# Early Reinforced Brick Floors in Germany: Historical Development, Construction Types, Dimensioning and Load Bearing Capacity

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ABSTRACT: Since fire-proof brick constructions had begun to replace the traditional wood structures following the Chicago Fire in the 1870s, reinforced brick floors have shaped the system of skeleton construction world-wide up to our times – in a wide range of multi-storey buildings as well as in many famous buildings of "classical modernism" from *Le Corbusier* to *Mies van der Rohe*. In recent years a research project at the Chair of Construction History and Structural Preservation of the BTU Cottbus, enabled by funds from the German Research Foundation DFG, gave the opportunity to investigate for the first time systematically the historical development and structural typology of early reinforced brick floors in the German empire from the beginnings in 1892 up to 1925. The first phase of the project was focused on historical questions as different construction types, proliferation, typical advantages and faults or historical methods of dimensioning. The research in this phase was based on patent documents and contemporary publications as main sources but analyses of brick production works and of the transport ways in the German inland water and railway networks were also used. Building on the results of the historical studies, the second phase of the project was dedicated to the structural examination of reinforced brick floors from a contemporary point of view. Aiming at a close-to-reality assessment of the load bearing capacity the usual calculation algorithms could be refined.

## HISTORICAL REINFORCED BRICK FLOORS

The first reinforced brick floors were developed in the USA in the 1870s when fire-proof brick constructions began to replace the traditional wood structures following the Chicago Fire, and when the first tower blocks began to be erected. Soon enough, hollow bricks were being mass-produced for this purpose. Thaddeus Hyatt patented what are considered the first reinforced brick floors in England in 1877 and in America in 1878. In Germany *Johann Friedrich Kleine* announced the patent of the first and still best-known reinforced brick floor in 1892. Here the years up to 1910 saw the emergence of a wide range of different brick floor types. The variety by far outnumbered that of the reinforced concrete slabs which were developed around much the same time, but first of all the reinforced brick floors gained a far wider distribution. Brick floors were used not only to construct the wide range of multi-storey buildings of the early twentieth century, but also in many buildings of "classical modernism", from *Le Corbusier* to *Mies van der Rohe* - structures which are often falsely believed to have been erected with reinforced concrete slabs. Good-value and easy to build, reinforced brick floors have shaped the system of skeleton construction world-wide since the late ninetieth century up to our times.
Many of these historical floors are still in use today (Fig.1). Nevertheless very little is known about them. Not only an accurate, close-to-reality assessment of their load-bearing capacity (for example in response to changes of use), but already their simple classification does however throw up considerable difficulties. In recent years a research project at the Chair of Construction History and Structural Preservation of the BTU Cottbus, enabled by funds from the German Research Foundation DFG, gave the opportunity to investigate for the first time systematically the historical development and structural typology of early German reinforced brick floors from the beginnings in 1892 up to 1925.

## HISTORICAL CONSTRUCTION SYSTEMS

At the end of the 19th century, German builders were able to make use of the first reinforced brick floor systems – beginning with the *Kleine'sche Steineisendecke* from 1892. These first systems were sufficient for a lot of construction tasks. Nevertheless the details of them could still be improved. An astonishing amount of improvement efforts, mostly patent-protected, can be noticed in the following two decades, focussed on raising the load-bearing capacity, on functional quality and on keeping production costs down. The result was not only a wide range of different brick types, but also to the formation of floors with different load-bearing behaviour and in some cases to the development of completely new types of floor as for example crossed reinforced brick floors or rib and block slabs.

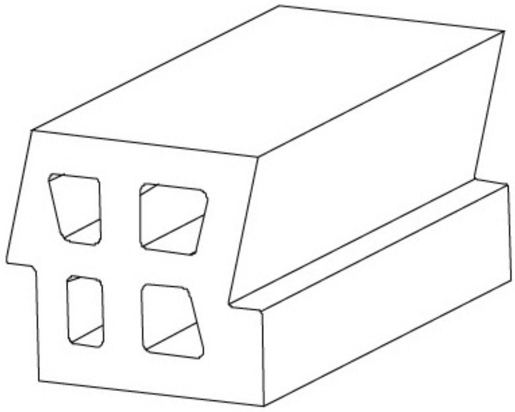


Figure 1 (left): Cross section of a typical reinforced brick floor from about 1910 showing brick, concrete and reinforcement steel; Figure 2 (right): Clay bricks fitted with grooves and springs

The remarkable process of differentiation may be demonstrated by using the example of the stages of development of new types of clay bricks.

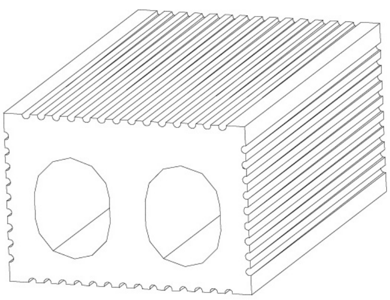
- Grooves and springs were developed in order to increase the resistance of the reinforced concrete slabs to falling loads and at the same time to increase the flexible load-bearing capacity of the floors (Fig.2).
- The void cells in the lower part of the brick cross-section were offset in order to enlarge the compression cross-sections and to optimise the capacity of carrying compressive stress (Fig.3).
- Base boards were added as a practical and satisfying solution, preventing the concreted mortared joints from showing through on the lower side of the floor; in addition, they provided a uniform width of joint and presented advantages in the grouting of the joints (Fig.4).
- Last but not least fully enclosed hollow clay bricks were developed to allow the reinforced brick slabs to be poured with concrete without this seeping into the brick cells (Fig.5).

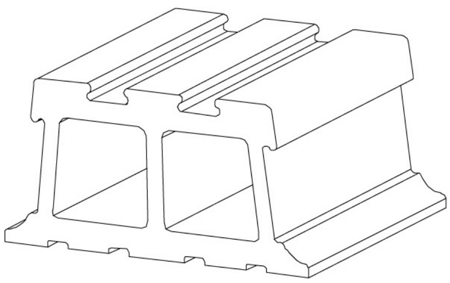
Especially the grouting of the joints made it possible to produce brick floors cheaply, as the work of brick-layers needed in their production could be minimised.

A total of 71 different systems of reinforced brick floors were found to exist in the area covered by the German Empire during the period between 1892 and 1925. As a first result of the research project, a typology (Fig.6) and a catalogue have been developed where, for each of the 71historical reinforced brick floors documented, in addition to all of the essential data from the patent or the pattern of implementation, information has been included on the clay bricks, reinforcement and mortar types used, the maximum spans, as on the specific characteristics and development stages of each floor type. (Fischer 2009)

A large number of these systems, however, were of limited or local importance in practise. Among those found nationwide, three clearly stand out:

- The *Kleinesche Decke*, well known as the classical example of a reinforced brick floor for many German engineers, proved to be the dominant floor system in fact and was found widely spread through almost all of the German territories (Fig.7).
- The *Förster-Decke,* which gained similar importance (Fig.8).
- The *Reformhohlsteindecke*, which was used particularly in the south and west of the German Empire, as well as in the Berlin area. It was built with *Ackermann* clay bricks, though one must qualify that these bricks were not only used in the construction of reinforced brick floors, but also for rib and block slabs, a special type of reinforced concrete slab floors (Fig.9).





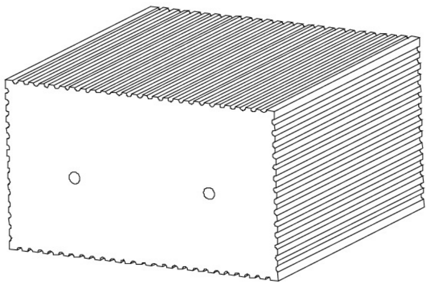


Figure 3 (left): Clay bricks with void cells in the tensile zone; Figure 4 (middle): Clay bricks with base boards
Figure 5 (right): Fully enclosed hollow clay brick

## HISTORICAL DIMENSIONING METHODS

No building regulations for the design of reinforced brick floors existed until 1904. Instead, load-testing gained a decisive role within the framework of the development of building permit regulations for reinforced brick floors. Load-tests were used by the municipal building inspection departments to certify reinforced brick floors for use; in addition they were often used for advertising purposes (Fig.10). According to contemporary reports on load-tests, the slab bays often displayed no or only negligible deflection or damage, even when tested under extremely high loads. A crucial reason for this was often the questionable testing structures used, in particular self-supporting test loads. One can assume that reliable test data is only to be found after 1900, when load-testing on reinforced brick floors, carried out in state testing institutions, was first introduced. At the same time, even the published reports from these tests are unreliable, as they contain insufficient information on the guidelines used, on the uniformity of the testing programmes, how they were carried out, analysis of results and documentation, all of which generally do not satisfy modern requirements or research standards. From a nowadays point of view, the results of the contemporary load-testing can only be used extremely restrictively in assessing the load-bearing capacity of these reinforced brick floors. By the way it can be assumed that the same is true for other reinforced concrete structures, above all for reinforced concrete slabs.

The first design guidelines for reinforced brick floors appeared in 1904 in the *Steineisendecken-Runderlass* in Prussia (NN, 1904). These extremely sparse first regulations given by the Prussian government contained the central message that the Prussian *Eisenbeton-Bestimmungen* (NN 1904), which had appeared shortly before as first regulations for reinforced concrete structures, had to be applied “correspondingly” to reinforced brick floors. This laid the basis for the dimensioning of reinforced brick floors, in that the so–called *n-Verfahren*, a working load design method, was adopted from the reinforced concrete guidelines for the calculations. Only with the redrafting of the *DIN 1045: Beton- und Stahlbetonbau* (DIN 1045 (1972.01)) in 1972 the *n-Verfahren* was replaced with a ultimate load design method as a standard for dimensioning reinforced concrete and reinforced brick floor construction.

Initially, the entire available cross-section above the neutral axis, without the subtraction of the cells, was used to find evidence of compressive stress in the framework of the design of the re inforced brick floors. This concept was a requirement of the *Steineisendecken-Runderlass* until the appearance of the new *Steineisendecken-Bestimmungen* of 1932 (DAfEb 1932). Only then the reduction to the net cross-section (without the cells) was stipulated. In the period from 1904 to 1932 there were considerable variations between the theoretically used and the actual compression areas within the cross section. Sample calculations using the historical method showed for the majority of the reinforced brick floors produced without an additional structural concrete topping that values of 30% to 40% of the theoretically calculated compression areas were situated within the cells. The engineers of the time were aware of this and compensated for it with very high safety measures.

## TYPICAL FAULTS AND FAILURE MODES

In order to ascertain the actual load-bearing capacity of these wide-spread floor systems in phase two of the project, it was essential to systematically analyse and classify any specific production and construction faults. For this reason, in addition to the evaluation of the current condition of the historical reinforced brick floor constructions carried out through trial exposures and drill cores, within the framework of this research project, above all also the steps in the historical processes of producing the different types of reinforced brick floors were analysed in detail. Typical faults proved to be:

- voids where concrete had failed to be applied to the reinforcement (Fig. 11),
- voids within the longitudinal joints,
- butt joints not completely filled with mortar,
- construction joints between the laid clay bricks and the subsequently added compression layer,
- an increased weight of the floor itself as a result of mortar having entered the clay brick cells.

Based on the documented faults the most probable mechanisms of failure in the case of exceeding the load-bearing capacity can be identified for different types of reinforced brick floors. The “theoretically” founded results are confirmed in the results of a range of recent load-testing experiments carried out on historical reinforced brick floors up to breaking point. First of all - hardly any production faults could be found in the reinforced brick floors, in terms of the taking up of stress through the reinforcement. Historical reinforced brick floors thus very rarely fail in the tension zone. The typical failure mechanisms fall into three groups:

- Reinforced brick floors constructed before 1900 often show damaged bond strength between the mortar and the reinforcement, which can lead to a failure of the mortar as a result of the adhesive tensile stresses.
- For floors constructed around 1900 and later, one can increasingly expect a failure of the compression zone.
- Reinforced brick floors constructed after 1910, in the case of exceeding the load-bearing capacity, often show a failure of the clay bricks, the mortar or the concrete through compression or shear stress.

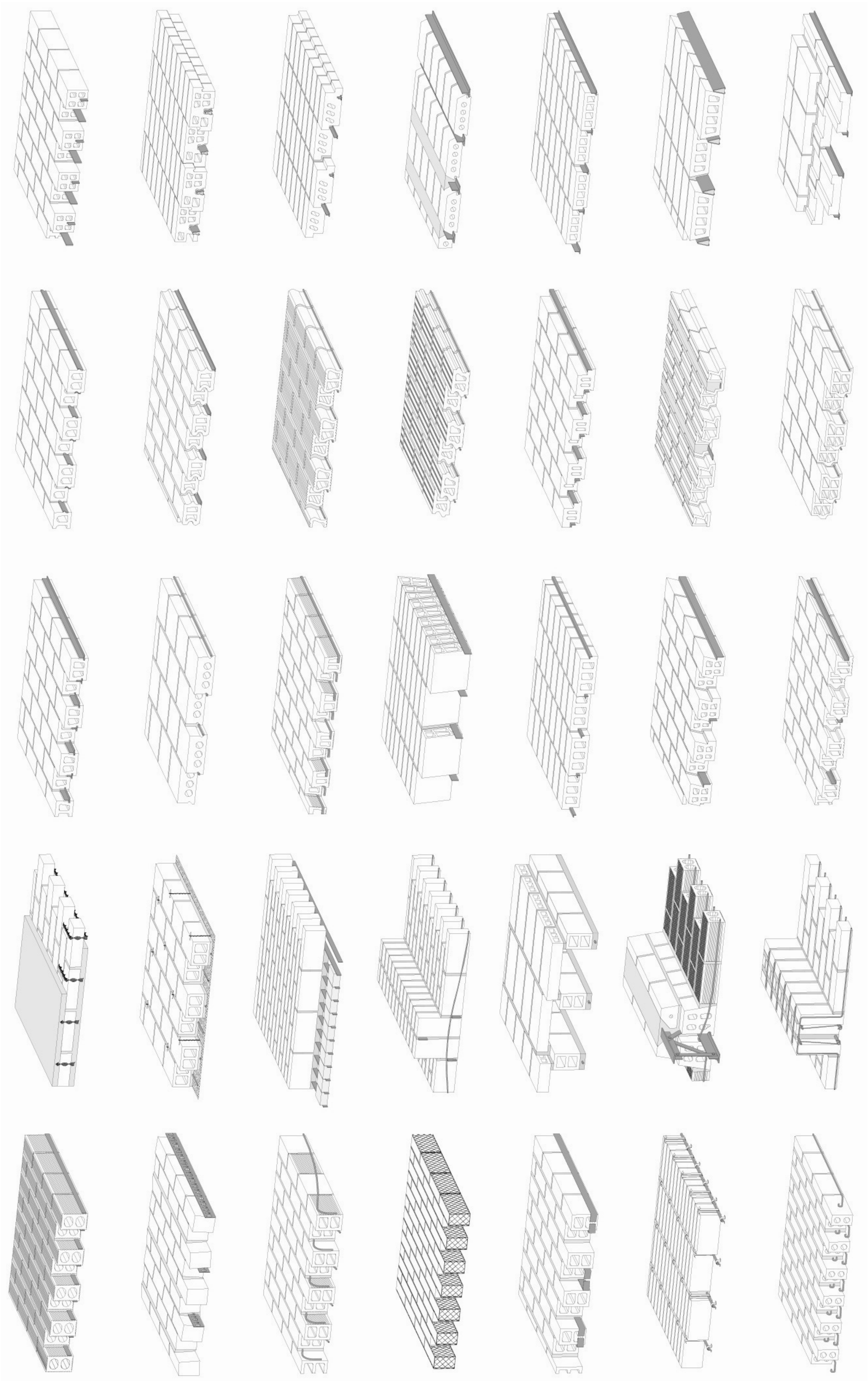


Figure 6: Systems of reinforced brick floors protected by patent in the German Empire up to 1925 – part a

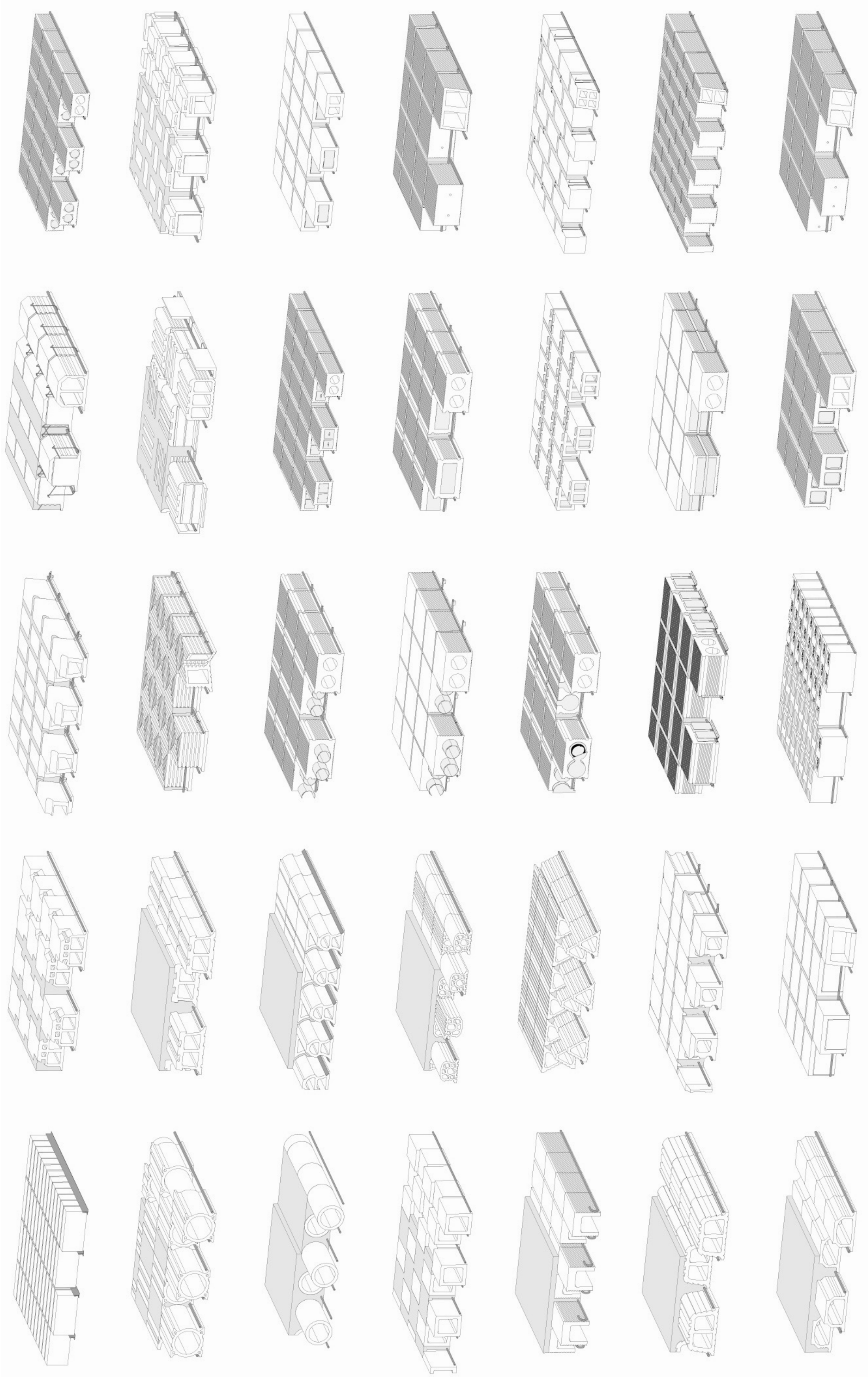


Figure 6: Systems of reinforced brick floors protected by patent in the German Empire up to 1925 - part b

**CHOOSING AN APPROPRIATE METHOD OF ANALYSIS**

Essentially, there are three methods to assess the load-bearing capacity of reinforced brick floors which are relevant to the nowadays engineer:

1. Assessment based on current codes of practice, rules and regulations for modern brick floors: Normally these do not do justice to the particular conditions of historical brick floors. Thus for example many historical mortars do not conform in the slightest to established German design codes (DIN 1045-100) just as the historical hollow bricks do not correspond to today's floor bricks and so on.
2. Assessment based on codes of practice, rules and regulations which were current when the floors were built: In this case, the assessment can be based on the original design parameters. However, historical methods of design only allow a limited analysis of the real load-bearing capacity of the structures.
3. Assessment based on load-bearing tests carried out in situ: As a complement to calculation-based assessments, loading tests can give reliable information about the true load bearing capacity of individual slab bays. This method has been used increasingly in the last few years and is even included in official recommendations in Germany. In comparison to calculation-based checks, however, it is expensive and only applicable in certain cases.

In conclusion none of the methods offers an applicable means of gaining accurate information on the load-bearing capacity of historical brick floors.

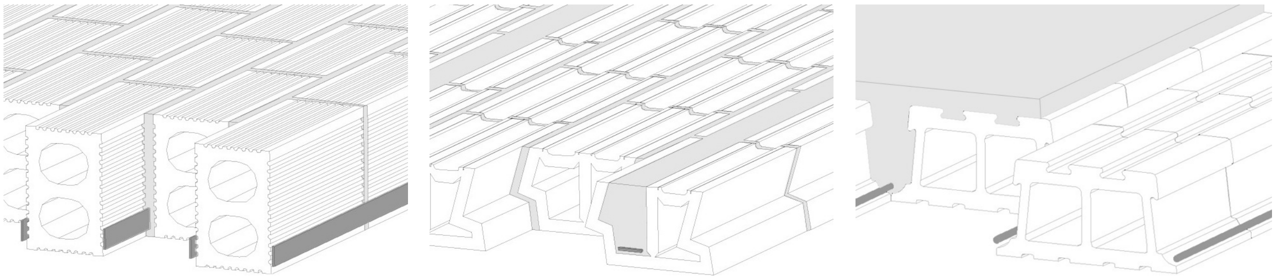


Figure 7 (left): Kleinesche Decke; Figure 8 (middle): Förster-Decke; Figure 9 (right): Reformhohlsteindecke

Based on the knowledge gained from the historical analysis the structural behaviour of reinforced brick floors could be examined more closely in the second phase of the research project in order to refine the calculation algorithms for a close-to-reality assessment and to detect possible reserves in load-bearing capacity. For this purpose five dimensioning methods were analysed initially, which reflect the development phases of the norms and design standards for reinforced concrete structures in Germany.

- n-method according to the regulations of 1904
- n-method according to the regulations of 1932
- the method according to the TGL 33405/01 of 1980, valid in former East-Germany (Fig.12)
- the method according to DIN 1045 of 1988
- the method according to the currently applied DIN 1045-1 of 2001.

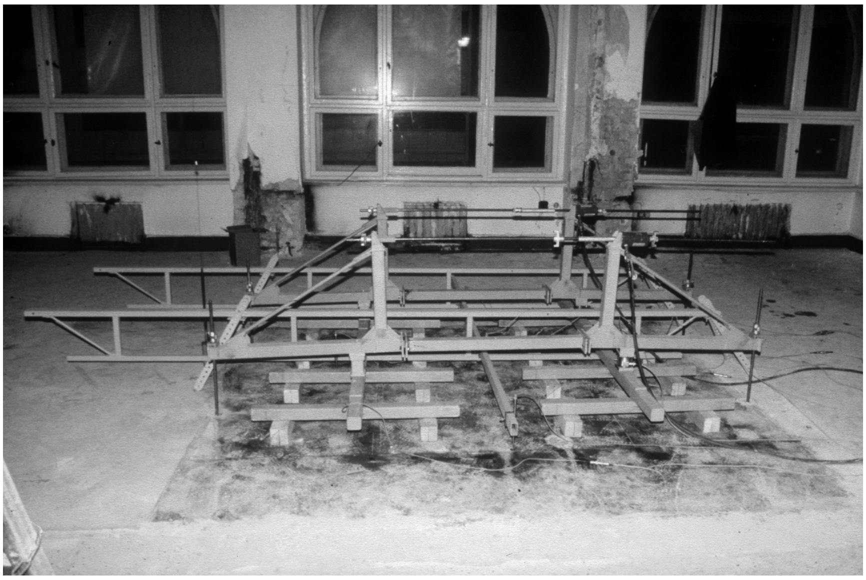
The aim was to determine the design method which promised to fulfill best the following four requirements:

- the conformation to the calculation conditions (e.g. the characteristic values of the material or the cross-sections of the clay bricks)
- the sufficient possibility for introducing and controlling additional design parameters (e.g. bearing fixations)
- the close-to-reality modelling of the real load-bearing capacity
- the simple application of the method in practice.

Of all five methods examined, the ultimate load design according to the TGL proved to be the most appropriate for the close-to-reality calculation of historical reinforced brick floors. The floor structures taken in consideration by the TGL are very similar to those of historical floors. In addition, the TGL encompasses a semi-probable safety concept, it can be carried out using a pocket calculator, and it allows for a high degree of utilizing the real load bearing capacity of the floor constructions, which is very close to the current DIN 1045-1 method (DIN 1045-1, 2001.07), (TGL 33 405/01, 1980). The historical design regulations for the reinforced brick floors often only allowed for a severely restricted degree of utilizing the load bearing capacity as a result of the mechanical model used. In addition, these relied on a global safety concept which makes it difficult to add or control new or still existing parameters. On the other hand more recent DIN standards are overly geared towards modern brick floor types and are only partially suitable for the calculation of historical constructions. (DIN 1045-100, 2005.02)

**POSSIBLE LOAD-BEARING CAPACITY RESERVES**

The TGL design method chosen subsequently formed the basis of the more detailed analysis, the aim of which was to clarify concretely whether, and if so how, existing load-bearing reserves could be considered. Four parameters were examined in particular.



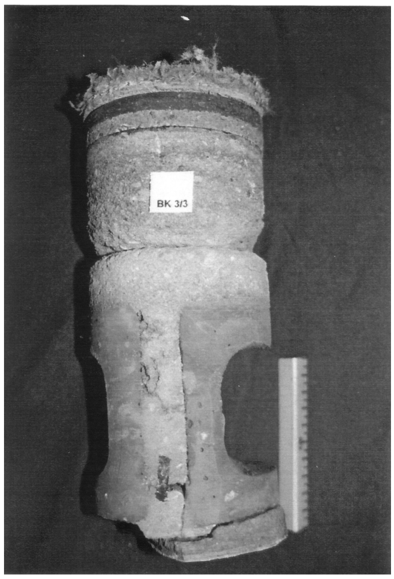



Figure 10 (left): Load-testing of a reinforced brick floor
Figure 11(right): Typical voids where concrete had failed to be applied to the reinforcement

1. Triaxial stress conditions of the mortar joints: The triaxial stress conditions of the mortar joint and therefore the various brick and mortar compression strengths could not be integrated into the calculation algorithm. In principle, it would have been possible to introduce the relevant parameters; however, comparative calculations showed that the consideration of a separate brick material was only sensible if its strength was at least double that of the strength of the mortar. In such cases, this could result in a theoretical increase in the load-bearing capacity of up to 6%, yet the given design parameters – sufficient anchoring of the longitudinal reinforcement, a minimum degree of reinforcement of 1%, no structural concrete topping, and clay bricks with a distinct compression boom - could not generally be guaranteed in the historical reinforced brick floors. Within the framework of the improved calculation algorithm, the minimum compression strength of the concrete, the joint mortar or the brick is taken as the determinant resistance.
2. Load-bearing reserves of vaulting effects: The evaluation of the load-test experiments revealed that in each floor examined, vaulting effects made a decisive contribution to the general load-bearing capacity. This observation was additionally supported by the fact that the bending failure of the reinforced brick floors examined almost always corresponded with a failure of the concrete compression zone. In the case of interior slab bays the surrounding bays can absorb the additional horizontal forces of the compression arch and transmit them to the stiffening walls. In these cases it is possible to take into consideration the increase of load-bearing capacity caused by vaulting effects in the improved calculation algorithm.
3. Degree of restraint of the bearings: Even the first regulations from the early twentieth century allowed the possibility of treating reinforced brick floors as well as reinforced concrete floors under certain circumstances as partially restrained in their bearings. Also in the improved calculation algorithm a restraint can be considered if the slab bearings fulfil the necessary parameters such as a continuous joint and sufficient bearing depth.
4. Variable partial safety factors: The safety coefficients of the TGL are very similar to that of the current DIN 1045-1, however, the TGL had introduced an additional coefficient specially for the design of reinforced brick floors. This reduced the design resistance of the concrete in designing reinforced brick floors by 40% (Wiese 2005). Closer analysis of this additional adaptation coefficient showed that it simply served to reduce the values resulting from the TGL method to the level of the values delivered by the historical n-method. The committee responsible for norm standards in the former G.D.R. at that time viewed this reduction as necessary as it did not have the resources required to carry out the necessary technical analysis that would have proven that the reinforced brick floors surveyed using the TGL method possessed the same load-bearing capacity as similar reinforced concrete floors. For that reason the reduction factor, introduced in the TGL, was removed for the improved calculation algorithm. This provides an average increase in calculated load-bearing capacity of 10%; in individual cases, increases in calculated load-bearing capacity of up to 40% are possible.

The improved calculation algorithm proved to reflect the real load bearing capacity of the reinforced brick floors very well. In order to check the calculation algorithm, its results were compared with results of recently realised load tests. The relevant documentations were made available by the Bundesanstalt für Materialforschung und -prüfung, Berlin (BAM), the Fachhochschule Potsdam/Baulabor Konstruktiver Ingenieurbau, the Bauhaus Universität Weimar/Abteilung Versuchswesen, and from the Technische Universität Berlin/Institut für Erhaltung und Modernisierung von Bauwerken. Using load tests these institutions had proved a sufficient load bearing capacity for a total of 4,5 kN/m² live load of 29 historical reinforced brick floors, where a calculation according to usual modern codes had failed previously. The recalculation of these floors using the different improved algorithms showed that 9 of the systems should have been proven for that live load using the original TGL code and further 7 floors using the more detailed calculation check. The significance of the parameters examined was proven by the final 7 reinforced brick floors, whose load bearing capacity could not have been verified by calculation without the consideration of vaulting effects and restraints of the bearings, as well as the removal of the original adaptation coefficient of the TGL for the concrete strength. (Fischer, Lorenz 2009)

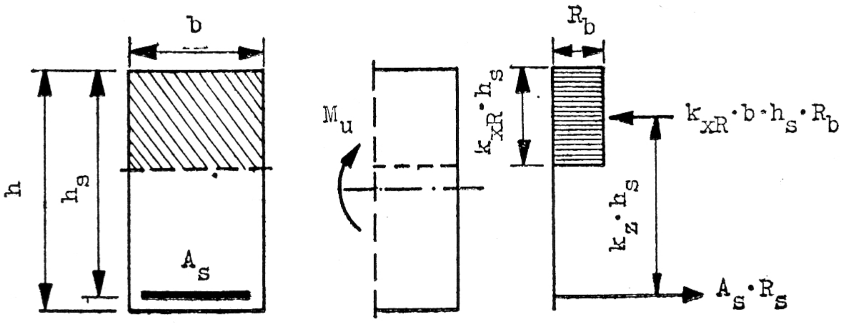



Figure 12: TGL design approach for reinforced concrete structures; (TGL 33 405/01, 1980)

## OUTLOOK: TOOLS FOR THE CLASSIFICATION AND THE STRUCTURAL ANALYSIS

With the typology and the catalogue developed in the first phase of the project, now detailed information is available on the reinforced brick floor systems present on the German construction market between 1892 and 1925 as a structured basis for planning tasks. An internet database (www.steineisendecken.de) simplifies the task of exact classification and provides the user with a modern tool to deal with these structures. In addition to this, the overviews created within the framework of this analysis of the faults caused during production and construction allow one to react to the characteristic structural properties when planning for each existing floor. These overviews give practical information as to which aspects of the construction of the historical reinforced brick floors are of particular importance on site. The database has been designed in such a way as to be able to support and promote the information exchange of planners in their dealings with historical reinforced brick floors. The improved calculation algorithm developed in the second phase which will be published in detail in another publication soon, gives the engineer dealing with a historical reinforced brick floor the ability to better consider its real load-bearing capacity without the need for expansive load-testing.
The described project at the BTU Cottbus was just as a first step in discovering the multifaceted history and typology of reinforced brick floors. New floor systems and types have been developed in Germany after 1925, but first of all rather different systems have been used beyond the German borderlines in Europe and the USA. Comparative analyses are likely to provide interesting results and help to understand and maintain in a better way these fascinating testimonials of modern construction history worldwide.

## REFERENCES

Photos and figures 1 to 11are taken and drawn by the authors.


DAfEb, 1932: Deutscher Ausschuss für Eisenbeton (ed.): *Steineisendecken-Bestimmungen. Bestimmungen für Ausführung von Steineisendecken*. pp. 47-54.

DIN 1045 (1972.01): *Beton- und Stahlbetonbau – Bemessung und Ausführung*.

DIN 1045 (1988.07): *Beton und Stahlbeton – Bemessung und Ausführung*.

DIN 1045-1 (2001.07): *Tragwerke aus Beton, Stahlbeton und Spannbeton*.

DIN 1045-100 (2005.02): *Ziegeldecken*.

Fischer, M., 2009: *Steineisendecken im Deutschen Reich 1892-1925*. Dissertation thesis at BTU Cottbus.

Fischer, M.; Lorenz, W., 2009: *Leitfaden zur Bewertung der Tragfähigkeit von Steineisendecken – verfeinerte Bemessungsalgorithmen, Planungs- und Arbeitswerkzeuge für die Praxis*. DFG – Arbeits- und Ergebnisbericht (unpublished).

NN, 1904: Eisenbeton-Bestimmungen. Bestimmungen für die Ausführung von Konstruktionen aus Eisenbeton bei Hochbauten. *Zentralblatt der Bauverwaltung* 24, pp. 253-257.

NN, 1904: Steineisendecken-Runderlass. Runderlass, betreffend die Grundsätze für die Anwendung der Bestimmungen für die Ausführung von Konstruktionen aus Eisenbeton bei Hochbauten. *Zentralblatt der Bauverwaltung* 24, pp. 258.

TGL 33 405/01, 1980: *Betonbau – Nachweis der Trag- und Nutzungsfähigkeit*.

Wiese, H., 2005: Vergleich des ETV Beton und DIN 1045-1. *Beton- und Stahlbetonbau* 100 (9), pp. 784-794.