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Construction in existing buildings - assessment for the suitability of current reinforcing and design rules for reinforced concrete structures

-short report-

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1. Introduction

Due to the present age of existing structures refurbishment of existing buildings is becoming increasingly important in Germany and exceeds the volume of new construction since several years. Reason for this development is that 60% of the residential buildings were built before 1968. As a result of conversion of the existing buildings, modifications of the building structure and repair works as well as up-grading measures in many cases the re-analysis of the existing structures is required. To follow up demands of building authorities this task must principally be done according to current codes.

However, the current codes almost exclusively cope for the erection of new buildings. Therefore they can be applied to a limited extent for construction in existing buildings only. Another special feature is that the knowledge about the existing building structure to be encountered is usually incomplete and the appropriate execution methods, building materials and construction steps often can only be decided on after the start of the work.

For technical and economic reasons the knowledge of codes in force during the planning and construction is necessary for the assessment of old buildings. The ability to judge the relevance of conservation and enhancement measures compared to re-construction measures anticipates extensive knowledge of historic materials and construction methods.

With this project, the identification and compilation of such basic requirements to be observed in the business of construction in existing buildings, as well as an assessment of the applicability of current reinforcing and design rules on existing structures made of reinforced concrete is achieved. As a result of the project, a general know-how and hints are developed, which shall help the parties involved in the business to run construction projects in existing buildings technically according to the current state of the art and to manage them successfully in view of economics.

2. Fundamentals for design and detailing of reinforced concrete components in existing buildings

2.1 Code Systems

First rules of the type of construction referred to initially as reinforced concrete, which found professional recognition in Germany, were published in 1904 by the Association of German Architects and Engineers Societies and the German Concrete Society. However, patents established by individual companies had been crucial for the early development of this type of construction. The decisive code of design and construction was originated in 1925 with the introduction of DIN 1045, which is going to be replaced on July 1st, 2012 by the EUROCODE 2. With the updating of the standard the scope has been multiplied and in addition, new areas of application of concrete construction led to a further need for regulation. From just under 50 pages in the beginning the code of practice dedicated to reinforced concrete construction has increased tenfold with the introduction of EUROCODE 2 regulations to over 550 pages.

However, EUROCODE 2, as all other regulations relating to the reinforced concrete construction method, is exclusively established for the erection of new buildings. Because normatively regulated design formats initially are supposed to be valid only in conjunction with the corresponding reinforcing and design rules, the design formats included in the current rules are not necessarily applicable to historical construction methods. Hence, no reinforcing arrangement can be expected in existing structures, which meets the requirements of current standards in all details, which is why all variations individually have to be verified on its own using engineering judgement with regard to their impact on the structural stability and serviceability.

For example, recommendations on the approach for construction in existing buildings in terms of rehabilitation, strengthening and modernization of existing structures and information on characteristic material properties are included within the “Instruction Notes” issued by the German Concrete and Construction Technology Association [Deutscher Beton- und Bautechnik-Vereins (DBV)].

The guidelines "Protection and repair of concrete components" and „Loading tests for concrete structures“, published by the German Committee for Reinforced Concrete (DAfStb), as well as the Guideline no. 6200 issued by the Association of German Engineers (VDI), provide directives to the approach for construction in existing buildings, but without dealing with issues for design and detailing.

Particular information on the re-analysis of road bridges under its authority are given in the “Guidelines for re-analysis of bridge structures”, issued in May 2011 by the German Federal Ministry of Transport, Building and Urban Development (BMVBS). Furthermore, the Swiss code collection SIA 269 copes with all issues occurring in existing buildings and is divided in specific parts related to the type of construction method.

The owner/authorized user are responsible to cope with the regulations enacted by the building authorities for ensuring sufficient structural stability of the loadbearing system as part of an existing building. Recently the Conference of Ministers and Senators of the 16 Federal States in the Federal Republic of Germany in charge for urban planning, building, construction and housing (ARGEBAU) have published "Directives and examples for the procedure to demonstrate structural safety in the field of existing building structures" (date: 07.04.2008)".

2.2 Structured registration of common errors corresponding to construction in existing buildings

In due course of a survey, commissioned by the German Association for Concrete and Construction Technology (DBV), the most common sources of error in the field of construction in existing buildings have been identified. In order to sort out the background of such errors, an interview of structural designers was conducted by the Rhineland-Palatinate Chamber of Engineers on the basis of a catalogue of questions. At the same time a poll among clients, construction companies, engineering companies, property developers and authorities was carried out by experts coming from the Technical University Kaiserslautern.

To sum up, most errors in the field of construction in existing buildings refer to an improper dealing with the subject at all stages of performance which is based on one hand on the ignorance or underdeveloped awareness of problems arising and on the other hand on an underestimation of the complexity of such projects.

A main source of error, strongly agreed by all respondents, is contributed to a failing or incomplete survey and assessment of the existing building, which frequently is done in due course of the building works themselves and rarely performed in the required working depth. Resulting in that, discrepancies between the actual building condition and the anticipated state of the building occur, leading afterwards repeatedly to larger problems, construction time extensions and cost increases.

Looking on the planning, engineering specialists are often involved too late and it is failed to work out a mode of execution tailored to the project at an early stage. Following from these mistakes is a construction-related planning procedure tight up with the progress of works with all kind of corresponding interface problems then inevitably arising or, as a consequence of not regarded site conditions, urgent re-design will become necessary causing significant cost increases.

The required construction period for the upcoming construction works is mostly underestimated. Decisive for this misdoing is that over and over again only the core activities with regard to material and time are put in the focus, whereas the supplementary works necessary to be accomplished too are neglected.

Compared to the erection of new buildings the possibly limited use of machinery, lifting equipment, means of transport as well as restricted storage and access may be decisive for an underestimation of the required construction period.

2.3 Assessment of the existing building

For building in existing buildings the assessment of actual building conditions represents one of the first and most important steps in order to gain a reliable judgement of the existing building body. As a dependable basis for the structural engineering, the state of the building structure to be re-constructed must be established in advance of the start of construction works. This includes identification of characteristic material properties, construction details and future actions affecting the building structure.

The more painstakingly and the more comprehensively the assessment of actual building conditions is performed, the probability of a smooth construction process and of a successful action in both the technical and economic point of view is the greater.

As a first step to come up with the assessment of actual building conditions the sighting of old documents (for example building files) is recommended. Conclusive from this source, helpful hints on possible weaknesses of the design may result because each building era has its favourite types of construction. After a building inspection based on this forgoing information is done, the subsequent building investigations can be restricted to critical areas.

Part of the assessment of actual building conditions is deemed to determine the state of load-bearing building components, their geometry and their structural function including the reinforcement content. For this purpose a variety of different means is available. In addition to the regular destructive test procedures, which are, due to its damage to the structure, up to a point insusceptible only to the building component in question and in any case to be kept to a minimum, there is a variety of other non-destructive testing methods. As an example, the radar or ultrasonic procedure shall be mentioned in this context, which allows determining for instance the reinforcement arrangement within the building component in a non-destructive way.

Further important elements of the assessment of actual building conditions are the determination of concrete cover and the depth of carbonation as well as the progress of corrosion of reinforcement including the identification of concrete and reinforcement corrosive substances.

Usually required for the assessment of actual building conditions are the combination of local, destructive testing such as drilling cores for the determination of absolute values and in addition, the performing of area covering, non-destructive investigations to define the absolute values.

To sum up, it is evident that a reliable assessment of actual building conditions must capture always the total status of a building structure.

2.4 Determination of characteristic material properties

The determination of characteristic material properties for materials still used in the building is required for the re-analysis of existing structures in accordance with the current generation of codes and the semi-probabilistic safety concept contained therein. On the basis of extensive research characteristic material properties are calculated for the materials concrete and reinforcing steel specified to previous generations of codes.

Basic assumption for this investigation is that the materials used were supplied in compliance with the codes valid at that time. With the help of conversion factors different boundary conditions for testing such as specimen body geometry and storage conditions can be taken into account. The determined characteristic material parameters are used for preliminary design and must be scaled by material samples taken from the building components in order to re-analyse and to verify the structural stability of the building components in question.

The approach described in this paper to determine the characteristic strength figures will provide slightly different results compared to the values published in the DBV-guideline "Concrete and reinforcing steel". The reason for which is owing to the approach in determining the characteristic strength figures. While in the DBV-Guideline its determination is centred on comparison of permissible stresses, the findings in this paper are based on mathematical-statistical methods.

2.5 Modification of partial safety factors

All design codes, currently introduced in Germany, are compiled for new buildings or newly to be erected building components. These standards are subject to the semi-probabilistic safety concept, which in combination with the partial safety coefficients and characteristic parameters listed in DIN 1055-100:2001 is deemed to warrant the required reliability.

The subsequent design of reinforced concrete members in existing building structures, which, for example, had undergone a load increase as a result of its changed service conditions, has on principle to follow the current rules of DIN 1045-1:2008 or EUROCODE 2. But in many cases the direct application of the formats of design verification given in DIN 1045-1 is inexpedient for construction in existing buildings.

Since for construction in existing buildings many constraints, being covered for new buildings as unsafe elements in the safety concept with partial safety factors, can be determined within the framework of a qualified assessment of actual building conditions, the application of partial safety factors appropriate for new buildings is not required. These conditions include the geometry of building members, material properties, the location and quantity of existing reinforcement and the future actions.

After quantification of the previous mentioned varying items, an adaptation of the partial safety factors to the prevailing variation of the strength values and the geometrical dimensions in the structure can follow.

Because of this reason, modified partial safety coefficients were calculated on the resistance side which were compiled in accordance with the required reliability level for design formats common for construction in existing buildings.

Using these modified partial safety factors a practical and economic verification method for structural stability, pending on the material variation encountered in the existing building in application of the semi-probabilistic partial safety concept of the current code generation, will be enabled.

3. Background for reinforcing and detailing design rules

In 1925 the first edition of DIN 1045 was published, which was based on the Royal Prussian provisions of 1904, 1908, and 1916. Seven years later, in 1932, the design rules for the detailing of selected components were added. With the output of DIN 1045:1972 significant changes resulted from the codification of ribbed reinforcing steel and, facilitating by this new material, the possible bondage of longitudinal bars without hooks, the introduction of the ultimate limit state procedure for assessing the member sections instead of the n-procedure and the approach of reduced shear reinforcement.

The version of 1972 included a fundamentally new concept relating to the design calculations as compared to the previous standard DIN 1045:1959. There were significant changes in design for bending and shear and the verification of structural buckling. The concept of the elastic behaviour of concrete and reinforcing steel was abandoned for bending design and the classical truss analogy was extended for small and medium-sized shear forces.

In 1978 again the standard was amended in order to switch on the binding SI-system of units and newly introduced symbols, which both had 1969 established. Substantial design rules have been changed or newly incorporated. Such directives for reinforcing details include the harmonising of rules for bondage of reinforcement bars, the introduction of shear reinforcement inserts as a new type of reinforcement element, the implementation of rules for reinforcing details in frame corners and the reinforcing with bundles of bars.

In 1988 further changes and additions have been implemented while retaining the basic concept of the standard of 1972 and 1978, respectively. Comprised within this issue were an increased minimum concrete cover to improve the durability, the approach for limitation of crack widths, the codification of concrete steel BSt 500/550, the adaption of directives to cope with revisions of other standards and guidelines in the field of concrete construction.

The last major revision was introduced in 2001. Background for this revision was constituted by the preparation of the introduction of European harmonised standards (Eurocodes). In this context, the transition from the global, deterministic to the semi-probabilistic safety concept took place.

4. Applicability of current reinforcing and detailing design rules in the field of reinforced concrete construction

The reinforcing and detailing design rules in the field of reinforced concrete construction in accordance with the current generation of standards are, pending on the erection time of the structure, not unrestrictedly transferable to existing structures. Reason for this reservation is that at the outset normatively regulated formats for design verification are applicable in conjunction with the corresponding reinforcing and detailing design rules only.

In developing the various generations of standards many changes followed with regard to the reinforcing and detailing design rules , which is why each in each project-specific case their applicability, pending on the code system valid at the erection time of the plant, must be checked. It is advisable to note that with the introduction of new standards transitional periods were considered and practically in many cases, even for quite some time, one has been worked with the previously valid standard. Therefore, dates of years cannot represent exact application periods.

In looking on existing structures the following reinforcing design rules have generally been proved to be critical:

- **Concrete cover:** According to Eurocode 2 the concrete cover to ensure bonding firstly must meet at least the bar diameter. This requirement is mostly met by existing structures.

  Within the guidelines of 1904 a concrete cover by not less than 10 mm was requested. In case of bars with diameter less than 10 mm and an extra covering of plaster the concrete cover could be reduced to 5 mm. The provisions of DAfEb (=Deutscher Ausschuss für Eisenbeton)of 1916 provided a concrete cover at the soffit of floor slabs by at least 10 mm and for the cover of stirrups at ribs and columns at least by 15 mm. A minimum concrete cover by 20 mm was requested in outdoor components.

  In DIN 1045:1972 the concrete cover was ranked for the first time as a function of bar diameter and environmental conditions. With the output of DIN 1045:1988 the requirements for the concrete cover have been greatly increased as of durability criteria and heavily augmented with the introduction of exposure classes in DIN 1045-1:2001.

  From that reason outdoor components, built before 1988, are critically to be assessed because they generally do not exhibit the concrete cover required for the current generation of standards in terms of corrosion protection. Thus, constraints arise in view of lack of durability. Corresponding aspects of fire protection appear disregarded.

- **Bending diameter:** The bending diameter was regulated for the first time in 1916 as part of the directives of DAfEb. In due course of time, the bending diameter was adjusted to cope with the increase of yield strength of reinforcing steel from 220 N/mm^2 took (BSt 220/340 (I)) to 500 N/mm^2 (BSt 500/550 (IV)) within the respective standard editions accordingly.

Already in 1916 a distinction were made whether to look on bend-ups for longitudinal reinforcement or to the type of anchorage having been done with bends or hooks. In order to limit deviation stresses in the concrete, always a greater bending diameter is called for since, as it is the case for stirrups and anchorage elements such as hooks and loops.

However, over the course of each standard generation, the bending diameter was slightly increased only. Therefore deficits in comparison to an interpretation according to Eurocode 2 exist for older building parts only.

- **Rebending of reinforcement:** According to Eurocode 2 extensive demands on rebending of reinforcing steels are given. Compared to the unique bending the requirements for the minimum bending diameter have been increased and reinforcing bars up to a diameter of 14 mm are permitted to be bent in cold condition only. Nonetheless, there is a restriction on the allowable steel stresses as a result of rebending.

  As in the past occasionally reinforcing steel were used, which had been totally unsuitable for rebending, in the worst case a bar fracture could occur already with the first bending. Generally, a rebending test prior to performing the means of reconstruction is recommended as far as the used types of reinforcing steel are not classified seriously critical in the DBV-Guidelines "Concrete and reinforcing steel".

- **Minimum spacing of reinforcing steels:** Early in 1916 the minimum clear distances of reinforcing bars to ensure a concrete section free of cavities were fixed in the directives of DAfEb. Requested were minimum distances of at least 20 mm and of at least one bar diameter in size.

  However, particular existing structures built before 1972 reveal in many cases, that the necessary attention was not paid for to the regular requirements with regard to minimum bar spacing of reinforcing steels. This results in concrete cavities, which can cause corrosion problems in outdoor components.

  Ribbed floor slabs, widely used until the 1950s, are typical examples of concrete construction in which the bar spacing as well as the concrete cover often did not comply, and in view of the used formwork could not be maintained either.

- **Anchorage of longitudinal reinforcing bars (plain steel):** The anchorage of plan reinforcing bars on the basis of the code generation until 1972 cannot be justified with the current verification formats. Decisive for this shortage is that the load transmission of plain reinforcing bars with hooks largely is done by rope friction for the activation of which some slipping is going to be inevitable.

  In the past this type of anchorage was ensured but by testing; therefore a sufficient capacity in the ultimate limit state can generally be assumed, as long as the bends and hooks are undamaged and not hampered in their function.

  In case of load increase, this point with regard to the constructive compatibility of the overall design should be aware of, because limitations of serviceability can be resulting by deflections and cracking.

- **Bonding conditions / bonding stresses for reinforcing steel:** For the first time in DIN 1045:1943, permitted stresses depending on concrete grade were tabulated.

Previously, fixed values independent of the concrete quality were taken for this part of detailing. Proof of bonding stress was requested but only for bars with diameter larger than 26 mm.

The distinction into two areas of bonding was first introduced in 1954 in the approval certificates for ribbed reinforcing steels. With release of DIN 1045:1972 allowable bonding stresses pending on the strength class of concrete, the surface structure of reinforcing steel (plain, shaped, ribbed) and the location of reinforcing bars within the component section were introduced. The values contained are not comparable to those made in previous code issues.

With updating the code system and, apart from the terms for the bonding areas, allowable bonding stresses were modified in order to enable, as far as respective for the given application, always a review of the local conditions, based on the valid regulations at erection time. In case of doubt as to the quality of bond, a selective drilling and testing of cores is deemed to be recommended to assess the tightness of concrete surrounding the steel.

- **Coverage of tensile forces in flexural reinforcement:** After having been pointed out by various researchers in the 1960s that as a result of the truss model pressure and tensile force forces are offset against each other, tensile forces resulting from the displacement measure must be covered by reinforcement since 1972. In components, which have been made before 1972, the coverage of tensile forces is therefore not necessarily guaranteed. Coming apparent from longitudinal reinforcing bars inclined under 45°, the size of displacement at full coverage of shear force (45°-truss model) comes down to zero, so that for the share of shear force carried by stirrups only deficits in terms of coverage of tensile forces are to be expected.

  As long as one part of the longitudinal reinforcement was run up to the support, no problems result in practice. In view of the fact that the reinforcing steel can be accounted for pro rata along its anchoring length since introduction of EUROCODE 2, any shortage rates be reduced also.

- **Shear reinforcement:** In 1904 the value of permitted shear stress within the concrete cross section was fixed straight forward to 4.5 kg/cm² (≈ 0.45 N/mm²). Only the calculated stress in the cross section above and beyond this limit was to cover by inclined bars and to be anchored in the compression zone. Thus, the concrete compression strut was adopted always at an angle of 45°.

  This design model, with the consequence that some portions of beam could be designed without any shear reinforcement, result in a very low shear reinforcement level found in other areas.

  This deficit was reduced with the DAfEb-Guidelines issued in 1916. Therein, it was requested that in areas exceeding the permissible concrete shear stress of 4 kg/cm² (≈ 0.4 N/mm2) the shear force should be fully covered by shear inserts. Still, an upper limit was fixed for the shear stress of the total cross section at 14 kg/cm² (≈ 1.4 N/mm²) above which the dimension of the concrete cross section were to be increased.

  Only since introduction of DIN 1045:1925 stirrups along beams had to be arranged continuously, which also could be accounted to reduce the inclined reinforcement bars required for the design for shear forces. In addition, it was requested to fully cover the existing shear force by shear inserts.

Therefore, just after the code is updated in 1925, the coverage of all shear forces by reinforcing steel is required. In particular previously manufactured components are critical to judge in view of its resistance against shear forces.

5. Load-bearing capacity of ribbed floor slabs

In a barracks "in situ" load tests were carried out at ribbed floor slabs made of reinforced concrete. At the same time testings at ribbed floor slab components were made in the laboratory of the Institute of Concrete Structures and Structural Engineering at the Technical University Kaiserslautern in order to determine the load-bearing capacity of ribbed floor slabs with a construction set-up like existing in the barracks.

The findings of these load testings have demonstrated that the load-bearing behavior often shows considerable extra over load-bearing capacity whereas the load-bearing capacity of the "in situ" ribbed floor slabs could not be verified in accordance with the current design standards. Furthermore, these load testings have confirmed that the load-bearing behaviour of ribbed floor slabs cannot be concluded from such of individual ribs, but always the whole floor slab system must be regarded with its three-dimensional structural performance.

In such cases load testings established in accordance with the relevant DAfStb Guidelines are basically suitable to capture the actual load-bearing behaviour including all side effects realistically. In due course of these load testings and due to lack of failure not being announced in advance the determination of shear force resistance put a problem unless the structures are not charged up to the appropriate ultimate limit of action to be used.

6. Summary and outlook

For building in existing extensive requirements and various challenges are to be faced by all participants in the construction business. The reason is that for building in existing structures a building subject must be touched, for which the key parameters are chiefly unknown.

Moreover, the current reinforcing and design rules are not directly be transferable to construction in existing buildings; hence the various regulations and directives have to be judged in such specific cases in question.

Within this research report, the essential principles and practices for handling of construction projects in existing building structures are itemized. After listing of codes, guidelines and data sheets to be used options for determining characteristic material properties are indicated and the procedure to perform an assessment of the existing building is outlined.

Additionally, modified partial safety factors on the resistance side have been explained which can be used advantageously for the re-analysis of building structures following the assessment of the existing building.

The focus of the report is put on the review of the applicability of the current reinforcing and design rules for reinforced concrete construction in existing building structures. In this chapter, the relevant rules in accordance with their development in due course of the different generations of standards are presented and discussed.

It turns out that a large amount of building structures in existing buildings cannot completely be verified according to the current design rules, nonetheless the building components prove to be structurally adequate. To determine such load-bearing extras sometimes load testing is successful.

Generally all existing structural components with regard to their durability and fire resistance have to be checked, because the demands on the concrete cover in earlier generations of DIN 1045 were much lower. Construction details also to be reviewed are the anchorage of longitudinal reinforcement and the coverage of its tensile force as well as the shear force resistance of the components.

Depending on the erection period of a building structure and the valid design rules associated the specific insufficiencies must therefore be identified and taxed for each structural element. To do this, the key reinforcing and design rules are treated and compiled with regard to its development over time. With the help of this compilation, the deficits arising from the development of the code system can be recognized and substantiated by in-situ investigations.