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Timber-masonry composite structures – a bearing structure model

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Abstract

Timber is the principal material used in old framework buildings. Present research suggests that the vertical loads are exclusively applied to the timber girders, but the timber frame can not bear all vertical loads if the posts are spaced wide apart. These structures have nevertheless remained stable for over 100 years.
Our present knowledge is not sufficient to determine the ultimate load-bearing capacity of this type of construction which has gone out of use.
The Institute has conducted practical tests and theoretical studies which make it possible to forecast buckling failures for wall systems as a function of vertical load.

1 Structure and material

1.1 Structure

Stud walls are framework structures in which the spacing of some posts equals their length, giving square infill areas in a number of cases. There is normally no strutting, with the exception of the bays nearest to the outer wall, and the attic.
The cross section of the pine timber posts suits the wall thickness which is ½ brick (12 cm thick). The horizontal girders are head rails arranged under the floor beams. (Fig. 1)
The masonry is butt-jointed to the timber structure. Recesses in the posts and mortar-sealed joints between the posts and masonry are rare. Equilibrium moisture

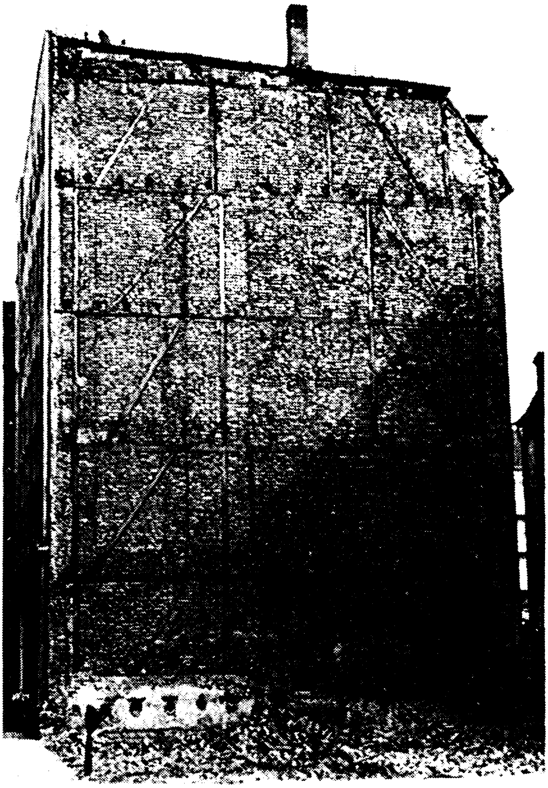

Figure 1: building with the descripted form of framework

was achieved in covered open buildings by allowing them to stand empty for one winter before putting in windows, followed by alternate heating and airing to drive out more moisture.

1.2 Material

To simplify classification, timber quality can be described as grade 10 (DIN 4074) in present terms (pine wood). The carpenters of the time selected timbers by appearance, and members intended for high loads will often have been of an even better grade, but this will be neglected here.
Due to a strong demand for bricks, the number of clay pits and brick yards rose rapidly, with new types of bricks being developed and patented all the time. Brick quality therefore differed largely even within a single building.
In our studies, three different strength classes for bricks (Fig. 2) were found in four walls of two buildings erected almost at the same time (1874 and 1876). For another

building with inner walls made of porous bricks, a statistically significant average compression strength was established.
Mortar quality is very much a function of aging, and chemical analysis of mortar composition at the time of production allows no conclusion as to its present compression strength. Partial sampling so far would put most of the masonry structures only in mortar group I. Following Bröcker's findings, the admissible compression stress is assumed to be σ=0.6N/mm² (Bröcker, [1]).

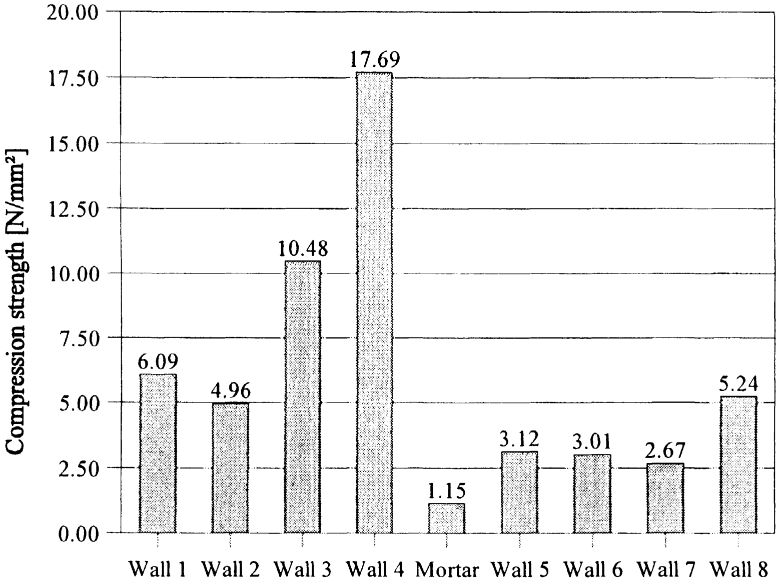

Figure 2: Probable lower value of the compression strength of bricks/mortar in the eight walls tested

2 Models

2.1 Framework

Load transfer in framework structures is by posts which need not bear bending loads. In conventional framework walls, the members form joints which more or less give this effect. Stiffened by (diagonal) struts, the compound unit as a whole functions as a slab.
Infill walls render the building shell and/or partitions impermeable. No allowance has so far been made for the load-bearing effect of these infills which were put in afterwards and consisted of clay, twisted straw or masonry. In most cases, the stability of a structure/building can be represented by a bar model. In cases where the infill is given a considerably greater share in the load-bearing structure, the bar

the infill is given a considerably greater share in the load-bearing structure, the bar model no longer represents the actual load transfer.

When it is assumed that the load-bearing function is performed by timber posts alone which are spaced more than 2 m apart, then a stud wall reaching down to the ground floor carries approx. four times the admissible load – without failure. The model of the conventional framework wall in this type of structure, then, does not reflect the actual load-bearing behavior.

2.2 Masonry diaphragm held on both sides

At the average spacing found, the timber posts accounted for less than 10% of the wall area. In these cases, the infill provides a great deal of the overall stiffness, which in turn depends on the compression strength of the masonry.

When a stud wall is seen as a slender cross wall, assumptions can be made for the masonry instead of the timber posts.The horizontal rigid head rail suggests that the linear load on the snap headers is evenly distributed. In a first assumption, the vertical edge of the infill area is not held, meaning that the cross wall is seen as a one-way static system held on both sides.

When the infill is very high, however, the load-bearing capacity of the slender wall is greatly reduced by the risk of buckling, and the resulting loads cause the infill masonry to fail.

2.3 Refinement of boundary conditions

A more realistic description of load-bearing behavior is expected when the infill is approximated to a slab, which makes the boundary conditions particularly important. The fixing moment from the head rail and burden can not be transferred to the vertical edges unconditionally.

Our own studies of the area of contact between the timber post and masonry have shown that in the great majority of cases the infill was butt-jointed. In the absence of positive locking, forces can only be transferred by friction. Another critical element is the cross joint which is ½ brick (12 cm) away from the timber post. If force transfer by the cross joint is excluded, the shear forces have to be sustained by 50% of the bricks.

Deformation of the wall out of its plane causes strutting between the posts (Euler & Biegholdt [2]). The frictional force then exceeds the reaction required to stabilize the vertical edges of the cross wall. This means that a four-sided support can be assumed for the infill area.

In contrast to DIN 1053-1 (1996), however, this support is not rigid but characterized by the flexural rigidity of the timber post. The conditions of support for the posts are defined by mortise and tenon joints in the upper and lower head rails. These transfer the horizontal forces to the adjacent solid or stud walls and act as stiffening slabs, an effect which has been sufficiently demonstrated even in steel and concrete frames (Schmidt [5], Wang [7]).

2.4 Equivalent timber-masonry bar model

Recording the combined load-bearing effect of framework and masonry cross walls is expected to approximate the actual load-carrying behavior. The lateral timber posts prevent the infill from buckling out of the wall plane. When allowance is made for the variation in cross section rigidities, then most of the vertical load is transferred by the masonry. Due to their stiffening effect, the timber posts mostly have to carry horizontal loads. In a first step, the cross wall is represented as a socketed bar which is hinged on both sides. Halfway up the wall the restrained transverse bending helps to stiffen the bar. Due to the flexural rigidity of the timber post, the "transverse beam" is an elastically bedded bar whose cross-sectional width is assumed to be half the wall height. (Fig. 3)

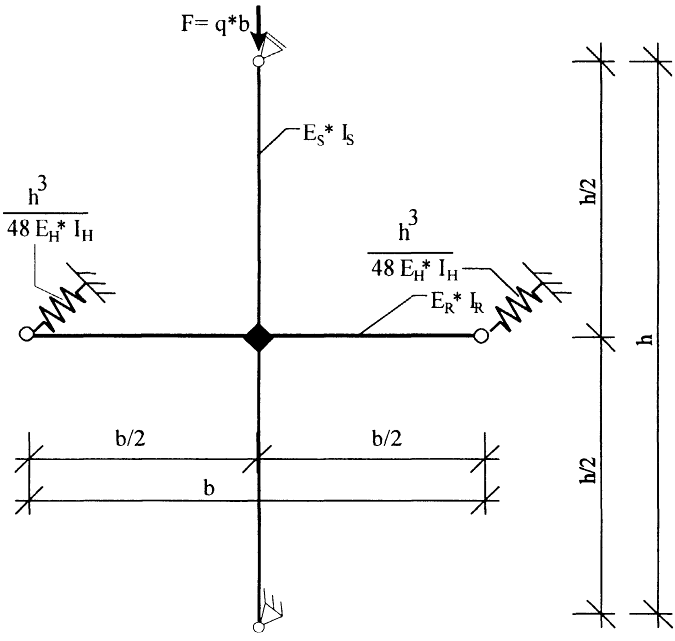

Figure 3: Barmodel with springs to allow for the rigidity of timber posts, head rails and masonry

The elastic rigidity of the lateral support is covered by the flexural rigidity of the timber post. The elastic moduli of the masonry are equated for both the horizontal and vertical directions.

For the vertical bar, a parabolic predeformation with a max. value of h/300 in the wall center joint perpendicular to the wall plane is assumed, which corresponds to the undesired eccentricity acc. to DIN 1053-1 (1996).

The rigidity conditions can be used to determine the displacement from the wall plane resulting from the vertical load F (Fig. 4).

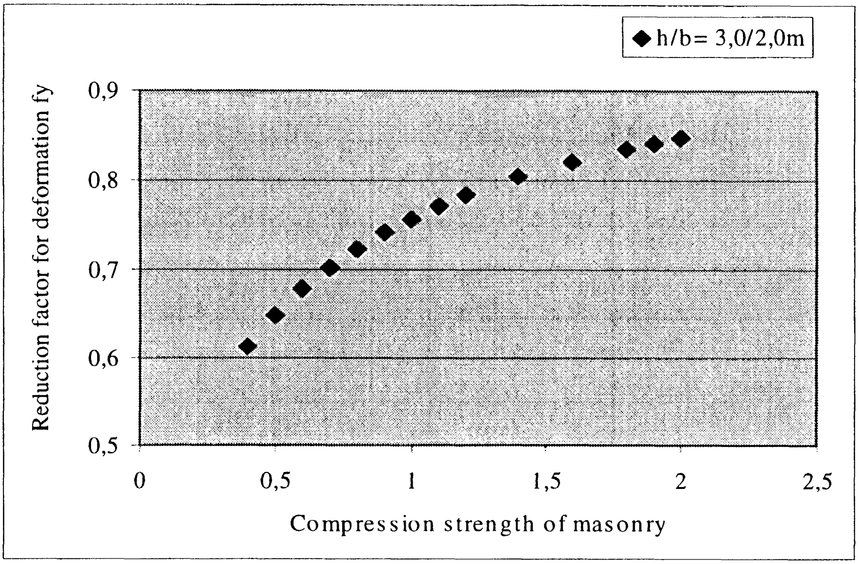

Figure 4: Reduction factor f for deformation f_y as a function of masonry strength

Reserve load-bearing capacity can therefore be detected by improving the masonry model. The stabilizing effect of the timber posts on the vertical edges, as in the assumption of a cross wall held on four sides, leads to a reduction in buckling length. The timber post is almost free from vertical loads and subjected to bending stress.

2.5 Slab model

Assuming a wall held on four sides, the infill can be designed as a slab. With the equivalent bar model, a buckling length reduction to b/2 can be calculated because the infill geometry generally results in b<h. The stress is induced by the burden and planned eccentricity which is also calculated acc. to DIN 1053-1 (1996). The deformation of the lateral vertical edges generates an extra element of elastic bar deformation and creep deformation with regard to the infill (see also 2.3). When the admissible stress is maintained, a correction value for the effect of lateral deformation is to be used in slab design. This means that the internal forces for the selected system have to be determined acc. to the 2^{nd}-order theory. The computational model acc. to (Mann & Fasser [3]) compares the eccentricity-related bending stress on the wall with that from a horizontal load. The horizontal reaction values can be determined and at the same time indicate the deformation of the lateral timber posts, which in turn enables calculation of the extra share of

deformation f_2 at the center of the wall, and the admissible burden. The slab model only deals with the infill area. The timber members represent the boundary conditions for the slab, meaning that the timber posts and head rail have to be computed with regard to stress from the slab in order to exclude buckling failure, for instance.

3 Practical tests

3.1 Description

The model of the cross wall elastically supported on the vertical edges was to be verified by practical tests on four walls with different geometries in existing buildings. Load application was by hydraulic cylinders and two yokes arranged on the two horizontal edges of a wall. Tie rods were used to apply defined loads (Fig. 5), and the test was concluded after displacement-controlled initial cracking. The

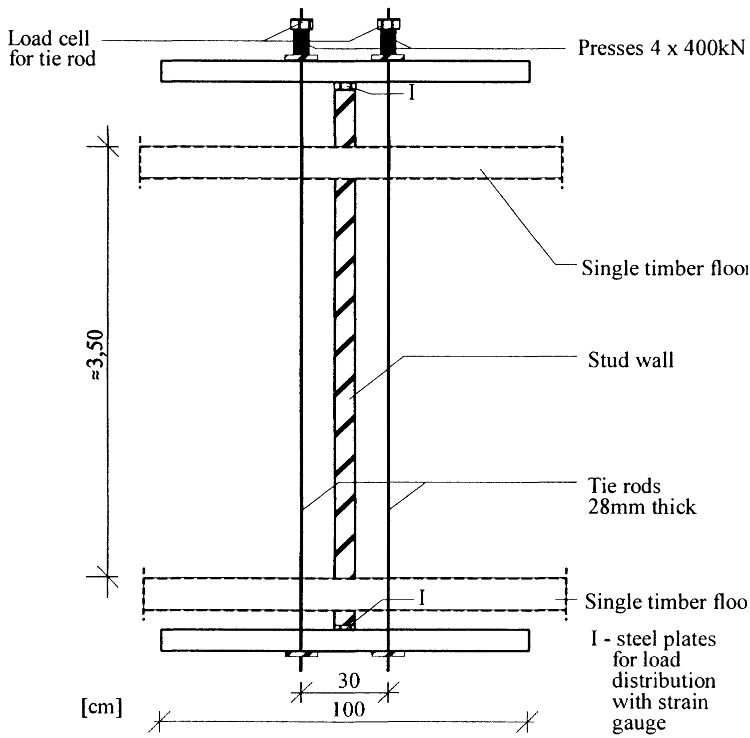

Fig. 5: Model of load application to determine deformation out of the wall plane and failure loads

deformation of the infill and timber posts out of the wall plane as a function of loading was measured with displacement transducers.
The use load and failure load can be determined from the load deformation path. System failure is characterized by failure of the masonry infill. The deformation values measured for the masonry wall enable comparison with a slab held on all sides.

3.2 Results

The tests resulted in failure stresses which far exceeded the fundamental values of the admissible compression stress. For test 3 is in Fig. 6 given a grafic for the deformation in vertical direction of plane surface. On the right side is the post, on left side a wall.

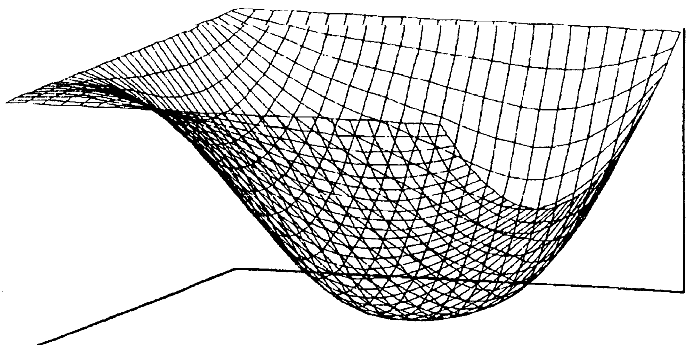

Figure 6: deformation fy in results of vertical force (test 3)

Acc. to (Pieper [4]), the safety factor for experimentally determined load-bearing capacities of existing structures can be reduced to $\gamma = 2.0$. Thus, for low masonry strengths, the findings in Fig. 7 show an admissible stress in the wall which roughly corresponds to the fundamental value of admissible stress. (The freak value in test 3 is due to the fact that the test had to be broken off before reaching breaking strength because preliminary damage had caused a shear wedge in the wall which was threatening to force the outer wall outward.)

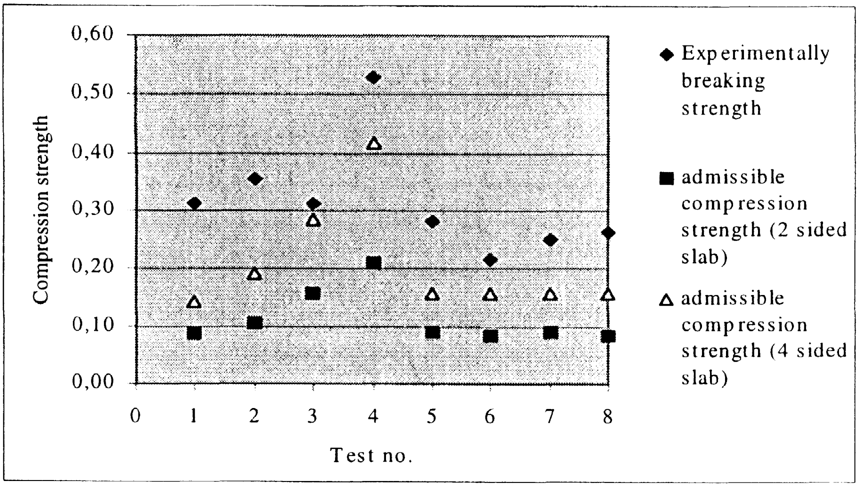

Figure 7: Experimentally determined and admissible compression strengths of walls

4 FE analysis

There are financial and technical limits to the number of practical tests which may be conducted. The finite element method (FEM) is therefore used to supplement the findings obtained from tests and the simplified model and to determine the stability of structures.

The results of load-bearing behavior analysis were in good agreement with a comparison calculation (Siebeneichler [6]) using FEM (ANSYS).

The load-bearing behavior was rather ductile, as shown by the force deformation curve for the center of the wall and a selected geometry. Comparison calculations for a number of height-width ratios and a range of brick strengths have indicated significant load reserves resulting from the consistent formulation of the boundary conditions for a slab held on four sides. In a departure from the bar model, the lateral vertical edges showed no predeformation. The lateral support relative to the timber post was represented by a rigid contact element in the earlier test calculations.

When the compression strength of the infill masonry is low, the deformation capacity generates considerable strutting forces between the timber posts. The vertical load on the posts is low, and most of the loading from the infill is horizontal.

Compared with a design acc. to DIN 1053-1 (1996), greater sustainable loads have been found for the system as a whole, generally giving a higher load-bearing capacity with safety levels also depending on geometry and materials.

5 Prospects

Assuming a stiffening anti-buckling effect of the timber posts and vertical load transfer via the infill, the loadbearing action of the masonry which has so far been neglected indicates great reserve load-bearing capacities for the compound unit as a whole. The studies described suggest that the load-carrying capacities of stud walls are better described by the composite structure design model.
This makes it possible to determine loadbearing safety and enables more accurate assessment of these old structures by planners. It also facilitates the preservation of historic buildings which often have to sustain higher loads when converted to modern use, and reduces or eliminates the need for reinforcement or replacement.
The model described here also allows the quantification of load reserves for conventional framework buildings and explains the considerable load-bearing capacity of framework slabs compared with designs as rod bearing structures. Various infill materials with different rigidities can be included in the design.

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