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EXTERNAL STRENGTHENING OF MASONRY STRUCTURES WITH NATURAL FIBERS

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ABSTRACT

Masonry construction has a very long tradition and is the most commonly used type of construction. Because of its simple and economical production it will continue to be of major importance also in the future. In particular, its properties in terms of building physics ensure that it remains economically relevant. Nevertheless, low tensile, flexible, and shear load bearing capacity can be a great disadvantage of masonry. In countries with high earthquake risk and social and economic problems, construction materials of poor quality are being used quite often. Especially in rural areas, use is made of bricks and mortar of low tensile strength classes that are hardly used any longer in Europe. The masonry panels used as braces in one and two storey constructions are hardly able to withstand earthquake loads and display a low shear capacity. Since other types of construction are impossible to apply for economic and ecological reasons, these constructions should be strengthened retrospectively after

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they have been erected. One method used in recent years is the retrospective strengthening using fiber composites applied adhesively to the masonry surface. The most commonly used fibers are carbon fibers (CFRP) and glass fiber-reinforced synthetic materials (GFRP). These materials in combination with synthetic resin systems are already common for example in Switzerland and the USA, but because of their high cost and low availability are hardly used in earthquake regions with economic problems, such as in the Near and Middle East or Latin America. In addition, modern reinforcement materials such as CFRP and GFRP are too rigid for "weak" masonry and can lead to compatibility problems. For this reason, clearly less expensive materials that are adapted to properties of the masonry described are necessary. Natural fibers in combination with filler compound of an epoxy resin base or epoxy resin enriched fine filler on a cement base can, for both cost and compatibility reasons, provide a very attractive alternative. Test results on masonry strengthened with such natural fiber textiles and theoretical investigations as well as a pilot application to the World Cultural Heritage site Arg é Bam (Iran) will be presented. The research whose results are reported in this contribution was conducted at the Institute for Materials Engineering (Professor M. Schlimmer) of the Faculty of Mechanical Engineering in cooperation with the Institute of Structural Engineering (Professor E. Fehling) of the Faculty of Civil Engineering at the University of Kassel. The pilot project at the world heritage site was implemented by the first author in a period of self employment with the support of UNESCO and Sika Schweiz AG.

Key words: External Strengthening, Natural Fibers, Earthquakes, Masonry Structures, Seismic Retrofit, Fiber Reinforced Polymer (FRP).

Introduction

In order to reinforce load bearing walls exposed to earthquakes the bearing resistance and ductility should be increased. With increased ductility the deformation capacity of the bearing structure can be increased. Between these two variables there is a close reciprocal relationship. A bearing structure must therefore display a high bearing resistance or low ductility or vice-versa. It can also of course have a medium bearing resistance and a medium ductility. All these possibilities are able to protect the building from collapse (Figure 1).

From observations and experience of numerous research studies and damage from the horizontal effects of wind and earthquake four different global failure types can be distinguished. Figure 2 contains a schematic representation of the various failure types.

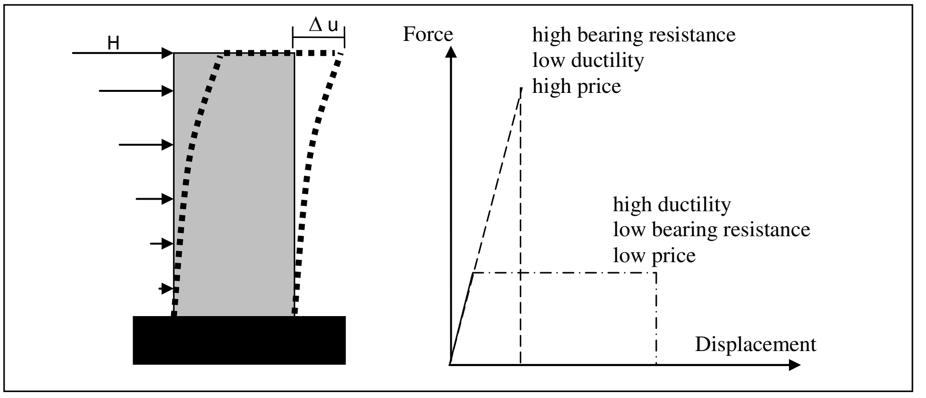

Figure 1 : Various possibilities for the design of a bearing structure for an earthquake of a particular scale Error! Reference source not found.]

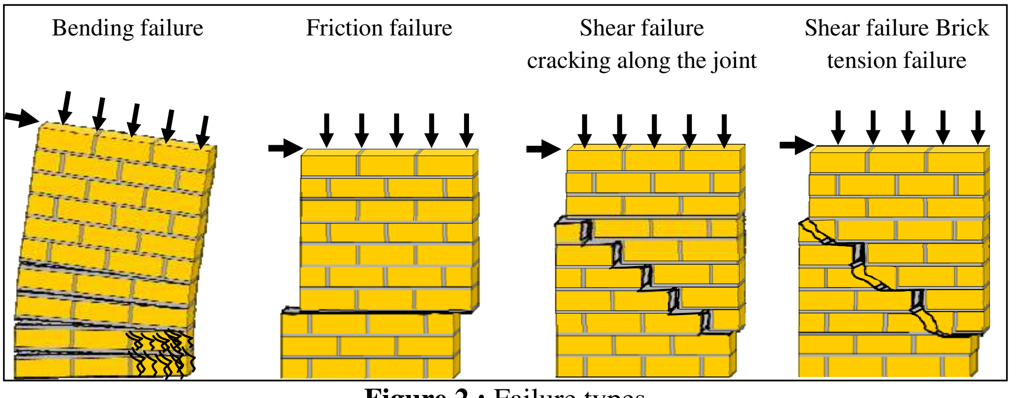

Figure 2 : Failure types

In detail the failure types can be divided into:

1. Bending failure: This type of failure arises principally with thin masonry structure panels. In this case the stress on the masonry is due to bending. Depending on the tensile and compression strength of the masonry it is possible for the joints to develop cracks or for the masonry to fail on the compression side.
2. Friction failure: This type of failure occurs when the vertical load is clearly low in comparison with the horizontal load. In this case the crack develops along an entire horizontal joint.
3. Shear failure: Because of the combined load critical principal compression and principal tensile stresses occur, which for low strain and weak bonding between brick and mortar lead to the step-shaped cracking along the layer and butt joint. In the case of good bonding and lower brick strength the crack runs through the bricks, and the failure occurs in a brittle manner because of brick tensile failure.

In reality one type of failure rarely occurs alone, and mostly it is a mixture of the different types of failure. In Figure 3 various types of failure type can be observed in a bearing wall.

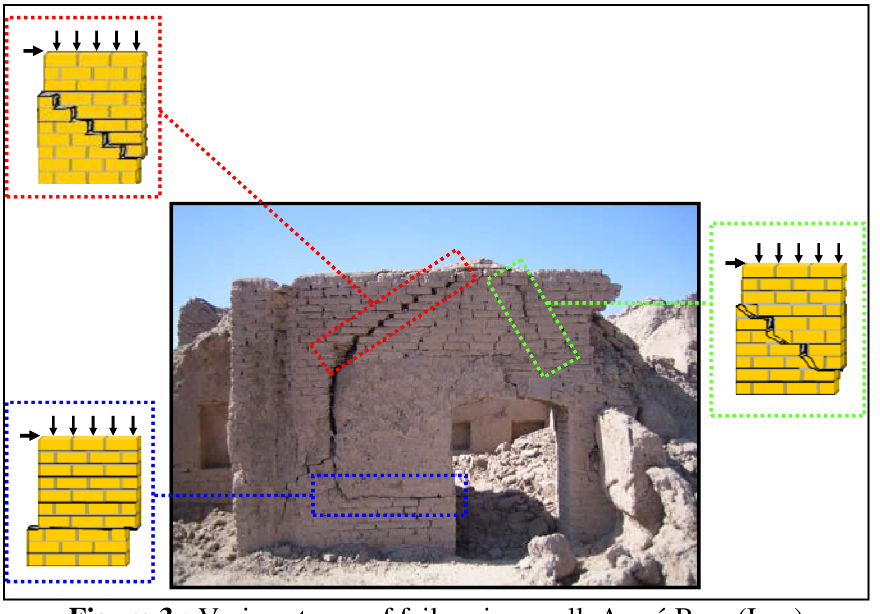

Figure 3 : Various types of failure in a wall, Arg-é Bam (Iran)

Idea and Study Analysis

Although natural fibers have been in use for several millennia in buildings (e.g. mud plaster reinforcement with straw) systematic studies, particularly on reinforcing masonry walls, have so far never been made. Natural fiber reinforcement can consist of flax, hemp, jute, Abacá or other natural fiber types. Within the framework of this study jute fibers have been selected for reasons of economy and availability. In the comprehensive, to some extent novel studies, adhesive, natural fiber composite and small masonry studies were made. In the composite studies various fiber orientations were studied in terms of the main tension direction (direction of force). The aim of the study was to determine the properties of the composite depending on the fiber orientation. Because large wall tests (construction part tests) are expensive and time and resource consuming, representative test areas in the form of small masonry areas were selected in order to simulate load states.

To determine the initial shear strength three-brick tests were carried out in accordance with DIN EN 1052-3 (Figure 4). In this study unreinforced and reinforced sample areas should both be studied. For a pre-selection of the various adhesive systems and woven matting the three brick test without mortar is the first to be carried out. Instead of mortar, a polystyrene plate (10mm) was used to maintain distance between the bricks (Figure 4/a). A horizontal/vertical orientation [0°/90°] and a diagonal fiber orientation [+45°/-45°] against the main stress axis were tested. The effect of the reinforcement directly without mortar was investigated. In the case of bond shear strength with mortar and without reinforcement the pure initial strength between mortar and brick can be determined (Figure 4/b). The bond shear strength is defined as a bonding between brick and mortar, where the load is introduced parallel to the mortar joint without perpendicular stress. With the latter test variation the effect of mortar and reinforcement can be analyzed in combination with each other (Figure 4/c).

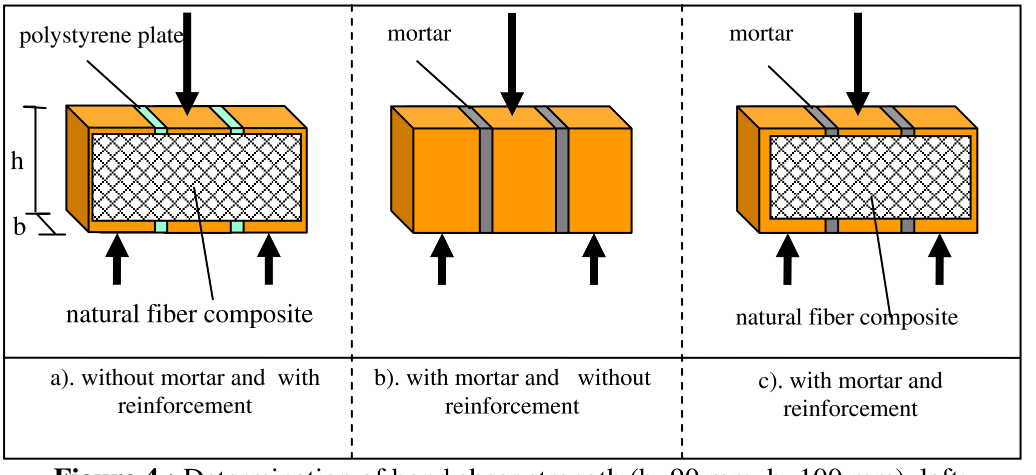

Figure 4 : Determination of bond shear strength (b=90 mm, h=100 mm), left: reinforcement without mortar, mortar without reinforcement, mortar with reinforcement (DIN EN 1052-3)

The maximal achievable shear stress is a function of initial shear strength (cohesion) between brick and mortar and the product of the friction coefficient of the horizontal joint with pressure normal stress. To investigate this dependency with natural fiber reinforcement the three brick area was studied with normal pressure stress (Figure 5).

The load resulting in the failure criterion "bonding failure" is a perpendicular tensile strength to the horizontal joint. As substitute testing procedure the adhesive tension strength between brick and mortar is determined. As with the studies of shear load, the samples were also investigated for tensile load with reinforcement-without mortar, with mortar-without reinforcement and the combination of the two (Figure 6).

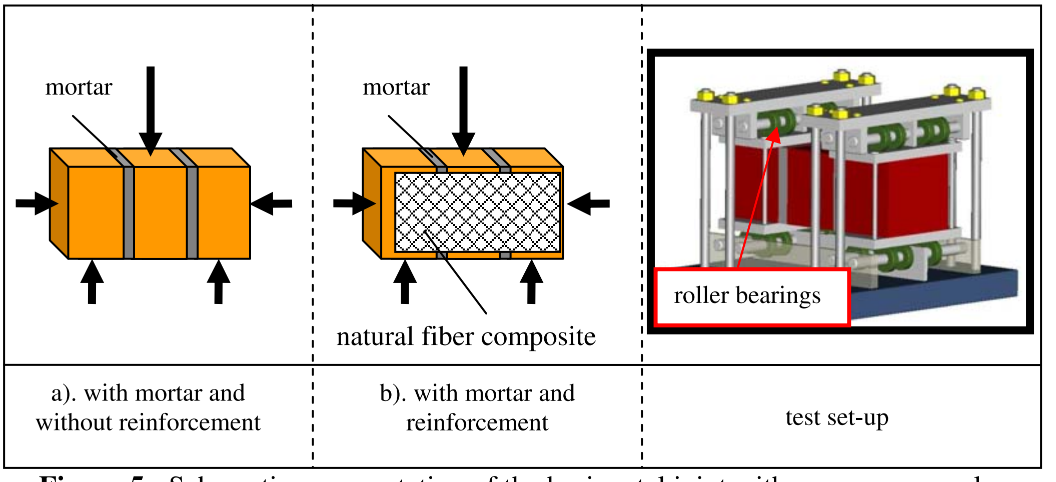

Figure 5 : Schematic representation of the horizontal joint with pressure normal stress, left: mortar without reinforcement, mortar with reinforcement. Right: apparatus for studying the three-brick areas. If necessary, the roller bearing can be blocked or released.

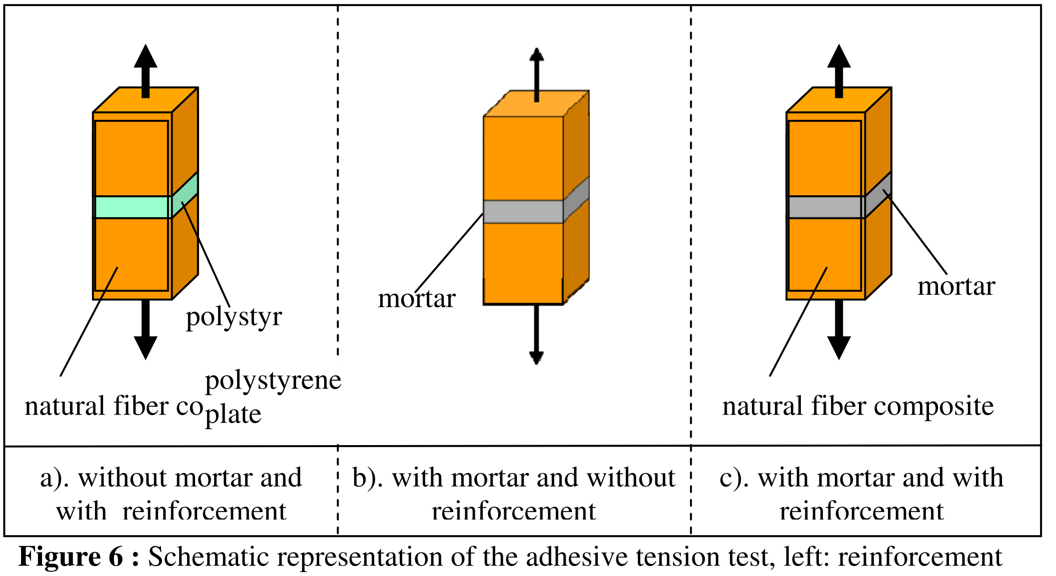

Figure 6 : Schematic representation of the adhesive tension test, left: reinforcement without mortar, mortar without reinforcement, mortar with reinforcement

For clarification the experimental results are summarized in a σ–τ–diagram. In the representation the one-axis and the combined test results can be compared with each other in a diagram. The experimental results are subdivided into a linear-elastic boundary stress and the stress maximums are calculated from the median values of the various test series (Figure **7**).

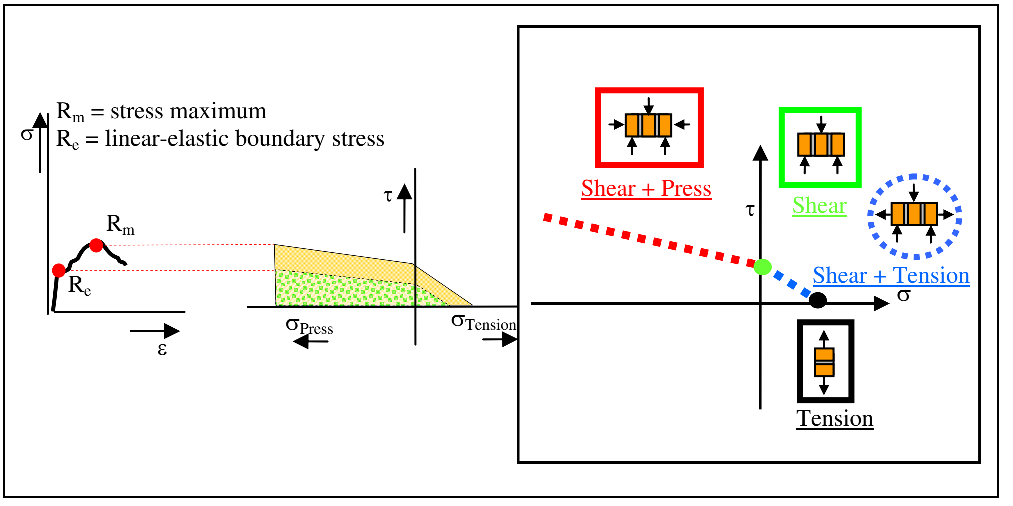

Figure 7 : Representation of the experimental results in σ–τ–diagram for liner-elastic boundary stress and stress maximum

In Figure 8 the unreinforced results are compared with the reinforced results. Both the in the diagonal and horizontal/vertical reinforcement it can be seen that even the results of the linear-elastic boundary stress with reinforcement are above the stress maximums of the unreinforced samples. The representation of the results reveals in the τ-σ-diagram a clear increase of stability for both reinforcements compared with the unreinforced variants.

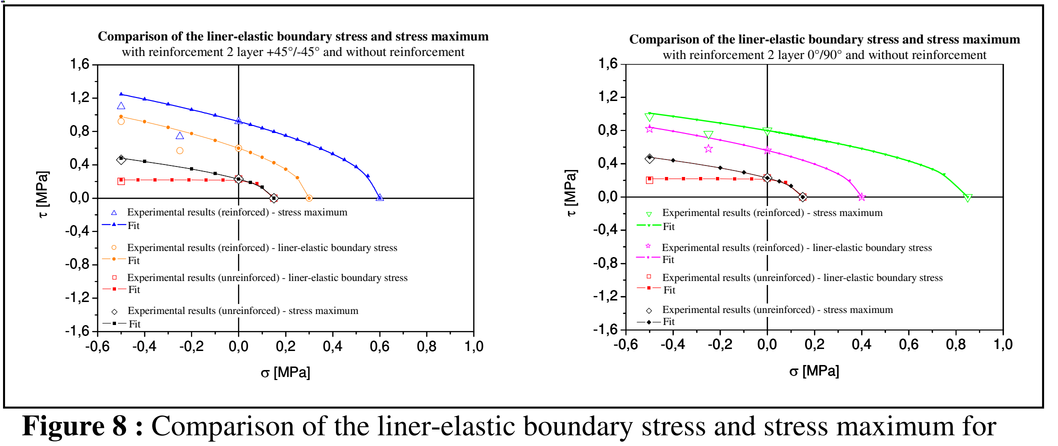

Figure 8 : Comparison of the liner-elastic boundary stress and stress maximum for unreinforced and reinforced sample with 2 layers - Left: fiber orientation of [+45°/-45°], right: fiber orientation of [+45°/-45°]

Application in World Cultural Heritage

Within the framework of a pilot project supported by UNESCO and Sika Schweiz AG, the rebuilding of Arg-é Bam known as the Recovery Project of Bam's Cultural Heritage for which the Iranian Authority for Monument Conservation, the method of reinforcing buildings using natural fibers was applied for the first time. Two sample structures were created: the first was created using sun-dried mud bricks and pure mud as a mortar; the second with burnt bricks (greater stiffness) and cement mixture as a mortar. Before reinforcing the sample building the necessary working materials will be prepared. The simple preparatory works include mixing the adhesive, cutting the matting to shape and cleaning the working surface with a brush. In the second stage the adhesive is applied to the wall surface using a trowel. Figure 9-right shows an expert applying the first layer of the adhesive to the wall surface with a trowel.

Figure 9 : Left: mixing the two-component adhesive with a mixer - cutting the jute matting to reinforce the walls. Right: Application of the first adhesive layer with a trowel

Next the matting is applied to the wall surface in the correct position and first put on the wall surface with a flat hand in order to press out the undulations from the matting. Figure 10-left shows the expert positioning and smoothing the matting. In the next stage the laminating of the matting on the adhesive layer is carried out. This is done with a simple plastic roller. The last stage is the covering of the matting with a sealing adhesive layer (Figure 10-right). By covering the natural fiber with adhesive the natural fiber is protected from environmental influences.

Figure 10 : Left: Positioning and smoothing of the matting on the adhesive layer, Right: The lamination of the matting onto the adhesive layer - application of the adhesive layer on the matting

In Figure 11 the already reinforced buildings are represented. The buildings have been in the World Cultural Heritage for over a year and have been visited by many experts and non-experts. So far no delaminating or other negative effects have been observed.

Figure 11 : Left: with natural fiber reinforced burnt brick. Right: with natural fiber reinforced mud brick.

Conclusion

It has been possible to demonstrate that the subsequent reinforcement of small masonry structures by natural fiber composites (jute) leads to an increase in the stability and ductility properties. The advantage of this method is that the level of stability or ductility can be varied by the variation of the number of layers or fiber orientation. The number of layers is to be determined according to the strength of the brick surface, type of masonry and mortar properties. In this work numerous preselected adhesive systems and natural fiber types are examined. In the pre-selection of the materials great value was attached to factors of economy and sustainability. In the examination of various natural fibers and textile types the best results were obtained by jute in the form of woven pieces with an area weight of 275 g/m^2. It has been possible to show in this work that sustainable reinforcement of small masonry structures using natural fiber compounds (jute) increases the properties of stability and ductility. The advantage of this method is that the level of stability or ductility can be varied by the variation of the number of layers or fiber orientation. In general, diagonal fiber orientations (+45°/-45°) display a slightly higher level of stability. On the other hand, in the horizontal/vertical fiber orientation (0°/90°) a more ductile behavior could be observed. The stability can be improved in the case of reinforced small masonry structures for pure tensile load by a factor of 4 and the deformability, in the case of maximum load, up to 650 times. In the case of pure shear strength the stability could be improved by a factor of 4.5 and the deformability by a factor of 20. The current price of 2-layer reinforcement is 12 Euro / m2, of which the adhesive is the more expensive component. The method is very simple and practical that can also be done by local workers. This has been proved by the work in Arg-é Bam. The examples in Bam made it possible to observe and document the long-term behavior. However, a systematic investigation with regard to the long-term behavior is urgently necessary. Further extraordinarily important points of investigation are the requirements of construction physics and fire protection that have not been taken into account in this study.

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