Reconstruction of the “Neues Museum” in Berlin – support structure planning pro preservation of historic buildings

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Abstract

“While no work can be understood without knowledge of its technology, no technology can be understood without knowledge of the work, either”. The reconstruction of the “Neues Museum” in Berlin is a great challenge for all participants in terms of Adorno. Historical structures, especially arched components, usually have amazing bearing capacities. It is rarely possible to verify these only by calculation. Some examples will show how calculation and experiment complement each other in analysing the load capacity. Thus historical structure components can be admitted to modern utilisation.

Keywords: monument protection, loading test, maintenance, experimental assessment of bearing capacity, clay pots, mosaic floor, Neues Museum.

1 Introduction

In terms of planning and type of construction, structures are often designed for special requirements and a limited period of use. In the age of sparse resources, frequent changes of use, environmental damage and the consequences of inadequate building maintenance, questions arise with existing structures regarding the change of use, building modifications and the remaining service life as the basis for decisions about investment. A prerequisite for the retention of the capital represented by existing structures is the verification of their serviceability and load-bearing capacity. The usual computational analysis assumes that, apart from the geometry, support and loading, all the major material properties and state characteristics are known and that behaviour under load can be described realistically by mathematical methods.
However, in reality and particularly with older structures, one or more of the requirements for a calculated verification are usually not known or cannot be determined with sufficient accuracy. Experience shows that the main reasons here are inadequate or missing static documentation, constructional defects, material damage and undefined load paths. Consequently, computational verification often results in strengthening measures being employed which are questionable or unacceptable for the preservation of historical buildings.

In such cases it is sometimes worth carrying out a loading test in situ on the existing structure. A prerequisite here though is that this is carried out without causing damage which might impair the load-bearing capacity or the durability of the object. The application of a reliable, economical and rapidly deployable, mobile on-site measurement system is required.

In this contribution some examples of the reconstruction of the “Neues Museum” at Berlin will show how calculation and experiment complement each other in analysing the load capacity. Thus historical structure components can be admitted to modern utilisation.

![Figure 1: The New Museum Berlin.](image)

## 2 Methods

The method of experimental verification can be most simply described as shown in Figure 2:

During the loading test an existing structural component with an (unknown) effective load-bearing resistance is stressed, subsequent to a prior assessment of the actual condition, with additional applied loads and their effects on the structure (e.g. deformations) are measured. At the start of the test the sustained loads are already present in their actual magnitudes. During the load test
additional external loads are applied. The sum of all loads which represent the
test target load $F_{\text{target}}$, must not be greater than the test limit load $F_{\text{lim}}$ for which
the criteria according to a guideline [1] are decisive.

Figure 2: Safety concept; $\Delta Q = \text{increase of live load}$.

The external applied part of the load can be produced effectively through
internal force circulation using steel mobile loading equipment (Fig. 3). This
solution enables high controllable test loads, is versatile in use and failure-safe
due to the application of hydraulic presses for creating the test load rather than
forces produced by masses with the associated risk of collapse.

Figure 3: Test application (principle vault field).
3 Ceilings of clay pots

The New Museum in Berlin had been built on behalf of Friedrich Wilhelm IV under direction of August Stüler, an alumnus of Karl-Friedrich Schinkel. One major problem had been that the centre of Berlin has a bad foundation soil. To save weight, the intervening floors had been brick-built using fired clay pots with very thin walls, forming one and two-way curved honeycomb shells (Fig. 4).

Figure 4: Clay pots and model of distribution of forces.

A programme to estimate the load-bearing capacity of the clay pot ceilings was developed from findings of a static analysis:

- In situ scanning test of an existing four-section barrel vault for system identification
- Basic investigation of small sample bodies
- Loading investigation of a new built test vault
- Development of a suitable calculation model, static analysis for all clay pot systems
- Confirmation of the calculation model and with this, of the load-bearing capacity by loading tests of selected positions
- Including gypsum floor into the load-bearing investigation and its contribution to the ceiling areas to be built new.

The system identification of the four-section barrel vault was obtained using sampling tests (Fig. 5). Then the existing, preventatively higher dimensioned test set-up was used to carry out successfully an experimental verification of load-bearing capacity for live loads of p = 3.5 kN/m² in order to produce a basis for comparative tests after refurbishing the vault ceiling with topping concrete.

A two-section test vault was erected in an unused area of the New Museum to assess the load-bearing capacity of clay pot vaults, to be built new, as well as for calibration and refining of calculation models for existing load-bearing systems.
(Fig. 6). In addition to the structure-relevant results, important knowledge was gained for the workmanship, call for tenders and quality control (shuttering, positioning sequence of the pots and stones, joint picture, necessary mortar consistency) for this no longer used construction.

![Figure 5: Loading tests of two vaults of clay pots.](image)

![Figure 6: Measurement devices at vault underside (strain, deflection and acoustic emission).](image)

The loading tests were carried out without and with gypsum floor. While the live load without gypsum floor had to be limited to $q = 3.0 \text{ kN/m}^2$, a live load of
q = 5.0 kN/m² could be proved with gypsum floor. A final breaking load test showed a breaking load of \( q_u = 17.8 \text{ kN/m}^2 \) at an apex bending of \( f = 25 \text{ mm} \).

4 Limestone pillars

In the middle axes, pillars from different natural stone materials (sandstone, limestone, marble) have been installed in the individual exhibition rooms (Fig. 7). The pillars are loaded, in addition to their own weight, with higher working loads by the museum operation and, in part, load increases from the installation of an additional technics floor under the roof. The preservation status of the individual pillar elements plays a significant role, as, due to the long period as an unprotected ruin, the materials were exposed to weather influences. Therefore, the pillars had to be thoroughly investigated. 8 pillars still stand in their original positions. 2 undamaged and four broken pillars are stored in the depot. The pillar shafts are manufactured from so-called “Pyrenees marble”. This is not a classic marble, but a limestone of the type “marbre campan melange”. An initially carried out analysis of the pillar shafts showed by far sufficient pay load reserves under the favourable assumption of a homogeneous cross-section.

Figure 7: Ancient picture of pillars and barrel vaults.
However, the calculated proof of the load-bearing capacity was not goal-orientated, as the inner load behaviour of the stone layers is in fact inhomogeneous and could not, even idealised, be satisfactory modelled. The degree of interlocking and the geometric shape is different in every joint and cannot be calculated. Therefore the load-bearing capacity of the pillars must be proved by calculation and experiment (hybrid proof).

With the aid of results from refined radar investigations all pillar shafts and broken pieces were classified with regard to damages, inhomogeneities and crevasses. A multi-step procedure was developed to assess the load-bearing capacity:

- Step 1: Scanning test to assess the joint behaviour
- Step 2: Loading tests of the two removed pillars
- Step 3: Investigation of the pillars installed in NMU

To simplify the tests and avoid the transportation of pillars, a mobile loading device was developed for in-situ use in the pillar depot (Fig. 8).

The load introduction is carried out with 4 hydraulic presses via Dywidag pulling rods. Elastomer foil-clad sliding bearings (Teflon) excluded a constraint of lateral expansion at the pillar ends. The pillar shafts were loaded centric and eccentric, lying, in a mobile test press.

![Figure 8: Loading tests of limestone pillar.](image)

The tests showed that both pillar shafts are sufficiently safe for centric loads (Safety factor $\gamma > 2.1$). However, even for small eccentricities ($M/N = e \leq d/8$), the permissible normal load must be restricted due to the inhomogeneity of the limestone. The determined wide scatter range of the elastic constant supports the assumption that also the material strengths scatter widely.
5 Mosaic floor

To clarify the later usage possibilities (accessibility for foot traffic, transportation, exhibits) the permissible contact pressure of the mosaic floor, under preservation order, has to be proved. This information is also important for loading tests of historical floor ceilings, as the loads must be introduced via the floor. Previous tests classified the floor according to its layer construction into three status classes (good, medium, bad). The pre-tests were to be verified by loading tests (Fig. 9). For this, special precautions against damages due to load introduction had to be taken.

The results of all 36 tests with four different loading plate areas did not confirm the pre-tests, as no clear difference was detectable between the three status classes. A limitation of the areas was recommended for future usage, which does not exceed a contact pressure of $\sigma = 4.0 \text{ N/mm}^2$.

![Figure 9: Equipment for loading tests of mosaic floors.](image)

6 Cast iron girders

A further typical construction type for ceilings in the New Museum is domed ceilings between cast iron girders. The load-bearing safety for current requirements could not be proved by calculation neither for the vaults nor for the
cast iron girders. Loading tests, before and after reinforcement of the girders with FCK- bars, should verify

- The restoration success, as well as
- The fitness for use and
- The load-bearing safety

of the ceiling construction as a substitution for a building supervisory authority approval in an individual case (Fig. 10).

The planned test loadings could all be achieved. While the test load, as planned, remained restricted to \( q = 2.0 \, \text{kN/m}^2 \) in the un-reinforced status, the traffic load of \( q = 5.0 \, \text{kN/m}^2 \) could successfully be proved at a quasi linear-elastic behaviour in the reinforced status. The restoring success was quantified by clearly reduced building reactions after the bar reinforcement.

![Figure 10: Loading tests of ancient ceilings of cast iron girders.](image)

### 7 Conclusion

If computed 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 using some examples. The experimental method opens up chances of retaining building structures, particularly for buildings subject to historical preservation.

For the New Museum, the most important task for the engineers was to recognise at an early stage that pure theoretical approaches would not achieve the goal and, further more, all persons involved in the building, have to be involved in a moderated discussion. For the historical structures of the New Museum, concepts could be evaluated with the support of the experimental load-bearing analysis, which allow an adequate use. The work on the building substance of the New Museum, under preservation order, have started in 2004.

References