The Fleischbrücke in Nuremberg: A stone arch bridge as an object for researching the History of Building Technology

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This paper describes the aims and methodology of the Fleischbrücke research project currently in progress at Potsdam University of Applied Sciences and provides selected insights into the construction history—in particular the competition process and the quality of the design drawings. The variant studies of the foremen—often contained in one and the same drawing—sharpened their insight into the force path, which lead to a robust, albeit from a modern viewpoint over-designed structure. However, due to its structural reserves it was able to cope with the changing demands from horse-drawn carts to heavy lorries, yet is nevertheless affected by the destructive force of water entering from the bridge surface and also horizontally. Refurbishment of the Fleischbrücke in accordance with guidelines for historic monuments is therefore urgently required.

INTRODUCTION

The Fleischbrücke is generally known as one of the most significant historic bridges of the early modern age. It was constructed from sandstone between 1596 and 1598 as a flat single-arch bridge under the supervision of «Ratsbaumeister» (council master builder) Wolf-Jacob Stromer (1561–1614) with a clear span of around 27 m and a width of 15.3 m. Up to 1700, the Fleischbrücke (Fig. 1) was the only bridge within today’s German territory with a single arch exceeding a clear span of 18 m.

Master mason Jacob Wolff the Older (c. 1546–1612) and master carpenter and builder Peter Carl (1541–1617) also made significant contributions to the design and construction. The Fleischbrücke is in the same league as the Ponte Santa Trinity, the Ponte Vecchio in Florence and the Ponte di Rialto in Venice. Compared with the Rialto bridge, the Fleischbrücke has an even flatter arch, advancing modern engineering skill even further. The Stari Most bridge in Mostar had a similar span, but with near semi-circular geometry similar to Roman bridges. The Ponte degli Alidosi dating from around 1500 has semi-circular geometry and a huge span of 42 m. The oldest preserved stone arch bridge, built 595—605 in China, has a similar span, but a flat arch: The Zhaozhou bridge in Hebei province is classified as a World Heritage Site (Table 1).

STATE OF THE STRUCTURE

The Fleischbrücke has survived centuries largely undamaged. Whilst the air raids of January 1945 destroyed approximately 90% of Nuremberg’s old town, the Fleischbrücke only suffered damage to parts of the parapet and the bay (Fig. 2).

The load-bearing structure still exists in its original substance. Interventions did, however, occur. In 1928, for example, water pipes were installed in the indented bridge section. After the war, parts of the southern abutment including the slanting piles were demolished during the construction of a flood relief tunnel. The
space between the flood relief tunnel and the abutment was back-filled with concrete. The refurbishment of the visible surfaces in the 1970s has to be seen as a problematic intervention. The eastern elevation consists almost entirely of replacement stone. The Fleischbrücke has been under a preservation order since 1974, but had already been regarded as a monument before then. Nevertheless, several interventions occurred without appropriate documentation.

In February 1999, icicles were discovered inside the arch, which led to the conclusion that water had found its way through the bridge structure. As a result, the «Landesgewerbeanstalt» carried out numerous investigations and produced a first report (Stolarski 2001), which provided initial data and statements about material parameters. The basic tenor of the report leads to a recommendation for urgent refurbishment, including structural repair and measures commensurate with the preservation of historic monuments, particularly complete sealing of the decking and of the underground abutment components. The lower authority for the protection of

### Table 1. Rise-span ratios. Data from different sources vary, see also http://www.structurae.de

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Location</th>
<th>Span l of the largest arch [m]</th>
<th>Rise h [m]</th>
<th>Rise ratio h/l over</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zhaozhou Brücke (An Ji, Anji)</td>
<td>Provinz Hebei</td>
<td>37.02</td>
<td>7.23</td>
<td>5.12</td>
</tr>
<tr>
<td>Ponte Vecchio</td>
<td>Florenz</td>
<td>30</td>
<td>4.4</td>
<td>6.82</td>
</tr>
<tr>
<td>Ponte degli Alidosi</td>
<td>Castel del Rio</td>
<td>42.17</td>
<td>19</td>
<td>2.22</td>
</tr>
<tr>
<td>Stari Most</td>
<td>Mostar</td>
<td>28.69</td>
<td>12.02</td>
<td>2.39</td>
</tr>
<tr>
<td>Ponte Santa Trinita</td>
<td>Florenz</td>
<td>32</td>
<td>4.57</td>
<td>7.00</td>
</tr>
<tr>
<td>Ponte Rialto</td>
<td>Venedig</td>
<td>28.8</td>
<td>6.4</td>
<td>4.50</td>
</tr>
<tr>
<td>Fleischbrücke</td>
<td>Nürnberg</td>
<td>27</td>
<td>4.2</td>
<td>6.43</td>
</tr>
</tbody>
</table>
The Fleischbrücke in Nuremberg

Figure 2
Destruction in 1945, the Fleischbrücke from the south-west.
StadtAN: FiF3

historic monuments and the Bavarian state department for the preservation of historic monuments have been involved.

THE RESEARCH PROJECT

Preliminary remarks

Why is there no monographic treatise about this bridge, neither about its structural design, nor about its architectural design and effect? After all, following its completion historians and chroniclers beyond the European region praised it as a grand structure. The decoration is sparse. A cornice and a type of bay in the centre of the bridge with a stone patrician coat of arms, four stone rosettes on each side and the «Ochsenportal» gate connecting the bridge with the «Fleischhaus» provide some structure. The bridge itself integrates unspectacularly into the townscape. It is austere and simple without much decoration, following the council specification for town houses (Mulzer et al. 1954, 50–51).

An example for the lack of public recognition is a city guidebook for tourists covering the historic mile in Nuremberg, which is currently available on the internet. Visitors are guided to 35 stations. Each station has a page describing the respective historic «jewel» (usually rebuilt). The last station is the «Fleischhaus» at the Fleischbrücke. Whilst scarcely anything remains of the original substance of the former «Fleischhaus», some historical details are nevertheless reported. In contrast, the bridge is not mentioned at all.

Nevertheless, the Fleischbrücke has been described in a variety of publications, not least by Prof. Dr. Wolfgang von Stromer (1922–1999), who stressed the significance of the bridge as an outstanding piece of engineering of the late 16th century. He saw his forefather, «Ratsbaumeister» Wolf-Jacob Stromer, as a «hitherto unrecognised great architect of European standing» (Stromer 1997, 179). Approximately 100 design drawings are in existence, scattered across different city institutions. Whilst they should themselves be seen as documents of historic significance, up to now they had not been systematically evaluated and recorded.

Aim and methodology

Within the research project «The Fleischbrücke in Nuremberg», two somewhat contrary theses were developed. The aim of the project is to demonstrate the functional relationship between them.

One thesis is a historic one:

— Over the centuries, the estimation and appreciation of the bridge has developed in such a way that for engineers it has become a model for the whole European region, but it has not gained the status of an art-historically significant structure such as the Rialto bridge.

The second thesis is a structural one:

— Notwithstanding the lack of structural-constructional calculations, the evaluation of the results from the building survey and the construction history show that the bridge not only met the direct requirements of its time, but could also cope with increasing utilisation requirements.

The examination has structural engineering/historic character, but work on the theses also requires techniques usually employed by historians such as source-critical approaches or by preservers of historic monuments such as creating an inventory.

The examination of the two theses initially leads to
the construction history, with necessary reference to the original, historic sources. The structure itself on the one hand provides information about facts that could not be gleaned from historic sources, such as the material properties, and on the other hand about current damage. The combination of the historic data with the material parameters provided by the Landsgewerbeanstalt Nuremberg (LGA) leads to the creation of structural models and to structural-constructive analysis. This aims to compare structural calculations from today’s viewpoint with the historic techniques for determining the load carrying capacity. For the evaluation, both knowledge on the subject of «arched bridges» published in treatises preceding the construction of the Fleischbrücke and comparisons with any predecessor or successor structures were used. This leads to an evaluation from today’s perspective and in the context of the time of construction (Fig. 3).

Bibliography and catalogues

The research project also includes a chronological bibliography of relevant publications, transcription of «Ratsverlässe» (council orders) and design drawings, lists of all the drawings found in different archives and institutions, and a comprehensive, separate catalogue part with photographs, maps, design drawings, engravings etc.

Digital archive

In future, the design drawings will be accessible within a digital archive in database form with retrieval management. This digital Fleischbrücke archive serves as a pilot project for the management of documents about historic monuments run by the state of Brandenburg at the Potsdam University of Applied Sciences, since it integrates the documents «virtually» in a single place, i.e. it separates the technical information from the historic carrier. This enables fast, comparative access.

SOURCES

Unprinted sources — the archive situation in Nuremberg

The Fleischbrücke was constructed during the era of the «free cities» under the jurisdiction of the free city building authority. Through the annexation of the free city in 1806, the city records and a large number of other documents came into the possession of the kingdom of Bavaria. The royal Bavarian archive was created, from which ultimately today’s «Staatsarchiv» Nuremberg (StaatsAN) emerged. After the reinstatement of self-government in 1818, the state returned part of the archive material, including the files of the free city building authority, to the city of Nuremberg. These items formed the basis for the «Stadtarchiv» Nuremberg (StadtAN), established in 1872.

During the 18th and 19th century, various documents were deliberately weeded out. Via second-hand markets, some of them ended up in private collections and from there in city museums or the German National Museum (GNM).
Parts of the archive of the family of «Ratsbaumeister» Wolf Jakob Stromer were located at castle Grünsberg, including two large-format «Baumeisterbücher» (master builder books — BMB I and II).\footnote{After Prof. Stromer’s death, they were donated to the Staatsarchiv.}

Documents about the Fleischbrücke created since 1879 are held by the city of Nuremberg in today’s civil engineering department.

There is no longer a complete official record about the Fleischbrücke, and it is no longer possible to determine what it may have contained. Along many other free city building authority documents, a repertory was also destroyed in the 2nd World War that provided information about the items held in the city archive. This necessitates a comprehensive search for individual inventories and other sources (e.g. «Ratsverlässe» (council orders) concerning the construction of the Fleischbrücke). In his «Baumeisterbuch» I, the «Ratsbaumeister» had indeed intended to gather drawings that would highlight significant stages of the construction process, such as the building site facilities, different falseworks and pile foundations. Stromer (1984) regards these volumes as town planning text books. However, neither the «Baumeisterbuch» nor the foremen attempted to present the Fleischbrücke retrospectively in a similar way to Perronet’s description of the bridge at Neuilly: this comprised a complete documentation of the structure completed in 1782 including design drawings, material data, the construction process over the years, and more (Perronet [1788] 1987, 25–120). They left a clear field for historians. The master builders of the Fleischbrücke were not yet concerned about the endeavours expressed by Eitelwein in 1819 in his foreword to the German translation of Perronet’s work, namely how important it is for other master builders that those «who have build a significant structure should not content themselves with completing the building successfully, but should also make known any difficulties encountered during the design, construction and execution» (Perronet 1820, a2). The historians showed little interest in structural engineering questions. For them, it was more important which coats of arms adorned the bridge and which inscriptions were shown on the commemorative coins that were placed with the foundation stone.

Publications

In the preparation of a bibliography about the Fleischbrücke, the passing-on of wrong information was also pursued, for example incorrect spans\footnote{or the alleged extreme settlement after removal of the falseworks that was quoted repeatedly.} or the model character of the Rialto bridge reported in several sources (e.g. Mislin 1997, 289).

Building survey

Apart from the historic sources, the structure itself provides information. For example, the drawings do not show unambiguously whether the arch stones or the joints are wedge-shaped, because there is no drawing showing a section of the arch stones. Proof of the slight wedge-shape was found at the western elevation of the structure in stones that can deemed to be original due to their weathering.

The joint width or the stone bond in longitudinal direction were established during the survey of the underside of the bridge carried out jointly with the LGA (Fig. 4), which also included changes and damage to the structure and forms an essential basis for the refurbishment.

Construction history

The Fleischbrücke had special significance, since seven European long-distance trade routes met in Nuremberg, with the Fleischbrücke at their intersection. It carried the heaviest urban and transit traffic (Stromer 1988, 162). After the wooden predecessors of the Fleischbrücke had been destroyed
by fire or floods, a two-arch stone bridge was constructed in 1487.

In 1595, floods damaged or destroyed all of Nuremberg's bridges. Damage to the Fleischbrücke was such that it was decided to demolish and rebuild it. The council invited bids for a competition, in which more than 20 masters that are known by name took part, 16 of which were from Nuremberg (Pechstein 1975, 74).

Written proof of the technology transfer in terms of bridge construction can be found in the above-mentioned «Ratsbaumeisterbuch I» in form of a letter in Italian from the Florentine architect Pietro Cecini dated 30 May 1597 (Fig. 5), which commences as follows: «One will be able to build the bridge for the city of Nuremberg with a single arch with a span of 90 to 100 cubits . . . ». He also mentions the Ponte Trinita, a profile drawing and a plan view of which he says to have sent. Yet by the time the letter was written, the plans for the design competition had already been submitted, and without actually announcing a winner Peter Carl and Jacob Wolff were asked to carry out the work under the supervision of «Ratsbaumeister» Wolf-Jacob Stromer. Furthermore, the council had already decided that the rise of the arch should be 15 shoes.¹⁰

Nevertheless, we will initially examine the design ideas of the competition participants. The master builders and foremen of the «Peunt», the city of Nuremberg stone yard, had special instructions to protect the bridge from floods by a variety of measures (Reicke 1896, 573). A suitable structural measure for relieving the flood problems is a larger flow section. It is therefore not surprising that a recurring idea throughout the design reports is the desire to resist the floods and to provide free drainage for any ice that may accumulate. The decision for a single-arch bridge without centre pier was made for these reasons!

The choice of a flat arch, however, was based on the urban situation. For the tradespeople and their vehicles it was important that steep slopes should be avoided, and the residents did not want the entrances and windows of their houses and shops obstructed, which would have been the case if a high bridge with associated access ramps had been built (Falter et al. 2001a, 18; 2001b, 894–895). The effects of the new structure on the existing buildings are documented in a water-coloured pen drawing (Fig. 6).

Ultimately, the discussion resulted in a flat single-arch solution, which meant that issues relating to increased horizontal pressure on the supports and increased compressive strain at the apex had to be addressed. To what extent the foremen recognised
these problems and what structural and engineering solutions they used in response can be gleaned from the design drawings and reports.

**DESIGN PROCESS: STRUCTURAL EXPERIENCE VS STRUCTURAL PROCEDURES**

**The know-how contained in treatises written prior to the construction of the Fleischbrücke**

Whilst the dimensioning of the semi-circular Roman stone arch bridges was based on experience, the master builders of the Fleischbrücke could have done with guidelines for dealing with the modified arch thrust resulting from flatter arch designs. The master builders were able to study Vitruvius’ work (c. 84-10 BC), which reflects the Roman knowledge level, from 1548 after it was printed in Nuremberg and translated in German by Rivièrs. Whilst Leonardo da Vinci’s (1452-1519) thoughts and sketches of the «Codices Madrid» about the dependency of the arch thrust on the shape of the arch had already been published several times in Italian. In 10 books about architecture, the broadly educated humanist wrote his own work, having previously studied the work of Vitruvius. In the chapter about bridge construction, he was the first person to formulate empirical formulae for dimensioning stone arch bridges in the sense of a geometric structural design (Mislin 1997, 274). However, the work referred to semi-circular bridges, and so the rules were not directly applicable to the Fleischbrücke. Alberti’s recommendation for the arch thickness was as follows: «The stones should have a thickness of no less than a tenth of the chord» (Alberti [1912] 1991, 209). A comparison with the dimensions of the Fleischbrücke shows that the designers chose a smaller thickness at the apex, and a greater thickness at the springings;

Fleischbrücke \( d = \frac{1}{10} \times 27 = 2.70 \) m.\(^{11}\)

Dürer (1471-1528) provided rules of thumb in particular for the dimensioning of walls and foundations, but not for arches. Nevertheless, for the vaults in the castle he doesn’t recommend semi-circular arches, but says: «These vaults should all have arches of approximately a third of a circle» (Dürer 1527).

In summary it can be said that the treatises did not provide adequate dimensioning rules for flat stone bridges. Vault theories did not emerge until later. The master builders had to rely on their experience, relevant model structures and innovative ideas.

**Structural understanding in design drawings and reports**

However, neither clues about model structures whose rise-span ratios one had to adhere to or could possibly dare to exceed, nor justifications for the choice of dimensioning have been passed down. There is clear evidence of the conflict between compliance with an absolute upper limit for the rise from a town planning point of view and the structural requirement for the arch to be not too flat for the given width of river.

In order to achieve a more favourable rise-span ratio yet keep the absolute height of the bridge low, the solution that was suggested repeatedly for the single-arch bridge appears logical: a reduction of the clear width of the river. Extending the piers into the river by up to 12 shoes, either on one side or equally on both banks was suggested several times, since one didn’t yet dare to build even flatter arches. The suggested rise-span ratios varied between 1:3 and 1:6.3.\(^{12}\)

There is little evidence of structural considerations. If structural problems are mentioned at all in the
different reports, they refer to the movement and the flexibility of the abutments. Peter Carl’s opinion can be found in a kind of design brief on a water-coloured drawing (Fig. 7): «... The long main piles have to be fixed in such a way that no movement occurs between the grate and the piles. ... The piles inserted laterally into the ground should be seen as a strong strut providing support for the large load at the abutments, in order to minimise horizontal movement of the arch.»

The need to avoid «movement of the arch» is also stressed by other foremen and shows that they saw divergence of the foundations as the most problematic load case for a flat arch. This finding is confirmed by Failer following an examination of the thrust lines (1996, 131, 156).

A dispute recorded in writing in a council order about a structural engineering solution confirms that Peter Carl tried to persuade the stonemason Jacob Wolff to build the arch with constant thickness, in contrast to the decision by the council to increase the thickness towards the abutments. However, the «Ratsbaumeister» instructed Jacob Wolff to build the arch as agreed, namely to «combine the spandrels with the arch, and to ignore the attempted interference by master Peter Carl». Unfortunately, no justifications of the two designs were provided.

In combination with the evaluation of the different design drawings, the above-mentioned two examples demonstrate the debate about the force path and the structural engineering response. The intention was to increase the arch section towards the abutments, with integration and transition of the arch into the foundation, including a slanting stone arrangement. The ends of the slanting undercut abutments sit on slanting grates and slanting piles and appear to continue the arch into the ground (Fig. 8). For further information about the foundations see Bormann (1992, 164–172) and Stolarski (2001, 33).

**Single-arch vs. two-arch solution**

Some of the competition participants initially offered several solutions, i.e. designs for a conventional two-arch bridge and a single-arch version. In some cases, the single-arch and the two-arch versions can be found one above each other on a single sheet, or the single-arch solution was dotted into the two-arch design. These different comparisons between «single-arch—two-arch», together with the associated verbal reports appeared to have served as a basis for the decision by the council and the «Ratsbaumeister».

**Variation of the rise-span ratio**

For single-arch designs, dashed lines show various versions from flat to semi-circular, from a rise of 10

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**Figure 7**
Design brief by Peter Carl. Museums of the city of Nuremberg, collection of drawings: Hopf 5584

**Figure 8**
Water-coloured pen drawing of the pile foundations with horizontal and slanting wooden grates. GNM: HB 1406
shoes to 48 shoes (Fig. 9). The drawer appeared to assess quasi visually what degree of flattening of the arch he considered to be feasible.

Another drawing shows flat arches with different rise on the left and the right (Fig. 10).

**Variation of the integration of the arch in the area of the springing**

The radial or slanting arrangement of the stones near the foundation is developed gradually in one and the same drawing (Fig. 11). Initially, only the arch is continued radially into the foundation (top), then the extended arch starts to become integrated into the abutment (centre), until the designer has convinced himself that a radially laid foundation will optimally transfer the arch forces into the subsoil (bottom). Studies about this radial stone arrangement across the whole body of the bridge can be found on many of the drawings. This corresponds to the actual bridge structure and is also continued inside the bridge, as confirmed by drillings carried out by LGA.

For the transition from arch to perpendicular masonry, different stone sections are tested in two labelled partial elevations (Fig. 12).

**Radial masonry arch as response to structural considerations**

The implementation of the complete arch structure including the abutments in radial masonry as an arch with increasing thickness is more demanding for the stonemasons than a ring of wedge-shaped stones and horizontal backing. After all, all stones of the arch have to be wedge-shaped. An evaluation of the design drawings leads to the thesis that the master builders, be it Peter Carl, Jacob Wolff or Wolf Jacob Stromer, considered it to be mandatory for «structural» reasons to use this stone section for transferring the forces into the subsoil and into the slanting piles as clearly as possible. We can only speculate whether they were aware of corresponding design drawings for the Rialto bridge. This radial placement of the stones even in the area of the foundation differs significantly from the usual method of constructing stone arch bridges, where
understanding of structural engineering in the late renaissance in Germany:

- gathering, selecting, concentrating and substantiating of structural engineering know-how in the form of tenders,
- formation of a project-related structural engineering community,
- inclusion of qualitative structural considerations in the design process through verbalisation,
- systematic utilisation of drawings for design and construction variants.

Nevertheless, the structural engineering know-how gathered during the construction of the Fleischbrücke was not published after completion: with the completion of the Fleischbrücke, the structural engineering community disintegrated.

**1821: FIRST TIME UNDER THE SPOTLIGHT OF ENGINEERS**

According to Kurrer (1997, 87–114), the vault theories continued to develop with De la Hire, 1695, Bélidor and Couplet, 1729, A. F. Frezier, 1739 and Charles Auguste Coulomb, 1776, who calculated the limit values of the arch thrust with the aid of extreme-value and differential calculus, and Jakob Bernoulli, 1704, who determined the shape of the thrust line vault via the principle of virtual work.

None of these scientists used the Fleischbrücke as a model. But around 200 years after its construction, practising engineers became very interested in it and it assumed model character. G. L. A. Röder was grand-ducal Hessian major of the artillery suite and «Chausseebaudirektor» of the province of Starkenburg. In his two-volume work he provides a «complete practical description of bridge building science according to the most reliable technicians and mathematicians and the best existing models of each type, written for road and bridge construction engineers». The Fleischbrücke was the only German bridge to be included as a model structure. For 35 European bridges, the author offers «a catalogue of some interesting bridges in Europe and their significant components, for determining useful bridge dimension ratios» in tabular form (Röder 1821, 194).
Röder not only provides the absolute dimensions, but also ratios relative to the span:

1. Height of the keystone / span
2. Thickness of the abutment / span
3. Thickness of the central pier / span
4. Height of the piers / span
5. Distance to chord / span.

At the time, bridge engineers still used compliance with these ratios as a standard for their construction, instead of static calculations.

In contrast, in his book «Theory of arches, revetment walls and iron bridges» chief architect Dr. Hermann Scheffler (1820–1903) calculated 40 bridges according to the principle of smallest resistance. The results collated in list form also include the Fleischbrücke as the only German bridge (Scheffler 1857, 76). In addition, Scheffler offers dimensioning tables that are no longer based on selected model structures, but on calculations.

Calculations carried out by Nuremberg’s civil engineering department in 159514 show the knowledge level at the time for determining the structural behaviour of stone bridges. With the aid of the thrust line technique, the thrust line for the load case of dead weight and single-sided traffic (one main lane only) was shown to lie within the core, and the bridge thus classified as bridge class 30.

Structural calculations for analysis purposes are also part of the current research project. They are based on data verified by the drillings carried out by LGA, both in terms of the geometry and the material properties. They also aim to compare structural calculations from today’s viewpoint with the historic techniques for determining the load carrying capacity.

CONCLUSIONS

Despite the fact that it is one of the most significant historic bridges of the early modern age, the Fleischbrücke — built between 1595 and 1598 — with its flat single arch is nevertheless insufficiently documented. This paper provides insight into the aims and the methodology of the current research project «The Fleischbrücke in Nuremberg» at Potsdam University of Applied Sciences, which is scientifically accompanied by Prof. Dr. W. Lorenz1 and Prof. Dr. A. Kahlow.2

The project includes the topics of construction history, building surveying in cooperation with the «Landesgerbereiamt» Nuremberg (LGA), department of historic structures, and the structural analysis and finally the assessment of the quality of this bridge both from a modern angle and within the context of its time. It also involves collating scattered design documents, copies of which are recorded in a digital archive.

As a selected example for the history of construction, the design process is explained by means of designs drawings and reports from different workmen and master builders. Built without static calculations, the Fleischbrücke with its large span yet flat arch has been under the spotlight of engineers since the first half of the 19th century, using different techniques to gain a quantitative understanding of the structure.

NOTES

1. Prof. Dr.-Ing. Werner Lorenz, BTU Cottbus. Chair for history of building technology, http://www.tucottbus.de/bautechnikgeschichte/index.html
2. Prof. Dr. phil. Andreas Kahlow, FH Potsdam, Department of structural design history, http://www.fhpotsdam.de/-Bausing/personen/lehrende/kahlow.htm
4. Prof. Dr. Dr. rer. pol. habil. Wolfgang Frhr. Stromer v. Reichenbach.
5. StaatsAN: Stromer archive, B15.
6. e.g. span 15.6 m: Mislin (1997, 300).
7. e.g. Sporhun-Kempel and Stromer (1962, 282); Pechstein (1975, 75).
8. StaatsAN: Stromer archive B15, BMB I, fol. 79.
10. StaatsAN: Ratsverlass Nr.1658, No 13 fol. 33/33 verso, 7.4.1596.
11. Equations for the arch thickness depending on the theory see also Falter et al. (2001a, 25; 2001b, 898).
12. GNM: Hs 31700 or transcribed in Pechstein (1975).
13. StaatsAN: Ratsverlass 1686, No 3 fol. 44/45, 8.7.1598.
REFERENCE LIST


