LOADING VEHICLE BELFA
DEVELOPMENT AND EXPERIENCE GAINED IN 10 YEARS OF PRACTICE

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ABSTRACT:

Test loading of existing concrete and masonry bridges appears to be an alternative way of proving structural safety in case of failure of conventional methods. Throughout the last decade, methods and equipment for in situ loading tests have been improved significantly. A German research team dealt with the experimental safety evaluation from 1992 through 2003. Methods and equipment have been improved during this work and the team contributed into

- the formulation of a national technical guideline for loading tests [7] and
- the development of a special loading vehicles for both road and railway bridges

In this contribution the concept of experimental safety evaluation is discussed, the loading vehicle for road bridge testing as well as essential operating experiences gained in practise is described.

KEYWORDS: experimental safety evaluation, structural health monitoring, in-situ loading test, loading vehicle

1. INTRODUCTION

Assessment of bridges is necessary because their condition deteriorates with time, and accordingly their capacity to carry load also declines. The traffic is concurrently increasing in terms of frequency and weight [1]. To maintain the safety it is thus necessary to confirm that the load capacity of bridges is sufficient for the current and foreseeable applied loads, without accelerated deterioration, so they can remain in service.

Several methods are available for the assessment of the load-carrying capacity of bridges. These include simple conservative mathematical methods or other semi-empirical methods, and recently developed computerized methods such as FEM. In addition to their particular limitations, conservative methods often underestimate the load carrying capacity, which may result in uneconomical or unnecessary mitigation measures being taken to maintain or replace bridges.

Conversely the analysis of structures for a safety evaluation requires input data concerning the current properties of the structure and the mechanical boundary conditions. These preconditions cannot be met always, especially not for existing structures. Possible reasons are an incomplete documentation, unknown effects of structural faults, and uncertainties in the modelling of the structural system with appropriate boundary conditions. Another problem occurs if the structures have a historic design: the

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contemporary technical recommendations are made for building of (new) structures and don't meet the requirements to assess historic designs.

In order to optimize the assessment procedure, the assessment of a particular bridge is carried out in levels of increasing refinement and complexity ([2], [3]). At an initial level simple and conservative analysis tools are used based on the most conservative assumptions on the geometrical and material characteristics or distribution of load. This level usually serves as a first filter to determine potentially under-strength structures. Higher levels of assessment with more sophisticated analysis methods are only carried out if the load carrying capacity of the bridge is shown to be inadequate in Level 1 assessment and the use of more complex analysis methods with less conservatism may provide higher assessed capacity. These more complex analysis methods usually require additional input information that necessitates site investigation, material testing and laboratory analysis of samples. Higher level assessment is also used when simple analysis tools are applied at lower level assessment but are considered inappropriate for the purpose of assessment (e.g. when the structure has specific features that are impossible to describe with a simplified model). If analytical assessments, including level 3 assessments with experimentally refined models, still do not give sufficient results, it is in certain cases worthwhile to determine the structural safety experimentally by performing an in situ loading test. This, however, has to be done without causing any damage which would impair the safety or the durability of the structure. There are two well-known procedures:

- Load tests up to service load (e.g. under normal traffic operation) – a computational extrapolation of the experimental results may follow for safety evaluation
- Use of special loading technology - the actual load carrying capacity may proved directly (see the following chapter)

2. TECHNICAL RECOMMENDATIONS

The progress in engineering sciences is based on empiricism. In the late 19th century experiments were used to understand the complex correlation of material and mechanical behavior as well as recommendations for structural design. As a result the first German recommendations, e.g. DIN 1045 for reinforced concrete ([4], published 1925), contained instructions for in-situ load tests of massive constructions. However the need of in-situ load tests was always discussed controversial. In the early 20th century the load application was made by death weight so that the tests needed a collapse protection and they were dangerous for workers. The actual state of the construction was analyzed by simple mechanical devices and it was assessed by the comparison of the remaining deflection to the total deflection ($f_{remaining} < ¼ f_{total}$; [5]).

The second half of the 20th century was affected by the introduction of electronic data processing. The finite element method (FEM) appeared to be suited to solve every engineering problem. The main focus of civil engineering was the development and building of new infrastructure, so that in Germany previous obligatory load tests of bridges or special designs disappeared: the revised recommendation DIN 1045 [4] was released in the year 1972 without any advice about load test – the previous chapter §7 „Load Tests" didn't exist anymore.

However, during the last decades, the technology of in-situ experimental safety evaluation has become more important again since the need of alternative methods was rising. More and more projects are dealing with existing structures. The research team EXTRA of the University of Applied Sciences Bremen, the Technical University Dresden, the Leipzig University of Applied Sciences and the Bauhaus-University Weimar dealt with the experimental safety evaluation from 1992 through 2001 [6]. Methods and equipment were significantly improved during this work. Furthermore, the team contributed into the formulation of a technical guideline for loading tests which has been issued in

2000 [7]. The guideline contains the safety concept and technical rules for loading tests as well as criteria for critical load levels, for example. Today international recommendations contain references to experimental methods, e.g. Eurocode 2, chapter 2.5 (01.2011): „Design assisted by experiments".

3. CONCEPT OF THE EXPERIMENTAL SAFETY EVALUATION

During a load test the existing structural component with an unknown effective load-bearing capacity is assessed. Though the effects of loading on the structure (e.g. deformations) can be measured, the magnitude of the present dead load as well as the ultimate strength is unknown. All equipment must work electronically and has to be integrated in an online measurement system to ensure that the critical load level is definitely identified, which is characterised by beginning damage processes. The experimental safety evaluation without causing any damage is tied to two important technical prerequisites:

- The application of the test loads has to be undertaken in a way that sudden failure of the structure is avoided even in the case of unexpected damage.
- During test loading, the behaviour of the structure has to be monitored continuously and evaluated in real time (e.g. deformations and micro crack formation). In this way, critical load levels are identified and the loading program may be altered in order to avoid damage to the structure. Limit criteria have to be determined prior to the test according to the recommendations [7].

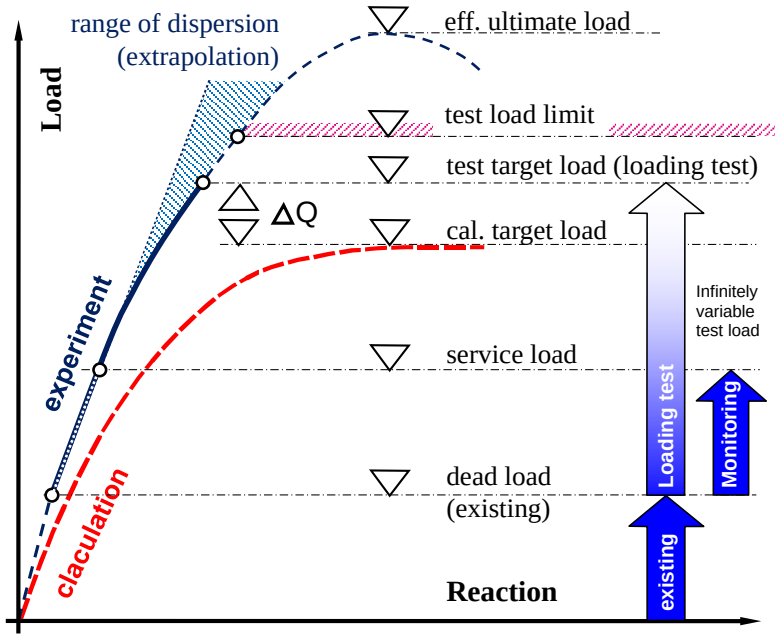

Figure 1: Theoretical and experimental load-reaction-curve of a structure

Consequently, test loading of bridges by gravitational forces, e.g. vehicle crossing or movable weights ([8] and [9]), is not considered to be an adequate way of safety evaluation (incl. partial safety factors), although it is technically the easiest alternative. For safety reasons the load level reached in this way should not exceed the service load (Fig. 1). However, a parallel application of experimental and computational methods may allow the extrapolation of experimental results to higher load levels. On the basis of the experimental observation, the input parameters required for the analysis are obtained. The advantage of the subsequent extrapolating analysis is its totally non-destructive character. However, the disadvantage is the remaining uncertainty concerning the correctness of the extrapolation

(Fig. 1, range of dispersion). Parametric studies or the consideration of large safety margins are means for handling these uncertainties.

The best results concerning a safety evaluation were obtained if the structural behaviour above the service load level can be assessed experimentally. Very often additional resistance reserves are revealed, especially in the case of inhomogeneous materials like concrete or masonry. This is often based on two effects:

- the characteristic properties of the non-metallic materials vary in a wide range, the assumptions for a calculation is often very underestimating the real value
- the real boundary conditions differ from the mathematical model

In numerous cases, the author and his team as well as other institutions [10] were able to prove much higher load carrying capacities of structures as estimated by calculation before.

A loading test is actually performed as follows. Before the loading test, an experimental target load has to be calculated which simulates the design load level including live loads and additional permanent loads. Different safety factors may be used for the several load types following the concept of load and resistance factor design. A part of the permanent loads is already acting before the test loads are applied (Fig. 1). These loads, mostly resulting from the self-weight of the structure, need not to be simulated in the experiment. During the test, the load-carrying behaviour is monitored starting from this level. During the experiments the load-reaction-curve usually reveals a higher stiffness of the structure as compared to the one obtained by structural analysis. Now the load may be increased gradually until reaching the precalculated test target load. In this case, sufficient structural safety is proved. In rare cases one or more measurement values reach a critical level and the test load limit so that the test must be stopped. Although the experimental safety evaluation must be considered to be unsuccessful, the results can be used to calculate the actual permitted live load based on the experiments. These are normally still higher than the results based on calculation.

As stated before, test loads have to be applied in a way that sudden failure is avoided in order to ensure the safety of the structure as well as the safety of test equipment and crew. Consequently, gravitational loads are not applicable in such experiments. Placing weights on a bending structure involves a considerable risk.

If, however, hydraulic actuators are used and a steel frame serves for transferring the reaction forces to the supports of the bending structure, see Fig. 2, the loading system is self-securing and it is able to apply high variable test loads. In case of unexpected damage the stiffness of the structure will automatically decrease resulting in reducing of the test load. Fig. 2 shows a reaction frame placed on a reinforced concrete bridge. The frame is anchored at the supports and hydraulic jacks are acting between structure and reaction frame. This procedure, however, had two major disadvantages: the road had to be closed for several days (relatively high expense in terms of time and cost for transport, setting up and dismantling) and the waterproof layer had to be perforated to anchor the frames at the supports in drilled holes. The need of an alternative loading technique was obvious and lead to a research project, whose results are documented in the following chapter.

Figure 2: Bridge load testing using a mobile framework

4. DEVELOPMENT OF A LOADING VEHICLE

For performing loading tests at road bridges in a more effective way, a special loading vehicle has been designed and built [11]. It is named BELFA after the German word *Belastungsfahrzeug* for *loading vehicle* and may be moved on public roads. It allows conducting these experiments without the cost and timing consuming construction of reaction frames [www.belfa.eu]. The project was funded by the *Bundesministerium für Bildung und Forschung* BMBF (about 1.85 million euros).

The German authorities were involved in the development. They were asked to define conditions which have to be achieved to obtain more acceptances of experimental safety evaluations. This leaded to the following prerequisites:

- Previous investigations to detect existing damages
- Infinitely variable test load (loading technique)
- Safe detection of beginning damage (measurement technique)
- Self-securing principle – indiction of failure
- Measurement devices to detect brittle failure (e.g. shear failure)
- Experienced experts only
- Assessment of load bearing capacity at the overall system
- Pavements act as a quasi-monolithic strengthening of the structure. Its influence has to be considered [12].

After a repetitive process of six concepts, the final design was found [13]. The loading vehicle, named BELFA, consists of a tractor truck with 4 axels and a special semi-trailer with 5 axles (Fig. 3). The total weight is 80 tons, the length amount to 22.5 m in transportation mode and up to 35.5 m in testing mode (table 1). BELFA may be used to apply loads up to 1500 kN so that the common load levels and loading diagrams can be conducted (e.g. in Germany: bridge class 60, wich ist the highest bridge class in the German standard DIN 1072).

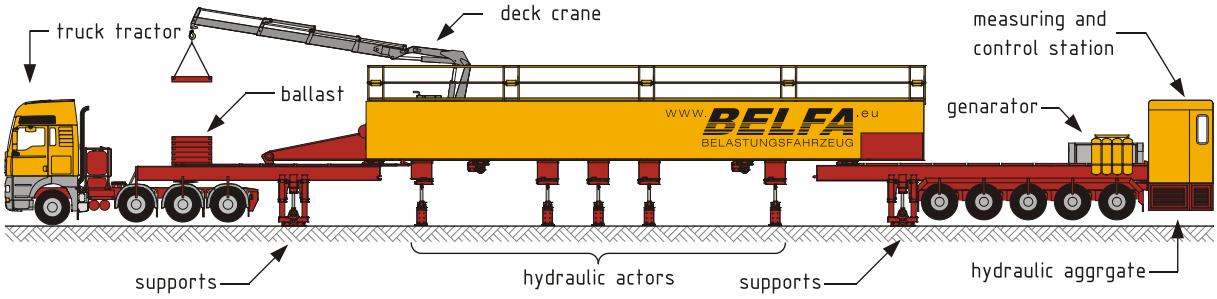

Figure 3: Basic elements of BELFA in working position

The research team, consisting of the University of Applied Sciences Bremen, the Technical University Dresden, the Leipzig University of Applied Sciences and the Bauhaus-University Weimar managed to finish the ambitious project in time. The loading vehicle BELFA left the factory work floor (*Eggers Fahrzeugbau GmbH*) in March 2001 to test the first road bridge near the city *Neu Kaliß* (Mecklenburg-Western Pomerania)

Table 1: Essential data of BELFA

Length in transportation mode:	22.5 m
Max. length in working position:	35.5 m
Max. distance between supports	18.0 m
Total weight	approx. 84.5 t
Max. test load (without additional dead freight)	approx. 750 kN
Max. permissible test load	1500 kN

5. OPERATION SEQUENCE

The loading vehicle BELFA is driven to the bridge using its own tractor truck (Fig. 4). A special driving permission is needed every time since BELFA has over length and overweight. It stops in front of the bridge where the truck is pulling out the front part while the rear axles are blocked. The saddle score of the truck can be reduced additionally by de-airing the pneumatic shock absorption of the last three axles.

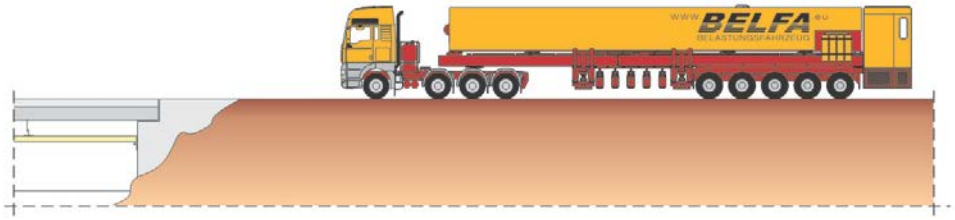

Figure 4: Arrival of BELFA in transportation mode

Thus the truck may cross the bridge, which load carrying capacity is still unknown, with the lowest possible weight. To ensure a riskless crossing it is expedient to assess the structural behavior using the measurement equipment that was installed before. When the first of the rear axles is reaching the bridge, they are blocked again and the middle part is pulled out, too (Fig. 5).

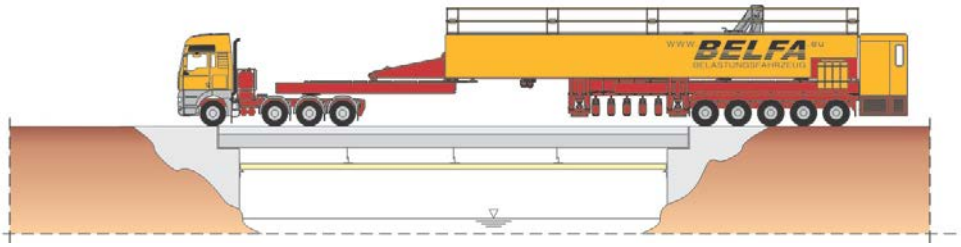

Figure 5: Crossing the bridge placing BELFA

BELFA is placed in the right position and fixed in the desired length. The maximum distance between these supports amounts to 18 m which limits the span of the bridges to be tested to this length. The correct position and length is important since the center of mass must be in accordance with the planned loading positions. Afterwards all axles are de-aired and are fixed to the vehicle chassis in order that all of the masses were usable as counter-force for the test loading. Four hydraulic jacks, two in the front and two in the rear, are lifting up the whole vehicle so that it serves like a reaction frame (Fig. 6). Now starts the self-driving deck crane, which can be moved in the longitudinal direction, to place entrained weights on the chassis. If this weight is not sufficient for compensating the test loads applied, additional ballast weight is required. For that, an on-board water bag may be filled with up to 20 t of water. If still the reaction force is too low, the BELFA may be anchored at the bridge supports by using high-strength steel bars or may be ballasted additionally with external weight. Doing so, the center of mass must be adjusted to the desired position. The hydraulic actors were moved to the test position, which may be at any point between the supports, and their load distribution beams were lowered to the pavement.

Figure 6: BELFA in operation mode, supported at both bridge bearings

In the testing mode, two engineers are controlling the experiment sitting in the control cabin that is located at the rear of the vehicle (Fig. 3). The test loads are generated by one to five hydraulic actuators that are able to apply loads up to 500 kN each (Fig. 3 and 6). Position and magnitude of the individual forces generated by the actuators are variable. In this way, different live load arrangements may be simulated according to the valid design code. Testing a one-span bridge will not last longer than about one day. This results in considerably shorter road closing times, 2 or 3 hours during the measurements at most. The installation of the sensors for measuring the reactions of the structure requires additional time. However, the traffic on the bridge is mostly not influenced by this work.

After the successful test the BELFA can be pushed together without restrictions and may be moved to immediately to the next challenge.

6. DETERMINATION OF TEST LOAD

To calculate the magnitude of the external applied maximum load (target load) the test planning must be worked out. The process should be optimized according to basic questions as follows:

- What is the magnitude of the maximum load (target load)?
- How and where should the load be applied?
- What has to be measured where?
- Which are the limit criteria which have to be kept to ensure the integrity of the structure (no damage / no destruction)?

These questions must be answered for each experiment – with different results each time. A static pre-calculation identifies the critical structural parts, where the reactions reach an extreme value. Hence the test target load is calculated by comparing stress conditions. The stress conditions applied during the experiments must be the same in location and magnitude as these caused by the theoretical load diagrams. The load assumptions of existing bridges can be consulted in outdated recommendations which were valid at the erection time [15]. If necessary, one proof may be divided in two or more load positions.

The German guideline for loading tests [7] shows the equation how to calculate the test target load ext F_{target}:

$$ext\ F_{target} = \sum_{j>1} \gamma_{g,j} \cdot G_{k,j} + \gamma_{q,1} \cdot Q_{k,1} + \sum_{i>1} \gamma_{q,i} \cdot \psi_{o,i} \cdot Q_{k,i}$$

with $0{,}35\ G_{k,1} \leq ext\ F_{target} \leq ext\ F_{lim}$

$G_{k,1}$ characteristic value of existing structural permanent action

$G_{k,j}$ characteristic value of additional self-weight j

$Q_{k,1}$, $Q_{k,I}$ characteristic value of variable action (traffic loads) respectively of main variable action i

$\gamma_{g,j}$ partial safety factor of permanent action G

$\gamma_{Q,1}$, $\gamma_{Q,I}$ partial safety factor of variable action Q

$\psi_{o,I}$ combination coefficient in case of several variable action Q

The particular values for partial safety factors and for combination coefficient can be found in pertinent recommendations or national appendices [16]. However one special feature of load tests is that the building exists and the self-weight is already acting. Thus this safety margin must not be included in the calculation of the test target load ext F_{target} ($\gamma_{g,1} = 1.0$). Dynamic effects are considered by increasing the variable action using a dynamic coefficient φ which is dependent on the bridge span. It's maximum is 1.4 for short bridges and cannot fall below 1.0 if the span exceeds 50 m [15].

During the loading test, influential factors can reduce the stress level, thus the attempted load conditions in the structure are not reached, e.g.

- system influences (part restraint, abutment settlement, lateral distribution)
- structural layers (sealing, slope/safety concrete, pavement concrete, road surfaces)
- formation of the cantilevers and caps (incl. solid railings)
- ambient influences (e.g. temperature)

If they do not have the same permanent effect on the structure, the test target load must be increased by an overload ΔF to compensate this reduction [12]. Then the effective test target load is ext F_{target} = F+ ΔF and generates the stress level in the structure to be verified according to the

recommendations. Prior investigations have shown that e.g. pavement acts as a quasi-monolithic strengthening of the structure:

The bridge erected in *Bad Sülze* in 1970 crossed a river bed (*Recknitz*) with a span of 12 m. Its cross section consisted of 19 prestressed precast concrete beams which were completed with poured in-situ concrete (Fig. 7).

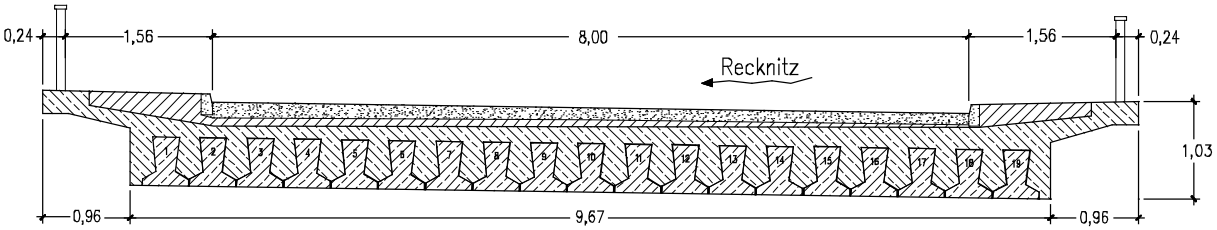

Figure 7: Cross section *Bad Sülze* bridge (mid-span)

Identical loading tests (place and magnitude) were performed in the following conditions of the bridge structure (Fig. 8):

(1) initial condition
(2) after removing the asphalt
(3) after removing asphalt and protection/sloping concrete
(4) after removing asphalt, protection/sloping concrete, pavement concrete

In this case the determined overload factor was 1.04 ($\Delta F = 0{,}04 \cdot F$) taking only the influence of asphalt into account. Further studies have shown that the coefficient can rise up to 1.26.

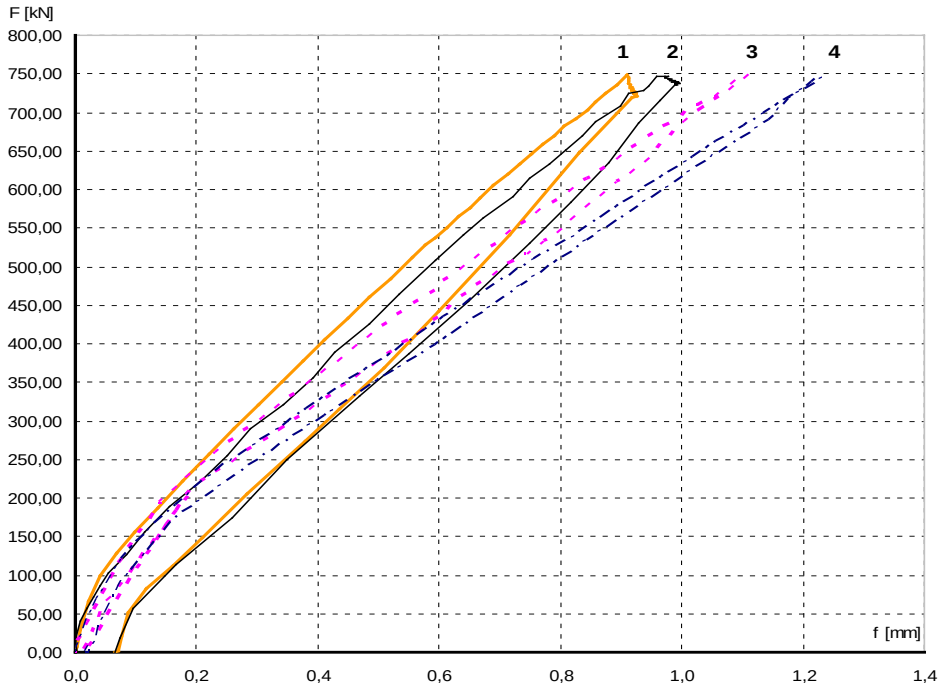

Figure 8: Load-deflection-curves (first loading cycle) at mid-span

In the case of constant factors such as restraint effects from concrete joints or earth resistance on the abutments, it is presumed that this influence has the same favourable effects for the residual use period.

These influences do not have to be taken into account in the form of an overload and can be used therefore as potential for a higher experimental bridge rating.

7. EXAMPLE

The operation of BELFA shall be described by an example. The reinforced concrete bridge was one of the last existing "*Möller-Bridge*", designed by Prof. Möller at the beginning of the 20th century [17]. The bridge crossed a small stream at the border between Lower Saxony and Saxony-Anhalt (L_s = 5.80 m). Due to the inner German Wall the bridge was nearly 40 years unused but without maintenance as well.

A bridge investigation assessed several serious damages as cracks, corrosion and spalling. The permitted loads were reduced to a total weight of 2.8 tons, so that the primary use of the state road was brought to an end. Load tests should proof if the permitted loads could be assessed for 16 tons (DIN 1072, [15]) at least.

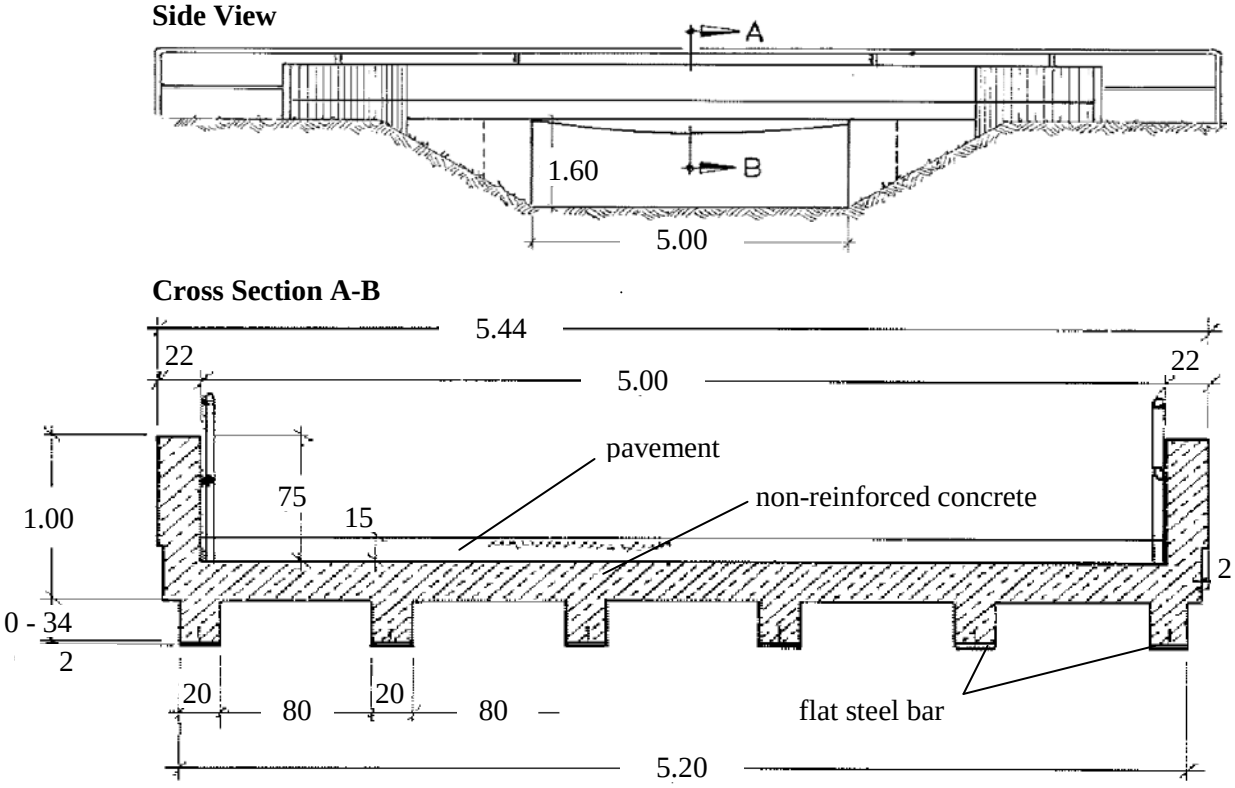

Figure 9: Side view and Midspan Cross section (*Möller-Bridge*)

The survey started with an inspection of geometry and local conditions as well as non-destructive investigations. They lead to a simplification of the testing program. The load tests could be reduced to one half of the bridge (width: b = 5 m, Fig. 9). However, this was necessary since the bridge laid in a bend and BELFA could be positioned only on one half of the bridge. The load tests consisted of three phases:

- Crossing of the tractor truck (without semi-trailer) to get a first impression of the structural behavior and to confirm equal load bearing-behavior across the bridge
- Crossing of the truck with semi-trailer (Fig. 5 and 10)
- Self-securing load tests

Figure 10: Möller-Bridge: monitored BELFA-crossing

The experimental safety evaluation involved the superstructure, the supports, the abutments and the foundations. The load was increased infinitely variable using the dead weight of the BELFA as counter force, which was supported as far away from the bridge as possible to avoid interaction neither with the abutments nor the foundation. The target loads were calculated in advance to reach the maximum stress conditions of each building element. They took into account all dead loads and live loads according to the recommendations including partial safety factors (Chapter 6).

Several reactions were measured during the tests to analyse the particular condition of the structures, e.g. deflections, settlement of abutments, crack width, steel strain. They were recorded and at the same time monitored on a screen as load-reaction-curve. All reactions stayed below the precalculated prognosis (table 2), which presumed conservatively that the load of one wheel is carried only from one girder. In fact, the the load was carried from more than one girder (Fig. 9).

Table 2: Comparison of calculated and measured deformations (midspan)

Load Case		**Deflection** [mm]	**Steel Strain** [μm/m]
Single Axis in midspan Service Load F_Q = 210 kN	precalculation	2,7	30
	measurement	0,5	67
Single Axis in midspan Target Load F_{target} = 338 kN	precalculation	4,4	49
	measurement	0,86	115

Every load case was completed with an assessment of the long term behaviour (change of reactions under constant service load). After approx. 15 minutes the load was reduced again since the reactions were constant. It was proven, that the load carrying behaviour doesn't change and the influence of creeping effects was insignificantly low.

The successful experiments were concluded as following:

- The deformation behavior (superstructure / foundation) is predominantly linear-elastic
- The deformations are smaller than the calculated (conservative) prognosis
- The load distribution across the bridge is intact – several girders share the load
- Cracks open and close under load, critical crack widths were not reached
- The massive parapets take some of the load
- High wheel loads lead to longitudinal cracks in the slab between the girders (visible, $w \leq 0{,}1$ mm)

Additional investigations showed solutions to ensure durability: none of the detected faults affected the load carrying capacity. Nevertheless some rehabilitation measures were supposed, e.g. the renewal of the waterproofing layer or the rebuilding of the corrosion protection at the exposed flat steel bar.

8. EXPERIENCE GAINED IN PRACTISE

Initiation of Operation

The first years upon completion BELFA was extensively tested. During the research project 10 bridges and 2 sewer constructions have been proved. The results showed the high potential: the permitted service loads could be increased, the road block was mostly reduced to 1 day and the overall costs were still moderate.

After the finalized research project, BELFA was ceded to the University of Applied Sciences Bremen which is carrying on the operation. BELFA may be rented with or without operating staff (www.belfa.eu).

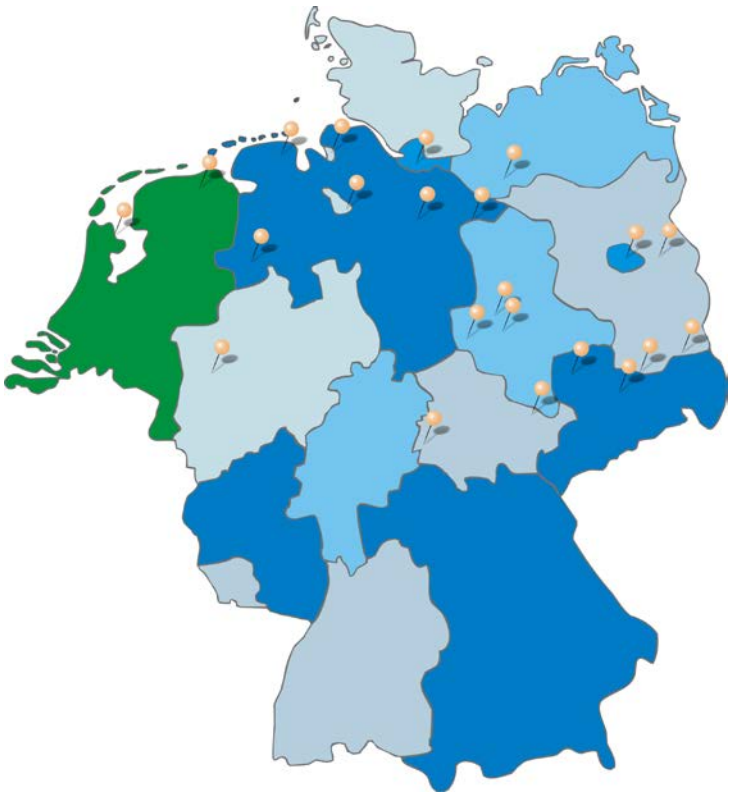

Figure 11: Sites of BELFA-operation in Germany and The Netherlands

Record

Up to now BELFA tested 2 sewer constructions and 45 bridges (number of spans: 77) in Germany and The Netherlands (Fig. 11). A few times we planned to load test roof trusses of a hall, for what BELFA may be used as well, but were not ordered.

The frequency of deployment, however, was lower than expected (10 tests per year) although the projects were very successful. Either the primary service load of the constructions could be proven experimentally, despite of existing faults and missing documentation, or the permitted service load could be increased (Fig. 12).

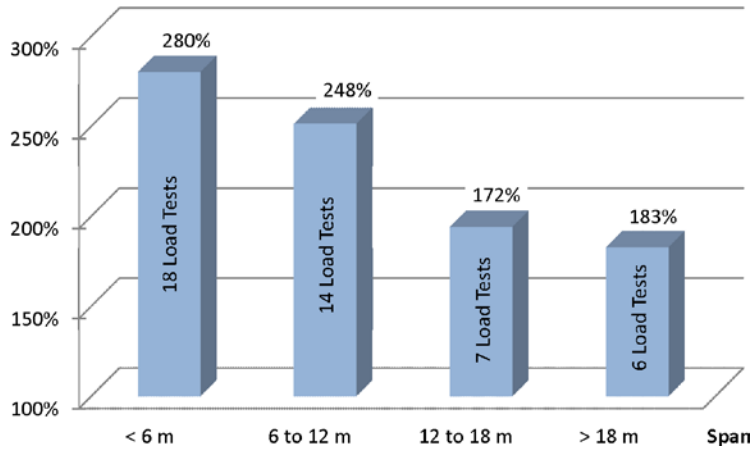

Figure 12: Increase of service load (statistical analysis) (100% = result of pre-calculation)

The best enhancements were achieved interestingly on the bridges with short spans ($l \leq 12$ m). Though it was irrelevant whether the bridge had to be tested including superstructure, supports and foundation, which load carrying system existed (arch, slab, girder grid) and which material was used to build the constructions (Fig. 13). More than 50 percent of the assessed constructions were built in the years between 1945 and 1960 (Fig. 14).

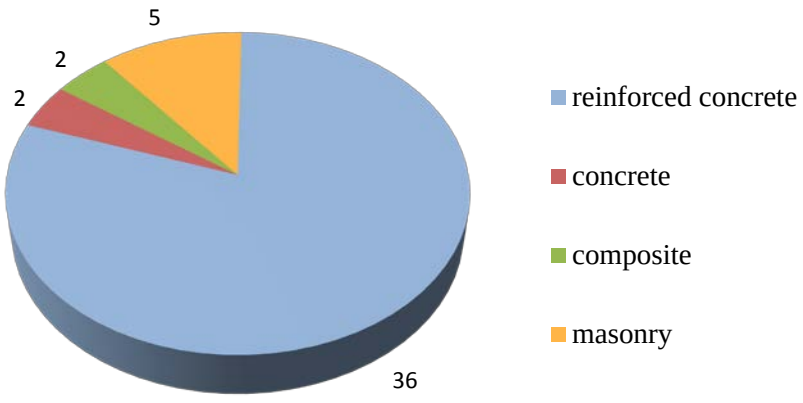

Figure 13: Building Materials of tested bridges (statistical analysis)

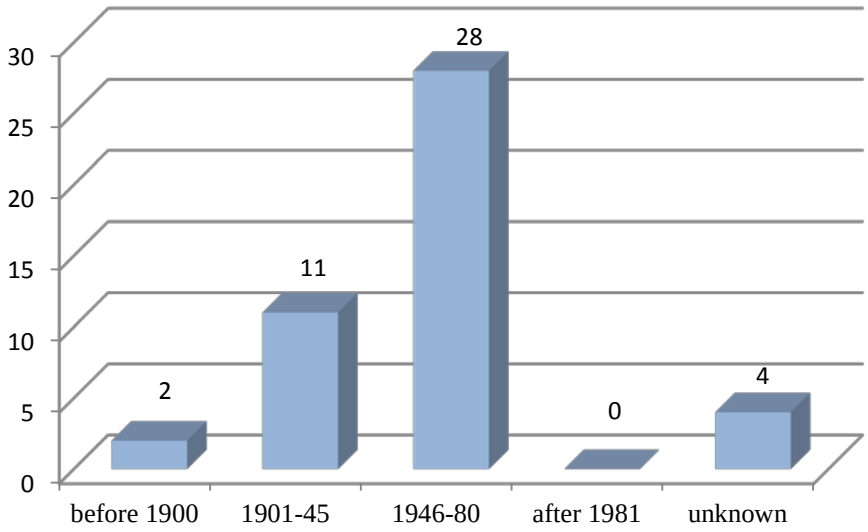

Figure 14: Statistical analysis: number and age of tested bridges

Costs

The average rental costs of a BELFA-operation amounted circa € 13000 (= 17000 $ or 1700000 ¥). This amount didn't include the measuring effort. The rental cost could always be reduced when several constructions could be combined to one campaign.

9. LIMITATIONS AND LESSONS LEARNED

Load tests have limitations and often they are disputed controversially by the involved parties (table 3). BELFA, for example, has generally a technical limitation to bridges with a span less than 18 m or to the maximum target load (bridge class 60). Furthermore the experimental approach is not suitable or economical for every bridge. In the case of extensive damaged bridges it might be better to demolish and rebuild the structure or to use conventional measures to strengthen it.

All previous projects have shown that it is possible to prove much higher live loads than calculated. This led astonishingly to the reaction of some involved persons which criticised that we would reduce the existing safety level permitting higher live loads. Load tests identify and exploit latent bearing reserves, of course. However the load carrying safety is proven including all specified safety factors so you may not call it a reduction of safety.

The load level causes stress values that are higher than any level that have occurred before or will occur after the tests. Thus some people criticise that load tests above the service load level "damage" the structure. A concerted measurement concept eliminates the risk of severe damages to a very low probability. Cracks in reinforced concrete structures are not taken into account since cracks are inherent to the material and the crack width is monitored as well. Vice versa our experience was that some concrete structures didn't show any cracks during the test although nearly double service load was applied.

Every load test can only assess the current behaviour and conditions so that a statement is not possible, how long the remaining use time is going to be. Nevertheless the results of the experiments are staying valid as long as the conditions and the state aren't changing. This is in fact the same approach as for any new built construction. Periodic inspections take care that any changing state is monitored. In Germany the DIN 1076 recommends a small inspection every 3 years and an intensive inspection with a 6 years cycle [18].

Table 3: Pro and Contra of Loading Tests (experiments)

Pro	Contra
Realistic material and boundary parameters are assessed by experiments only	Finite element models (2D / 3D) are able to solve nearly every problem
Load Tests assess the load-stress-relationship as it is, even in case of non-linear behavior!	Load tests "damage" structures, e.g. since they cause cracks (although cracks in reinforced concrete structures are inherent to the material)
Crack formation (AE) and crack width are monitored during the tests	
Proof of Serviceability (e.g. stress limitation, crack width) is proved directly	
Experiments (load tests) lead to a reduced effort for mitigation or maintaining measures	High financial effort without guaranty for success
	Politics, Engineers and Industry is focused on conservative mathematical methods and measures (strengthening, rebuilding)

10. CONCLUSION AND OUTLOOK

The projected service life of solid road bridges is about 80 years. Due to the damaging effects of the environment and increased traffic loads, it is in reality reduced to about 50 years. The ensuing need for reinvestment can only be covered taking into account financial resources and environmental concerns if the service lives of existing bridges are significantly extended. Load tests on solid bridges can make an important contribution here.

If computational verification does not give realistic results due to inadequate or missing building documentation, complex load-bearing behaviour or obvious or hidden defects, then, after appropriate preliminary investigations, experimental assessments of load-bearing capacity can supply information about the real structural behaviour with the inclusion of all existing conditions. In these cases the experimental investigations usually produce more favourable results than the static computation, as has clearly been shown analysing 45 examples (Fig. 12 to Fig. 14). The increase of the permitted live loads laid between 30% and 50%, in some cases nearly 100%.

However loading tests have to be performed in a way that any damage to the structure is avoided. During the last decade, the technology of in situ structural testing has made significant progress. Result of this development is for example BELFA, a special mobile loading device for road bridges. Its usage allows conducting loading tests more efficiently. The applicability of the new equipment has been proved by successfully testing several bridge structures.

Figure 15: Load tests of a masonry arch bridge

Figure 16: Load tests of a culvert

Figure 17: Load tests of pillars

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