Zukunft Bau

SHORT REPORT

Title

Adobe Masonry: Design and construction principles for a wide application in residential construction, under consideration of climatic conditions of temperate zones at the example location Germany
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Motive / Initial Position

Based on the evidence of historical earthen buildings as well as on structural engineering calculations and building physics, our research is supporting the assumption that masonry with modern, large format adobe blocks have a much higher performance potential than currently assumed. This applies particularly to its sustainability. The biggest apprehension until today relates to the water sensitivity of this building material in regard to structural stability. This can be countered however with reliable, prophylactic safeguarding principles of construction.

Scientific scope

Material tests and calculations on the strength behavior of adobe masonry

In the following section, essential tests relevant for the strength behavior are presented, which include the dependency between loss of strength and ambient moisture. The precision block compressive strength test was carried out in accordance with DIN 18945 (2013).

Adobe – compressive strength depends on the relative humidity rH

In Figure 1 it can be seen that, regardless of manufacturer, block geometry and the composition of the material, the compressive strength decreases with increasing humidity (at a constant 23 ° C).

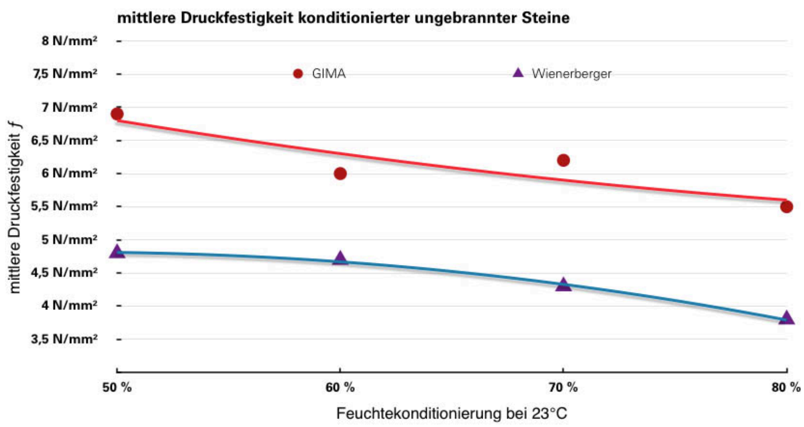


Figure 1 Reduction of compressive strength with increasing rH - conditioning

Interestingly, however, there is an approximate constant reduction. The reduction of the compressive strength in the conditioning of 80% rH for both types of blocks leads to a compressive strength loss of max. 20%. For the test batch with the conditioning of 60% rH, an unexpected loss of strength was observed for the GIMA test blocks, which was not noticeable for the Wienerberger test blocks. As has emerged in the course of the work, this could be attributed to a pre-weakening of the block material, namely a more or less strong longitudinal center drying crack.

Adobe masonry – compressive strength test

A total of four rows consisting of at least three masonry test specimens according to DIN EN 1052-1 (1998) were tested. Two different test pieces were used for the test specimens. For the characteristic compressive strength can be determined according to 10.2 of DIN EN 1052-1:

$$f_{k,GIMA} = \frac{f}{1.2} = 3.63 \text{ N/mm}^2 \quad (1)$$

$$f_{k,WB} = \frac{f}{1.2} = 2.36 \text{ N/mm}^2 \quad (2)$$

Elastic modulus according to DIN EN 1996-1-1 (2013), see 3.7.2 (paragraph 1), or DIN EN 1052-1 (4.2):

$$E = \frac{F_{i,max}}{(3 \cdot \varepsilon_i \cdot A_i)} \quad (3)$$

$$\varepsilon_i = \frac{\Delta l}{\left(\frac{h_s}{3}\right)} \quad (4)$$

Measurements elastic modulus for masonry bodies with GIMA test blocks:

Test specimen series GIMA_3 or GIMA_4: E = 1,500 N / mm^2 or 1,900 N / mm^2

Measurements elastic modulus for masonry bodies with Wienerberger test blocks:

Test specimen series WB_TM or WB_Ps: E = 1,000 N / mm^2 or 1,200 N / mm^2

For the modulus of elasticity, it should be noted that in masonry pressure tests according to DIN EN 1052-1 with different test blocks, a comparable value with respect to the modulus of elasticity results in terms of the factor range:

E = 420 - 520 · f_k

From the test values of adobe masonry test specimens with the GIMA test blocks the limiting factor for the carrying capacity according to EC6 (see DIN EN 1996-1-1, cf. Meyer & Schlundt (2014)) can be calculated to be used for further tests, e.g. a 3m high wall.

$$N_{Ed} = N_{Rd} = \Phi \cdot t \cdot f_d \quad (5)$$

Φ → Eccentricity of the applied load: for further tests: central load introduction Φ = 1

t = 240mm

$e_i = 0 \geq 0{,}05 \cdot t$ will not be considered

buckling length h_{ef} = ß · h = 0.75 · 3.00 = 2.25 m

reduction factor:

$$\Phi_m = 1.14\left(1 - 2\frac{e_{mk}}{t}\right) - 0.024\frac{h_{ef}}{t} \quad (6)$$

according to National Annex NA to DIN EN 1996-1-1 Annex G

$$\Phi_m = 1.14 \cdot 1 - \ 0.024\frac{2.25}{0.24} = 0.92$$

$$f_d = \frac{f_k}{\Upsilon_M} \tag{7}$$

Limit state load bearing capacity of the masonry to be tested:

durability factor ζ = 0.85

reduction factor Φm = 0.92

N_{Ed} = 0.92 · 0.85 · 240mm · 3.63 N/mm^2 · / 1.5 = 453 N/mm = **453 kN/m**

If the decrease in strength is considered by permanent increased max. expected humidity conditions, this results in the ultimate limit state:

80 % rH at 23 °C → 20 % reduction of compressive strength

N_{Rd}, 80%rH = 0.92 · 0.85 · 240mm · (3.63 N/mm^2 – 3.63 N/mm^2 · 20 %) / 1.5 = 453 kN/m · 0.8

= 362 kN/m

Fire stress test – load-bearing adobe masonry

Two fire tests were carried out. A non-load-bearing adobe masonry wall was tested according to DIN EN 1364-1 (2015) and a load-bearing wall according to DIN EN 1365-1 (2013). The non-load-bearing wall was tested with the test objective EI 30 and achieved the classification EI 90 without any problems.
The load-bearing wall was loaded with **$N_{Ed,fi}$ = N_{Rd} · 0.7 = 317 kN/m**, according to DIN EN 1996-1-2/NA (2013), cf. also Meyer & Schlundt (2014), and tested with the test objective REI-M 90 and achieved the classification EI 60 after more than 68 minutes of loading.
A compressive stress of 1.32 N/mm^2 was achieved, which the wall to be tested withstood without any problems during the 68 min test. Excluding a structural weakening of the blocks due to the manufacturing process, a successful achievement of the test goal can be expected during a renewed fire stress test.

Technical tests - design and manufacture

The following is an insight into further research findings.

Construction site / build up adobe masonry / prefabricated element production

On the construction site, masonry with unfired blocks can be erected using the usual methods. The application of clay thin-bed mortar is carried out with a plaster laying machine and is smoothed to the required flat mortar layer thickness using a specially developed smoothing carriage.
Talks with blocklayers at the construction site of the new Zinsendorf grammar school building in Herrnhut confirmed that the non-load-bearing adobe masonry walls were built with modern, large-format adobe and clay mortar, as usual with conventional blocks and cement-bonded mortar.

It is possible with modern adobe masonry to produce prefabricated elements in the factory to increase the degree of prefabrication, for example, to minimize the construction time:

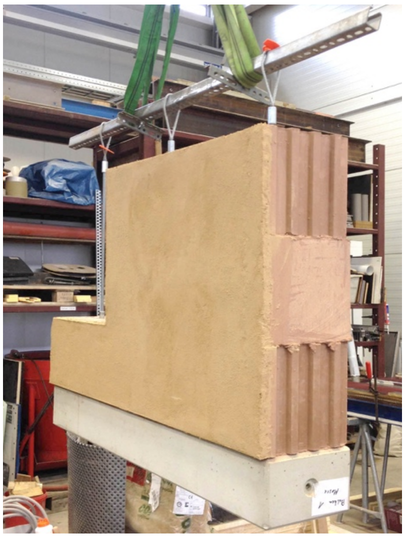


Figure 2 Lifting test wall element - avoidance of stresses in masonry Variant I: Lifting traverse - no transverse forces occurring

Figure 3 Assembling and locking the individual elements for model bodyshell construction

Construction to be open to diffusion

Depending on the ambient humidity, unfired blocks absorb water or release it back into the environment. In order to be able to guarantee moisture transport from the inside to the outside and to ensure long-term stability, the wall structure should be designed to be open to diffusion.

Further studies carried out

For the modern adobe masonry, further tests were carried out which could influence the load-bearing capacity. For the completeness of the research work, further experiments should be mentioned here:
It was examined whether and how the modern adobe masonry creeps. It was found that the adobe masonry was largely completed in the first six months. When the masonry is fully loaded, a comparatively very low creep behavior can be expected, which is unlikely to have any effect on the overall structure. The creep behaviour was measured regularly over more than six months using three test specimens and then estimated over the long term using a regression model according to Ross (1937) or Kvitsel (2017) with high accuracy.
In addition, the adhesive shear strength of the clay mortar used was tested according to DIN EN 1052-3 (2007). DIN EN 1996-1-1 (2013) shows that the shear strength of masonry increases under load, especially in the case of precision block masonry.
In addition, the driving rain resistance of the exterior wall construction with curtain walling was investigated using various methods based on Cziesielski & Maerker (1981) and DIN EN 13050 (2011). The result shows that, in compliance with the construction rules, the masonry does not get wet even during heavy and permanent driving rain.

We simulated the building physics processes of essential constructive connections and wall constructions using the computer program Delphin of IBK of the TU-Dresden. To feed the program with authentical data we examined four wet cells (baths) of multiheaded households under real conditions approx. 11 months. The result is that the maximum permanent relative humidity of 70 % is not normally exceeded. This value was used as the initial value for the component simulation. As a safety value a reduction of strength of max. 20 % for the room-bounding walls of wet cells made of load-bearing adobe masonry should be considered.

Design and Construction principles

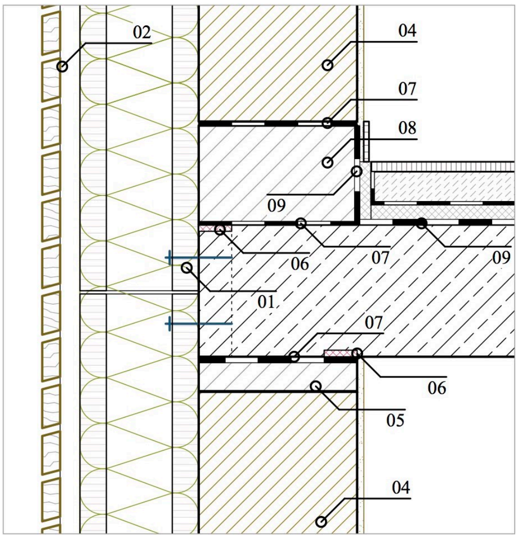
In the research work on which this manuscript is based, planning principles for the building design and construction were derived on the basis of the empirical results and building physic structural-component simulations. The design and construction sets were illustrated in a component catalogue for all essential connection details for a residential building. In the following sections, the planning principles are only summarized in the planning guidelines and exemplarily presented with two construction details.
The main principles which characterize the processes of design and construction are to be emphasized:

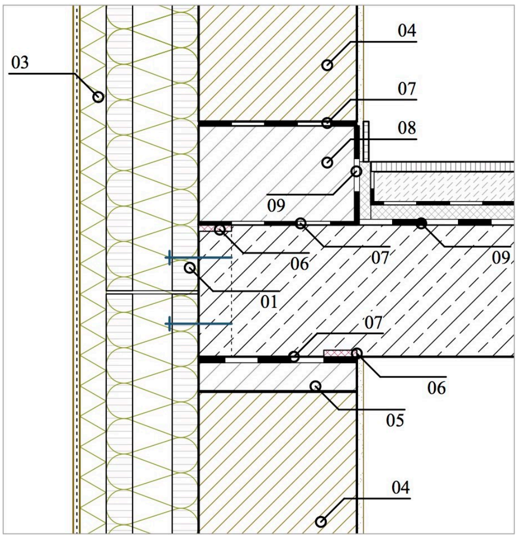
1. **Damage prevention**
   - New construction: design, planning and execution period
   - Accompanying use: Safety and maintenance concept
2. **Redundancy**

Damage prevention principles serve to reduce potential sources of damage in the design and construction of comprehensive planning. Redundant measures are taken to avoid existing damage due to material failure, for example. A redundant system then takes over the function of a possibly damaged system. This is especially the case for sealing in the roof area and for emergency protection in wet areas and wet cells. A maintenance concept is essential.

Exterior wall construction

The exterior wall construction is decisive for the load-bearing capacity of the adobe masonry construction. To prevent moisture from accumulating in the masonry and to reduce the load-bearing capacity, the wall structure must be constructed with a diffusion-open external wall insulation. At least two facade types can be used: the thermal insulation composite system (ETICS) and the curtain wall facade (CW-F). Both facade types are manufactured with renewable raw materials, in particular the insulation and the facade substructure. Both facade types can be fastened from ceiling to ceiling, so that fastening to the adobe blockwork is not necessary. The non-adhesive fastening also enables the masonry to be recycled in a single type.
Typical for the ceiling connection is that the masonry begins with a first layer of waterproof blocks, which ends at least 5 cm above the finished floor. In wet cells and wet areas, the raw ceiling including the first layer of waterproof blocks is fully sealed. Intermediate waterproofing, the horizontal barriers, prevent rising water into the adobe masonry, especially during the construction phase. The last layer of blocks on the adobe masonry also consists of waterproof blocks which, when a concrete ceiling is applied, together with a seal, protect the load-bearing masonry from water.
In order to avoid edge pressure and the resulting potential local damage to the adobe construction, centering strips made of a soft elastic material are inserted.





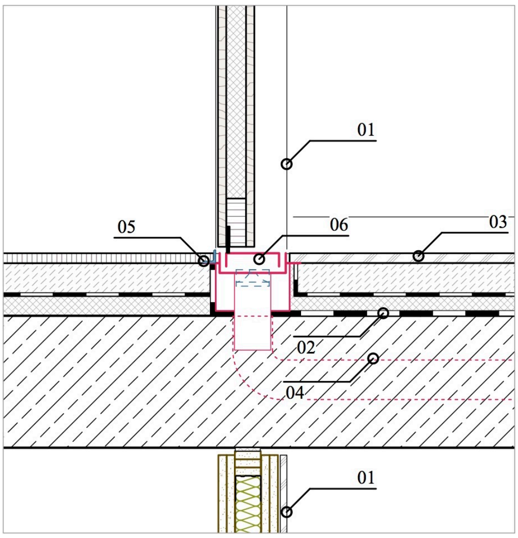
01 Substructure facade construction double web beam of wood-based material fixed from ceiling to ceiling, **02** curtain wall, **03** thermal insulation composite system, **04** load-bearing adobe masonry, **05** water-resistant keystone, **06** centering strips, **07** horizontal barrier, **08** first layer of water-resistant stone, **09** surface sealing only required in wet cells (bathroom) - other living spaces are produced without surface sealing

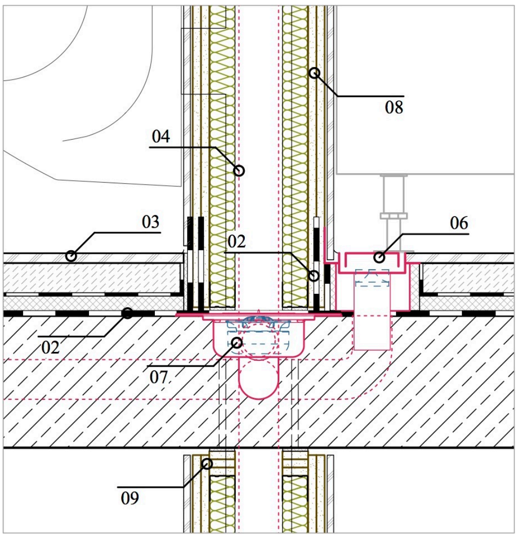
Figure 4 wall construction CW-F

Figure 5 wall construction ETICS

Constructive emergency safeguards using the bathroom as an example

In wet cells and wet areas, emergency drainage discharges excess water in a controlled manner in the event of damage, so that no water can damage the adobe masonry wall. The drains, which can be inspected, are, for example, effectively installed in the door sill. All water-carrying pipes are routed in a separate shaft, which consists of a water-resistant material and also has an internal emergency drainage system. In addition, water-bearing pipes are monitored by pressure switch systems and flow limiters.





01 non-bearing inner wall (adobe masonry possible, if no shaft is integrated), **02** surface sealing, **03** floor structure, screed on separating layer and waterproof impact sound insulation, **04** redundant emergency drainage system, **05** starting angle, **06** Installation of drainage pipe (DN50) with sleeve, with odor and vermin protection, **07** Installation of drainage pot DN50 with silicone lip seal, odor and vermin protection, **08** Fire-resistant shaft wall - dry wall system for sanitary, **09** Sliding ceiling connection

Figure 6 emergency drainage door threshold

Figure 7 Water bearing shaft wall

Conclusion

Even with a maximum reduction in strength of 20% due to moisture, a compressive strength of 1.50 N/mm^2 still exists for the ultimate limit state of the load-bearing capacity. With the fire resistance of more than 60 minutes, that it is possible to build multistorey residential detached houses. This shows that the efficiency of modern adobe masonry is higher than currently assumed, provided that the structural and technical building safety principles for modern adobe masonry developed in the work are adhered to.
Unfired blocks were used for the material tests which are intermediate products from the block industry and could not be further processed by the manufacturer due to the small batch size. These still showed various weaknesses in the tests, e.g. considerable shrinkage cracks. However, the manufacturer of the bricks states that he is able to eliminate these imperfections and produce adobe precision flat blocks. Despite the mentioned imperfections the results of this research suggest that the performance will be a) more constant in relation to the strength of the individual blocks and b) higher in relation to the compressive strength of the completed walls.

Key data

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