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Undulating rammed earth surfaces

Erosion control and design potentials using small-size wall elements as an example

Unplastered and unstabilized rammed earth walls which are exposed to the elements are sometimes subjected to severe erosion caused by driving rain. This poses the main risk to structural integrity, durability and surface quality of the building element. When it comes to erosion by rainwater, not only raindrops striking the surface play a role, but also water draining off. While the degree of erosion by impacting raindrops is primarily determined by the orientation of the surface (angle to the vertical), erosion by draining water increases with the speed of the water [1] [2]. A proven principle of constructive erosion control which applies here is the integration of thin horizontal layers of lime or fired brick into the facade which Rauch[1] refers to as "erosion checks". These erosion checks are typically distributed at equal vertical distances. They protrude from the earthen surface and slow down or stop the vertical flow of water.

As a possible alternative principle, this paper introduces the undulation of the surface and examines its general suitability. The purpose of the undulation is to force the draining water to continuously change direction. This slows down the flow of water and, thus, reduces erosion. In contrast to vertical surfaces, however, the undulation creates areas which are exposed differently to driving rain. Based on Rauch's [1] idea of checking erosion, in addition to strategies for limiting erosion, this paper also examines ways of controlling the erosion process. The main focus here is the interaction between the function and design of the examined techniques.

The underlying investigations were conducted as part of a seminar for graduate students of the architecture master course at the RWTH Aachen University. This paper shows the results of the first of two work stages which offered an introduction to the topic. The goal of this paper is to give a first qualitative assessment of the investigated principle and its application. Based on current results, a quantitative assessment did not seem feasible as the conditions for production, drying as well as testing were not accurate enough. For example, there were at times considerable differences between the moisture content of the soil mixes at the time of installation, the degrees of compaction and the surface qualities of the test specimens. The tests carried out so far show that the erosion behavior greatly depends on the moisture content and the surface quality of the test specimens.

Methods

Research was carried out using small-size rammed earth elements as an example. Applying the fundamental principle, two surface designs for equal basic volumes (4DF block format, 24×24×11.5 cm) were drawn up. Then, for each design a test wall element at a width of 49 cm and a height of 99 cm was produced. 6 full and 4 half elements each were made.

Production

Using hand rammers, the earthen building elements were rammed in two layers into individually fabricated wooden formwork. The soil used was an industrially produced rammed earth ready-mix with grain sizes of 0-16 mm. To produce the undulating surface of the elements, CNC-milled molds were made and placed into the formwork before ramming. (Fig. 1)

In contrast to common practice, compaction was not carried out in the direction of future loading, but orthogonally to it. This change in direction was primarily decided on because it allowed for the creation of surface geometries which would have not been possible using the standard ramming direction, for example due to undercutting. Experiences gained during the construction of a rammed earth dome at the ETH Zurich have shown that compaction or-

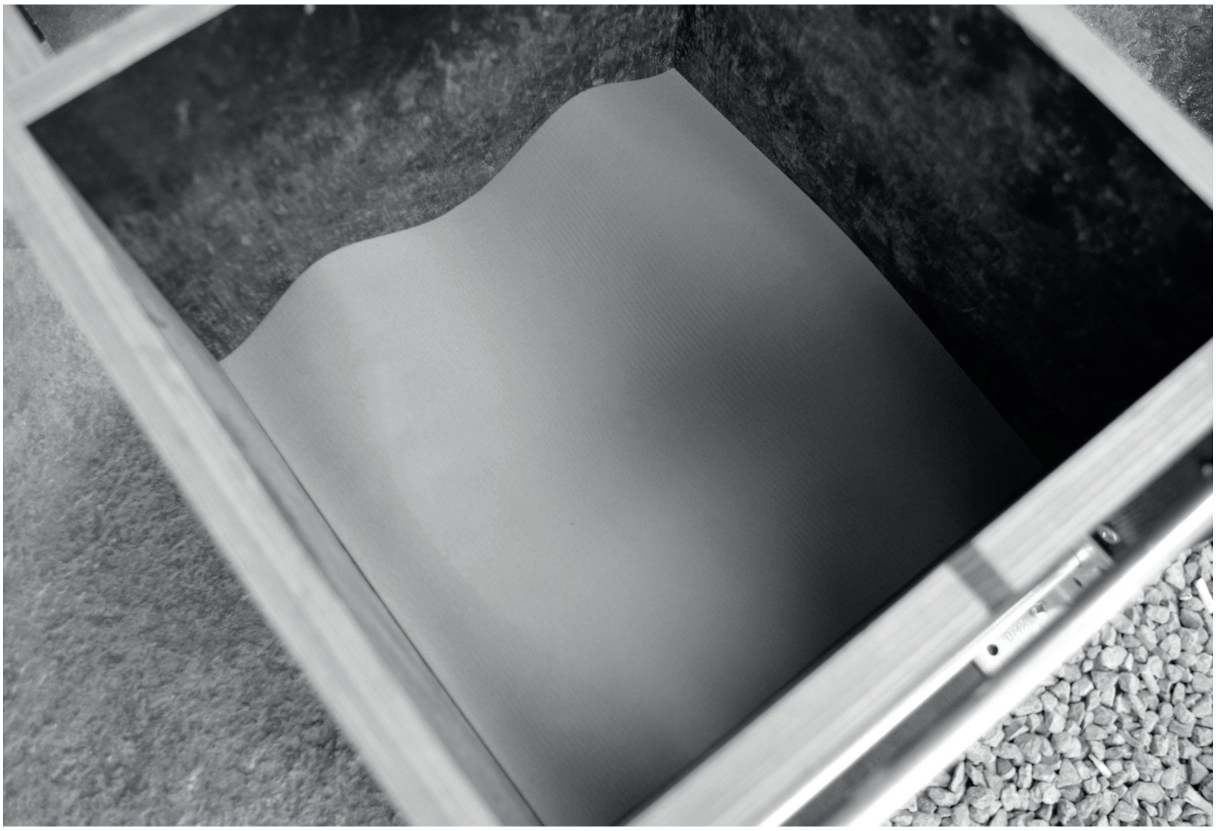

Fig. 1 Formwork with inserted mould

thogonally to the direction of loading has no negative impact on the compressive strength or structural integrity of a building element [2].

In the period between the production of the elements and the scheduled test date (approx. 10 days), unfavorable storage conditions (low air temperatures and very high humidity) prevented the building elements from drying out completely. The specimens were prepared as test building elements by laying them in a full bed of mortar (head and horizontal joints with 1 cm of earth mortar each) on bases made of fired brick. After an additional drying time of 48 hours, the rain tests were carried out

Erosion simulation

As Heathcote [2] writes, a realistic simulation of erosion stress on vertical earth building elements by natural rain requires a high degree of technical and time input. The objective of the first rain test was therefore a simulation which allowed for an initial assessment of the draining behavior of the water on the individual wall surfaces as well as the erosion stress in various areas of the building elements. Due to restricted possibilities, the parameters of intensity, drop size and kinetic energy as well as impact angle of the raindrops could only be taken into account to a limited degree.

For the rain test, a standard lawn sprinkler was calibrated to produce an intensity of approx. 1.8 l/min. m^2 of horizontal surface. This corresponds to the average heavy rainfall which, according to DIN 1986-100, is to be used for locations in Germany [3]. The wall surfaces were exposed to rain for a duration of 5 minutes. The tops of the walls were covered by a board which protruded 2 cm on all sides and was equipped with a drip edge. Because the edges of the building elements were exposed, they received a disproportionately high amount of stress and were therefore excluded from the assessment. Fig. 2 shows a schematic diagram of the test setup.

Description and evaluation of the test building elements

Fig. 3 shows sections of both test building elements as axonometric diagrams. The basis of the design of test building element 1 is a uni-axial undulation (y-axis). An undulation profile which exhibited different curve radiuses, frequencies and amplitudes was selected. The idea of the design was to create the surface in such a way so as to allow the elements to be placed on top of each other in the same direction or turned by 180°. This would create a seemingly irregular sequence of undulations producing a more open vertical arrangement of the wall building element.

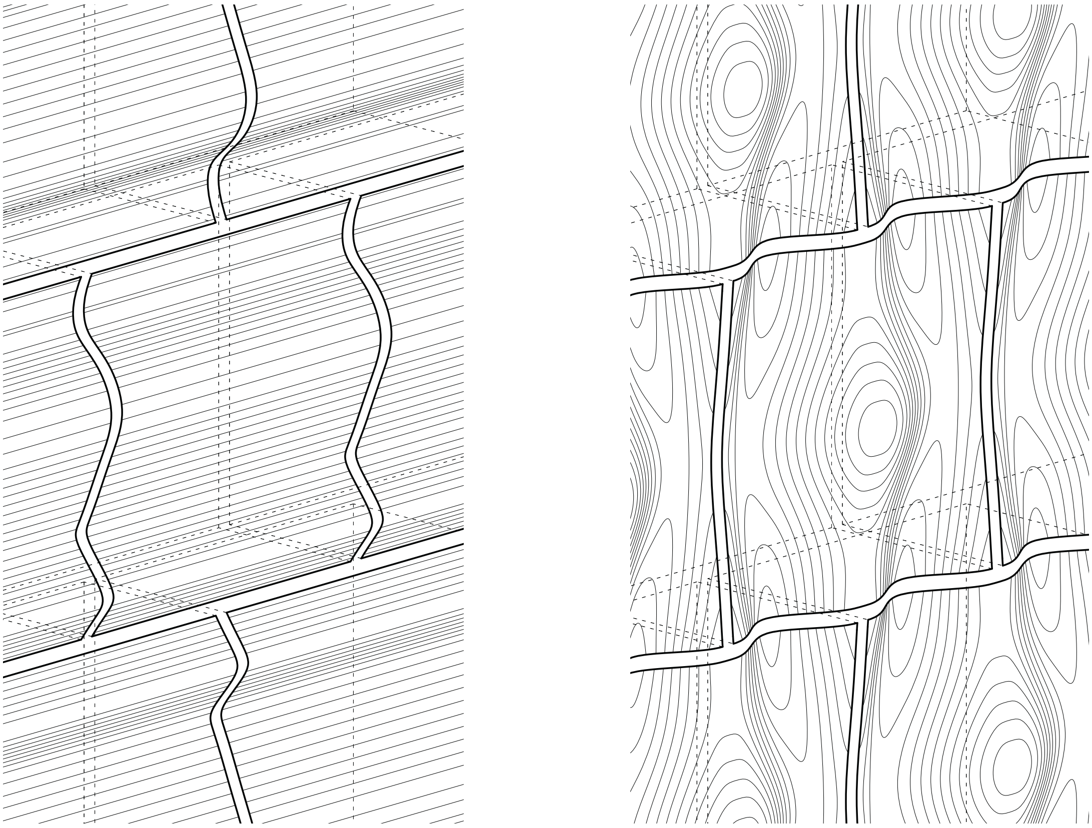

Fig. 3 Test building elements 1 (left) and 2 (right), section axonometry

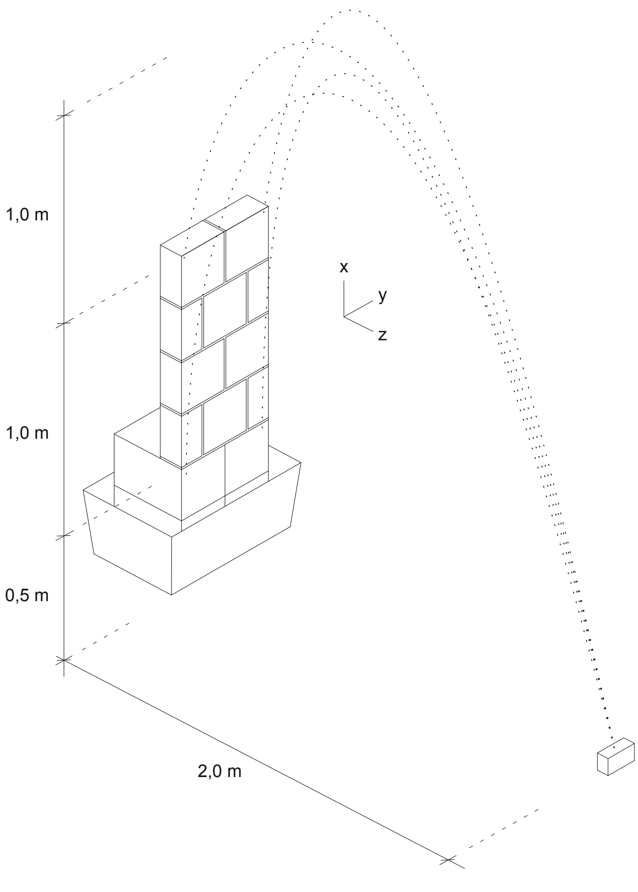

Fig. 2 Schematic diagram of test setup

The tests show that the undulations by and large cause the water flow to visibly slow down. Areas with smaller wave amplitudes exhibited a different behavior than areas with larger amplitudes.

The higher the amplitude the stronger the tendency of the draining water to follow the geometry of the wave. With smaller waves, however, and depending on the strength and speed of the water flow, the water tends to jump from crest to crest which prevents a slowing down and creates a high degree of stress on the front edge of the wave. The smaller waves also proved to be more prone to erosion due to the high degree of stress created by impacting raindrops and the risk of deeper moisture penetration in the upper areas of the more pronounced curves. Fig. 4 shows views of the test building element before and after the rain test.

In contrast, the design of test building element 2 used a bi-axial undulation of the surface. Here, the draining water is diverted both orthogonal (y-axis) and parallel (z-axis) to the wall axis. The design of vertically continuous concave areas ("valleys") seeks to encourage a slight channeling of the draining water. To relieve the joints in the building element, which tend to be

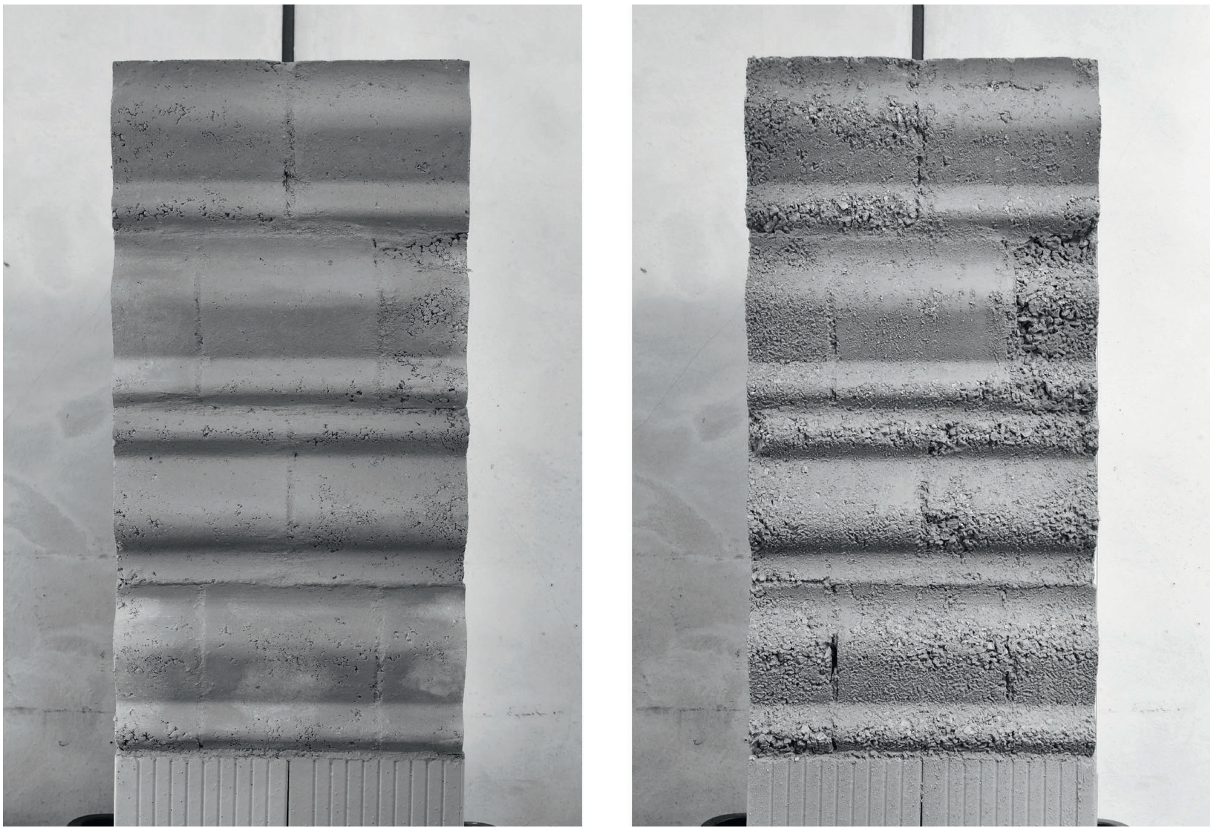

Fig. 4 Test building element 1 before and after rain test

more prone to erosion due to smaller grain sizes, the water is diverted away from them.

As expected, during the rain test it could be observed that the design of the vertical valleys caused the draining water to channel slightly. It also became apparent, however, that the intended diversion of the water flow is too low both in the y-axis and the z-axis to cause a sizable decrease in speed.

With an increase in rain duration and erosion, a slight smoothing of the surface topography became visible. The convex areas of the surface showed a tendency towards stronger erosion, particularly in the fine-grained range. The concave areas eroded to a lesser extent. This means that the increased flow of water along the valleys did not cause an increased erosion stress which could be connected to the better protected location of the concave. Fig. 5 shows a test building element before and after the rain test.

During the rain test, both test building elements showed, at times, extreme erosion in individual sections of the surface. This can only be explained by the high residual moisture content of the test specimen. Already during the first few minutes of the rain test, convex areas of porous surfaces experienced deep moisture penetration, resulting in the surfaces' instability..

Conclusion and outlook

In view of partly inadequate test conditions, the current results can only lead to limited conclusions regarding the erosion behavior in practice. While the erosion created by moisture penetration of the surface can only provide little insight, the erosion behavior which is directly linked to the geometry of the building element might be more conclusive. In addition, we hope that the results of the second stage of work will provide further insights and conclusions. For this next stage it is crucial that the complete drying of the test building elements is ensured.

The principle of undulation could be confirmed in its basic effectiveness for slowing down the draining of water. Further research, however, seems to be necessary to be able to better evaluate the principle when applied to rammed earth surfaces.

This requires further investigation of the relationship between the geometry, material characteristics and quality of the surface. A crucial question could concern the balance between contrary performance characteristics of small/narrow waves (greater diver-

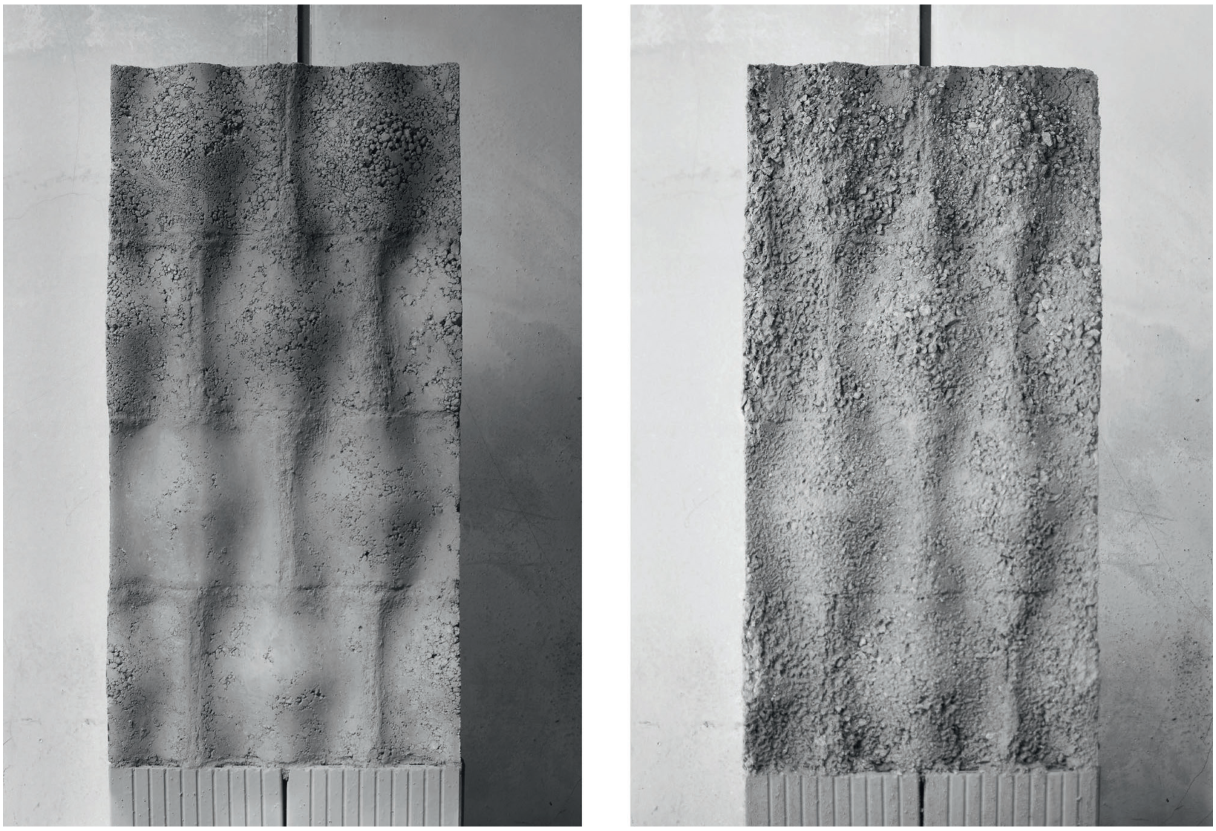

Fig. 5 Test building element 2 before and after rain test

sion of the water, but higher susceptibility to moisture penetration of the protruding volume) and larger waves (small diversion, low susceptibility). It also remains to be examined whether the comparatively high degree of erosion of convex areas could be limited by the addition of coarse grains which act as stabilizers by creating a deeper anchoring in the building element.

From a design perspective, the undulation of the surface shows great potential. In contrast to wall elements which are divided by horizontal erosion checks, this technique could be used to create homogeneous, purely earthen surfaces as long as its practical suitability is confirmed. Here, uniform as well as irregularly undulating surfaces of different designs are conceivable. It is also very appealing to use the erosion process as a design feature. The effect of the stronger erosion of fine grains in the convex areas, which was described above, causes a roughness gradient on the surface over time which – depending on the geometry of the waves – contributes to the expressive qualities of the facade. The undulating surface exemplifies an appropriate application of rammed earth as a building material and is reminiscent of the stylistic language of vernacular earthen architecture.

The next step will be to carry out a more in-depth, systematic investigation of different curve geometries, amplitudes and frequencies which will enable a quantitative evaluation of the principle – also in comparison to alternative principles.

References

[1] Rauch, M., 2003: Konstruieren mit Stampflehm. In: Detail, Serie 6/2003, Munich 2003

[2] Heathcote, K. A., 2002: An investigation into the erodibility of earth wall units. *https://opus.lib.uts.edu.au/bitstream/10453/20153/2020/02 Whole.pdf* (last accessed on 1 July 2016)

[3] ETH Zürich, Professur A. Spiro, 2014: *http://spiro.arch.ethz.ch/de/lehre/wahlfach-materialwerkstatt/stampflehm_gewoelbe.html* (last accessed on 1 July 2016)

[4] Deutsches Institut für Normung e.V., 2008: DIN 1986-100, Table A.1