HISTORIC BRIDGE BEARINGS – IDENTIFYING
MATERIAL CHARACTERISTICS:
COMPRESSION TEST

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ABSTRACT
In the context of the ongoing efforts to maintain historic bridges still in use the corresponding bridge bearings made from cast iron or from steel are re-entering the perception of the engineers. For their structural assessment the minimally invasive identification of relevant properties of the material proves a central issue. The paper presents experiments with small-scale material samples in order to determine essential mechanical properties of bridge bearings made from cast steel which had become the material most widely employed for bearings by the end of the 19th century. The material samples, which we could retrieve for our purposes, stem from bearings of bridges built during the early decades of the 20th century. The relevant tests are part of a collaborative research project performed by both the Brandenburg University of Technology in Cottbus and the BAM Federal Institute for Materials Research and Testing in Berlin for the examination of historic bridge bearings. The entire project is being funded by the German Research Foundation (Deutsche Forschungsgemeinschaft).

Keywords: Bridge bearings, Historic bearings, Cast steel, Compression test

1. CONTEXT
With the number of existing bridge structures having to be maintained or refurbished, we find the historic steel bridge bearings re-entering the engineers’ field of view. Due to their sturdiness they are mostly found to be in sound condition despite having served for more than a century, often only negligently maintained and carrying increasing loads. But if still in use, we have very little reliable information regarding their structural assessment. This uncertainty often leads to the costly replacement of bearings that look intact. This premature exchange contributes to a permanent loss of historic fabric (Fig. 1).

Fig. 1 Typical historical bridge roller bearings [10]

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The experiments presented in this paper are part of a research cooperation between the Brandenburg University of Technology, Cottbus and the BAM Federal Institute for Materials Research and Testing, Berlin, to establish the foundations for the structural assessment of historic bridge bearings. The ongoing project is being funded by the German Research Foundation. Part of the project is the development of minimally invasive methods for the in-situ-inspection of historic bridge bearings made from steel. Non-destructive forms of inspection always entail a residual uncertainty, which can only be diminished by choosing minor-destructive approaches. But the applicability of established procedures for mechanical material testing ceases at this point, since the purpose-optimised geometry of the bearings allows larger samples for experimental purposes to be withdrawn only from the narrow and structural less relevant margins of the bearing plates. However, due to conditions of production, these regions often contain impurities in the metal structure (Fig. 4 – left) prone to distort the test results. Even small-scale tensile specimens, known from steel-construction, will not be available under normal conditions due to their prerequisite size (> 60 mm).

The experiments presented in this paper were to explore the potential reliability of small-scale compression specimens, because they

- can be performed on relatively small-bodied samples,
- do not require any addition in length to be gripped in the testing appliances,
- are able to accommodate volumetric flaws better than tensile specimens (Fig. 2).

![Fig. 2 Size of standard-tensile specimen compared with small-scale compression specimen](image)

2. TESTING OBJECT

The bearings for the experiments stem from the 1910 built viaduct belonging to the elevated metro line no. 2 in Berlin-Prenzlauer Berg. In the course of an overhaul in the year 2008, they were retrieved for the purpose of a scientific analysis. All of them were part of section LII, a 140 meter stretch in the viaduct which covers a 1.7 km distance. Each of these line-rocker sliding bearings consists of a massive base body (280 × 170 × 70 mm) with a sliding surface that is one-way arched in the sliding direction, on top of which a comparatively thin bearing plate performs sliding and rocking movements (Fig. 3).

The bearings belong to the generation of bridge bearings made from cast iron or from steel. The historic field of bearings made from iron and steel has been the theme of a recent dissertation [2].

![Fig. 3 Left: Viaduct from below; Middle: Bearings’ position between cantilevered framework and suspended beam; Right: Dismantled sliding bearing](image)
2.1. Material
The material for the samples was extracted from the massive base bodies of the dismantled bearings. The base bodies were made from cast steel – a material still relatively new when deployed in the viaduct in 1910. Although the origins of casting steel go back well into the 18th century, it was only the establishment of new refining procedures in the second half of the 19th century, which allowed the production of steel on an industrial scale at low costs and in large quantities. And to produce steel-castings the molten steel had to be poured directly into the moulds yielding the final product. So some time before 1900 engineers were equipped with a material for bridge bearings combining the advantages of the two different iron materials widely used at that time – cast iron and rolled steel: the possibility of free shaping to create a product with high compression and(!) tensile strength. Beyond of that the material’s malleability allowed for machining the surface if required. Furthermore the application of an appropriate thermal post-treatment (normalising) would yield highly ductile bodies that were mostly isotropic in texture (Fig. 4) [3].

Proof of the contemporary high standard of steel-castings’ quality is the fact that the retrieved sliding bearings performed their tasks reliably for nearly one century. It is fair to say that casting bridge bearings was not anymore a real challenge in the Imperial Germany of 1910. On the eve of the First World War the technology for casting steel was defined by the engine building industry requiring steel-castings of high loadability usually involving complex alloys for products of extreme delicacy.

![Fig. 4 Grinding samples of unalloyed cast steel: Left: Unetched sample showing typical non-metallic inclusions and shrinkage holes; Right: Etched sample showing the typical ferritic-pearlitic structure [4]](image)

2.2. Reference data
Comprehensive examinations performed on the bearings during spring 2011 at the BAM Federal Institute for Materials Research and Testing in Berlin, established the outstanding quality of the material in the majority of cases. Altogether 10 bearings that were structurally identical (nos. 0 to 9) were subjected to a variety of analytical procedures. The results have been extensively published in [3].

The current paper now presents tests with small-scale compression specimens to see how the mechanic-technological parameters derived from the compression tests correlate with those from the tensile tests. Table 1 shows the average values of the tensile tests. Fig. 5 represents the position of the specimens inside the bearing.

<table>
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<tr>
<th>Bearing-No.</th>
<th>$R_{el}$</th>
<th>$R_{ct}$</th>
<th>$R_{pl,2}$</th>
<th>$R_m$</th>
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Table 1 Results of the tensile tests given in N/mm² [5]
2.3. **Test specimen**

The extraction of the standardised tensile specimens yielded cuttings, which could be used to produce small-scale specimens for the compression tests. Their geometry was chosen in compliance with DIN 50 106 [6] providing the basis for any such testing of metal materials. It requires the specimen to be cylindrical in shape with a diameter between 10 and 30 mm. The proportion of height $h$ to diameter $d$ has to be

$$1 \leq \frac{h}{d} \leq 2$$

(1)

Accordingly two series of specimens for the small-scale compression tests were produced:
- 1. series: $d = 10$ mm with $h = 10$ mm ($h/d = 1$)
- 2. series: $d = 10$ mm with $h = 20$ mm ($h/d = 2$).

Fig. 6 shows the two test specimens derived from bearing no. 9.

The recommendation of DIN 50 106, to use samples with the dimensions of $d = 20$ mm and an aspect ratio of $h/d = 1$ for examining metals from bearings contradicted the purpose of the current tests, which was to explore the smallest geometry possible for this kind of analysis.

3. **TESTS**

These experiments were performed in the Research and Material Testing Institute, BTU Cottbus in September 2011. A material testing bay with the accuracy class 1 was employed. The specimens were fixed between transfers made from round steel. Small, well-contoured pieces of high-carbon steel were welded onto their ends allowing for both the best possible positioning of each specimen and a good transmission of the applied load. The strain was recorded with the help of an extensometer directly fixed to the specimen. To reduce the contact friction occurring at the fixing points small strips of Teflon were inserted (Fig. 7).
The problems usually encountered, when compression experiments are to determine material properties, have been discussed in the literature, since material testing evolved as a discipline – cf. [8/p.45], [9/p.175]. Thus the compressive strength of ductile materials is usually not represented as a clear-cut point of failure. Furthermore the multi-axial condition of strain in the specimen inhibits a simple determination of the modulus of elasticity. Therefore the focus of the author was solely directed towards a reliable identification of the compression yield point. In the case of steel this should be by and large equivalent to the tension yield point.

4. RESULTS

Regarding the geometrical properties of the specimens the results yielded a clear vote for the long ones with h/d = 2. This is in marked contrast to the recommendations for bearing materials as suggested by DIN 50 106. Fig. 8 shows the results for the samples taken from bearing no. 3 and displays the systematic character of the tests in representing the compression yield point depending on the specimens’ geometry. Whereas the yielding of the material was only hinted at in the case of the short specimens (h/d = 1), a clearly defined yielding field was observed with the long samples in most of the cases. Thus the compression yield point could be determined with considerable precision.

If the preceding tensile tests did not produce a clearly identifiable tension yield point (cf. Table 1), then similarly the compression yield point was barely distinguishable in the respective tests – even in the case of using large specimens with h/d = 2. Fig. 9 contrasts the respective results for tensile and compression tests.

In the course of the test series, however, most of the samples showed a distinctive yielding (Table 1). If such a behaviour of the material could be observed, the compression yield point arrived at in the small-scale compression test was convincingly equivalent to the tension yield point resulting from the tensile test (Fig. 10).
In accordance with the assumptions beforehand, the compressive strength of the material could not be described as a point of failure. If the test load was increased beyond the compression yield point, the short samples (h/d = 1) were squashed in a progressive fashion: the specimen bulged outward on the sides becoming barrel-shaped, because friction between the specimen and the end plates (and in spite of the strips of Teflon) prevented lateral expansion. However, no signs pointing to the destruction of the internal structure of the material could be observed (which occurs when testing brittle cast iron). The longer samples (h/d = 2) showed the tendency to escape the load by lateral buckling caused by any minute imperfections as for instance impurities in the texture of the material or imprecisions in the specimens’ fixing (Fig. 11). If the compression stress amounted to some 900 N/mm² – i.e. regions exceeding the ultimate tensile strength by far (cf. Table 1) – the experiments were stopped for safety reasons.
5. CONCLUSIONS

Overall these experiments performed in the Research and Material Testing Institute at the BTU Cottbus confirmed the principal suitability of small-scale compression specimens for analyzing the material properties of bearings made from cast steel. The tests generated first insights into the appropriate geometry of the specimens and demonstrated that small-scale compression specimens allow for a reliable determination of the yielding point of the material. Future experimentation will have to examine, to what extent these results may be generalized for cast steel from other periods and how the experimental set-up as well as the geometry of the specimens can be improved in order to yield results for the compressive strength (as another crucial property of the material) as well. However, the reliable determination of the yielding point makes the small-scale pressure specimen a valuable instrument for the in-situ-assessment of historic bridge bearings, since it creates the possibility to produce dependable information on the qualities of the bearing’s material by extracting comparably low amounts of sampled material.

ACKNOWLEDGEMENTS

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REFERENCES

[10] Archive of the Chair of Construction History and Structural Preservation, BTU Cottbus.