FORTIFICATIONS AT TELL EL-RETABA*

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The article is on construction technique and materials, especially mudbricks and their composition, vis-a-vis specific situation in Tell el-Retaba. Bridging over a thousand years, the construction recommendations of Vitruvius are compared with the current situation on the tell. This article briefly describes three defence walls so far unearthed in Tell el-Retaba and focuses on the research of local ancient mudbricks. It presents results from the examinations of several samples of mudbrick and soil done during recent archaeological seasons. The samples were examined mainly by sieve analysis, testing density, dimensions, walling technique, etc., what also indirectly helps to determine approximate strength of mud bricks and their usage in single structures. The main result, grain-size curves, describing mudbrick composition and their relationship and potential reusing in constructions, are presented. Basic dimensions of the fortress's gate – Migdol, and defence walls, based on preliminary static calculations of the bearing capacity of the subsoil are also estimated from the point of view of construction engineering.

Key words: Tell el-Retaba, defence walls, Migdol, mudbrick, grain-size curves

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1. Introduction

Archaeological and interdisciplinary research established the existence of an important Ancient Egyptian site at Tell el-Retaba in Wadi Tumilat. The first regular excavation of the tell was conducted more than 100 years ago by Swiss researcher Henri Édouard Naville (1844 – 1926) in 1885.[1] Sir William Matthew Flinders Petrie (1853 – 1942) conducted an excavation season about twenty years after Naville; his publication[2] practically remained the primary published English source of information on Tell el-Retaba by the start of the Polish-Slovak excavations.

There were, however, also other archaeological activities at the site in the 20th century. Tell el-Retaba was surveyed and excavated by several Egyptian and foreign archaeological missions.[3]

The joint Polish – Slovak Archaeological Mission started archaeological works at Tell el-Retaba in 2007. Since then an important occupation from the Second Intermediate Period, a settlement from the early New Kingdom, Ramesside fortresses, controlling the desert routes among the Upper Egypt, north-eastern Delta, Sinai and even further eastwards[4], were discovered and/or confirmed at the site, besides extensive Third Intermediate Period´s occupation and some traces from the Late Period.[5]

The excavations did not confirm expectations that occupation on the site was mainly limited to the area confined by the later Ramesside defence walls. Unfortunately, the site has been damaged over time and even now it is endangered by modern development (Fig. 1).[6] The excavations shall therefore use every opportunity to salvage endangered monuments and to fill gaps in the knowledge of the site.

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[1] NAVILLE, H. E. The Shrine of Saft-El-Henneh and the Land of Goshen (1885), p. 24ff.

[2] PETRIE, W. M. F., DUNCAN, J. G. Hyksos and Israelite Cities, p. 28ff.

[3] RZEPKA, S. et al. Tell el-Retaba 2007 – 2008. In *Ägypten und Levante.* Internationale Zeitschrift für ägyptische Archäologie und deren Nachbargebiete. Bd. XIX/2009, p. 241ff.

[4] HUDEC, J., FULAJTÁR, E., STOPKOVÁ, E. Historical and environmental determinations of the Ancient Egyptian Fortresses in Tell el-Retaba. In *Asian and African Studies*, 2015, Vol. 24, No. 2, pp. 247–262.

[5] RZEPKA, S. et al. Tell el-Retaba from the Second Intermediate Period till the Late Period. Results of the Polish–Slovak Archaeological Mission, Seasons 2011–2012. In *Ägypten und Levante*, *Internationale Zeitschrift für ägyptische Archäologie und deren Nachbargebiete.* Bd. XXIV/2014, pp. 39–120.

[6] RZEPKA, S. et al. Tell el-Retaba 2007 – 2008. In *Ägypten und Levante.* Internationale Zeitschrift für ägyptische Archäologie und deren Nachbargebiete. Bd. XIX/2009, p. 242, Fig. 1.

2. A brief description of the mudbrick and its material

So far the oldest mudbricks were found in Anatolia (Asikli Huyuk, over 9,000 years; Catal Huyuk around 8,000 years); these mudbricks had a regular prism shape, resembling today's ones. They were the standard shape in geometric ratio 4:2:1, and dimensions 32-16-8 cm. Around 8,000 years ago mudbricks were used in the lowermost layers of Knossos in Crete. Dried bricks perpetuated by fire relate Knossos mainly to Anatolia.[7]

In Egypt dwelling construction technique have been developed for several millennia. Egyptians have built huts made of wooden poles and rush mats covered by layers of mud since the Neolithic period. Bricks dried in the sun have been used since the Predynastic period. Production of mudbricks was recorded on the paintings in the tomb of Rekhmire (18th Dynasty). Men moisturised dug out soil, kneaded it with minced straw and transported it to a place where they moulded it into rectangular forms (Fig. 3) into bricks, which were then placed in the sun to dry.[8]

Unfired, sun/air-dried bricks, loosened with chaff or sand, were not only easily obtainable and cheap construction material, but, in the dry heat of the Nile valley, still play an important role in basic air conditioning inside buildings.

Everyday Ancient Egyptian architecture – huts, houses, stables, workshops, etc. – were located on both banks of the Nile, on the humid valley floor. Soil as a building material is very sensitive to humidity and also to direct water, e.g. rain or flowing water, which could cause the destruction of mudbrick structures. These structures were also subject to damp and intense use, so that after a few decades it became necessary to replace the old, dilapidated buildings with new ones; it was not a too expensive process in view of ease obtainable building material. Over the centuries and millennia, this rapid cycle of building, collapsing and (re)building raised the level of villages and towns and formed small hills. These hills, tells in Arabic, now mark the sites of ancient settlements; even modern towns could sit on a pile of "rubble".[9]

Roman engineers, especially Vitruvius, who served during the reign of Emperor Augustus in the first century B.C., paid great attention to soil types and to the design and construction of solid foundations. There was no theoretical basis for the design; experience was extracted from trials and errors.[10] Vitruvius mentioned that a mudbrick wall, thick at least 2 or 3 brick

[7] KORECKÝ, M. Objevy pod pyramidami [Discoveries at the pyramids], p. 12.
[8] STROUHAL, E. Život starých Egypťanů [Life of the ancient Egyptians], p. 11.
[9] WILDUNG, D., STIERLIN, H. Egypt. From Prehistory to the Romans, p. 8.
[10] BUDHU, M. Soil Mechanics and Foundations, p. 1.

lengths, was the width of 1.5 foot (1 Roman "*pes*" = 29.667 cm; 1.5 *pes* = 44.5 cm) not able to bear more than one floor.[11]

The Nile River transported and deposited mud over thousands of kilometres from East Africa, through Nubia, and the valley and delta in Egypt during the annual floods. These mud deposits were used to make sun-dried mudbricks.[12] The mud provided the most important building material, especially for secular architecture, from ancient times to the 1970s, when the Aswan High Dam terminated the annual flooding cycles in Egypt.

The high medium silt content of the Nile mud determines the high medium silt content in the alluvial mudbrick. The suspended material which is brought down by the Nile and makes up the Nile mud is derived from the disintegration of igneous and metamorphic rocks under weathering influences.

Soils are formed from the physical and chemical weathering of rocks. Physical weathering involves the reduction in size without any change to the original composition of the parent rock. The main agents responsible for this process are exfoliation, unloading, erosion, freezing, and thawing. Chemical weathering causes both reductions in size and chemical alteration of the original parent rock. The main agents responsible for the chemical weathering are hydration, carbonation and oxidation.[13]

The mineralogical character of the sand and silt fractions include angular crystalline fragments of quartz, feldspar, hornblende, augite, mica and other minerals derived from disintegrated rocks. The clay fractions mainly consist of kaolin, a clay mineral which is a common decomposition product in the weathering of felspathic rocks. Thus, an alluvial bricks have a similar mineral composition in Egypt.[14]

From a physico-mechanical point of view individual components are applied in dependence on grain size. Clays have an ability to bind water according to its colloidal particulate. Considerable volumetric change depends on the quantity of received or released water. Clay gives plasticity (in a wet state) to loam and provide an internal cohesion and also some tensile strength. But clays are the main cause of material degradation by atmospheric climate influence. As water receiving clay is swelling, and shrinking by evaporation cracks accrue. At repeated volumetric changes the total collapse of soil constructions occurs.[15]

[11] OTOUPALÍK, A., BOUZEK, J. Deset knih o architecture [Ten books on architecture], p. 85.

[12] WILDUNG, D., STIERLIN, H. Egypt. From Prehistory to the Romans, pp.7–8.

[13] BUDHU, M. Soil Mechanics and Foundations, p. 12.

[14] FRENCH, C. A. I. A sediments analysis of mudbrick and natural features. In KEMP, Barry, J. (ed.). *Amarna Reports I. Occasional Papers 1*., 1984, pp. 198–199.

[15] SUSKE, P. Hlinené domy novej generácie [Clay houses of new generation], pp. 69–70.

Based on size, grains and fractions of soil are divided in Table 1 in accordance with recent STN EN ISO 14688-1.[16]

Tab. 1 Nomenclature of main grain sand fractions

Grain size [mm]	Name	
	Grain	**Fraction**
< 0.002	Soft	clay
from 0.002 to 0.063		silt
from 0.063 to 2.00	Coarse	sand
from 2.00 to 63.00		gravel
from 63.00 to 200.00	Very coarse	stone
> 200.00		boulder

According to a mudbrick structure and its practical use it is obvious that coarse-grained soils (sand and gravel) gives strength (a solid frame) to a mudbrick. It is not, however, possible without fine-grained soil (clay and silt) and perhaps an additional adhesive, which bonds single coarse-grained fractions together and creates a compact (well workable in a wet state) and long-lasting (sufficient stiff after drying up) unit. An optimal grain ratio (granulometry) could help to obtain an ideal composition of mudbrick material, which results into strong mudbrick by well compactions with as narrow as possible position of the soil fractions.

According to laboratory research executed in France[17] the ideal granulometry of soil intended for building purposes should respond to Tab. 2 and Tab. 3.

Tab. 2 Granulometry

Sieve openings [mm]	Recommended composition [%]	Acceptable composition [%]
40	100	100
15	87-100	87-100
10	72-100	72-100
5	51-100	51-100
2	37-69	37-100
0.5	21-45	21-100
0.08	15-35	12-50

Note: Contents of organic particles cannot be more than 2%

[16] STN 72 1001, 2010, p. 11.
[17] MARIOTTI, M. La terre-materiau de construction, pp. 16–24.

Tab. 3 Contents and composition of clay

MUDBRICKS	Recommended characteristics	Acceptable characteristics
	$200 \leq f * Ip \leq 400$ $8 \leq Ip \leq 15$	$170 \leq f * Ip \leq 500$ $7 \leq Ip \leq 20$
	Optimum: f = 25 Ip = 10	-

f = percentage of particle less than 0.08 mm, Ip = plasticity index

Inadequate granulometry can be improved by adding particles needed to obtain ideal material composition. The quality or degree of compaction is also significantly influenced by the proper process of compaction and the right amount of water contained in the soil. Water content should range from 7 to 25%, according to a type of loam.[18]

Proportions of clay, silt and sand in the Nile alluvium are dependent and differ by particular site. If the clay level content was too high, bricks, would slowly dry in the sun, could crack, shrink and lose their shape. In such cases it was necessary to mix the alluvium material with sand, straw pieces or other sealant, such animal dung. Sand reduces shrinkage and cracking during drying and chopped straw and animal dung increases the strength and plasticity.[19]

The mudbrick constructions are water sensitive in general, which negatively influences relatively low strength of material and results into more massive proportions of constructions compared to other materials like baked bricks or stone. Mud plaster in mudbrick constructions therefore function not only to improve appearance of the wall and cover irregularities, but also partially to secure masonry before mechanical damages and protect walls against rain.

Sensitivity to water, along with lower strength parameters, formed specific morphology and structural principles of earthen architecture from time immemorial. Production of mudbricks was suggested in the spring or autumn time to dry them out in one stroke. Bricks manufactured in midsummer were wrong; the harsh sunlight prematurely dried up their top layers. Such mudbricks seemed to be dried, but they were still wet inside. Subsequent shrinking broke up layers which had dried up earlier. As a result such bricks were unstable. Thus, about two year old bricks, which were dry in depth, were far more suitable for constructions.

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[18] SUSKE, P. Hlinené domy novej generácie [Clay houses of new generation], pp. 82–83.

[19] MORGENSTEIN, M. E., REDMOUNT, C. A. Mudbrick Typology, Sources, and Sedimentological Composition: A Case Study from Tell el-Muqdam, Egyptian Delta. In *Journal of the American Research Center in Egypt*, 1998, Vol. 35, p. 129.

The quality and durability of mudbricks also depended on soaking a mixture of mud and straw in water for several days. The straw degraded during soaking and released somewhat mucus. The mucus impregnated the mud; it increased viscosity and ensured cohesion of mud during the drying.

Bricks were connected together by a mortar made from mud blended with sand, straw and chaff. Walls were generally tapered upward. Plaster had composition similar to mortar. Interior and exterior walls of houses were almost always lime-bleached.

A floor was most frequently made of trampled clay, or a layer of bricks. The design of a ceiling and/or a roof (particularly flat) was usually made up of beams and/or half beams of date palms. At greater length they were supported by pillar or pillars of a palm beam. From above, the beams were overlapped by a layer of palm leaves, bunches, or reed rugs, mudbrick, or by a layer of earthen clay. The surface was covered by a sloping waterproof layer of soft mud, to ensure run-off for rainwater.

Stairs or ladders were used to climb roofs. Window openings were small, either low and wide or tall and narrow. They were usually located at the tops of walls to prevent over-heating of rooms. Also, entrances to homes and vents in walls were situated towards the north, whenever possible.

According to the rules of traditional architecture, walls of mudbricks should not be longer than 5 m without stiffening elements (corners, transverse walls). The surface of openings should be less than about one third of the total surface. Maximum width of openings should not be more than about 1.2 m. Mortar should have approx. the same composition as mudbricks and its thickness should be from 1.5 to 2.5 cm. Too high a mortar layer decreases the strength of masonry. Because of slow drying mortar it is not suggested to brick up masonry more than one meter high because the weight of the mudbricks could cause the mortar joints to collapse.[20]

Average resistance to pressure of mudbricks in the area of Tell ed-Der was approx. 5.5 kg/cm^2. Various modern Egyptian mudbricks have a crushing strength in the range of 4-6.5 kg/cm^2. Based on tests at the Centre for Research and Application of Clay construction (CRATerre) indicative compressive strength stabilised by fibre is possible from 0.5 to 2 MPa when using clay in the construction.[21]

When using mudbricks it is also necessary to take into account its lower strength and poor resistance to humidity and non-uniform settlement of masonry, due to poorly built foundations. Poor resistance of bricks to humidity

[20] OTOUPALÍK, A., BOUZEK, J. Deset knih o architecture [Ten books on architecture], p. 85.

[21] CRATerre, 1985, p. 72.

was not an obstacle in a land where it rains rarely and briefly. According to data[22] from recent 10 years, in the Tell el-Retaba area rainfalls mainly come during winters with about five average rainfall days per month and to 14 mm precipitation. Despite to relative small quantum of rainfalls, they are intensive enough to systematically decay mudbrick constructions, as it was seen at Tell el-Retaba (Fig. 2).

3. Description of Fortifications at Tell el Retaba

The fortress from the time of Ramses II (Wall 1) had its broken ground plan revised after rebuilding under Ramses III's rule (Wall 2 and Wall 3), but although the later fortresses were significantly expanded eastward in general, there was minimal extension on the western side. In this area a gravel layer with dug-in Hyksos tombs has been found. The bedrock gravel indicates the existence of a river or a channel at this place, what could also be the reason for the specific ground plan influenced by the river's aggradation mound, especially in the case of the Ramses II's fortress.

As reported by Vitruvius (70 BC-15 AD), foundations for defence walls and towers were necessary to be dug down to a bearing ground, whenever possible. They should be wider than walls or gates. Towers must protrude outside from the wall in order to enable hitting an enemy from them. The walls should be built along steep places; roads to gates should not keep in a straight direction, but should turn left. The width of the walls on the top should enable circumvention of fighters. Tanned olive pales should be walled across the entire width of fortification walls as densely as possible; so the fronts of the wall are then tied together as connectors. The distance between towers should not be more than a range of an arrowshot so that attackers could be repulsed by fire from the next towers. However, the walls and towers are more secure when they are associated with earthen mounds, then the enemies are not able neither harm nor ram, nor undermine them.[23]

Due to more than a thousand years' time span between Ramessides and Vitruvius, the construction of the walls at Tell el-Retaba indicates several differences from the recommendations of Vitruvius.

It would be a question, what could represent a "bearing ground" at Tell el-Retaba. If the sand gravel of aggradation mound was considered, it does not

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[22] World weather online, Available from http://www.worldweatheronline.com/ismailia-weather-averages/al-ismailiyah/eg.aspx [cit. 10 May 2016].

[23] OTOUPALÍK, A., BOUZEK, J. Deset knih o architecture [Ten books on architecture], p. 49.

represent the case. The walls run above the mound whenever possible, but at least on the western side of the tell the wall foundations were not dug into. Although, the builders excavated some older cultural layers (and very probably used them for making mudbricks for the wall) they did not entrench the foundations into the aggradation mound.

The walls utilised, however, the relative height of the aggradation mound to get some external slope (probably not very steep). The walls were probably also protected by a channel from western, southern and eastern side and by a lake or marches from the northern side. A unique sand buttress was discovered supporting the internal side of Wall 2, so far on its western and southern part; an earthen buttress was used in rather later periods (Fig. 30) to absorb the energy of shots by siege machines and weapons.[24] Buttress dams are also known, but also in rather later periods.[25]

The only permanent gate seems to be from the west; Petrie indicated a small gate in the middle of southern Wall 3[26], and there is another gate on the eastern side of Wall 2 (closer to the NE corner of the fortress) indicated by geophysical prospection.[27] Neither external road, leading to some of the above mentioned gates, neither earth mound or moat (e.g. similar to Buhen) have not been uncovered so far.[28] Almost the same position of the main gate on the west implies that a main access road should approach the fortress from this side.

Foundations of neither of the three walls were not much wider than the walls themselves and the same observation is valid for the Migdol-gate. The walls are, however, poorly preserved and therefore it is difficult to determine the exact angle of their tapering (about 3º, see below), or other details of their internal construction (e.g. pales, etc.), or width of the walls on their top (disposable to fighters). Also so far, no towers were surely detected as incorporated into Tell el-Retaba defence walls.[29]

[24] CAMPBELL, D. B. Besieged. Siege warfare in the Ancient world, p. 202.

[25] CAMPBELL, B. Rivers and the Power of Ancient Rome, p. 229.

[26] PETRIE, W. M. F., DUNCAN, J. G. Hyksos and Israelite Cities, Tab. XXXV.

[27] RZEPKA, S. et al. Retaba 2007 – 2008. In *Ägypten und Levante.* Internationale Zeitschrift für ägyptische Archäologie und deren Nachbargebiete. Bd. XIX/2009, p. 276, Fig. 33.

[28] Whether older gate to Wall 1 was protected by a moat is not sure (see HUDEC, J. In RZEPKA, S. et all.: Tell el-Retaba from the Second Intermediate Period till the Late Period. Results of the Polish–Slovak Archaeological Mission, Seasons 2011–2012. In *Ägypten und Levante*, *Internationale Zeitschrift für ägyptische Archäologie und deren Nachbargebiete.* Bd. XXIV/2014, p. 71f.

[29] There are some protrusions on Petrie's map of Wall 1 (PETRIE, W. M. F., DUNCAN, J. G. Hyksos and Israelite Cities, Tab. XXXV); they were not confirmed by recent excavations so far.

Structures visible to the naked eye include the earliest examined defence Wall 1, dated by Petrie to the Hyksos period (an obsolete dating). From the “Great House” (of the 18th Dynasty according to Petrie) and only very modest remains of a Ramesside temple can be traced on the surface. The paper will further focus mainly on defence walls (Petrie's Wall 1, Wall 2 and Wall 3), which are continuously being investigated together with other constructions at the Tell el-Retaba area.

3.1 Wall 1

Fortification Wall 1 was constructed with mudbricks. More types of mudbricks were used in repeated reconstructions. Wall 1 has been analysed near to south Migdol’s tower (Fig. 6) and also behind the trench, in Area 9 (Fig. 5).Wall 1inthe Migdol area is created by a core (width at the bottom 1.85m), internal extension (width 2.05 m) and external extension (width 1.40 m). Fine yellow sand was in the footing bottom of both extensions. The wall is more eroded in Area 9; several children's graves have been found below the internal extension of Wall 1.

The internal and external extensions of Wall 1 also contain greenish and black mudbricks, which indicates that both extensions could have been built at the same time or in a relatively short interval only. Wall 1 at Migdol was locally damaged at the core; greenish and black mudbricks were used in its reconstruction and extension. These bricks were not, however, used in the foundations or edge area, probably due to their fragility and enhanced water sensitivity. Individual samples of mudbricks and sand from the footing bottom of Wall 1 are shown in Tab. 4.

According to the same dimensions of mudbricks used in both extensions and due to the same bonding pattern of bricks (Fig. 7) it is possible to assume that both Wall 1 extensions were made almost at the same time to widen and heighten the defence system of the fortress dated to the reign of Ramses II.

Wall 1 in Area 9 was also created by a core (width at the bottom 1.80 m), internal extension (width 1.30 m) and external extension (width 1.40 m). At the footing bottom of the internal extension is a gravel bed with shards; it is about 20 cm higher than the foundation level of the wall’s core. The external extension is at a lower level than the core, by about a brick height, on a sand layer thick by about 5 cm. It seems that in this part the core of the wall and external extension were built at the same time. It could not be excluded the external extension was built first and only then the core of the wall was built on a sand layer about 15 cm thick. Rusty coloured gravel is below.

Tab. 4 Analysed samples for Wall 1

Name	Type	Location	Description	Position	Dimensions
S-MB1	mudbrick	Wall 1 (behind the Migdol)	regular brown mudbrick	core, 4th row	9x19x38cm
S-MB2	mudbrick	Wall 1 (behind the Migdol)	regular brown mudbrick	external extension, 5th row	9x19x39cm
S-MB3	mudbrick	Wall 1 (behind the Migdol)	regular brown mudbrick	internal extension, 9th row	9x19x39cm
S-MB4	mudbrick	Wall 1 (behind the road)	regular brown mudbrick	core, 2nd row	9x15x34cm
S-MB5	mudbrick	Wall 1 (behind the Migdol)	black mudbrick	core, 5th row	9x19x39cm
S-MB6	mudbrick	Wall 1 (behind the Migdol)	greenish mudbrick	external extension, 10th row	9x19x33cm
S-S1	soil	Wall 1	yellow sand	external extension, footing bottom	-

3.2 Wall 2

Besides the walls uncovered by the Polish-Slovak excavations, some walls can still be seen on the surface due to their research by an Egyptian mission at the beginning of the 21st century[30]. Especially the thick walls of the Ramses III fortress (Petrie's Wall 2 and Wall 3)[31] in their southern (Fig. 8) and western sections are quite easy to discern. Even the casemate structure of the Wall 2 is to be recognised close to the south-eastern corner of the fortress. Both walls were also recorded by archaeological rescue works of H. Goedicke and M. Fuller (Fig. 9) during construction of a trench for a high-capacity pipeline, which cross-sectioned the middle of the site from north to south.

[30] RZEPKA, S. et al. Retaba 2007 – 2008. In *Ägypten und Levante.* Internationale Zeitschrift für ägyptische Archäologie und deren Nachbargebiete. Bd. XIX/2009, p. 243f.
[31] PETRIE, W. M. F., DUNCAN, J. G. Hyksos and Israelite Cities, 1906, Tab. XXXV; RZEPKA, S. et al. Retaba 2007 – 2008. In *Ägypten und Levante.* Internationale Zeitschrift für ägyptische Archäologie und deren Nachbargebiete. Bd. XIX/2009, p. 246–252.

Petrie's Wall 2 was easily recognised in the trench; nine rows of mudbrick (locus 106) were preserved in the section. The width of the wall measured 10.52 m. The maximal preserved height of the Wall 2 was 1.8 m. The inner face bricks were laid in a header bond and were arranged to make a3 degrees inward slope. The outer face of the wall was not constructed of mudbrick, but composed of puddled mud. The latter material was also used in the core of the wall. Mudbricks along the inner face had a sandy texture, pale brown colour and averaged dimensions of 10x22x46cm. The foundation of the wall consisted of 5 courses of mudbricks (locus 105) which rests upon a 10 cm thick layer of grey sand (locus 107). The foundation was laid in alternating courses of headers and stretchers. The bricks were identical in size and colour to the sandy mudbricks used in the main body of the wall.[32]

Wall 2 has been for the moment analysed mainly in the section in Area 9 (Fig. 10).The wall in this area is circa 4.5 m wide. In the footing bottom is grey sand (sample S-S2) and mudbricks (sample S-MB7) are placed about 3 cm in it. A side and front view of Wall 2 in Area 9 is shown in Fig. 11. Individual samples of mudbrick and sand from the footing bottom of Wall 2 are shown in Tab. 5.

Wall 2 at the Migdol towers was built on a solid platform of mudbricks (Fig. 16); some older structures (e.g. Black house 1) were uncovered below the platform, built from black mudbricks. Even older architectures from greenish mudbricks were discovered deeper, underneath the Black house1. It is possible the bricks of these structures were reused in Wall 1 or some other constructions. Other Black houses have also been found close to the south-western corner of the fortress.

Below Wall 2 next to the Migdol the footing bottom in also sandy. An uphill gradient of Wall 2's footing bottom is traceable from the south-western corner of the fortress northwards (towards Migdol).

Tab. 5 Analysed samples for Wall 2

Name	Type	Location	Description	Position	Dimensions
S-MB7	mudbrick	Wall 2 (Area 9)	regular brown mudbrick	1st row	9x20x45cm
S-S2	soil	Wall 2 (Area 9)	grey sand	footing bottom	-

[32] FULLER, M. J. Available from http://users.stlcc.edu/mfuller/Retaba/Retaba1981.html [cit. 12 May 2016].

3.3 Wall 3

Petrie's wall 3 was easily recognised in the construction trench of pipeline (see above). The heavy machinery damaged the south (outer) side of the wall

Tab.6 Analysed samples for Wall 2 and Wall 3

Name	Type	Location	Description	Position	Dimensions
S-MB8	mudbrick	Wall 2 (south tower of the Migdol)	regular brown mudbrick	6th row	12x21x45cm
S-MB9	mudbrick	Wall 2 (north tower of the Migdol)	regular brown mudbrick	5th row	12x21x45cm
S-MB10	mudbrick	Wall 2 (pedestal at the north tower of the Migdol)	regular brown mudbrick	1st row	12x21x45cm
S-MB11	mudbrick	Wall 2 (at the south tower of the Migdol)	regular brown mudbrick	4th row	9x21x45cm
S-MB12	mudbrick	Wall 3 (Area 9)	regular brown mudbrick	3rd row	12x20x39cm
S-M1	mortar	Wall 2 (pedestal at the north tower of Migdol)	bed mortar	footing bottom	-
S-S3	soil	Wall 2 (pedestal at the north tower of Migdol)	yellow sand	footing bottom	-
S-S4	soil	Wall 2 (pedestal at the north tower of Migdol)	brown soil	floor soil at the "*Black house 1*" under a pedestal of Wall 2	-
S-S5	soil	Wall 2 (threshold of Migdol)	yellow sand	footing bottom	-
S-S6	soil	Wall 2 (near the south – western corner of the fortress)	yellow sand used like bed layer	footing bottom	-
S-S7	soil	Wall 3 (Area 9)	yellow sand	footing bottom	-

making it impossible to get an accurate measurement on its width. The surviving portion was 7.46 m wide. Petrie had recorded the width of this wall at 8.81 m, 8.92 m and 8.94 m. The inner face of the wall stood 4 courses high (0.8 m).[33] The front view on Wall 3 in section Area 9 is shown in Fig. 12. A side and front view of Wall 3 in Area 9 is shown in Fig. 15. The footing bottom of Wall 3 in Area 9 is filled with sand, charcoal and shards.

Wall 3 was identified on the southern and eastern side of the fortress, however, its existence on the western and northern side and relation to the Migdol gate (Fig. 13, Fig. 14) is dubious, mainly due to both, deep erosion of the archaeological situation on the western and northern side and intense activities of *sabbakheens*.

Individual samples of mudbrick and soil from the footing bottom of Wall 3 are shown in Tab. 6. In the next seasons some other parts of the Wall 3 will be analysed to illustrate the wall building sequences and connections with Wall 2. Some relations between walls in Area 9 (view toward east) is shown in Fig. 17.

The relation between Wall 2 and 3 has already been examined by Goedicke (Fig. 19). The mentioned cross-section of these walls (Fig. 19) is situated about 190 m towards east, behind the cross-section shown in Fig. 17.

3.4 The Migdol

The Migdol's north tower (ground plan ca 22.5x14.0 m) touches Wall 1, but the south tower (ground plan ca 22.5x14.0 m) keeps a 1.2 m gap towards Wall 1. This gap was filled with fine yellow sand. At a height of approx. 1.5 m the masonry of the tower overlaid the gap and joined Wall 1, creating a "pseudo"-corridor.[34] The north tower overlaid by its western side a platform, as wide as Wall 2, which continued as Migdol's threshold toward/below the southern tower. The platform was founded on a mortar layer 2 to 6 cm thick, under which was a sand backfill. It seems that the tower had circumferential foundation mudbricks lower than in the middle of the tower, so the foundations were stepped. This space was filled by a rise of fine yellow sand.[35]

[33] FULLER, M. J., Available from http://users.stlcc.edu/mfuller/Retaba/Retaba1981.html [cit. 12 May 2016].

[34] HUDEC, J. In RZEPKA, S. et al. New Kingdom and theThird Intermediate Period. In *Agypten und Levante*. Internationale Zeitschrift für ägyptische Archäologie und deren Nachbargebiete. Bd. XXI/2011, p. 141f.

[35] HUDEC, J. In RZEPKA, S. et al. Tell el-Retaba from the Second Intermediate Period till the Late Period. Results of the Polish–Slovak Archaeological Mission, Seasons 2011–2012. In *Ägypten und Levante*, *Internationale Zeitschrift für ägyptische Archäologie und deren Nachbargebiete.* Bd. XXIV/2014, p. 72.

The preserved part of both towers are about 1.5 m higher than the door-step and compact, which indicates the purpose of towers on the ground floor as a part of an impenetrable defence system. Some rooms were probably located on the upper floors (see an architectonic reconstruction: (Fig. 31–32).
The north tower is connected to Wall 1 in a way that from entry corridor/south-eastern corner the tower overlaps Wall 1 by one mudbrick row, 115 cm above the fundaments, and the tower edge slopes towards Naville's section to the footing bottom of Wall 1. It seems that Wall 1 was completely damaged or absent in this area during the Migdol construction or the empty space represents the old gateway of Wall 1, which was already indicated by Petrie.[36]

4. Methodology of testing and description of actual state of mudbrick constructions

The composition and statistical measurements of mudbricks tested at a similar locality (el-Amarna) suggest that the all used raw materials are naturally occurring sediments. In the Delta area they have undergone the same mixing and sorting in situ, as a result of their manufacturing into bricks.[37]

The uniformly high medium sand content suggests an influence of wind-blowing as an agent of transport and deposition. The "puddling" during the brick manufacture process would tend to concentrate the finer size grades; the longer the suspension was allowed to settle. The excavation in el-Amarna revealed a possible working yard with piles of dung/alluvium and ash, which may have been intended for use in the making of bricks. Other inclusions found in the bricks at el-Amarna are grass, wood, seeds and pottery. This suggests that brick composition was very much a matter of what was easily and locally obtainable. Bricks with greater and coarser amounts of gravel were more often used in the lower courses of buildings (proper mudbrick for enclosure walls and foundation courses), but for the finishing whatever materials at hand was used.[38]

Appropriate tests for determining the ideal granulometric composition of a mudbrick are mainly based on sieve analysis (grain > 0.1 mm), hydrometer test (grain < 0.1 mm), specific Atterberg limits (shrinkage, plastic, liquid) and proctor compaction test.

At sieve analysis the weight of dry soil placed atop of the largest sieve is known and the set of sieves are shaken. The soil retained on each sieve is

[36] PETRIE, W. M. F., DUNCAN, J. G. Hyksos and Israelite Cities, Tab. XXXV.
[37] FRENCH, C. A. I. A sediments analysis of mudbrick and natural features. In KEMP, Barry, J. (ed.). *Amarna Reports I. Occasional Papers 1.*, 1984, pp. 194–195.
[38] Ibid. pp. 194–195.

weighed and the percentage of soil retained on each sieve is calculated. The results are plotted on a graph in percentages of particles finer than a given sieve as the ordinate versus the logarithm of the particle sizes as shown e.g. in Fig. 20 and Fig. 21.

The hydrometer test involves mixing a small amount of soil into a suspension and observing how the suspension settles in time. Larger particles will settle quickly followed by smaller particles. When the hydrometer is lowered into the suspension it is possible to determine the density of the suspension at different times. The hydrometer tests will be done in the next season for the remaining parts of mudbricks after a sieve analysis.

The particle size distribution of soil is presented as a curve on a semi-logarithmic plot, the ordinates being the percentage by weight of particles smaller than the size given by the abscissa. Size such as 10% of the particles is smaller than the size which is denoted by D_{10}. Other sizes such as D_{30} and D_{60} can be defined in a similar way. The size D_{10} is defined as the effective size. The general slope and shape of the distribution curve can be described by means of the coefficient uniformity of C_u and the coefficient curvature of C_c, defined as follows:

$$C_u = D_{60}/D_{10}$$

$$C_c = D_{30}^2/(D_{60}.D_{10})$$

The higher the value of the coefficient uniformity the larger the range of particle sizes in the soil.[39]A soil that has a uniformity coefficient of < 4 contains particles of uniform size (approximately one size). The minimum value of C_u is 1 and corresponds to an assemblage of particles of the same size. The gradation curve for poorly graded soils is almost vertical. Humps in gradation curve indicate two or more poorly graded soils. Higher values of uniformity coefficient > 4 are described as a well-graded soil and are indicated by a flat curve. The coefficient curvature is between 1 and 3 for well-graded soils. The absence of certain grain sizes, termed gap-graded, is diagnosed by a coefficient curvature outside the range of 1 to 3 and a sudden change of slope in the particle size distribution curve.[40]

A laboratory test proctor standard delivers a standard amount of mechanical energy to determine the maximum dry unit weight of the soil.

Dry unit weight is the weight of dry soil per unit volume. To denote unit weight:

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[39] CRAIG, R. F. Soil mechanics, pp. 7–8.
[40] BUDHU, M. Soil Mechanics and Foundations, p. 45.

$$\gamma_d = w/V \ [kN/m^3] \ (w - \text{weight of a dry soil, } V - \text{volume of the soil})$$

Relative density I_D is an index that quantifies the degree of packing between the most loose and most dense possible state of coarse-grained soils. The relative density correlates very well with the strength of coarse-grained soils – denser soils being stronger than looser soils.[41]

Soil densities were tested in the field and the loosest and densest states of coarse grained soil (sand) have been evaluated.

The minimum dry unit weight $\gamma_{d,min}$ of soil in loosest conditions were found by pouring dry sand, into a container of volume 1000 cm^3 using a funnel. The sand that filled up the container was weighed. The maximum dry unit weight $\gamma_{d,max}$ was determined by vibrating the container with the sampled soil. After 2 minutes of hand vibrating a new smaller value of soil volume were checked and the $\gamma_{d,max}$ were calculated.

Obtaining γ_d for non-cohesive soil directly from in situ tests is difficult and is important to measure an accurate volume from the sample pit. In the next seasons some in situ measuring of soil (sand) density will be done.

The grading curve is used for textural classification of soils which describe soils based on their particle size distribution. Various classification systems have evolved over the years to categorise soils for a specific engineering purpose. In general soils are separated into two main categories. One category is coarse-grained (non-cohesive) soils and the other category is fine-grained (cohesive) soils. Coarse grained soils are subdivided into gravels and sands while fine-grained soils are divided into silt and clays. According to Eurocode 7 and STN 72 1001 is a clay identified by a grain size less than 0,002 mm, silt has the grain size from 0.002 to 0.063 mm, sand has a grain size from 0.063 to 2 mm and gravel has the grain size from 2 to 63 mm.

For a mutual mudbrick comparison a grain size distribution curve of values were realised from sieve analysis (Fig. 20). For precise obtained data it would be appropriate to use an anti-coagulant (2% of a sodium hexametaphosphate or sodium pyrophosphate) according to a smaller percentage representation of fractions under 0.1 mm, so it will be used for the hydro-meter test in the next seasons also with additional mudbrick samples for checking results. Already obtained data are helping to illustrate the relationship between constructions and their material.

[41] Ibid., p. 37.

5. Evaluation of actual obtained information

From received information and observations available from the archaeological site relative to an engineering point of view, some findings of mudbrick analysis (Fig. 20) and comparison of soil from the footing bottom for individual constructions (Fig. 21) are presented. In paper mudbrick composition it was pointed out and also an examination for soil bearing capacity has been calculated.

5.1 Analysis of samples

A gravel layer was located in the area´s subsoil which exact position and thickness should be specified by additional drilling. The gravel layer is strongly (yellow – rusty) oxidised in its top deposit and only lighter oxidised in a lower deposit. Humidity and oxygen cause a reduction of ferrum in deposits and consequently ferrum´s possible flush. However, at a permanent water level the ferrum is kept preserved; it oxidises to yellow or rusty colour only after the water level decrease sand oxygen intakes. Oxidation at Tell el-Retaba confirms earlier soil science detection of fluctuating water levels at this site.[42]

Differently coloured bricks are (often secondary) used for (re)constructions and extensions of constructions. Black mudbricks were probably caused by an organic carbon (or an ash) considering the fact that all fractions were black. Used mortar was regular brown. It is possible to assume that greenish mudbrick material was mined for it production from a place with excessive reduction and wash-off conditions. After all reduced ferrum was washed away the soil in specific deposits changed its colour to greenish. Such greenish deposits were observed in deeper layers of other venues in Wadi Tumilat (Fig. 33).

It is obvious that the colour of mudbricks depends on the source of used material. The producers did use such material without too much care about improving the composition of mudbricks; it seems that accessibility of soil material was the prior motive in the majority of cases in Tell el-Retaba. During sampling very low strength and fragility of greenish mudbrick were noticed; some mudbricks even crumbled away. Grain size distribution curves of mudbrick and soil samples are shown in Fig. 20 and Fig. 21.

[42] HUDEC, J., FULAJTÁR, E., STOPKOVÁ, E. Historical and environmental determinations of the Ancient Egyptian Fortresses in Tell el-Retaba. In *Asian and African Studies*, 2015, Vol. 24, No. 2, p. 275f.

5.1.1 Interpretation of some results from grain-size curves

- Comparison of mudbrick composition from Wall 1close to the Migdol (sample S-MB1) and in Area 9 (sample S-MB4) indicates different dimensions of mudbricks (see Fig. 22) and probably also different used soil materials. From a preliminary evaluation of the coefficient uniformity of C_u and the coefficient curvature of C_c it is possible to assume that mudbrick S-MB1 was of better quality than S-MB4.
- According to very good match of mudbrick samples S-MB8 and S-MB9 we can assume that Wall 2 was probably built from Migdol next to the north and also to the south by the same mudbricks probably at the same time (see Fig. 23).
- The core of Wall 1 and its extensions (internal and external) were built by different mudbrick material, despite the mudbricks having had the same dimensions. The used black (sample S-MB5) and greenish (sample S-MB6) mudbricks have strong composition similarity, which will be explored in more details in future.
- Besides the important information about mudbrick material (grain-size curve) the type of the footing bottom, the bonding brick is also very important. Material from the surrounding area (sand and mud) was usually used in the production of mudbricks.
- The yellow sand from the footing bottom of Migdol's threshold (sample S-S5) was also used in the footing bottom of Wall 3 (sample S-S7) in Area 9 (see Fig. 24).
- Soil from the floor of Black house 1 (sample S-S4), located under Wall 2 platform connected to the Migdol, corresponds to mudbrick material from Wall 3 (sample S-MB12) in Area 9, what might indicate that bricks from Wall 2 could probably be reused at the building of Wall 3 (see Fig. 25).
- Also the match of sand from the footing bottom of north Migdol's tower (sample S-S3) and the mudbrick of south Migdol's tower (sample S-MB11) indicates that the same sand was probably used for making bricks as well as in the footing bottom (however, mudbricks from the north Migdol's tower have not been tested yet) (see Fig. 26).
- The sand sample S-S1 from the external extension of Wall 1 and sand sample S-S6 from Wall 2 near the south-west corner of the fortress used like a bed layer also match very well. Different underlying sand was used in the footing bottom of Migdol's threshold. It is possible to assume that several dunes of fine sand were blown into the vicinity of Tell el-Retaba fortresses in the 13th and 12th centuries B. C.; they were sources of a similar bed layer material in the New Kingdom (Fig. 27).

  But an alternative also might be possible that the construction of Wall 2 on the western side of the fortress started in the south–west corner on the regular surface and as subsequent works continued towards the Migdol some additional fill-up material was necessary, which can also be indicated by steps in the footing bottom of Wall 2 towards the Migdol. Further analyses will be needed.

Tab. 6 Analysed samples for walls

Name	**Type**	**Location**	**Cu[-]**	**Cc[-]**	**γ[kg/m^3]**
S-MB1	mudbrick	Wall 1 (behind the Migdol)	18,0	0,6	2010
S-MB2	mudbrick	Wall 1 (behind the Migdol)	-	-	1640
S-MB3	mudbrick	Wall 1 (behind the Migdol)	-	-	1765
S-MB4	mudbrick	Wall 1 (Area 9)	7,5	3,3	1650
S-MB5	mudbrick	Wall 1 (behind the Migdol)	-	-	1770
S-MB6	mudbrick	Wall 1 (behind the Migdol)	-	-	1530
S-MB7	mudbrick	Wall 2 (Area 9)	-	-	1820
S-MB8	mudbrick	Wall 2 (at south tower of the Migdol)	20,0	5,0	1920
S-MB9	mudbrick	Wall 2 (at north tower of the Migdol)	18,3	5,1	1880
S-MB11	mudbrick	Wall 2 (at the south tower of the Migdol)	12,6	3,5	-
S-MB12	mudbrick	Wall 3 (Area 9)	10,0	2,3	1790
S-S1	soil	Wall 1	3,3	1,2	1610-1930
S-S2	soil	Wall 2	2,1	1,3	1500-1900
S-S3	soil	Wall 2 (platform at the north tower of the Migdol)	3,0	1,3	1730-2020
S-S4	soil	Wall 2 (platform at the north tower of the Migdol)	5,0	1,9	-
S-S5	soil	Wall 2 (threshold of the Migdol)	2,4	1,1	1610-1810
S-S6	soil	Wall 2 (near the south – west corner of the fortress)	3,0	1,2	-
S-S7	soil	Wall 3 (Area 9)	2,2	0,9	1550-1710

- To refine a content of a fine-grained soil (silt and clay) of analysed mudbrick samples, an anticoagulant will be applied in the next tests previous to the sieve analysis and hydrometer test. The application will show non-cohesion among grains of soil and improve the course of grain-size curve, and verify the already performed tests (which were so far sufficient for adequate mutual comparison of individual curves).

The coefficient uniformity of C_u, coefficient curvature of C_c and soil density have been evaluated, based on individual soil samples and some parts of mudbricks what, together with grain – size curve, indirectly indicates the quality of mudbrick or soil material and its compacting option. Some of the test results for the analysed samples are shown in Tab. 6.

The coefficient uniformity of C_u and coefficient curvature of C_c both only show predisposition for ideal compaction and consequently possible material hardness, but the density has the final decision on how the material behaves as a mudbrick.

5.2 Examination of bearing capacity

The calculation of a bearing capacity of subsoil were realised according to observations at the site, using currently valid Eurocodes (e.g. STN EN 1997-1), to also respect the safety factor of the ancient construction. Although the constructions were not analysed with such a precision in ancient times, their extreme long durability could justify correctness of some safety reserve consideration, especially if the subject of the investigation is a military installation with increased demand for stability.

5.2.1 Input data –Migdol’s northern tower

- The depth of the foundation is assumed around 4 layers of bricks (min. 60 cm).
- The projected depth of groundwater level is estimated around 3 m below the foundation base (based on information about an ancient channel and the well, which was discovered at the site).
- The ground plan dimensions of the north tower of the western gate (Migdol) are L = 22.5 m, W = 14.0 m (values have been verified by an exposed building structures).
- The geological structure of the bedrock is projected on the basis of a descriptive classification in the excavation´s documentation and photographs (information was supplemented by direct specification according to the classification of soils and rocks in worldwide classification).

- A simplified engineering geological profile of subsoil (version 2013)
  0-2 m poorly graded sand S2-SP
  2-5 m silty gravel G4-GM
  5-15 m silty sand S4-SM
- Densities of mudbrick are taken as γ = 19 kN/m^3 (the average value of samples taken on the site).
- Load on the footing bottom by its own weight of the north tower is partly based on the tower of Migdol in Medinet Habu (Fig. 28).Estimated tower height is H = 15 m.
  Straight volume of the tower is estimated as G_0 = 2850 m^3, due to material (mudbrick), a similar model of the gate from the same period and its interaction with defensive walls and due to the total volume of construction value of one tower.
  The contact pressure on the footing bottom by its own weight of the tower:
  $\sigma_{g0} = (G_0 * \gamma) / (B \cdot L) = (2850 * 19) / (22.5 * 14.0) = 172$ kPa

5.2.2 Calculations report – Migdol's tower

Bearing capacity of subsoil has been calculated by software GEO5 with the following boundary conditions:

- Foundation geometry:
  Width B = 14.0 m
  Length L = 22.5 m
- Minimal foundation depth:
  d = 0.6m
- Assumed geology and soil parameters:
  Layer 1: Soil type S2 – SP, γ_1 = 18.5kN/m^3, c_{ef1} = 0kPa, ϕ_{ef1}=29°, h_1=2.0 m
  Layer 2: Soil type G4 – GM, γ_2 = 19.0kN/m^3, c_{ef2} = 0kPa, ϕ_{ef2}=30°, h_2=3.0 m
  Layer 3: Soil type S4 – SM, γ_3 = 18.5kN/m^3, c_{ef2} = 1kPa, ϕ_{ef3}=26°, h_3= 10.0 m
  (Note: γ_i–unit weight of soil, c_{efi} – cohesion, ϕ_{efi} – angle of internal friction, h_i – layer thickness)
- Partial factors:
  Design approach 2, combination: "A1+ M1+ R2"
  $\gamma_G = 1.35$, $\gamma_Q = 1.5$, $\gamma_\phi = 1.0$, $\gamma_c = 1.0$, $\gamma_{R,v} = 1.40$
- Contact pressure:
  $\sigma = \sigma_{g0}.\gamma_F = 233$kPa
- Examination of bearing capacity according to the equation for ultimate limit state (STN EN 1997-1):
  $R_d = c_{ef}.N_c.b_c.s_c.i_c + \gamma.d.\ N_q.b_q.s_q.i_q + 0.5.\gamma.B.\ N_\gamma.b_\gamma.s_\gamma.i_\gamma$
  R_d = 521 kPa

- Bearing capacity check:
  $\sigma = 233\text{kPa} \leq R_d = 521$ kPa Satisfactory!
- Note: If a more conservative examination were assumed, e.g. with safety factor for bearing capacity $\gamma_{R,v} = 3.0$ (valid in Brazil and other countries) very near values of suitable bearing capacity would be received.
  $\sigma = 233\text{kPa} \leq R_d = 243\text{kPa}$ Satisfactory!

5.2.3 Input data – Wall 2

- The depth of the foundation is assumed around 4 layers of bricks (min. 60 cm).
- The projected depth of the groundwater level is estimated around 3 m below the foundation base (based on information about the ancient channel and the well, which was discovered at the site).
- An average wall thickness of the defensive wall connected to the towers of Migdol is $b = 8.8$ m (value has been verified by an exposed building structures).
- The geological structure of the bedrock is projected on the basis of a descriptive classification in excavation´s documentation and photographs (information is supplemented by direct specification according to the classification of soils and rocks in worldwide classification).
- A simplified engineering geological profile of subsoil (version 2013)
  0-2 m poorly graded sand S2-SP
  2-5 m silty gravel G4-GM
  5-15 m silty sand S4-SM
- Densities of mudbrick are taken as $\gamma = 19$ kN/m^3 (the average value of samples taken on the site)
- Load on the footing bottom by its own weight of the defensive wall at Migdol is based partly on the model of Migdol in Medinet Habu (Fig. 29).Estimated height of the wall is H = 12 m.
  Volume of the defensive wall is estimated by the total volume of construction at 1m value $G_0 = 96$ m^3, due to material (mudbrick), a similar model of the defensive wall from the same period and its interaction with Migdol´s tower and due to the total volume of construction value of the wall.
  The contact pressure on the footing bottom by its own weight of the defence wall for 1 standard meter:
  $\sigma_{g0} = (G_0 * \gamma) / (L * B) = (96 * 19) / (8.8 * 1.0) = 208$ kPa

5.2.4 Calculation – Wall 2

Considering the related boundary conditions of Migdol, similar engineering-geological conditions were also assumed for the defence wall in this phase of examination.

- Foundation geometry: Width B = 8.8 m
- Minimal foundation depth: d = 0.6 m
- Assumed geology and soil parameters:
  Layer 1: Soil type S2 – SP, γ_1 = 18.5kN/m^3, c_{ef1} = 0kPa, ϕ_{ef1}=29°, h_1= 2.0 m
  Layer 2: Soil type G4 – GM, γ_2 = 19.0kN/m^3, c_{ef2} = 0kPa, ϕ_{ef2}=30°, h_2= 3.0 m
  Layer 3: Soil type S4 – SM, γ_3 = 18.5kN/m^3, c_{ef2} = 1kPa, ϕ_{ef3}=26°, h_3= 10.0 m
  (Note: γ_i – unit weight of soil, c_{efi} – cohesion, ϕ_{efi} – angle of internal friction, h_i – layer thickness)
- Partial factors: Design approach 2, combination: "A1+ M1+ R2"
  $\gamma_G = 1.35$, $\gamma_Q = 1.5$, $\gamma_\phi = 1.0$, $\gamma_c = 1.0$, $\gamma_{R,v} = 1.40$
- Contact pressure: $\sigma = \sigma_{g0}.\gamma_F$ = 281kPa
- Examination of bearing capacity according to the equation for the ultimate limit state (STN EN 1997-1):
  $R_d = c_{ef}.N_c.b_c.s_c.i_c + \gamma.d.\ N_q.b_q.s_q.i_q + 0.5.\gamma.B.\ N_\gamma.b_\gamma.s_\gamma.i_\gamma$
  R_d = 403 kPa
- Bearing capacity check: σ = 281kPa ≤ R_d = 403 kPa Satisfactory!
- Note: The most probable boundary conditions are assumed in the examination; it is possible that in some parts of the wall the situation could be better and more optimistic results could be received, however, for a responsible examination of the ancient structures a safety factor of the ancient construction must also be respected.

5.2.5 Review of bearing capacity examination

The ground plan dimensions of Migdol's tower were assumed at 14.0 x 22.5 m and the resulting height of the towers is postulated at approximately 15.0 meters. Established contact pressure on the footing bottom was 233kPa. Computing bearing capacity of the subsoil under conditions as described above was 521kPa.

Dimensions of the defensive wall were considered under a ground plan thickness of about 8.8 m, height of 12 m and the width of the wall at its top of approximately 6.9 meters. Established contact load in the footing bottom was 281 kPa. Computing bearing capacity of the subsoil under conditions as described above was 403 kPa.

From the results of the assessment it is clear that under the given boundary conditions of the calculation and present results of the archaeological research it is reasonable to assume Migdol´s towers height was about 15 m or maybe even a little more. The height of the defence walls could be about 12 m.

Verification of the individual building constructions boundary conditions (Sec. 5.2.1 and 5.2.3) will be complemented, which could help a consistent evaluation of building and technical conclusions for the various structural elements from the engineering point of view.

6. Conclusion and a recommendation for further research

Several building constructions (fortress walls, residential houses, buildings, etc.) in a different grade of preservation of foundations and wall parts have been uncovered at Tell el-Retaba. With regards to the geographical importance of the site the local architectures were also rebuilt (and building materials were reused in some cases).At present several structural interferences were done on the site (e.g. a mosque construction pit, a road extension, a second branch of high capacity water pipeline, etc.) which complicates the analysis of constructions.

All foundations are made of mudbricks and are founded relatively shallow assuming about today's knowledge of foundation design and examination of stresses and strains in subsoil according to a foundation load. At backward examination of assumed building constructions with preserved foundations is necessary to verify an individual aspect of limit states:

Ultimate Limit State (bearing capacity of the subsoil)
Limit State of Serviceability (subsoil settlement)
Foundation material failure, eventually overload of building material strength (e.g. mudbricks, mortar, etc.)

Although the individual construction details of walls and Migdol did not survive till present days, it is possible to reflect, on the basis of archaeological research, supplemented by the relevant assessment of survived foundation structures, how the fortress Tell el-Retaba could have looked like in a single phase of its existence.

In this report basic dimensions of the entrance gate–Migdol and defence walls were indicatively proven, by preliminary static calculations of the bearing capacity of the subsoil. The calculation has been realised in terms of currently valid Eurocodes, according to code STN EN 1997-1 and STN 73 1001, because it is not reasonable to check ancient structures without any safety factor, even though these buildings were not evaluated with today's accuracy in time of its origin, but due to their extreme long durability it is correct to consider some safety factors. The used methodology of assessment according to Eurocodes, which considered bearing capacity for vertical bearing capacity partial factor $\gamma_{R,V}$ = 1.4, along with the methodology of the design process with the emphasis on the input data to make a reasonable and responsible view of verification of individual building structures. Due to the necessary requirements of the survey, assessment of the second limit state (settlement) was not given.

Several samples of mudbrick and soil have been examined during archaeological seasons to check and verify some of the boundary conditions. They were tested and analysed with the resources available on the site mainly by sieve analysis, testing density, dimensions, walling technique, etc., what also indirectly helps to determine approximate strength of mudbricks and their usage in single structures. Some additional ingredients like pebbles, pottery shards, etc. were found in brick samples. The grain-size curves, describing mudbrick composition and their relationship and potential reusing in constructions, are considered the distinguished result of the research.

The acquired knowledge and amplified verification of individual building constructions, together with previous information on the archaeological site is systematically complemented by improved boundary conditions for an examination of the analysed construction by an engineering approach.

As was mentioned above, present destructive impacts (construction activities, *sabakheens*, etc.)influence construction examinations, however, they also bring an interesting opportunity to observe stratigraphy of soil layers through almost the whole width of the site and to locate a gravel layer belonging to ancient channel aggradation mound. It is also very interesting to analyse cross–sections of all three defence walls, process their building and mutual relations.

Also, the Naville´s trench through the north tower of Migdol permitted to specify building process, foundation parameters and also the way how Migdol was connected to Wall 1. The section of Wall 1 near to the southern Migdol´s tower allowed a clear view on dual – sided extensions of Wall 1.

Even though all the construction details did not survive till today, the archaeological research supplemented with interdisciplinary examinations contributes to reconstructions and descriptions on how the Tell el–Retaba fortress could have looked in the past.

In the next research verifications of building constructions is strongly recommend to continuously complement and improve boundary conditions assumed for an engineering approach together with all determining information obtained by archaeological research.

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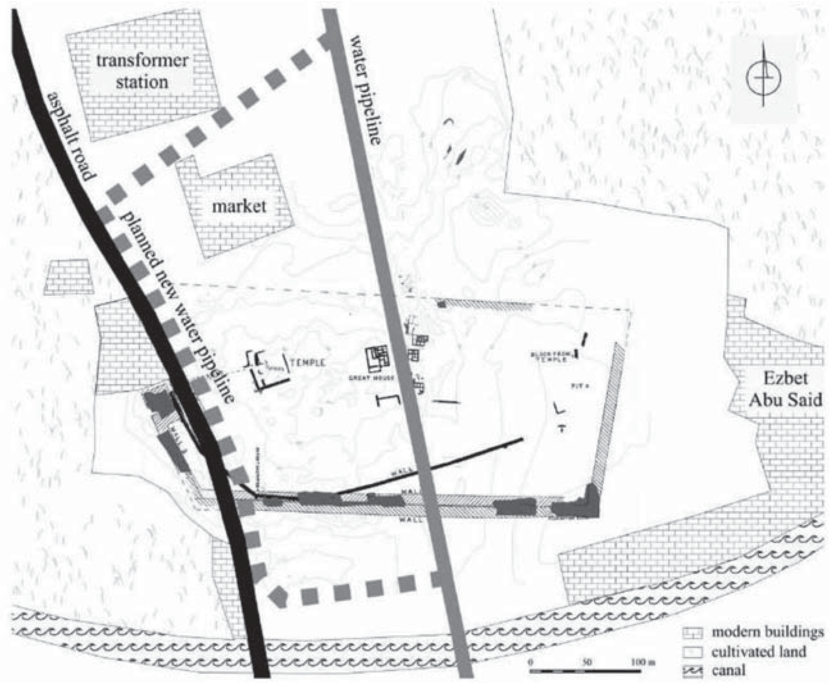
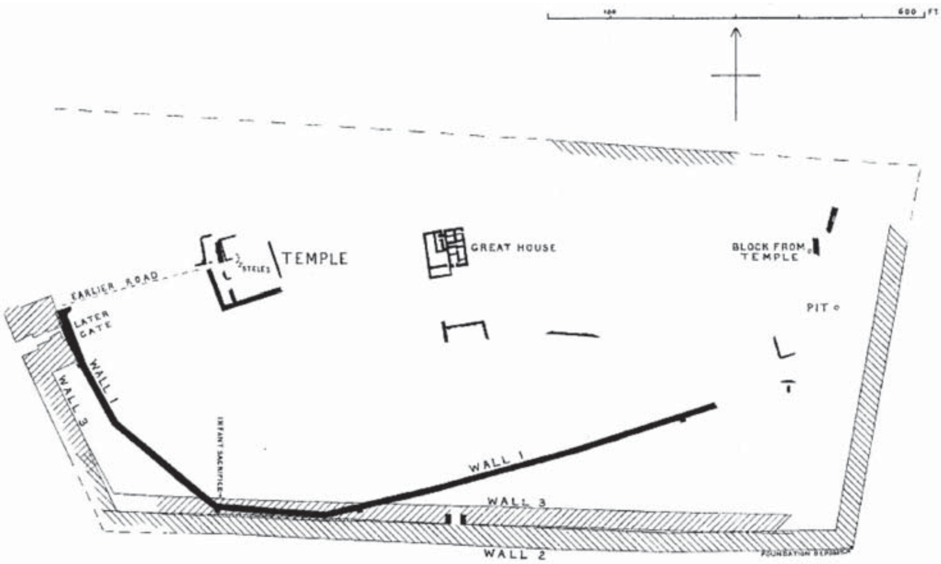
PLATES



ČERNÝ, HUDEC, Pl. 1. Map of Tell el-Retaba with areas destroyed or threatened by modern development (Drawing by Ł. Jarmuzsek)

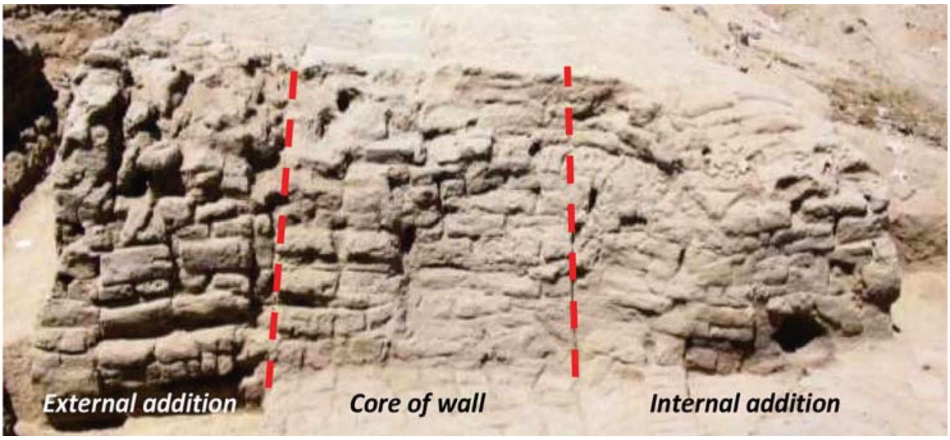
ČERNÝ, HUDEC, Pl. 2. Western part of northern Migdol's tower damaged by rainfall in 2014 (Photo by L. Podhorský)

ČERNÝ, HUDEC, Pl. 3 a – b. Left (a): Mudbrick form; Right (b): Trowel (Both in Manchester Museum)



ČERNÝ, HUDEC, Pl. 4. Petrie's Site map of Tell el Retaba (Petrie and Duncan, 1906)

ČERNÝ, HUDEC, Pl. 5. Cross section of Wall 1, Wall 3 and Wall 2 in Area 9 (Photo by J. Hudec)



ČERNÝ, HUDEC, Pl. 6. Cross section of Wall1 beside the Migdol, looking northwards (Photo by M. Černý)

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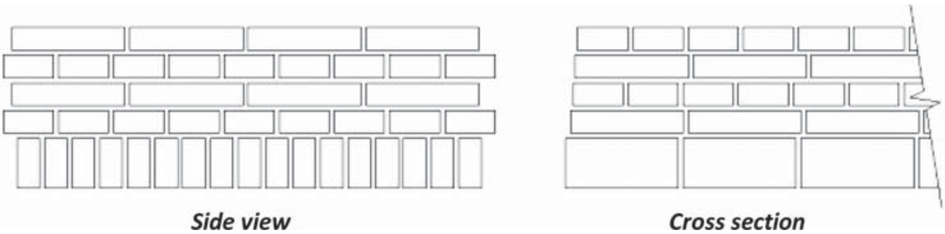
ČERNÝ, HUDEC, Pl. 7. a – c. (a) Wall 1 – side view of the internal extension; (b) Wall 1 – side view of the external extension; (c) mudbrick composition sketch (Photographs and graphics by M. Černý)

ČERNÝ, HUDEC, Pl. 8. Southern defence Wall 2 of the Ramesside fortress, Petrie’s wall 2 (Photo by S. Rzepka)

ČERNÝ, HUDEC, Pl. 9. Trench of pipelines crossing the site (Photo by M. Fuller)

ČERNÝ, HUDEC, Pl. 10. Front view of Wall 2 in Area 9 (Photo by J. Hudec)

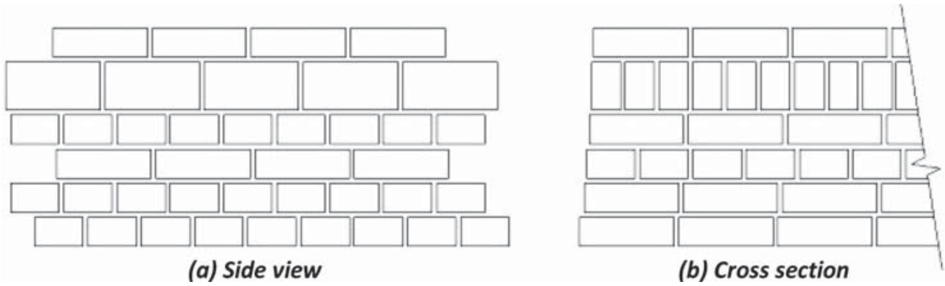


ČERNÝ, HUDEC, Pl. 11 a – b. Left (a): Side view of Wall 2; Right (b): Section view of Wall 2 (Drawing by M. Černý)

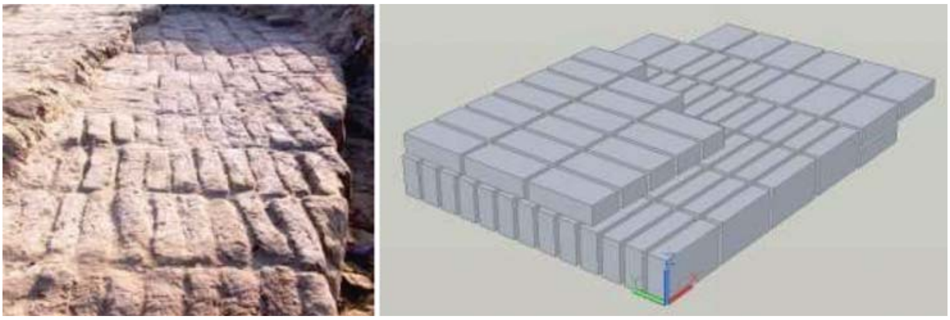
ČERNÝ, HUDEC, Pl. 12. Section view of Wall 3 in Area 9 (Photo by J. Hudec)

ČERNÝ, HUDEC, Pl. 13. View over north Migdol's tower attached to Wall 1 – mouth of the Naville's trench on the right (Photo by M. Černý)

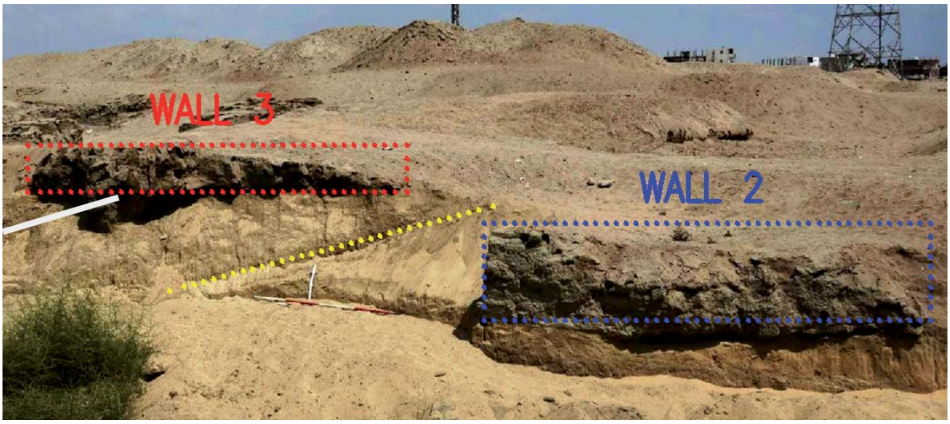
ČERNÝ, HUDEC, Pl. 14. View over Migdol's treshold into the fortress (Photo by M. Černý)



ČERNÝ, HUDEC, Pl. 15. a – b. Left (a): Side view of Wall 3 in Area 9; Right (b): Section view of Wall 3 in Area 9 (Drawing by M. Černý)

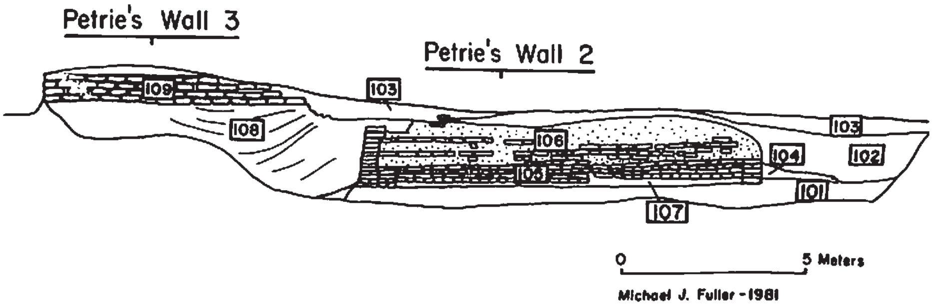


ČERNÝ, HUDEC, Pl. 16. a – b. Left (a): View of the Wall 2 platform at the Migdol's northern tower (Photo by J. Hudec); Right (b): mudbrick composition sketch of the Wall 2 platform at the Migdol's northern tower (Drawing by M. Černý)

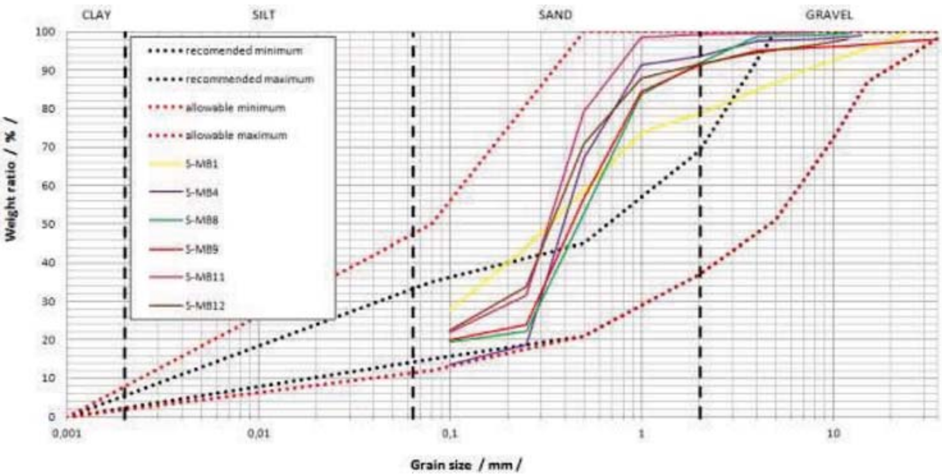


ČERNÝ, HUDEC, Pl. 17. Buttress of Wall 2 (yellow and white line) in Area 9 (Photo by J. Hudec; graphics by M. Černý)

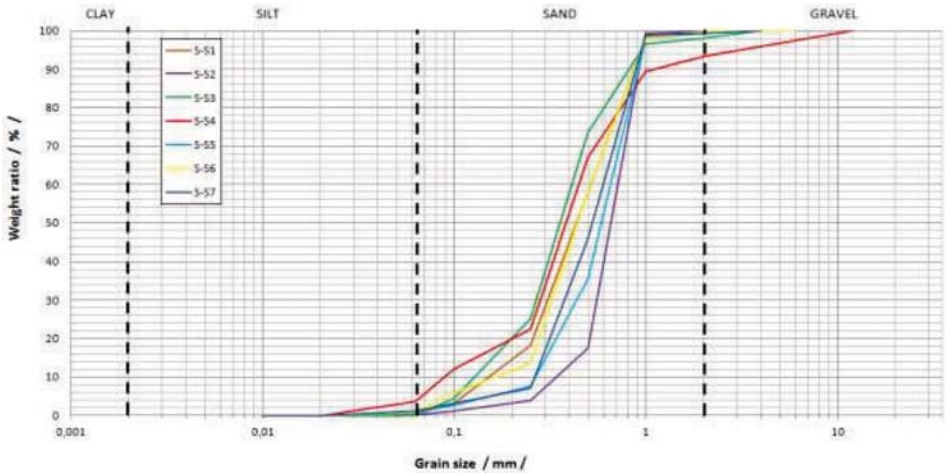
ČERNÝ, HUDEC, Pl. 18. View of a relation between Walls 1, 2 and 3 in Area 9 (Photo by J. Hudec)



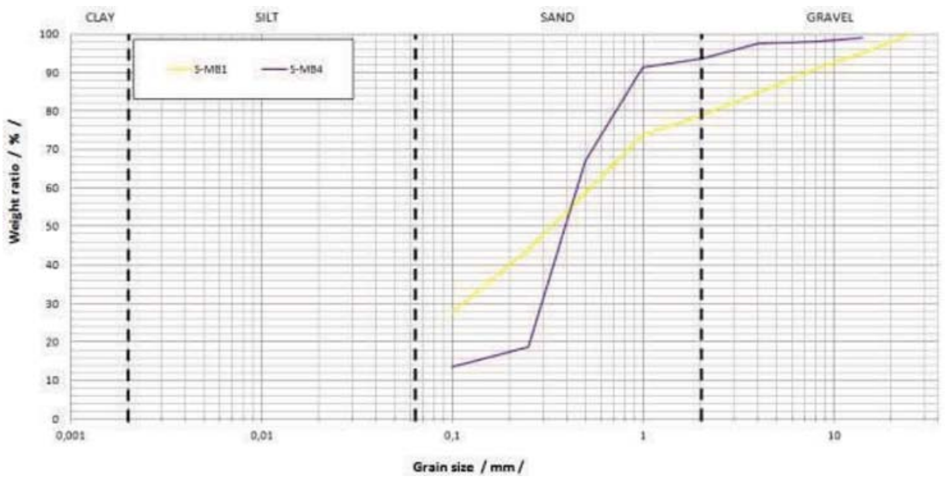
ČERNÝ, HUDEC, Pl. 19. Profile of defensive walls (Drawing by M. J. Fuller, 1981; http://users.stlcc.edu/mfuller/Retaba/Retaba1981.html)



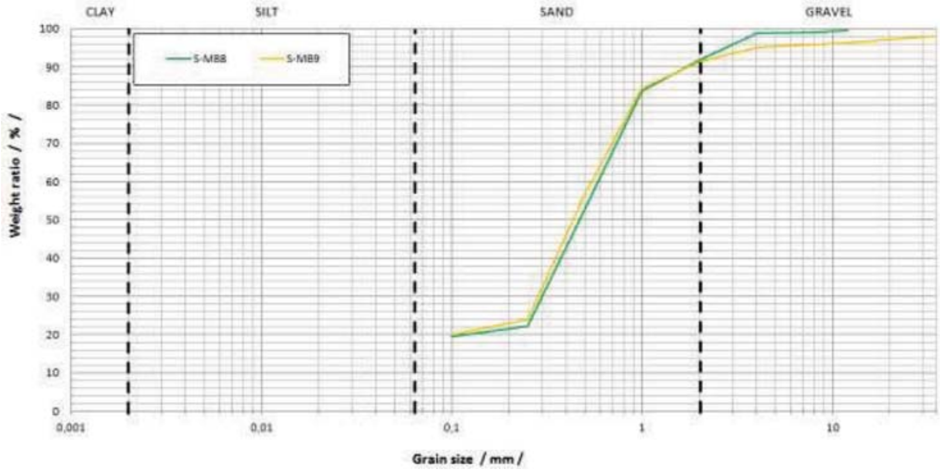
ČERNÝ, HUDEC, Pl. 20. Grain size distribution curve – Mudbrick samples (Diagram by M. Černý)



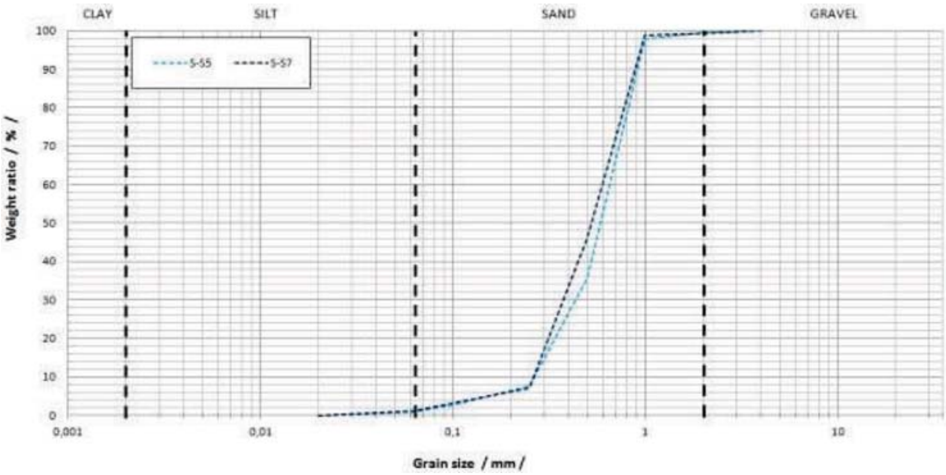
ČERNÝ, HUDEC, Pl. 21. Grain size distribution curve – Soil samples (Diagram by M. Černý)



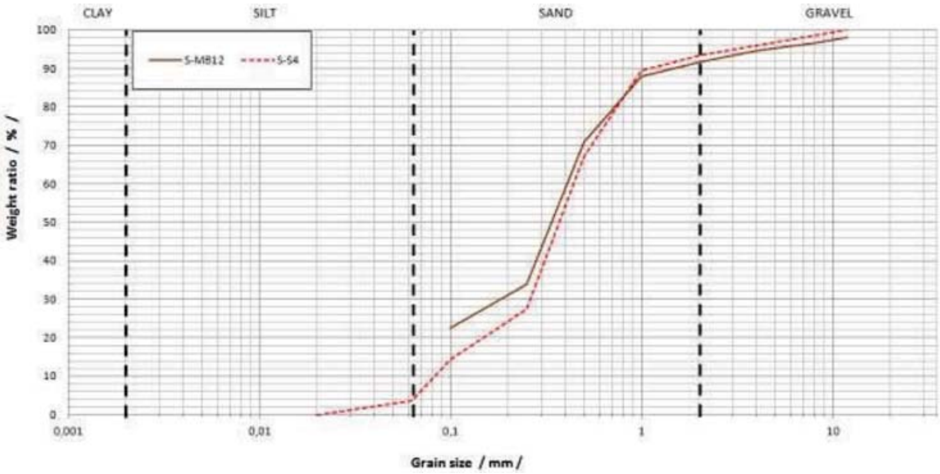
ČERNÝ, HUDEC, Pl. 22. Grain size distribution curve – mudbrick samples (Diagram by M. Černý)



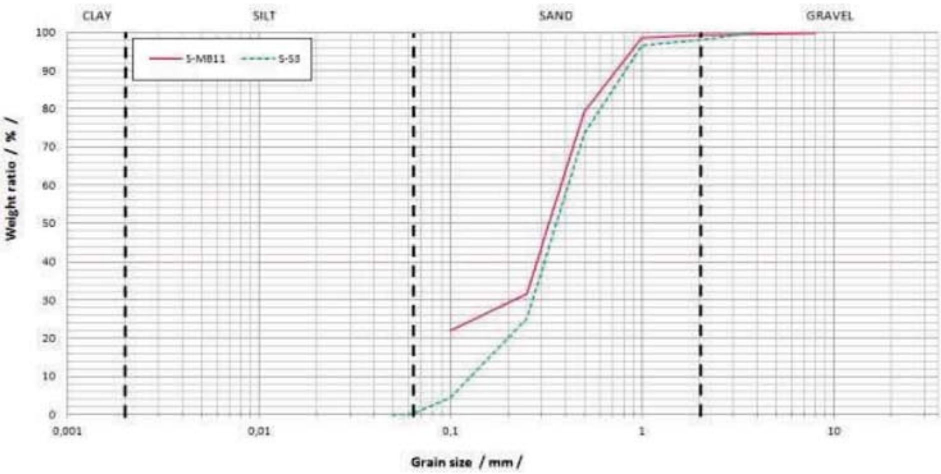
ČERNÝ, HUDEC, Pl. 23. Grain size distribution curve – Mudbrick samples (Diagram by M. Černý)



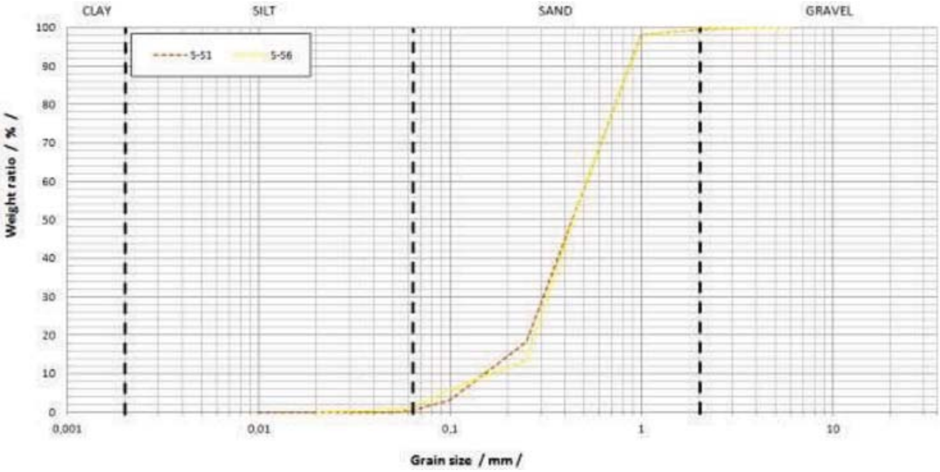
ČERNÝ, HUDEC, Pl. 24. Grain size distribution curve – soil samples (Diagram by M. Černý)



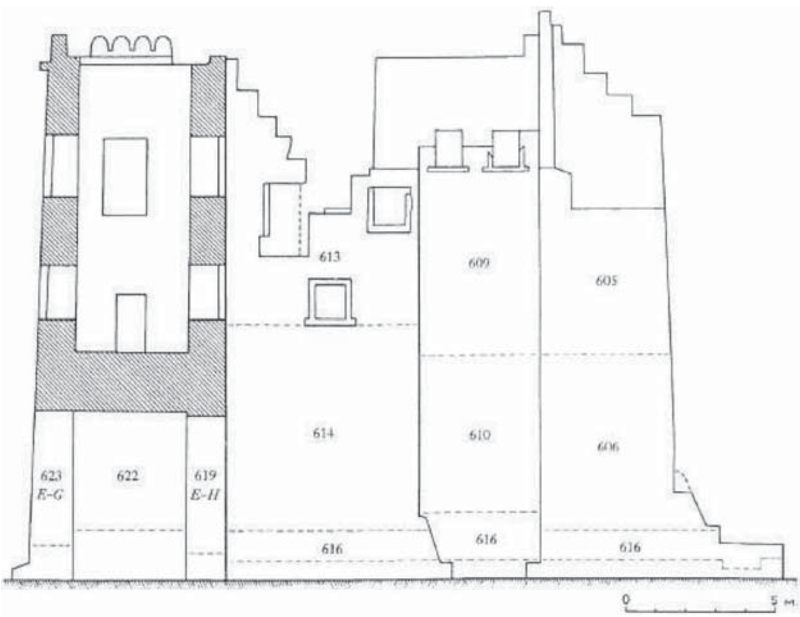
ČERNÝ, HUDEC, Pl. 25. Grain size distribution curve – mudbrick and soil sample (Diagram by M. Černý)



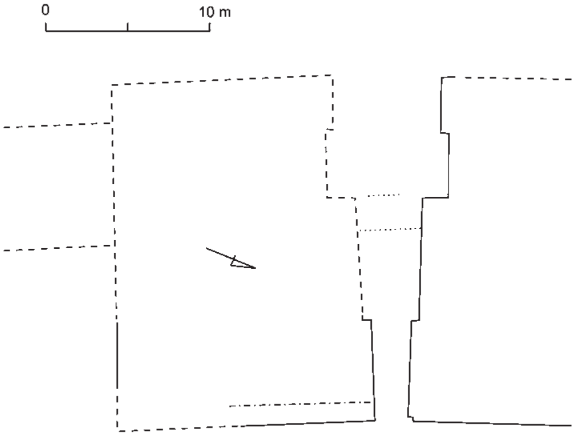
ČERNÝ, HUDEC, Pl. 26. Grain size distribution curve – mudbrick and soil sample (Diagram by M. Černý)



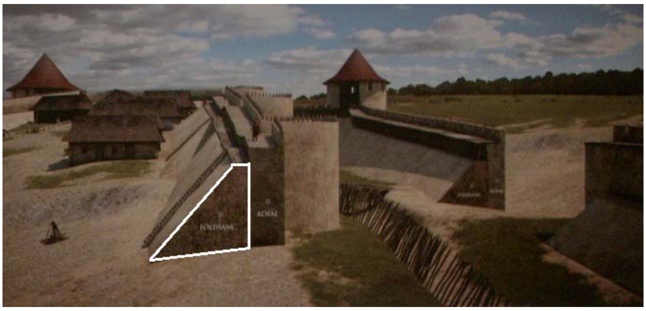
ČERNÝ, HUDEC, Pl. 27. Grain size distribution curve – soil samples (Diagram by M. Černý)



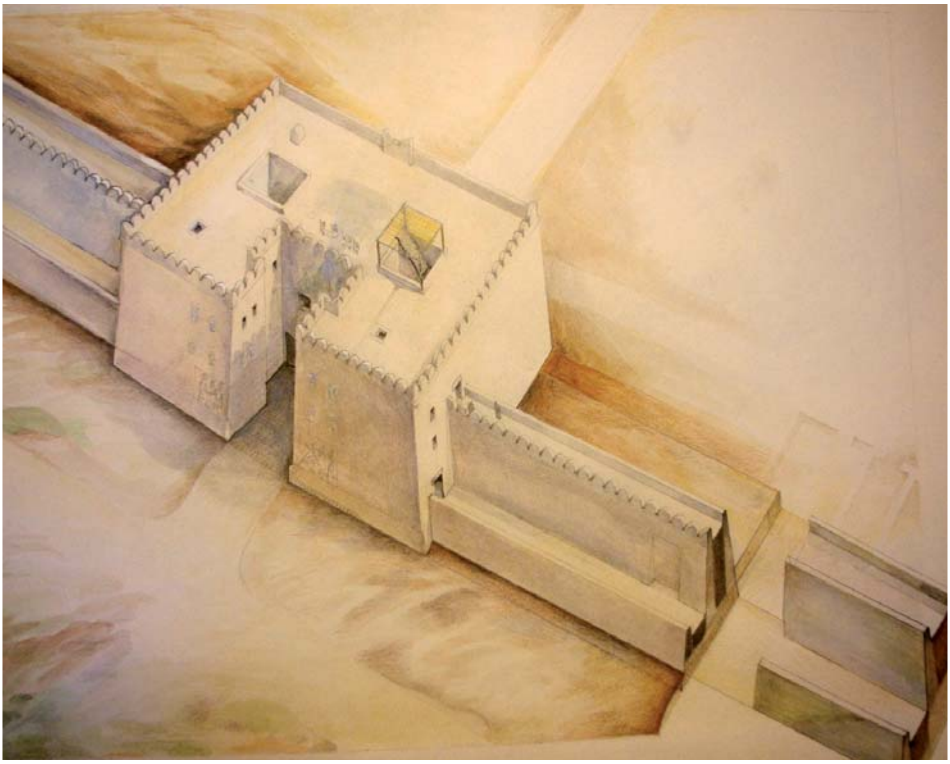
ČERNÝ, HUDEC, Pl. 28. Approximate scheme of Migdol in Medinet Habu (Epigraphic Survey 1970, Pl. 1.)



ČERNÝ, HUDEC, Pl. 29. Plan of western gateway based on excavations (Drawing by J. Hudec)



ČERNÝ, HUDEC, Pl. 30. Buttress of defence wall in Middle Ages (Source: Eger Castle Exhibition)



ČERNÝ, HUDEC, Pl. 31. Axonomic artistic reconstruction of Migdol (Drawing by J. Bruna)

ČERNÝ, HUDEC, Pl. 32. Axonomic artistic reconstruction of Migdol (Drawing by J. Bruna)

ČERNÝ, HUDEC, Pl. 33. Greenish deposits – Wadi Tumilat (Photo by J. Hudec)