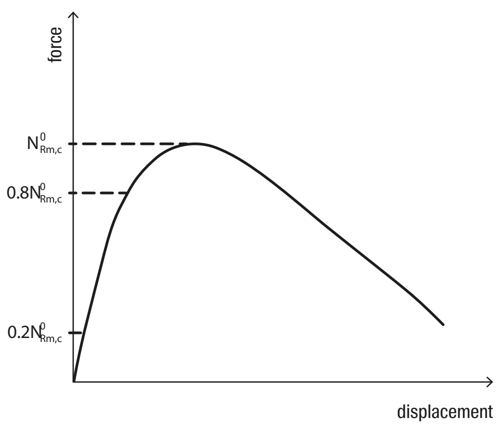
Failure modes in concrete

Anchorages under tension loading in concrete may result in the following failure modes:

- Steel failure
- Concrete cone failure
- Splitting failure
- Pull-out failure
- Bonded anchors: Combined failure of concrete cone and pull out failure



The realistic anchor behaviour is determined through centric tension tests



A load-displacement curve is obtained as a result of a tension test on the anchor

Boglárka Bokor has been working on developing innovative approaches for design of anchorages since 2016. In her PhD thesis, she developed a nonlinear spring model for anchor groups. She submitted her thesis at the University of Stuttgart in 2020.

»Knowledge transfer through scientific publications and open discussions with experts and end users are essential for us to implement innovative approaches in design.«

Dipl.-Ing. Boglárka Bokor

Senior Expert Technology Transfer and International Standardisation at fischer

Linear spring model

Calculation of the anchor force distribution within anchor groups.

The distribution of anchor forces within an anchor group can be determined using the linear spring model within the framework of finite element method. The anchor forces obtained from the linear spring model can be compared with the anchor forces obtained according to the theory of elasticity (linear strain distribution = infinite base plate stiffness) as per the CC method. Based on this comparison, designers can better judge the applicability of the approaches given in current standards. The application of a realistic base plate model through finite elements can also be used to take additional measures to fulfil the criteria of a rigid base plate. Only the ascending linear part of the load-displacement curve is taken into consideration in linear spring models. The anchor spring characteristics that depicts the load-displacement behaviour is mostly defined by the mean initial stiffness of the fastening (See Figure below: straight red line).

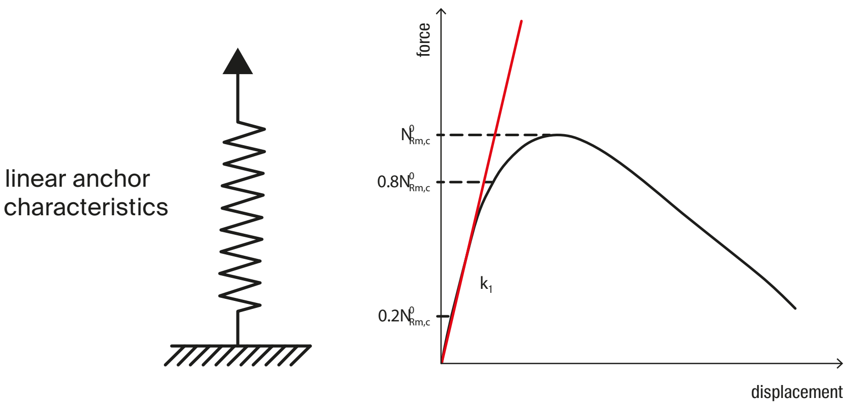
In linear spring models it is assumed that neighbouring anchors do not influence each other. All anchors of an anchor group are therefore assigned the same linear spring characteristics. Any possible edge and group effects are not considered in the calculation. Linear spring model calculations are always force-controlled. The external forces and moments are applied and the calculation is performed within a few iterations. Due to the use of linear spring characteristics for anchors in the finite element model, the calculations are rather fast. The disadvantage of a linear spring model is that it is limited to the determination of the force distribution within the anchors of a group.

Linear calculation approach

Calculations with a linear spring model provide the individual anchor forces within a group. The total sum of the individual anchor forces may vary from the acting external force due to the possible prying forces (compressive forces) below flexible base plates in contact with the concrete surface. Comparing the calculated forces with the anchor force distribution based on the CC method can be used to judge if the base plate is sufficiently stiff. Due to the force-controlled analysis in combination with linear spring characteristics, the re-distribution of anchor forces cannot be considered. Although the linear spring model is a great tool to evaluate the base plate stiffness, it cannot be directly used to design an anchorage with a flexible base plate.

Good to know:
The linear spring model can be used to check the stiffness of the baseplate and, if required, to optimise the design of the anchorage. Possible solutions to optimise the anchorage include:

- Increasing the base plate thickness
- Enlarging the connected profile
- Applying additional stiffeners
- Selecting a softer anchor system to optimise the force distribution



Typical load-displacement curve of a single anchor in the case of concrete cone failure. The linear anchor spring characteristics are idealised through the initial stiffness of the curve (straight red line).

Non-linear spring model
for the concrete cone failure mode.

Typical breakout body of an anchor group after tension test

Concrete failure cone of a group of 3 anchors close to a concrete edge

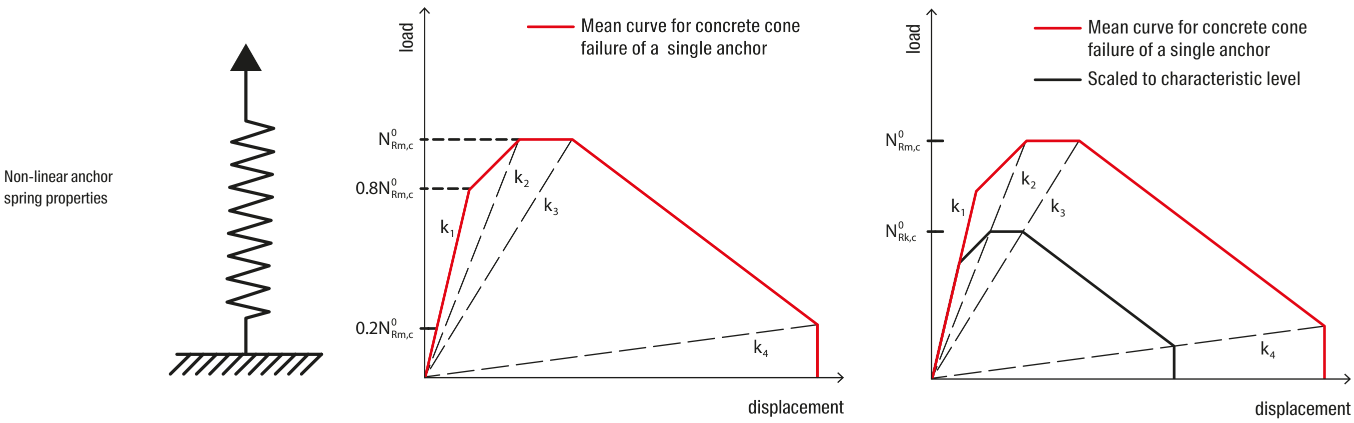
In the non-linear spring model, the anchors, the base plate and contact between the base plate and the concrete are realistically modelled (see figure on page 7). The non-linear load-displacement behaviour of the anchors is idealised typically in a pentalinear format. Five linear segments are used to idealise the load-displacement curve.

The curve is idealised with an initial stiffness line (stiffness = k_1) up to a certain load level (taken as 0.8 times the peak load in Figure below). This is followed by a second linear segment until peak load (secant stiffness = k_2), further followed by a plateau at peak load (secant stiffness = k_3) and a gradual descending branch until 0.2 times the peak load (secant stiffness = k_4). The last segment of the curve drops vertically down at the maximum displacement. In principle, the idealised multi linear load-displacement curves represent the anchor behavior at the mean level. Stiffness values and salient points are generally provided by the anchor manufacturer based on the results of tension tests in cracked and non-cracked concrete. Please note that different anchor types display different load-displacement behaviour. Therefore, the idealisation of the curves is product specific.

For anchorage design, the idealised load-displacement curves are scaled to the characteristic load level for the respective failure mode while the stiffness values remain unchanged (see figure below right).
By using the mean anchor stiffness values, the ratio of the base plate stiff-

Further Reading:

- Bokor, B.; Sharma, A.; Hofmann, J.: "Spring modelling approach for evaluation and design of tension loaded anchor groups in case of concrete cone failure." In: Engineering Structures, Vol. 197 (2019), 109414
- Bokor, B., Pregartner, T., Sharma, A., Hofmann, J.: "A non-linear spring model for design of tension loaded anchorages in concrete". In: Bauingenieur BD94, 2019, No. 9 9



The load-displacement curve of a single anchor is idealised with a pentalinear format.

ness to anchor stiffness is realistically captured in the calculation.

Projected area approach

The CC method utilizes a projected area approach (see also the “EN 1992-4” white paper) for concrete cone failure mode of tension loaded anchorages. The group effect (influence of neighbouring anchors) is considered through the ratio of the total projected area of the group ($A_{c,N}$) to the reference projected area of a single anchor ($A^0_{c,N}$). The failure cone is idealised as a pyramid with a square base. The area of this idealised square base is utilized as the projected area.

In order to determine the resistance of the anchor group against concrete cone failure, the ratio of the projected areas is multiplied with the characteristic resistance of a single anchor without edge influence or influence of spacing. Further influencing parameters such as eccentric loading, vicinity of an edge or dense surface reinforcement are accounted for through modification factors (Ψ factors). The non-linear spring model according to Bokor et al. (2019) utilizes a tributary area approach. The tributary area approach is based on tension tests with anchor groups failing due to concrete cone breakout. The validity of the approach is confirmed through a large number of tests. In this approach, individual anchors are assigned with a corresponding tributary area that is determined on the basis of anchor spacing and edge distance.

The characteristic resistance of an individual anchor of a group ($N^i_{Rk,c}$) is proportional to its tributary area $A^i_{c,N}$. The characteristic spacing and edge distance of the CC method for concrete failure are utilized here. The tributary area assigned to an i- th anchor of the group is used to scale the anchor spring characteristics (see box on right).

Non-linear analysis

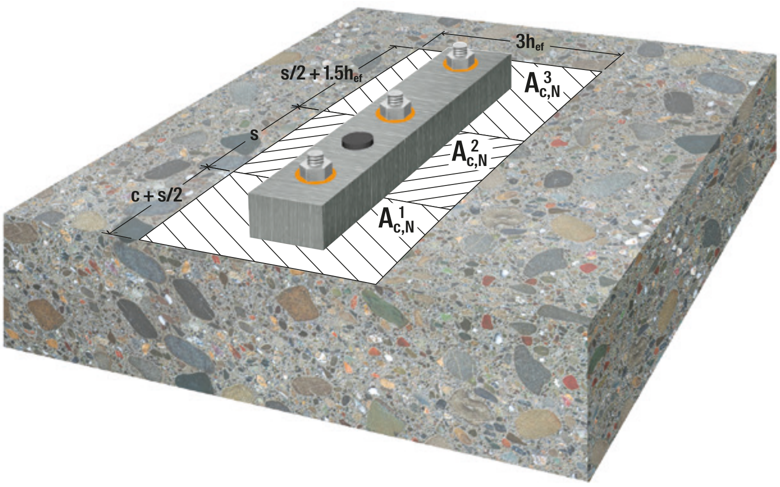
To consider the realistic force distribution and re-distribution among the anchors of a group as well as to account for base plate deformations, displacement-controlled nonlinear analysis is performed. Through a step-by-step nonlinear analysis, the change in stiffness is considered realistically. As the result of the analysis, the complete load-displacement curve for the anchor group is directly obtained.

Scaling of the spring characteristics using tributary areas:
In the nonlinear spring model, the characteristic resistance of the individual anchor of a group in case of concrete cone failure is given:

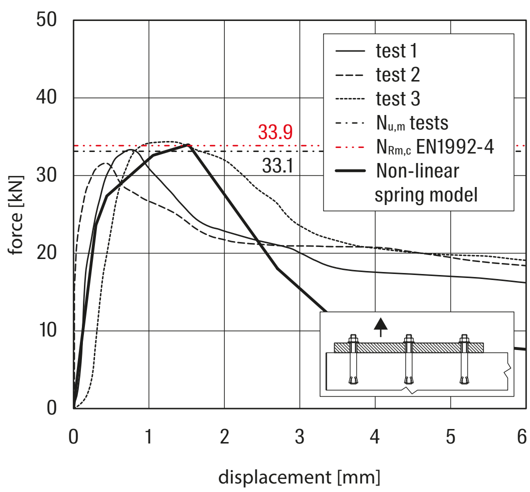
$$N^i_{Rk,c} = N^0_{Rk,c} \cdot \frac{A^i_{c,N}}{A^0_{c,N}}$$

Further Reading:

Bokor, B.; Sharma, A.; Hofmann, J.: Experimental investigations on concrete cone failure of rectangular and non-rectangular anchor groups. In: Engineering Structures, Vol.188 (2019), n.p. 202-217 7



The tributary area approach is applied to individual anchors of a group in the framework of the non-linear spring model. The further modification factors as per the CC method are not required.



The non-linear spring model was verified through numerous tests on anchor groups in concrete (see PhD thesis of B. Bokor at the University of Stuttgart).

Non-linear spring model
A glimpse into the advantages.

One of the main advantages of the non-linear spring model is the direct consideration of the baseplate stiffness in the calculation. The following example of a group of 4 anchors in one anchor row under eccentric tension loading is used to demonstrate the advantages of the non-linear spring model. Test results are available for this calculation case, however, this anchor configuration is not covered so far in EN 1992-4. The non-linear spring model can be used to calculate the resistance of such design cases for which currently no design rules are available.

Eccentric load case

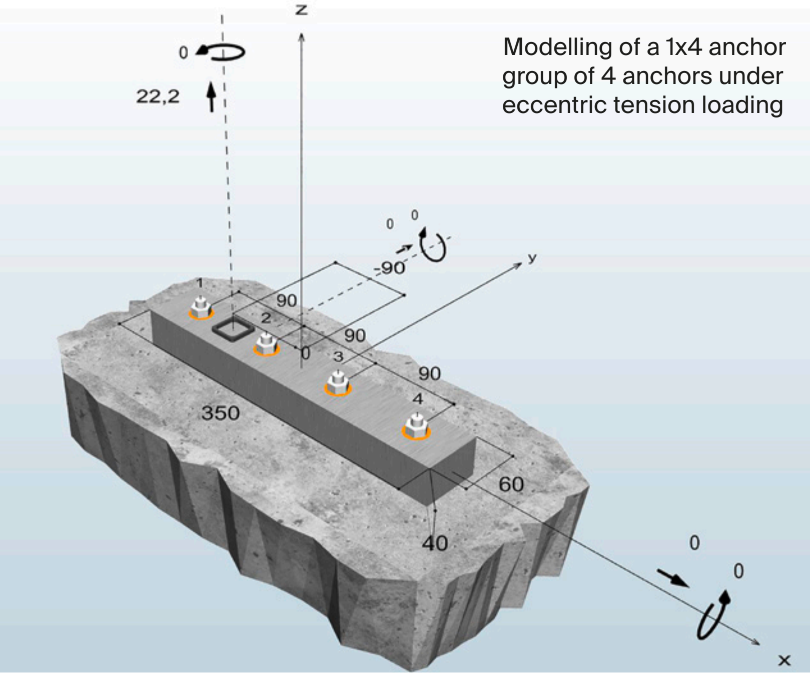
In this example case, the base plate thickness was varied from 5 mm to 60 mm. An influence of the base plate flexibility on the load-bearing capacity of the anchor group can be expected in this range. Adhesive anchors with a high bond strength and a relatively small embedment depth of 60 mm were used in order to provoke concrete failure. The selected anchor spacing of 90 mm is lower than the characteristic anchor spacing (180 mm). Therefore, we have an anchor group configuration in which the overlapping of the tributary areas of individual anchors is present. The eccentricity of the external forces is 90 mm, such that the force acts exactly in the middle of the outermost anchor and the neighbouring anchors.

Influence of the base plate thickness

The graph on the lower right-hand side shows the influence of the base plate thickness on the calculation result with the non-linear spring model in comparison to the result based on the CC method. It is interesting to note that the characteristic resistance calculated using the non-linear spring model increases with the increasing base plate thickness. This is due to the fact that with thicker base plate the activation of anchors gets higher and the prying forces are reduced.

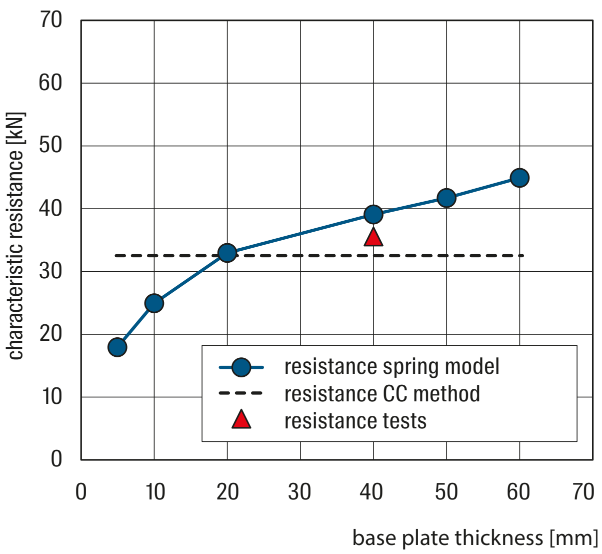
Further Reading:

Bokor, B., Pregartner, T., Sharma, A., Hofmann, J.: “A non-linear spring model for design of tension loaded anchorages in concrete”. In: Bauingenieur BD94, 2019, No. 9



Modelling of a 1x4 anchor group of 4 anchors under eccentric tension loading

Below: The influence of the base plate thickness on the characteristic resistance in the case of an anchor group loaded eccentrically using the non-linear spring modelling approach and the CC method.



By contrast, the value calculated on the basis of the CC method does not depend on the base plate thickness. In the case of eccentric loading, a realistic calculation using the spring model with a base plate thickness of 10 mm results in approximately 30 % lower resistance in comparison to applying the CC method which may have a serious safety implications on the anchor connection. A base plate thickness of 60 mm meanwhile results in 30% higher resistance. This demonstrates the main advantages of spring models and the corresponding realistic calculation.

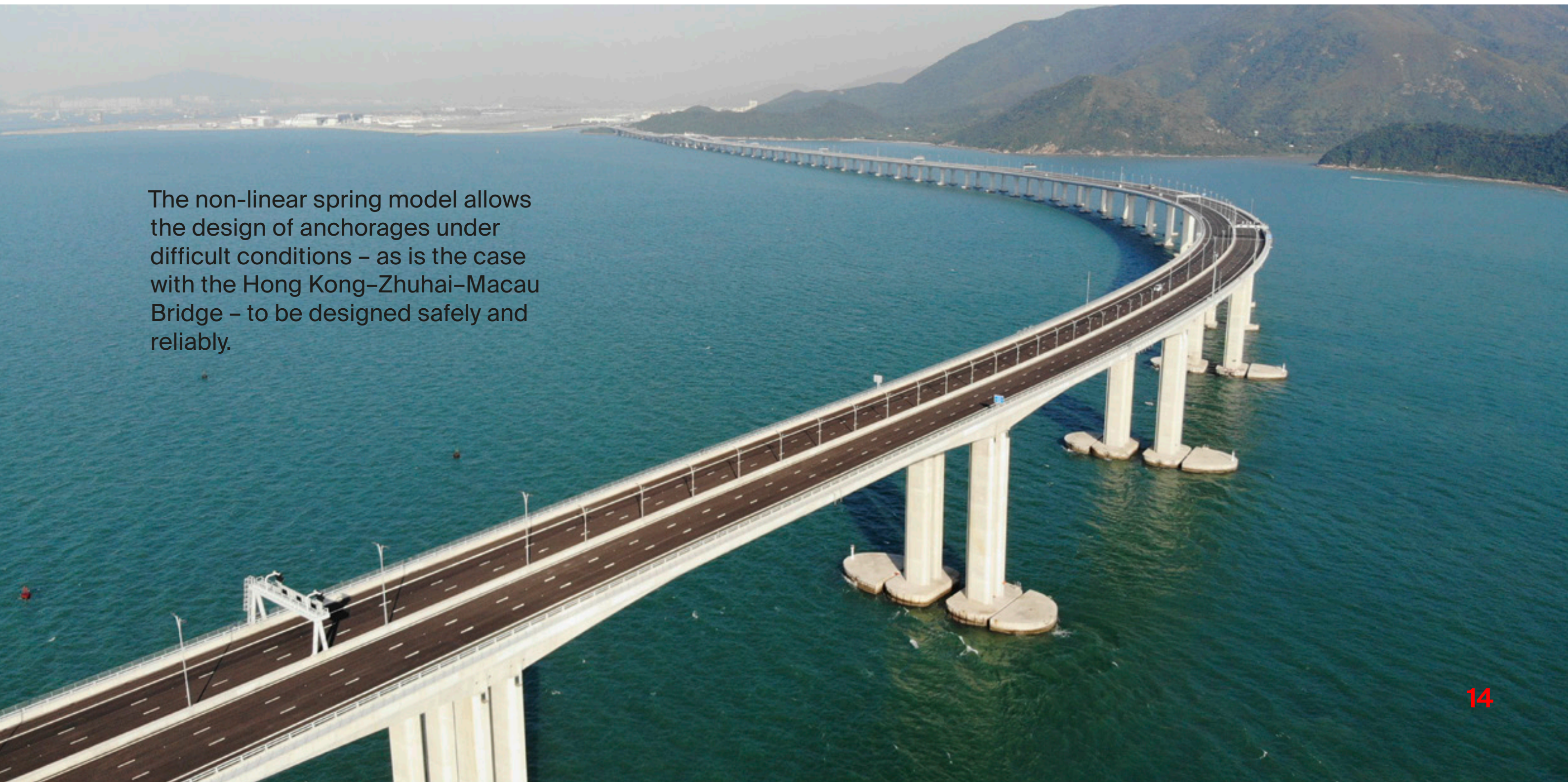
The effects previously shown may be less pronounced in the case of a softer anchor system compared to bonded anchors.

An overview of all advantages

The above-described example highlighted one of the major advantages of the non-linear spring model. By considering the non-linear anchor behaviour and the base plate geometry, the anchor force distribution and re-distribution is automatically accounted for. The model does not require the precondition of a stiff base plate. The modelling rules and deriving the anchor spring characteristics are objectively formulated and published in scientific papers. Through the consideration of the complete load-displacement behaviour of anchors and appropriate modeling of the base plate, the non-linear spring model can be used for the design of anchorages within and beyond the scope of current standards. This performance-based concept offers more realistic assessment of the anchorage and is not limited to the determination of load-bearing capacity.

For the end users: The non-linear spring model offers various possibilities in terms of anchor configuration, base plate thickness and loading condition going beyond the scope of the current standards.

i In the non-linear spring modelling approach, both the load distribution and resistance of the anchorage are assessed in a single calculation in a single calculation. The resistance of anchor groups are calculated considering the spring characteristics of individual anchors within a group.



The non-linear spring model allows the design of anchorages under difficult conditions – as is the case with the Hong Kong–Zhuhai–Macau Bridge – to be designed safely and reliably.

Prof. Akanshu Sharma has vast experience in structural engineering with a focus on strengthening methods with fastenings.

»It is a great leap forward to perform displacement-based nonlinear analysis using the spring model, which offers engineers unlimited possibilities for safe and reliable anchorage design«

Prof. Akanshu Sharma

Junior Professor Innovative Strengthening Methods with Fastenings, Institute of Construction Materials, University of Stuttgart

fischer Fixperience

Safety becomes calculable with the design software's C-Fix module.

Verification is required to prove that a selected product is suitable for the required load in order to prevent an anchor from failing. This makes simple design software for planners, structural engineers and construction engineers essential.

Design with C-Fix

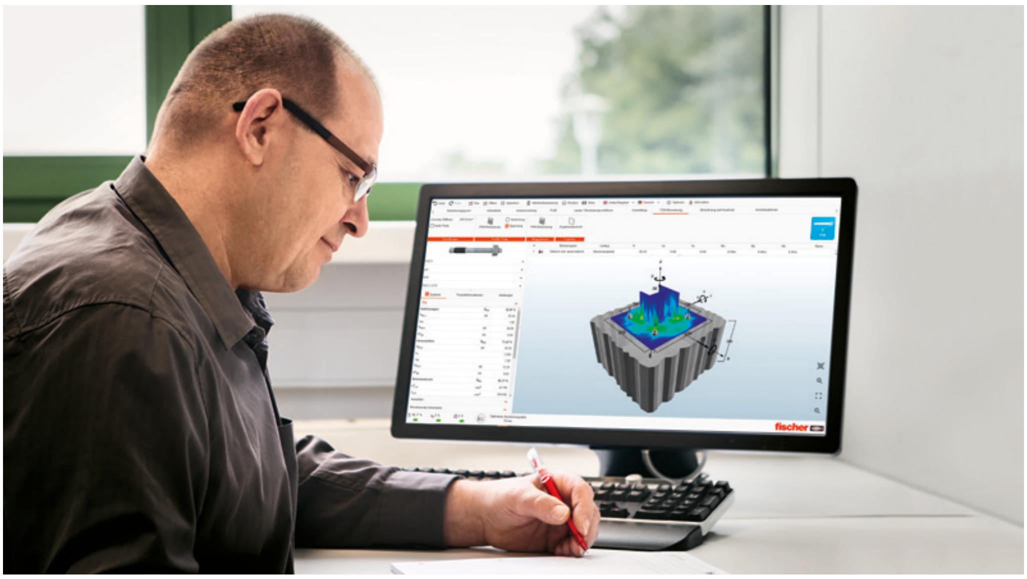
fischer's free Fixperience design software comprises engineering software in addition to seven specialist application modules. The C-Fix module is the right choice for the design of steel and bonded anchors in concrete. The program follows the logical approach of manual verification and is mostly self-explanatory. Planners and structural engineers can immediately commence planning their projects after registering and signing in. Base plates can be modelled according to requirements before adding the structural steel section and inserting the load actions. Next, the user selects the anchors of their choice. The program ideally confirms a valid design before generating a verifiable printout. If this isn't the case, then multiple designs can be carried out. The program calculates all applicable products before recommending suitable products.

Linear spring model already implemented

Fixperience undergoes continuous development to meet the design standards and requirements of planners and structural engineers. The new EN 1992-4 standard has already been fully integrated into C-Fix Online. Finite element modules have also been implemented into the latest version and is useful to check the sufficiency of the baseplate's stiffness with the help of the linear spring model. The base plate stiffness can then be optimised, for example, by applying additional stiffeners. The non-linear spring model will be implemented in the upcoming versions of C-Fix Online. The "spring model" module is available exclusively in the online version.

Try fischer Fixperience free of charge now!

Go to Fixperience



The online Fixperience module can be used in standard browsers without installation.

Dr. Oliver Geibig has successfully worked in the technical sales of fixing solutions and related software and services for many years. He has also taken an in-depth approach to Building Information Modelling (BIM) for more than 10 years.

»Fixperience Online with the integrated spring model is just one of many components within the context of digital transformation. In addition, fischer is also advancing digital solutions for its customers with BIM Engineering.«

Dr. Oliver Geibig

Head of Business Units & Engineering, Member of the Executive Board, fischer fixings systems

fischer Services
From a single source.

Our experienced Technical Advisors are available through all channels from Monday to Friday: By telephone, email and chat. Planners and structural engineers can receive competent support on issues such as static calculations or preliminary designs. fischer also offers product, application and certification training and provides support with the execution and evaluation of pull-out tests. We keep numerous planners and structural engineers up to date through newsletters, mail and personal contact.

Field specialists
Got a problem on your construction site? Our fischer experts are happy to support you on site. We provide advice and help to ensure everything is professionally fastened. On-site pull-out tests provide added security, particularly in difficult construction materials where performance data may not be available. Together with you we determine fixings solutions that are effective, safe and economical.

fischer Academy
We have been offering targeted seminars for professionals in the construction industry for over 30 years. The fischer Academy works in cooperation with trainers who understand their “trade”. All state-of-the-art training sessions provide information on current national and European standards and guidelines as well as statutory provisions and their implementation during planning and processing. Our trainers complete theoretical and

Be it online or on-site: A seminar at fischer’s Academy is always worthwhile.

practical training and development sessions year after year to guarantee the high standard of quality. And the best part: You decide whether the training takes place at our Academy, through OnlineSeminars or at your company.

Training for planners and structural engineers: Book the training session of your choice now!

www.fischer.co.uk/en-gb/training

Go to fischer’s OnlineSeminare

Our Technical Advice Experts are happy to help!
Contact fischer now.

T +49 7443 12 - 4000
(Mon. –Thur.: 7:30– 17:30 CET Fri.: 7:30– 17:00 CET)

intsupport@fischer.de

Summary.

White paper spring models summary.

Linear vs. non-linear spring model

Besides many advantages, spring models are ideal for assessing the stiffness of the base plates. Linear spring models allow the comparison of the anchor forces between a realistic calculation and the calculation according to the elasticity theory used in the CC method. By comparing the anchor forces, the base plate thickness can be iteratively optimised until the stiffness is sufficient to meet the requirements of the CC method.

Non-linear spring models, however, enable the direct calculation of the characteristic resistance of an anchor group considering the base plate stiffness and stiffness of each individual anchor. Thus, the non-linear spring modelling approach provides realistic calculations that go beyond the limitations of the current CC method.

Linear spring model application

The linear spring model involves a force-based approach using linear spring characteristics for anchors. The individual anchor forces can be realistically determined by taking into account the anchor stiffness, the base plate stiffness and the profile. With this approach, the influence of possible prying forces on the total internal forces of the anchors can be calculated.

Following the step-by-step optimisation of the base plate thickness with the help of the linear approach, users can obtain the required thickness of the base plate with which the CC method can be applied.

Non-linear spring model application

Unlike the linear spring model, which is based on a force-based approach, the non-linear spring model is based on a displacement-based concept. Non-linear spring characteristics are used to model the complete load-displacement behaviour including the descending branch.

This results in the realistic calculation of the characteristic resistance of the anchor group taking into account the base plate stiffness as well as the load-distribution and re-distribution among the anchors of a group. Non-linear spring model calculations, however, result in the determination of the complete load-displacement response of the anchorage. Therefore, the non-linear spring model can even be used to design anchorage configurations which cannot be designed according to the current guidelines.

Summary and outlook

Currently, spring models for design of anchorages are not included in standards. However, such models are currently being discussed in the committees for inclusion in the upcoming versions. The non-linear spring modelling approach has been developed and verified within the framework of the PhD Thesis of B. Bokor at the University of Stuttgart (to be published in 2021). Note, however, that additional considerations should be taken into account in case of shear loaded anchorages. Further publications on this subject will follow in the near future.

https://www.fischer-international.com

fischer's focus:

fixings systems
Automotive
fischertechnik
Consulting
LNT Automation

fischerwerke GmbH & Co. KG
Klaus-Fischer-Straße 1 · 72178 Waldachtal
Germany
Telephone +49 7443 12–0 · Fax +49 7443 12–8297
www.fischer-international.com · intsupport@fischer.de