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EXPERIMENTAL CULTURES IN EARLY CONCRETE CONSTRUCTION

Knut Stegmann¹

Keywords

Constitution, diffusion and transfer of knowledge; development of experimental cultures; history of the theory of concrete structures; relation between science and practice; building materials, their history and use (concrete)

Abstract

Concrete is sometimes attributed as a laboratory product. In fact, the countless experiments with concrete provided an important basis for the processes of creating and distributing knowledge in the field in the 19th and early 20th century. The experimental practice though was very heterogeneous: from single trials to systematic series of experiments. The protagonists were as heterogeneous as the experiments carried out. They ranged from often empirically working, early concrete pioneers, over engineers with university degrees to the materials testing laboratories established at many polytechnic schools in the 19th century.

The paper analyses the development of experimental cultures in German concrete construction in a broader focus and, in particular, looks at the actors involved, their backgrounds and strategies. The central thesis is that until the early 20th century concrete pioneers and their companies gave the main impetus for the experiments. Moreover, the impetus from the building practice was an important basis for the later scientification of the field. There are different phases in the development of experimental cultures: Firstly, concrete pioneers carried out experiments on their own. Hereby they laid the basis in terms of material sciences and explored new areas of application for concrete especially in the field of engineering construction. Secondly, concrete companies carried out spectacular public experiments and published the results extensively to persuade customers of their building technique. In short: experiments became important arguments in advertising. To evoke a more “neutral”, scientific appearance of the experiments the companies awarded contracts for testings to materials testing laboratories. However, the lack of theoretical superstructure compared to iron constructions became a competitive disadvantage that the concrete companies tried to fight with own research. The engineer Emil Mörsch, for example, developed as employee of Wayss & Freytag a “theory of reinforced concrete construction” which was published in 1902. Its enormous success mainly resulted from the verification by series of testings. With the appointment of engineers from leading concrete companies as professors at technical universities the development of theories of concrete construction in connection with systematic experiments became subject of the academic field.

The paper focuses on the actual development of experimental cultures in the 19th and early 20th century as well as on the means the results were spread by such as company publications or photos.

¹ LWL-Denkmalpflege, Landschafts- und Baukultur in Westfalen (State Conservation Office of Westphalia Lippe), Fuerstenbergstrasse 15, 48147 Muenster, Germany. Email: stegmann@architexts.net.

BACKGROUND

Strictly speaking, both concrete and one of its base materials, Portland cement, can be described as a “laboratory product” (Giedion 1928, 67). To be more specific, (chemical) analysis had already been an important basis for the development of hydraulic cements and the establishment of the first cement industry in Great Britain in the early 19th century (Stegmann 2014, 24–26). The English plants treated the manufacturing processes for cement as a trade secret. Therefore, their German successors had to base their replication of the processes also on systematic analysis. It is no coincidence that the first two major Portland cement plants in Germany, one near Szczecin (setup in 1852–55) and another near Bonn (1856–58), were founded by a chemist, Hermann Bleibtreu (1824–81). Many subsequent German start-up cement plants set up their own



Figure 1: Laboratory of the Dyckerhoff & Söhne cements works in Amöneburg, now part of Wiesbaden, undated photo (MAW).

laboratories (Fig. 1). These were intended to improve and ensure the quality of the cement which had to compete on the market with the established English cements. In their laboratories, the cement plants also developed the formulations for concrete, which they applied to their own simple concrete works like precast components. The laboratories also supported other early users of concrete which had to start out by working on the basics. In addition to concrete formulas for various fields of application, this included the learning about concrete treatment, properties and applicability.

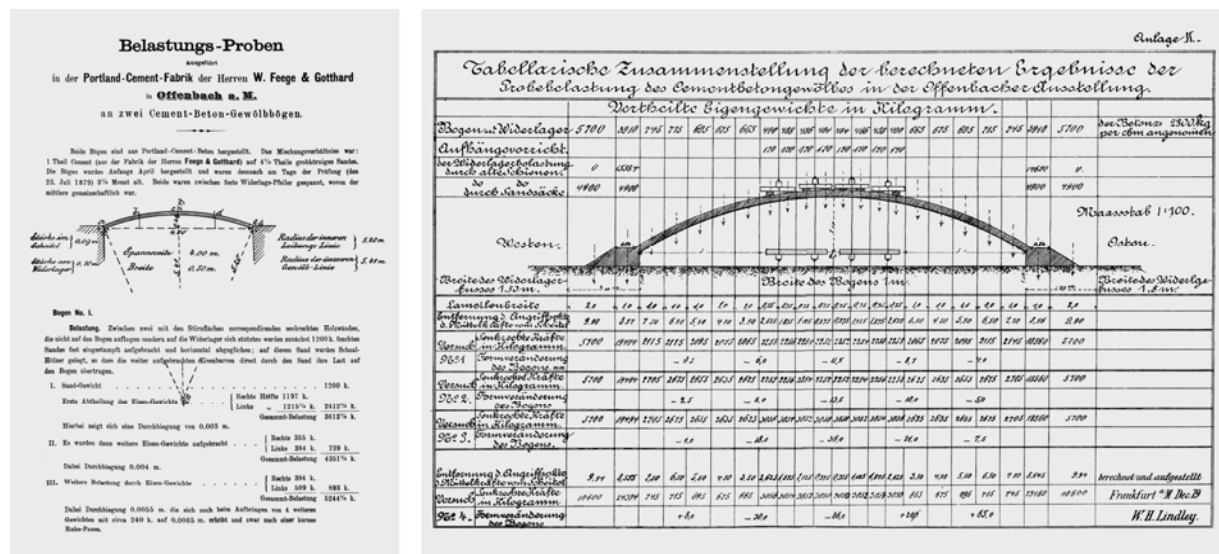
EXPERIMENTS AND EARLY MATERIALS TECHNOLOGY

Many of the early users of concrete were ordinary craftsmen who worked in concrete on a trial-and-error basis without systematic tests. As they usually worked only locally and did not publish, their practical knowledge could hardly be included in the interregional knowledge acquisition processes. Therefore, Berlin architect W. A. Becker, who had been experimenting with cements himself since the 1850s, published the book, *Practische Anleitung zur Anwendung der Cemente* (*Practical Guidelines for the Use of Cements*) in 1860–68 as an overview of contemporary knowledge on concrete (Becker 1868). The book is a compilation of practical insights from various sources. Above all it documents the lack of verified foundations of materials technology. The collected concrete formulations from workers in the field were not only somewhat contradictory but also anything but accurate. For example, the use of “fine and coarse sand” or of “gravel up to the size of a bean, pea or hazelnut” (Becker 1868, 72) is recommended. Due to the lack of a foundation, concrete was perceived, time and again, as an unreliable building material. This, in turn, considerably impeded its prevalence compared with established building materials.

In the meantime, however, a number of companies specializing in the application of concrete had been established – many of them as spin-offs of the cement industry (Stegmann 2014, 21–53). Some of these early companies responded to the lack of a foundation in materials technology by conducting systematic experiments with detailed experimental protocols. The French concrete pioneers were notable examples of this, particularly Francois Coignet (1814–88), whose

work became known through presentations at the World's Fairs 1862 and 1867. One of the most important German concrete pioneers was the Dyckerhoff & Widmann company, founded in 1865. In partial cooperation with the Dyckerhoff & Söhne cement works, Dyckerhoff & Widmann had already carried out series of breaking tests in the 1870s using concrete pipes with various types and quantities of aggregates. The aim was to determine optimal concrete compositions and pipe profiles (Stegmann 2014, 64–66). New aspects included not only the extensive written documentation of the test results, but also a more detailed description of the source materials, such as the definition of the aggregate sand on the basis of meshes with specified openings. This led to comparable results, thus ultimately enabling the systematic improvement of concrete.

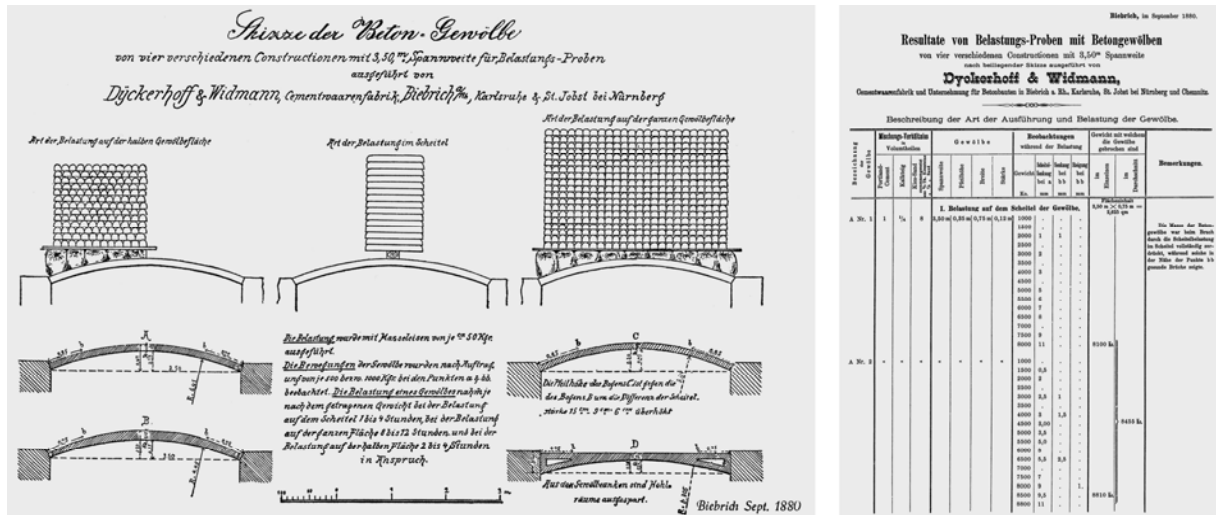
In addition to precast concrete components, the trials conducted by concrete companies soon focused on the development of load-bearing concrete structures. In particular, vaulting represented a highly promising new area of application. Previous testing, again primarily by French pioneers, had shown the potential of this field. What was new for the German approach was that companies were building extra experimental structures with considerable financial outlay. They then loaded these structures under precisely defined loading conditions, often to the breaking point. The carefully documented results were then frequently published. Among the earliest known experiments of this type is that of the W. Feege & Gotthard cement works. The company carried out loading tests on two experimental arches with 4 m span on the grounds of their factory in Offenbach am Main in July, 1879 (Fig. 2).



Figures 2–3: Printed records on the loading tests conducted by W. Feege & Gotthard in Offenbach 1879. Left: Title page of the documentation for loading tests conducted on two arches on company grounds. Right: Results of the loading test on the arch at the regional trade fair with signature of the head of the Frankfurt civil engineering department William Heerlein Lindley (1853–1917) at the bottom right (MAD III 11059).

The loading tests were followed by others in the same year on an arch, having a 16 m span und serving as a demonstration piece at the regional trade fair in Offenbach (Fig. 3). In order to give particular credibility to the tests, the company consulted a number of “neutral” professionals to act as observers; these are referenced in the protocols by name. However, it was difficult to obtain fundamental insights into concrete vaults from the few tests conducted in Offenbach. Nevertheless, the published results and conclusions from the experiments were intensely discussed in the renowned trade journal *Deutsche Bauzeitung* (Stegmann 2014, 68) and served as a catalyst for further experiments by other companies. Thus, only one year later, Dyckerhoff &

Widmann carried out a series of experiments with concrete arches at their branch in Biebrich. The experiments were primarily intended to demonstrate the influence of various arch cross-sections on load-bearing capacity. To this end, the company loaded five different types of arches under three different loading conditions, each to the breaking point (Fig. 4).



Figures 4–5: Documentation of test series by Dyckerhoff & Widmann in Biebrich 1880. Left: Sketch of the experimental setup. Right: Table of results (Author's archive/Deutsches Museum, Munich CD_65766).

The experiments provided key insights into the load-bearing behavior of concrete arches. The results were widely disseminated via a booklet (Fig. 5) and an article in the *Deutsche Bauzeitung* (Engesser 1881) by Friedrich Engesser (1848–1931). The tests were also a demonstration of the potential of such constructions, even if Engesser stressed that a theory of concrete arches could not be derived from these results.

DEMONSTRATION EXPERIMENTS

The early key experiments and test series with concrete were primarily initiated by construction companies with commercial interests and not universities or other academic institutions. In this respect, it is clear that there was not just an academic interest underlying the experiments. Rather, it was very much an issue of reducing the distrust of potential customers and the building authorities in relation to the new building material concrete. Therefore, many experiments were obviously designed to produce spectacular images which the companies then recorded photographically.

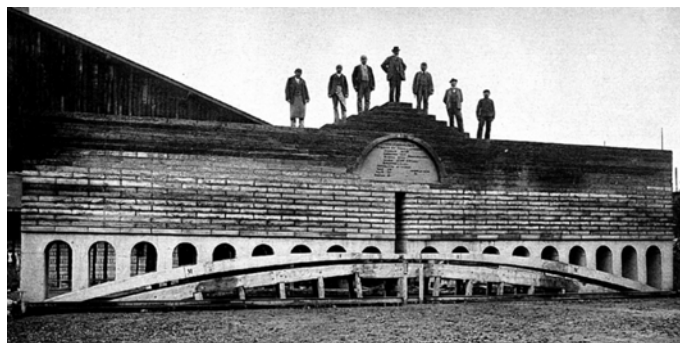


Figure 6: Experimental arch, Stuttgarter Cementfabrik Ehingen 1896 (Stuttgarter Immobilien- und Bau-Geschäft 1899).

The motifs were similar: Time after time, the photos published in trade journals and company publications showed towering loads, that sometimes included people. These photos were intended to illustrate the enormous load-bearing capacity and reliability of concrete structures (Fig. 6). Very little knowledge was gained from many of these demonstration experiments – not least as they were usually not comparable. Nevertheless, the reinforced



Figure 7: Test load on the bridge by Rudolf Wolle company at the Dresden City Exhibition 1903 (Bastine 1903, plate XVIII).

concrete companies particularly availed themselves of such successful demonstration tests as a promotional tool. Thus, about one-quarter of the famous “Monier Brochure” from 1887 is dedicated to describing such tests in Berlin, Cologne, Vienna and Wrocław (Wayss 1887). The tests are described in detail with drawings of the experimental setup and each certified by neutral experts. Obviously, however, the regionally scattered experiments were not systematically targeting at the greatest possible gain in knowledge. Rather, the German Monier licensees demonstrated the performance of reinforced concrete to

astonished audiences at their respective headquarters. The publication of the tests in the Monier Brochure was aimed at the nationwide, long-term dissemination of the results. The companies also gladly conducted loading tests on spectacular exhibition structures which they had erected on the grounds of the then popular trade exhibitions. The advantage of such exhibition structures was that they became known to a large audience (Stegmann 2012). One example of this is the exhibition pavilion built by the Leipzig based Rudolf Wolle company at the Dresden City Exhibition in 1903. The bridge in front of the pavilion was subjected to a photographically documented loading test (Fig. 7). This was, yet again, primarily a demonstration test. After the exhibition, however, a less representative loading test was carried out to the breaking point by the mechanical-technical laboratory of the Dresden University of Technology (Hanf 1905).

PROFESSIONALIZING EXPERIMENTS

Experiments performed by concrete companies were regarded with skepticism by independent experts and building authorities for several reasons: First of all, considering their commercial interest, the implementation and documentation of company experiments was hardly regarded as independent, even though they repeatedly called in neutral testimonies. Second, the many individual experiments were lacking in comparability, primarily because of the lack of standardization of the experimental conditions. Even for experts, it was therefore hardly possible to compare solely the static properties of the various systems of reinforced and non-reinforced concrete structures. Nor was a comparison with structures of traditional building materials possible. Finally, the experiments did not create a sufficient basis for theory development in the field of concrete and reinforced concrete structures. In response to this problem, and with support from government funding, concrete pioneers initiated extensive testing programs, carried out by organizations independent from the individual companies. In 1891–92, the Austrian Society of Engineers and Architects, on the initiative of the concrete pioneer Victor Brausewetter (1845–1926), first carried out comparative loading tests on arches with span widths of 10 m and 23 m in compressed concrete, Monier construction, brick and quarry stone masonry and iron construction (Fig. 8). Tests were also conducted on vaulted ceilings with span widths of up to 4.5 m in concrete and other building materials (Österreichischer Ingenieur- und Architekten-Verein 1895). For various reasons, the test results were not fully representative or comparable. So, the results

were falsified in some cases, e. g., by problems with the abutments, and the number of tests carried out was generally insufficient. The fundamental approaches of the Austrian tests, however, were important for the subsequent development of experiments in the field – in particular the company-independent conduct of testing and the effort to standardize experimental conditions.

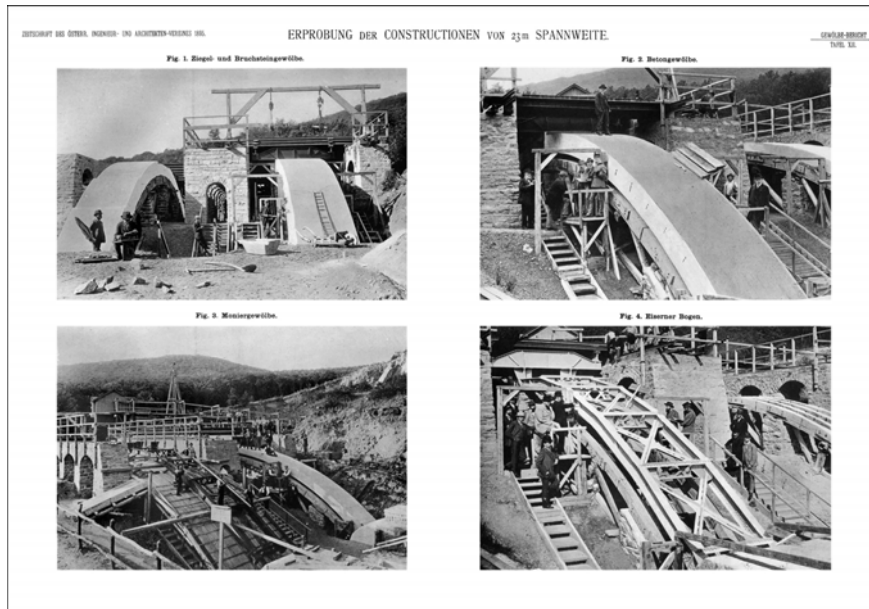


Figure 8: Tests on experimental arches in brick, quarry stone, concrete, Monier construction and iron as part of the Austrian vault experiments 1891/92 (Österreichischer Ingenieur- und Architekten-Verein 1895, plate XII).

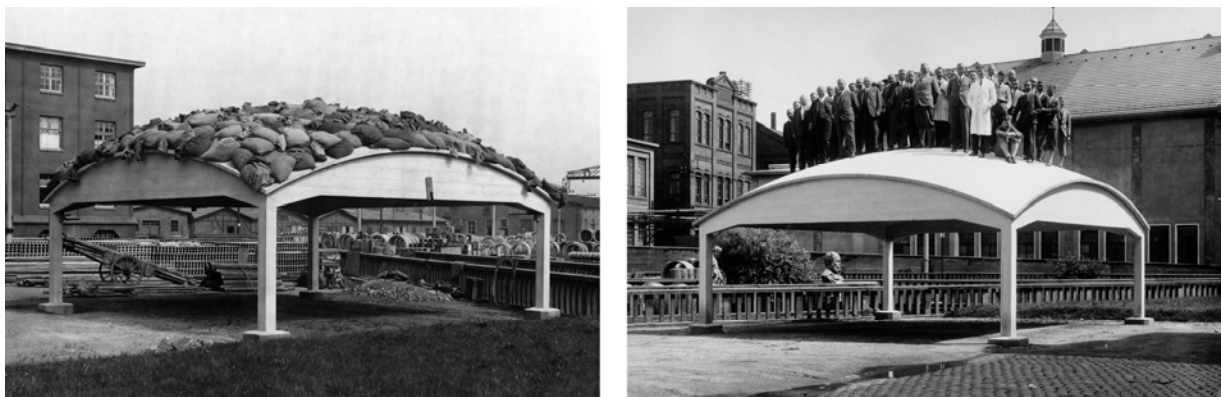
Subsequent to that, the German Concrete Association (*Deutscher Beton-Verein*), founded in 1898, introduced several major experimental programs in the German Reich and pushed for the systematization of the testing systems. Eugen Dyckerhoff (1844–1924), president of the Association since 1899, saw the results of such experiments as a particularly good selling point for concrete structures which were still eyed with suspicion in many places (Stegmann 2011, 415/416). The Concrete Association outsourced the experiments to the materials testing laboratories of the technical universities. By this means the protagonists demonstrated the neutrality and scientific integrity of the studies. This professionalization of experimental research was also retroactive in the concrete industry: A body of literature focusing on the entire field of scientifically correct testing procedures and topics such as the appropriate set-up of company laboratories came into being (e. g. *Chemisches Laboratorium für Tonindustrie*, Berlin 1908). In addition, with the help of the materials testing laboratories, devices such as a tensile strength testing machine to standardize concrete strength tests and a pipe testing machine were developed (Stegmann 2014, 158–159, 163–164). In its public relations materials, the concrete industry highlighted its cooperation with the materials testing laboratories as a kind of quality seal. For large exhibitions such as the 1902 Dusseldorf Trade Fair, cement and concrete testing machines, as well as the presentations of materials testing laboratories, formed an integral part of the concrete industry’s exhibitions.

Indeed, the test series of the materials testing laboratories did not only serve for promotional purposes. They also supported the implementation of load-bearing concrete structures as they created the basis for new calculation procedures. This is particularly evident in reinforced concrete structures, for which there was a “multiplicity of theories” (Kurrer 2002, 357) at the beginning of the 20th century. Virtually every company had developed its own, often incomprehensible, calculations for reinforced concrete structures. However, it was difficult for companies to

gain the trust of authorities and planners with this immense diversification, particularly as structural damage continually exposed the deficiencies in the “theories”. It was only by using the results from the materials testing laboratories that Emil Mörsch (1872–1950) ultimately succeeded in compiling a body of valid, that is to say, empirically based, methods of calculation from the multitude of theories. He published this body, with references to the respective experiments, in 1902 as book entitled, *Der Betoneisenbau, seine Anwendung und Theorie* (Wayss & Freytag 1902; English edition: *Concrete-steel construction*). The book appeared in numerous subsequent editions and became a standard work. Mörsch developed it not as an academic, but as an employee and at the expense of the company Wayss & Freytag. This illustrates the important role that the concrete industry played, for commercial reasons, for the development of an empirically verified theory for concrete structures. Demonstration experiments played no role in this scientifically anchored project. Accordingly, the experiments needed for the book were conducted purely as a service; Mörsch commissioned the Stuttgart Materials Testing Institute to carry them out; the experiments were not publicly acknowledged, but rather took place in a closed laboratory (some of the test documentation can be found in the Archive of the University of Stuttgart, stock 33). As a result, Mörsch received experimental protocols in the form of data streams, and for some experiments, unrepresentative documentary photographs of the tested specimen.

CONCLUSION

In addition to the frequently unsystematic experiments of the concrete pioneers and companies, particularly at the end of the 20th century, laboratory tests conducted by the materials testing laboratories of technical universities became increasingly important in concrete construction. The laboratories worked as service providers, using scientific methods with standardized testing conditions. These laboratory tests were, if for no other reason, because of their comparability and the scientific authority of the protagonists crucial to the formulation and validation of a theory of reinforced concrete construction. Despite the scientification of the field, up to the early 20th century, the concrete industry remained the driving force for experiments with concrete. Commercial interests were responsible for this commitment: The companies presented the experiments as evidence for the performance and reliability of concrete structures. It was only later that chairs at the universities initiated experiments driven more by a theoretical, epistemological interest.



Figures 9–10: Test shell on the premises of Dyckerhoff & Widmann in Biebrich, 1931. Left: Loading test with sandbags. Right: Employees on the shell as a representative demonstration (Dischinger papers, Fachgebiet Entwerfen und Konstruieren – Massivbau, Technische Universität Berlin/Stiller 1987, 85).

In parallel with the scientification and professionalization of the experiments, however, the concrete industry continued to conduct demonstrations which provided spectacular images for

advertising. One example is the loading test performed on a concrete shell in Wiesbaden in 1931, with numerous employees from Dyckerhoff & Widmann. The repeatedly published photo became a symbol of the performance and reliability of the new shell structures (Fig. 9/10).

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