'BAUPLATZSTATIK' – HOW STRUCTURAL THEORY ALTERED AVERAGE BUILDING PROCESSES AND HOW DAILY ROUTINE INFLUENCED STRUCTURAL ANALYSIS

Christoph Rauhut[1]

Keywords

Structural theory, structural analysis, construction site, role of engineers, reinforced concrete

Abstract

With the advent of structural theory in the nineteenth century, calculation and dimension processes began to be implemented in the design of various building elements. Structural theories and their models were used to explain the properties and performance of iron trusses, vaults and reinforced-concrete elements, amongst others. This development resulted in the creation of novel structures, a growing importance of the civil engineering discipline, an expansion of systematic material testing, etc., all of which are aspects of construction history that have been researched rather thoroughly.

However, almost completely neglected is the question of how this development changed the building processes on typical construction sites in the nineteenth century, such as those of housing, shops and schools. Moreover, the influence that these building practices have had on the structural analysis used at the time has only been scarcely discussed.

The first part of the paper discusses the implementation of structural calculations within the setting of a 1900's construction site: Were design and building processes being altered? Who designed the structures? Who was in charge of the calculations?

The second part analyzes the structural analysis used and shows how the calculations were altered for application on construction sites. The reasons for modification are discussed (such as constraints in the building process and the idea that certain aspects could be neglected in practice), as well as the significance of these modifications.

The main source of evidence for this line of argument is the analysis of the specific planning processes for a reinforced-concrete ceiling. The case is taken from the construction site of a municipal office building in Zurich during 1900, which can be seen as a representative site for typical building processes at the time. The overall aim of the paper is to enrich the history of structural theory and structural analysis through the perspective of 'ordinary' building activity.

[1] ETH Zurich, Institute of Historic Building Research and Conservation, HIT H 21.3, Wolfgang-Pauli-Strasse 27, 8093 Zurich, Switzerland, rauhutc@ethz.ch

INTRODUCTION

During the nineteenth century structural theory evolved to be regarded as its own discipline. This development was driven by a changing understanding of the role of mathematics and geometry within the field of building and a growing general reliance on science and its tools to describe and explain as well as to systematize and optimize (Hassler et al. Forthcoming). Consequently, structural theory and its various models to explain the properties and performances of constructions such as iron trusses, vaults or reinforced-concrete elements, amongst others, became ever more prevalent. This development resulted in the creation of novel structures, greater importance attributed to the discipline of civil engineering, an expansion of systematic material testing, etc., all of which are aspects of construction history that have been researched rather thoroughly, alike the history of the theory of structures itself (Kurrer 2002).

One lesser-discussed and lesser-taken account of this development is that the advent of structural theory also brought on the advent of structural analysis as a routine part for design, planning and construction. Ines Prokop has, for example, discussed this aspect in her work on iron constructions in Berlin at around 1900 (Prokop 2012), but it remains a research void in the wider perspective, owing to the fact that corresponding historical sources are rare and often not easily accessible (Kurrer 2011, 229). The aim of this paper is to help close this gap in the research, it proposes some methodical thoughts and exemplifies them with an example.

Two sides of one coin: Structural theory and structural analysis

The thesis of this paper is that the structural analysis differs, though directly linked, from structural theory. This derives not only from a systematic viewpoint, but also due to the direct link between structural analysis and the practice of construction.

The systematic difference arises from the condition that structural theory aims to develop models to extensively describe properties and performances. The process of modeling may involve confinements, which have been described as mapping (Abbildung), reduction (Verkürzung) and pragmatism (Pragmatismus) (Stachowiak 1973, 131-133), however models still aim to have a representative function and therefore remain fundamentally abstract. In contrast, structural analysis primarily aims to be a way to verify or predict certain properties and performances in a specific given case. Structural analysis builds on structural theory, but it is not the same – it is its application.

Moreover, structural analysis is also directly related to the practice of building. While the practice is in structural theory only one of many factors to consider, it is the key reference point in structural analysis. (This systematic difference was a main source for the famous Theorie-Praxis-Streit in the discipline of engineering (Heymann 2005, 58-82).) As a result, structural analysis cannot be conducted without considering the feasibility of execution or the fact that a practitioner with a certain degree of experience, credibility und authority in a specific cultural context is responsible for the calculations. It cannot be separated from the fact that material qualities may differ or that particular limitations may necessitate working within usual economic and technical conditions.

In the following, a special focus is placed on this quandary. However, study of distinguished engineering works is avoided, since this would ‘produce’ a too smooth and too successful outcome as a result. The paper rather proposes looking at examples of the overwhelming majority of contemporary buildings at the turn of the nineteenth century, such as the construction sites of housings, shops and schools. Despite the processes on the construction sites of these kinds of buildings having been barely discussed in regards to the influence of structural theory, they offer an example of the usual economic and technical conditions for building in that era. Thus, they illuminate the usual influences of the construction practice on structural analysis.

The case discussed in the following is the Stadthaus Fraumünsteramt construction site, an administrative building for the City of Zurich (Rauhut 2014; Stadthaus Fraumünsteramt. 1898–1901). This site was the site of a typical urban building at the end of the nineteenth century: the building, built between 1898 and 1901 under the aegis of Zurich's second Stadtbaumeister (Municipal Master Builder) Gustav Gull (1858–1942), was typical of the solid yet ambitious contemporary production and also a typical construction by academically educated architects and a professionalized public administration. Its construction site shows the contemporary variety of materials and construction types, alongside the plurality of the actors involved, while simultaneously exposing the restrictions bound by typical economic and technical conditions in play at the time. The site may therefore serve as an exemplar.

CHANGES IN THE 'DAILY ROUTINE' OF A CONSTRUCTION SITE

The emergence of structural theory was the basis for the rising of the modern form of discipline of civil engineering in the nineteenth century. In unition with the upcoming of modern building materials, it fundamentally changed the way bridges, towers or roof trusses were built. Moreover, it also changed the 'daily routine' of construction sites, even of the 'normal' buildings such as housing, shops or schools. Most notably, processes of planning undertaken by professionalized actors became a routine part.

The construction site of the Fraumünsteramt illustrates how those processes were integrated and what role they played at about 1900. In principle, traditional approaches determined the construction routine of a site such as the one of the Fraumünsteramt: The system of work was dominated by craftsmen with specialized tasks and responsibilities; many techniques of construction used were, despite the often industrialized production of the materials, derived with traditional approaches in mind; the architect was in charge of designing the building and the planning of its elements and their erection (sometimes supported by specialized staff).

The erection of building elements, which needed or involved structural analysis in their design and execution, for example reinforced concrete elements or iron roof trusses, did not change the systematic organization of a construction site. It rather meant an amplification of the different actors in the system of work: a development that was also linked to other new or improved materials with examples such as specialist craftsmen for Häusler roofing (Holzzementdächer) or fitters for the electricity.

In two respects, however, the erection of these kinds of building elements differed from the traditional modus operandi. The first was the way the work was assigned to the executing firm. Ever since the gradual introduction of the freedom of trade (Gewerbefreiheit), since about 1800, various modes of bidding processes became the usual way for assigning work in the building sector. The extensive number of contemporary handbooks on this matter may illustrate the high relevance one gave to theses processes (Nègre Forthcoming). The assignments usually included the execution of the work and the provision of the materials as a single duty (a change to the usual arrangement pre 1800), of which the quantification of the duty took place by using geometric units. In the case of institutional awarding authorities highly formalized procedures and forms for the bidding process were the standard.

However, even in the context of institutional builder-owners, such processes were usually not applied to assign a firm with the erection of a roof iron truss or a reinforced concrete ceiling.

Instead, direct orders were the standard. In the case of the respective structures for the Fraumünsteramt, single firms were invited to make an offer and this offer was then the basis for the assignment. A main reason for this modus was the rather limited number of competitors, or more precisely, of competitors that the architect (or accordingly the awarding authority) identified as capable of executing the work to the expected high standard. In the case of the supply of the iron trusses, for example, only one local firm was known for its high quality iron trusses (which they purchased in Germany, while the other larger local firm in the field purchased its iron trusses in France). Thus, the order for the delivery and erection of the entire iron truss construction was awarded to them. In the case of the reinforced concrete elements, the job was assigned to the only local patentee of Hennebique's patent.

The second change from the traditional modus operandi was the institutionalization of external design and planning processes. Previously, common practice was that the architect (or an equivalent responsible person) was in charge for almost all design and planning processes, certainly of those that were understood as explicit documents. However, the typical architect of the late nineteenth century was not educated in the design and planning process linked to the use of structural analysis. This was the domain of civil engineers. In the case of the construction of the Fraumünsteramt, the architect Gustav Gull, for example, defined where reinforced concrete for the ceiling should be used (choosing those ceilings with an above average span length), but he did not offer any further planning, however the civil engineer G. Brandenberger did this. Brandenberger was working for Froté & Westermann, the firm that had obtained the task of realizing the reinforced concrete structures. He designed and calculated for each different ceiling a number of options, varying the direction of load and the spacing between the supporting girders. He accounted for the preparation of all relevant documents of construction. He acted as a specialized technical consultant for one special part of the construction process, which was, at least for such small sites, systematically new in the late nineteenth century. Such a development can also be observed in other fields of 'scientifically' discussed constructions and systems, such as for heating installations.

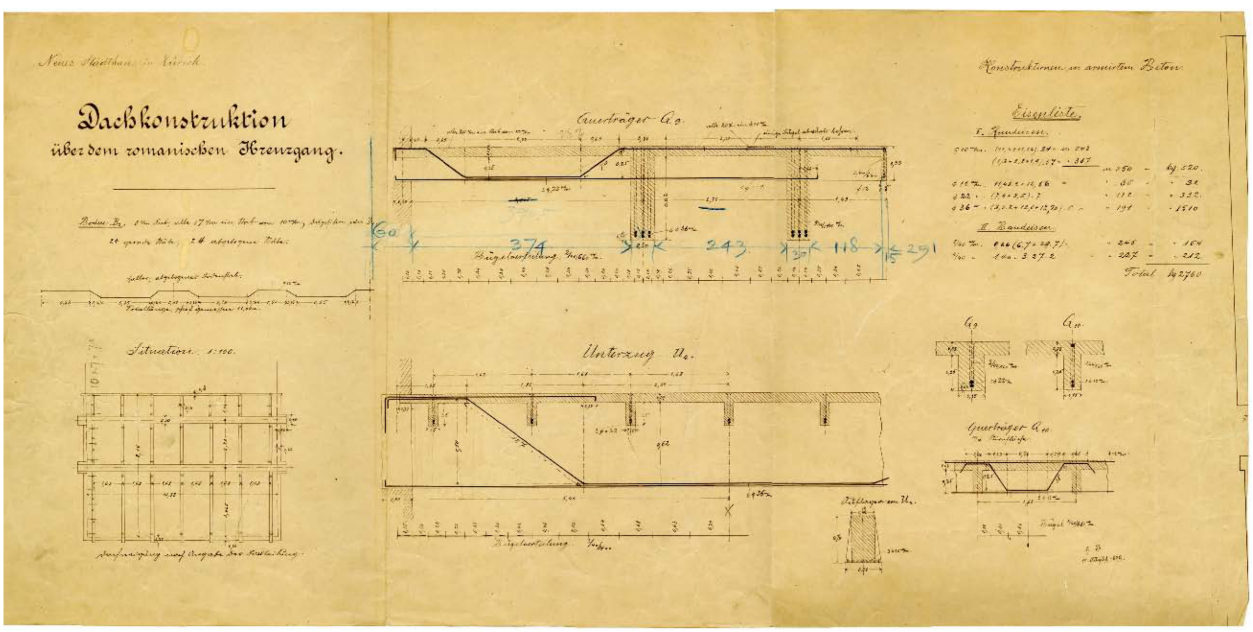

Figure 1: Drawing for a Reinforced Concrete Ceiling, G. Brandenberger, 71 x 35 cm, August 1899.

A significant detail, however, is that these external design and planning processes were not understood as a task assigned with a specific financial remuneration. Instead, geometric units were again quantizing prices. Thus the process of planning, hence also the structural analysis, was (still) conceived as directly associated with the task of execution.

STRUCTURAL ANALYSIS 'IN ACTION'

A direct link between the planning process, hence the structural analysis, and the task of execution can also be found in the structural analysis that was used. The structural analysis of the reinforced concrete ceiling of the Fraumünsteramt may serve to illustrate these interrelations.

The basic approach, alike the calculations, can principally be characterized as an iterative method. An assumed case was taken as a starting point, once proven to work the original case was optimized and proven again. To illustrate this point using the case of the Fraumünsteramt, the first part of the structural analysis was to determine the general form of the ceilings: In which direction was the main direction of load, which direction was secondary, what is the spacing between the supporting girders? In an initial step, the civil engineer Brandenberger proposed a first design. He also 'calculated' this design by proving its sufficient load bearing capacity (which was the common way to 'verify' reinforced concrete until about 1900). In a second step, he revised his designs in respect to constraints in the possible implementation (the overall height was not possible; a point of vertical load transfer was above a window lintel) and in respect to optimizing the structures, which was defined as a reduction of the concrete sections' dimensions. In summary, the execution of the design process, as well as accumulated, corresponding experience, played a great role in the design process and its subsequent structural analysis.

The calculations have to be considered in view of the contemporary discussion on structural theory of reinforced concrete (Kurrer 2002; Jürgens 2002). They generally followed the Hennebique approach, which is not surprising since Froté & Westermann was a patentee of Hennebique. The calculations were however 'updated' with some modifications by Brandenberger and with some newer approaches that were proposed by Swiss engineer and professor at the Zurich Polytechnic School Karl Wilhelm Ritter in an article in a Swiss engineering journal at the time (Ritter 1899). (Shortly after, the Hennebique approach was entirely suspended due to its inability to incorporate new insights.)

The basic approach was to prove a sufficient load bearing capacity using the iron's and concrete's compressive and tensile stress at midspan (with some further calculations made in regards to the shearing force within the beams). Some modifications and changes made in the subsequent process show how the practice, as well as corresponding experience, influenced the calculations.

One example is Brandenberger's change of the centroidal axis position. Hennebique's approach to set this line, which divides the beam's section into pressure and tensile zones, was a bisection. This approach was heavily criticized by Ritter, since it did not take the iron reinforcement into account. Therefore, in his article published in 1899, Ritter proposed a new approach with a repositioned centroidal axis, which Brandenberger implemented. (In fact, he had already used his reworked approach in the summer of 1898, well in advance of the publication. This conjuncture is probably due a personal acquaintance.) Hence, he 'intensified' the calculations' accuracy level in order to adjusted to a known problem.

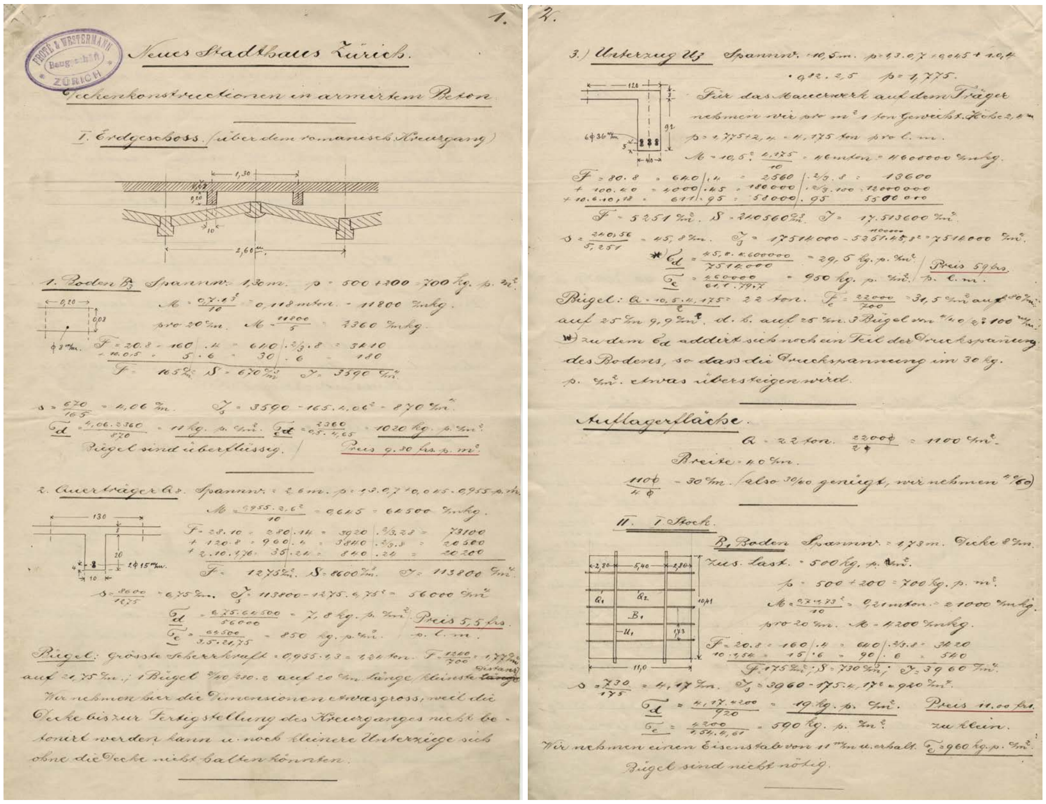

Figure 2: Structural Calculations for a Reinforced Concrete Ceiling, G. Brandenberger, July 1899.

Sometimes however, Brandenberger’s calculations tended in an different direction: the stirrup’s dimensioning is such a case: Hennebique had patented an approach referring to this in 1897 in which the key element was additional concrete corbels to reduce the overall number of stirrups. Brandenberger ignored this approach and substituted it with an easier method to calculate and to construct. He ‘refined’ the structural analysis to a more comprehensible representation and incorporated the feasibilities of realization.

Nevertheless, it is demonstrative that Brandenberger’s assumptions and corrections do not solely aim to generate more advantageous values: He uses the distance between axles, for example, for the calculation of a bending moment instead of the clear span length, which was the common and recommended approach at the time. In this case, he takes a larger bending moment into account in order to gain more precision in return.

An example of a certain caution, in regards to the results of the structural analysis, is the design of the points of load transfer between the beams and the wall. The calculation generally includes the assumption that the section of the concrete floor also absorbs some of the compressive stress. Ritter expresses doubt in his 1899 article if this assumption sufficiently holds true close to the points of load transfers. He suggests that the beams will probably have a higher compressive stress than calculated. Brandenberger reacts to this uncertainness by adding additional concrete corbels. Thus, he omits a yet unresolved part of structural theory, by taking the result of the subsequent structural analysis as a point of departure, but not as a value adaptive to construction.

In addition to these more general modifications to the calculations, Brandenberger also repeatedly modifies them at specific steps. The aim of these modifications is to make the calculation less complicated: He ignores stirrups, does not take stresses into account, and increases the concrete sections’ dimensions to accommodate more iron without changing the previous calculations. Often, short comments in the calculations serve as exculpation – for example: “Dazu addiert sich noch ein Teil der Spannung des Bodens […], so das hier die Spannung […] noch ein weniges überschreiten dürfte, also noch ganz gut zulässig." (Here some of the tension is transferred to the floor […], such that the tension […] will become a little excessive, but still remain tolerable.)

As a conclusion, one can say that Brandenberger modifies the structural calculations by taking personal experiences and perceptions as well as feasibility of realization into account. He modifies the structural calculations and leaves his own mark on them. He adjusts them to the economic and technical conditions at play. The hereby-established link between structural analysis and the practice itself is, in addition to the discussed systematic difference, a key distinguishing feature between structural theory and structural analysis. In a still to be written history of structural analysis it will certainly play an important role.

TOWARDS NORMS – AN OUTLOOK

Towards the end of the nineteenth century one can discern an increased interest in the introduction of norms and technical standards in the building sector. One driving force was the economic aim to standardize in order to improve production processes and enlarge markets (Vec 2006). The introduction of standardized profiles for iron trusses was such a case (Switzerland for example adapted the German standards introduced in 1880). A second important driving force was the fear of collapse of built structures. The case of the first Swiss norm for reinforced concrete is a well-known case: A commission to propose such a norm was already founded in 1898. However, this commission only really became active when a newly built house constructed with reinforced concrete (in accordance with the Hennebique patent) collapsed in 1901 (Geiser et al. 1901). As a result, a first (provisional) norm was published by the end of 1903. Public administrations played an especially important part in the establishment processes of such norms, demonstrating their involvement in making new construction techniques safe and, even more importantly, it offered them the possibility to supervise or, at least, establish such an idea. Obviously, such an argument was especially important in regards to constructions involving structural analyses, particularly since many different models were in use at around 1900.

The norms always included elements that pre-defined parts of the structural analysis. They defined what approach had to be used to prove a structure's performance, included presets on details of the approaches and set values for performance constants, which were still negotiated at the time. The first Swiss norm for reinforced concrete rules that calculate, for example, the bending moment as well as shearing force is principal and compulsory to any approach and limits the possibility to use an end-restraint in the calculation to reduce the bending moment (Schweizerischer Ingenieur- und Architekten-Verein 1904). Karl-Eugen Kurrer described this general shift as a change to a more recipe-like approach (Kurrer 2011, 214-220).

However, it is once again important to ask whether this development had the same influence on structural theory (and its representation in textbooks and literature) and on structural analysis as it was being used in practice. It certainly has been influential on all accounts, but one expects differences: In respect to the history of structural theory, it certainly caused a reduction of the pluralism of theories in respect to the many different detailed approaches; for the use of structural analysis, the pre-set performance constants seem to be more important. In regards to the use and application of norms in practice, it is furthermore crucial to verify whether they were used, if at all, in the described manner. The early norms often only applied to a selected set of construction tasks and the first norm-like Swiss rule on the calculation of iron roof trusses had, for example, only been applied to railway buildings. The title of the paper, 'Bauplatzstatik', was a term used by the Swiss engineer Arnold Moser (Moser 1915) to describe the fact that the structural analysis used on construction sites often did not equate to that pre-described by the norms. However, discussing how the further introduction of norms in the 20th century influenced the structural analysis used on the everyday construction site in more depth remains a yet unverified aspect of construction history.

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