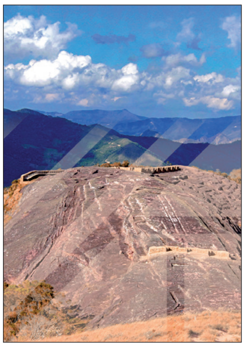

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Interpretation of traces of hypothetical quincha *walls in Samaipata*

Interpretacja śladów hipotetycznych ścian quincha *w Samaipata*

Introduction – the site and the scope of work

Despite the strong Incan characteristics of Samaipata, the site served as a sacred place for many pre-Hispanic local cultures, and its origins date back to around 300 AD. Its present form is mainly the result of activities from the time of Inca dominance over this area, which also coincides with the last century of the Inca Empire before it collapsed during the Spanish conquest in the 2nd half of the 16th century.

For more than two centuries, the site has attracted scholarly attention [1]–[4], mainly due to the unique scale and density of decorations covering the natural rock. These decorations include not only multiple terraces, platforms, and water reservoirs, but also many figural and geometrical petroglyphs, all of them arranged in a very complicated layout (Fig. 1).

Between those various carvings covering nearly the whole surface of the rock, several circular openings with diameters ranging from 8 cm to approximately 60 cm are extant. Apart from those that are of natural origin or caused by rock erosion, these openings are usually interpreted as offering holes for ceremonial libations. They typically neighbour figural petroglyphs either as singular holes or are grouped in irregular patterns. Up until now, much less attention was placed on another group of openings that are arranged in a long line alongside the northern slope of the rock (Fig. 2).

Two much shorter lines of such holes (Fig. 3) can also be found on the southern hillside on the border between sector W04 and W07, as well as on the border between sector W11 and S12[1]. During our survey in 2016, we detected yet another group of similar holes in sector S28 – barely visible traces of such holes are arranged there in a rectangular shape, measuring roughly 2.5 × 4.5 m.

The diameter of all the holes on the northern slope of the hill ranges from 12 to 20 cm, and they were drilled more than 20 cm into the surface of the rock (Fig. 4). There is a consensus among researchers that these holes were used to fix vertical wooden posts. The discussion, however, concerns the dating and the function that these posts served.

One local hypothesis assumes that the posts were used to attach torches that illuminated rituals performed on the rock. However, the most common interpretation is that the posts were part of the construction of traditional *quincha* walls. According to the authors of this article, three fragments of a *quincha* wall located on the southern slope are the relics of buildings that were once there. However, three separate sections of post-holes located on the northern slope we interpret as free-standing walls, not associated with any building.

Two arguments are usually raised against this latter interpretation. First of all, it is noted that at the base of a *quincha* wall, there is usually a shallow ditch. In our case, there is no such feature. The second argument considers the local weather conditions, namely the strong winds

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[1] Cf. J. Kościuk, G. Orefici, M. Ziółkowski, A. Kubicka, R. Muñóz Risolazo, *Description and analysis of El Fuerte de Samaipata in the light of new research, and a proposal of the relative chronology of its main elements*, in the same issue of "Architectus".

Fig. 1. El Fuerte de Samaipata, as seen from the west
(photo by J. Kościuk)

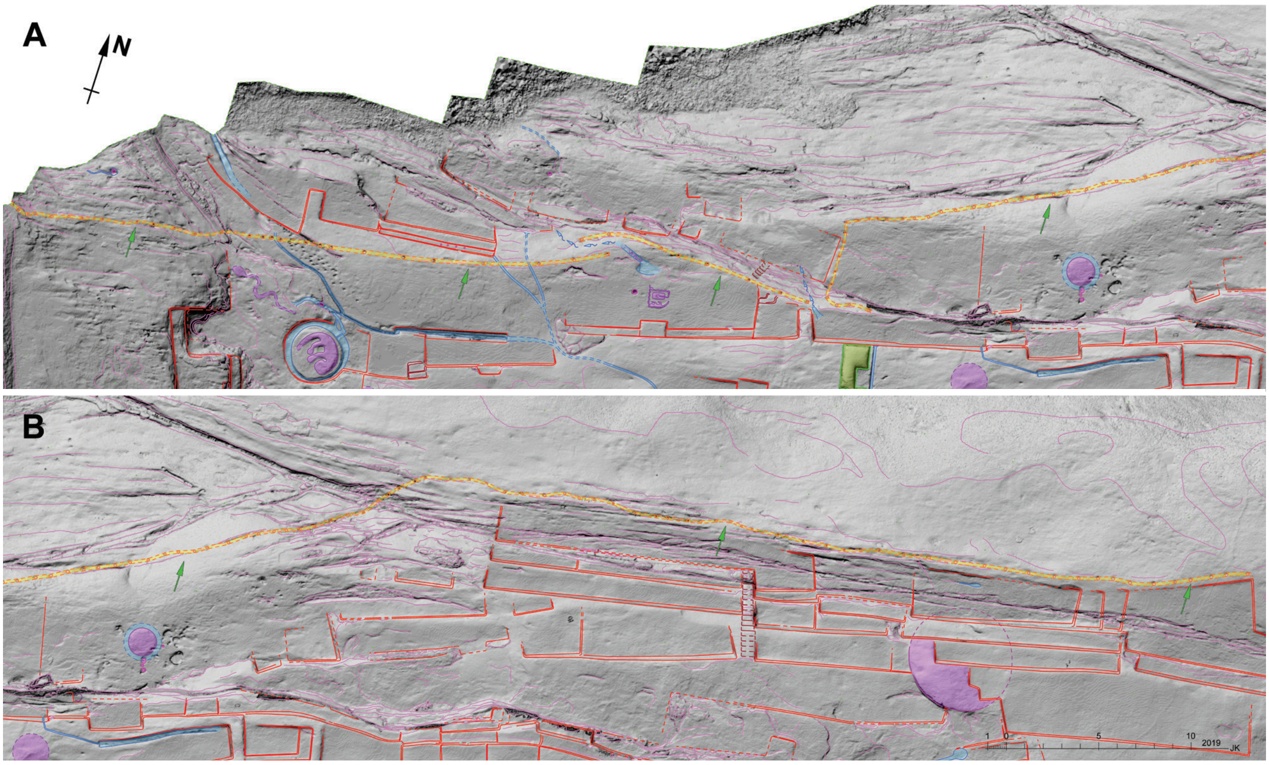

Fig. 2. The northern slope of Samaipata rock.
The green arrows mark rows of round holes for *quincha* posts.
The hill-shaded 3D cloud from terrestrial laser scanning (TLS) is used as the background:
A – the western part;
B – the eastern part
(elaborated by J. Kościuk)

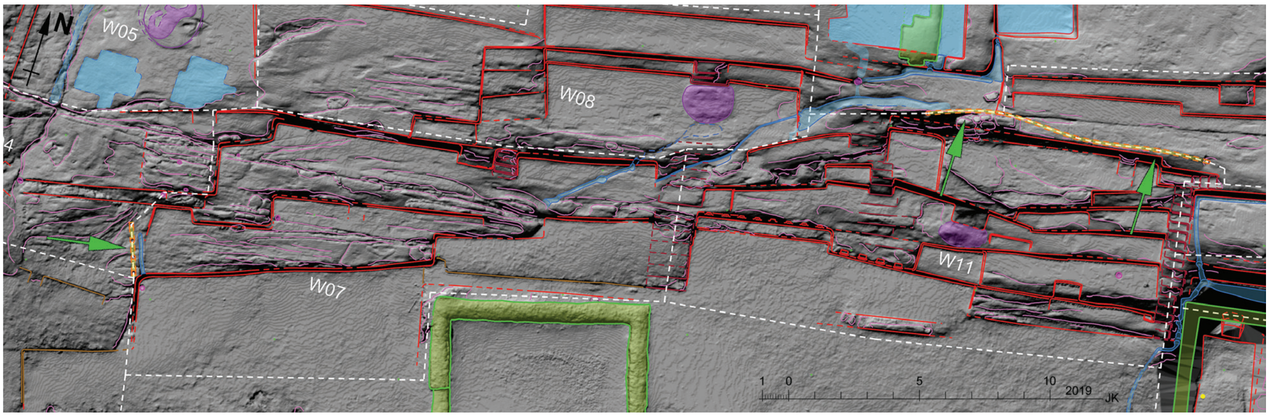

Fig. 3. The southern slope of Samaipata rock. The green arrows mark rows of round holes for *quincha* posts. The hill-shaded 3D cloud from TLS is used as the background (elaborated by J. Kościuk)

at the top of the rock. Therefore, the main objective of this study will be to prove that a *quincha* wall could withstand the windy conditions of the northern slopes of Samaipata.

Albert Meyers, the director of the German Samaipata Archaeological Research Project (Proyecto Arqueológico en Samaipata, PIAS) in the years 1992–1996, drew the authors' attention to another possible interpretation. The holes drilled in the rock may theoretically come from the colonial period and be a part of the Spanish fortifications strengthening the top of the hill as the last defence point. Such dating cannot be a priori excluded in the absence of any relevant evidence that could offer absolute dating of the drilled holes.

An exchange of e-mails resulted in the following conclusions. The Spaniards who arranged the military post there would have wanted to protect the margins of their settlement located south of the rock. Fortifying the top of the rock from the northern side, where the natural slope is so steep that one can hardly imagine any attacks from this side, makes no military sense. Therefore, providing shielding from the wind or undesirable observation remains the only plausible explanation for the function of the postulated *quincha* wall. Were Spaniards interested in this? During discussions, we did not find any arguments in favour of such an interpretation, so in our opinion, the most likely provenience is from Inca times.

Basic information on pre-colonial **quincha** *walls and interpretation of the function of vertical wooden posts*

The term *quincha* is borrowed from the Quechua verb (*Quinchani – cercar de septo*) [5] denoting separating by a septum. Unlike modern constructions also referred to as *quincha*, the pre-Hispanic *quincha* walls were not timber frame-based. The traditional form of this type of construction is still popular not only in the Andean region, but also in the whole of Central America (Fig. 5). Internet resources are full of webpages devoted to local initiatives promoting the use of this simple and economical construction technology [6].

In contrast, post-Hispanic and modern timber frame-based *quincha* constructions are of interest to many scientists, mainly due to their tolerance to seismic phenomena [7], [8] and problems related to the maintenance and conservation of architectural heritage [9]. Simple pre-Hispanic constructions of *quincha* walls are practically not analysed in terms of strength, and their models are not subjected to experimental strength tests. Due to this, it is difficult to solve our main problem solely using current literature on the subject.

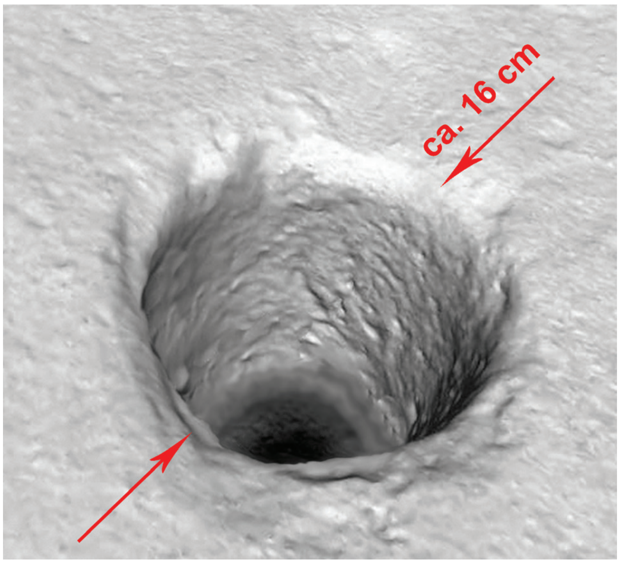

Fig. 4. 3D model of one of the holes on the northern slope of the hill (3D scanning with the structured light scanner and 3D modeling: M. Pakowska)

In terms of construction methods, traditional pre-Hispanic *quincha* walls can be divided into four distinct groups. The simplest structure, the single-interlaced type, consists of vertical posts between which horizontal, thinner branches or rods of local bamboo are intertwined (Fig. 6A). Such a construction can be additionally strengthened with successive vertical rods interlaced between horizontal crossbars – the cross-interlaced *quincha* wall (Fig. 6B). In both cases, clay mixed with chaff tightly covers the wooden construction. Variants are also possible when, instead of interlacing, individual elements are bonded together using

Fig. 5. Contemporary examples of traditional *quincha* walls (sources:
A – https://urbanscrawldc.files.wordpress.com/2014/07/dsc09652.jpg;
B – https://www.revistatierracultah.cl/?p=12501;
C – https://killpackpanamania.files.wordpress.com/2011/06/p4080190.jpg;
D – https://killpackpanamania.files.wordpress.com/2011/06/p4080227.jpg
[accessed: 17.12.2017])

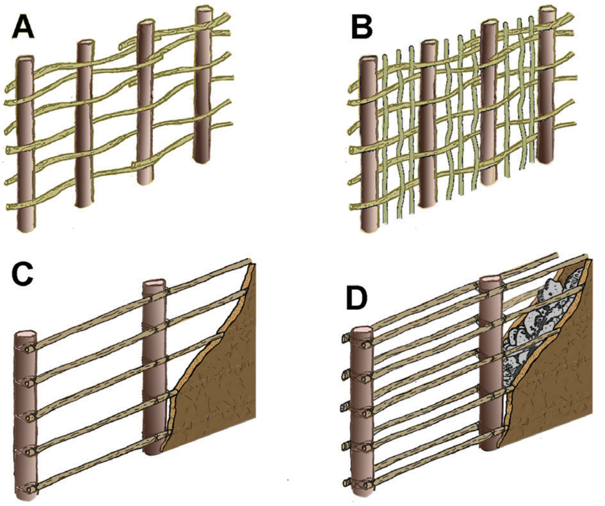

Fig. 6. Main types of pre-Hispanic *quincha* walls:
A – single-interlaced; B – cross-interlaced;
C – one-sided; D – double-sided (elaborated by A. Kubicka)

plant fibres. The next two types differ slightly in their construction. Horizontal elements connecting vertical posts are still present, but the clay filling the wooden construction is much more compacted. Depending on whether the horizontal crossbars are attached on one or both sides of the post, the two further types of wall are distinguished as one-sided (Fig. 6C) or double-sided (Fig. 6D). In the last type, we often notice an infill of small stones or more frequently of adobe.

One of the essential advantages of such constructions is the use of local, easily accessible materials: clay with the addition of organic chaff, small tree branches, bamboo sticks, and trunks of trees of appropriate diameter for vertical posts. Detailed identification of plant species that may have been used in the 14th and 15th centuries by Inca builders is difficult. For natural reasons, such organic materials are rarely preserved in a state that allows for the identification of originally used species on archaeological sites. An additional complication is the 15 climate zones specific to Peru and Bolivia [10], each with typical vegetation. Thus, it is difficult to determine which particular plant species were used by builders on the eastern slopes of the Bolivian Andes. Contemporary tutorials that promote the reintroduction of traditional *quincha* construction recommend the use of hardwood species for vertical posts – preferably *madera tornillo* (*Cedrelinga catenaeformis*) [11], and for horizontal elements and wattle work, local bamboo, *caña brava* (*Gynerium sagittatum*) or *caña guayaquil* (*Guadua angustifolia*) [11], [12].

Discussion of hypothesis

The only common point of discussions about the purpose of the round holes drilled in the northern slope of Samaipata is that they were for fixing vertical, wooden posts. According to the authors of this paper, the hypothesis of using them as support for torches is too fanciful. Additionally, in many places, the holes are located not on the edge of the hill, but on its steep slope, making some posts practically inaccessible (Fig. 7).

Therefore, the only plausible alternative interpretation seems to be that of *quincha* walls. Their function could have been to shield people from the wind, to cover the ceremonial zones to avoid undesirable observation from outside, or, as we will later try to prove, to enlarge the ceremonial platforms behind the walls.

It is worth noting that the line of post-holes on the northern slope of Samaipata rock is interrupted in two places. These coincide with specially shaped channels enabling rainwater to flow down the slope (Fig. 8). This observation alone indicates that once, along the line of holes, there was an artificial barrier that allowed for rainwater runoff. This is one of the crucial arguments supporting the hypothesis postulated by the authors about the existence of a *quincha* wall in this place. Based on the preserved traces, this interpretation seems to be most likely.

As already mentioned, in some places, the line of post-holes does not run directly on the edge of the artificially carved platforms, but it traverses the slope obliquely to the contour lines (Figs. 7, 9A). A hypothetical wall placed along such a line would not protect the platform behind it from the wind or unwished-for observation from outside. It seems likely that, between the line of wooden posts and the steep slope behind it, there was originally a backfill that enlarged the platform above (Fig. 9B). Today, similar constructions still occur in Bolivia – even in the immediate vicinity, at the ticket offices at the entrance to Samaipata (Fig. 10).

What would a backfill enlarging the terrace behind the *quincha* wall look like? Except for the round holes for the posts, there are no traces that could provide guidance. However, the question can be formulated otherwise – how would this kind of platform be properly built and do we know of any examples from the pre-Hispanic era?

Looking at the issue from an engineering point of view, we have two fundamental problems to solve here: how to

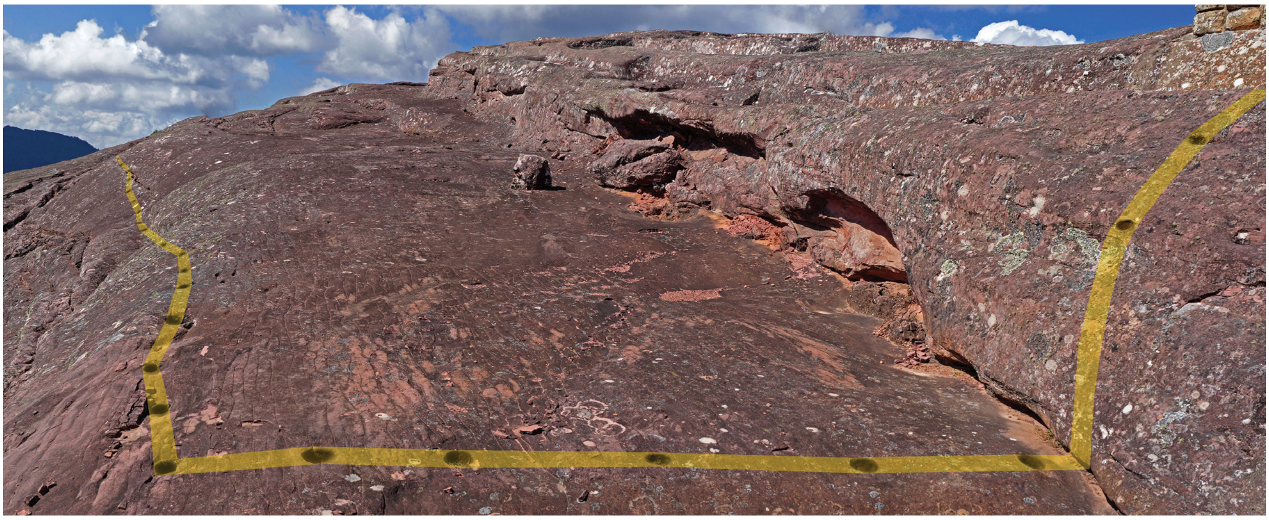

Fig. 7. The line of post-holes on the northern slope of Samaipata rock (photo by J. Kościuk)

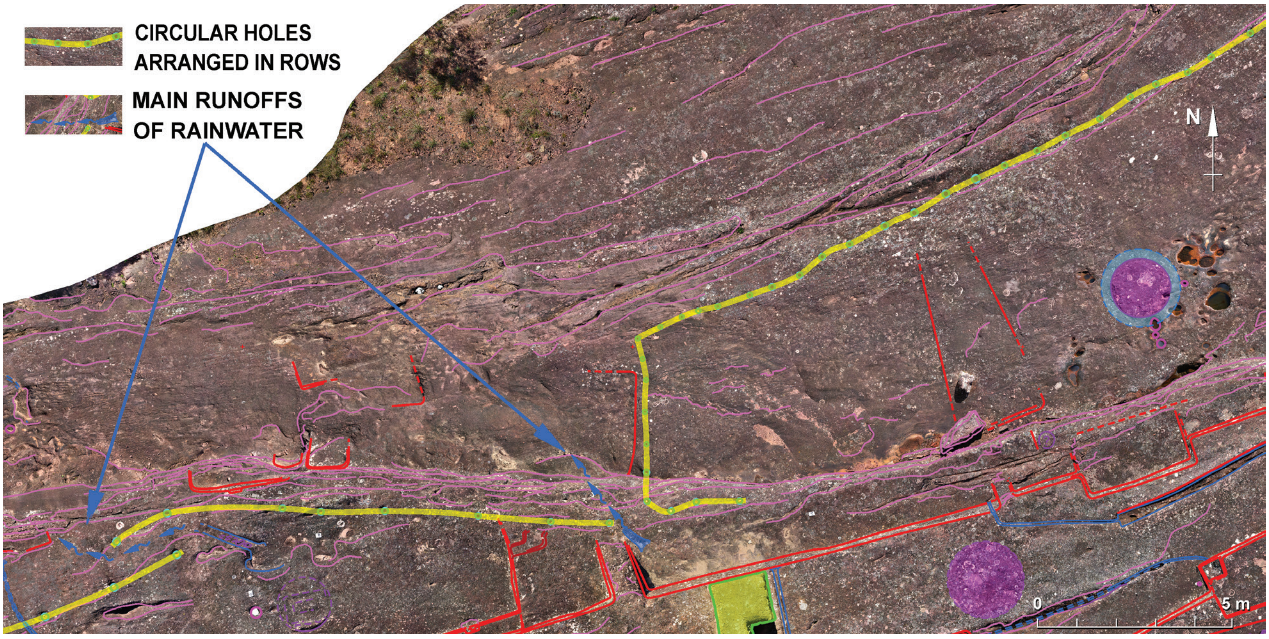

Fig. 8. Hypothetical reconstruction of three sections of the *quincha* wall on the northern slope of Samaipata rock. An orthoimage is used as the background (elaborated by J. Kościuk)

prevent the backfill from sliding down the slope, and the problem of backfill drainage.

We have ample evidence that Inca builders coped with such problems perfectly. The most known are probably the constructions of the terraces on the slopes of Machu Picchu, where both problems had to be solved simultaneously. Admittedly, stone-retaining walls were used there, not *quincha* walls as in the case of Samaipata, but the essence of the solution ensuring adequate drainage and stability of the hopper remains analogous – the bottom layer consisted of […] *larger stones overlain with a layer of gravel and above that a layer of somewhat sandy material* [13, p. 39, Fig. 5–6]. The use of the lowest layer of broken stone with sharp edges, especially if the terrace was founded directly on a steep slope of solid rock, had another advantage – it increased the friction between the layers of the backfill and the face of the rock. Such a solution was observed in the case of the retaining terrace (Fig. 11) of the Inca astronomical observatory El Mirador de Inkaraqay [14].

In the case of Samaipata, the application of this engineering knowledge could have resulted in a similar solution (Fig. 12). It takes into account both the methods of construction of traditional *quincha* walls that we know of, and the principles used by Inca engineers in the construction of terraces. This hypothetical reconstruction introduces one more element – plant-fibre mats laid between layers of the backfill (Fig. 12, item 2). Their function is analogous to the geotextiles used today. The use of plant-fibre mats is already known from the architecture of the pre-Inca Wari culture [15]. We can, therefore, assume that it was also known to the Inca builders.

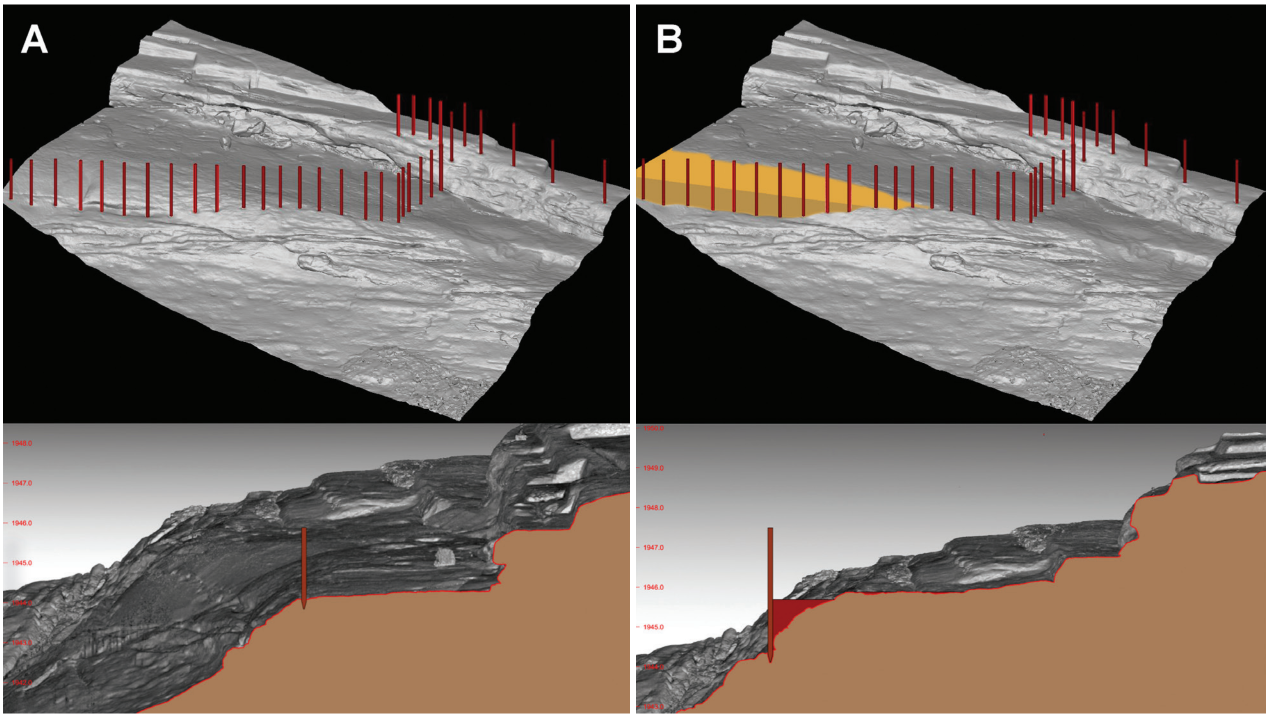

Fig. 9. 3D model of a fragment of the northern slope of Samaipata rock:
A – reconstruction of wooden post line; B – hypothetical reconstruction of the backfill behind the post line (elaborated by J. Kościuk)

Nevertheless, the problem of the lack of shallow ditch at the base of the wall remains unsolved. However, from a structural point of view, such a ditch, usually filled with stones, is mandatory for *quincha* walls placed directly upon uncompacted soils. It acts as a foundation, securing the proper anchoring of piles and evenness of wall settlement, and ensures adequate tightness at the foot of the wall. In the case of *quincha* walls erected directly on solid rock, such a foundation, and therefore the ditch, is not necessary from a structural point of view. This may explain the lack of it in our case. The proposed reconstruction is one of the many ways in which, at the-then level of building skills, this problem could have been solved. In summary, it can be said with a high degree of certainty that the round holes in the rock (and the posts that were likely once embedded in them) indicate the existence of a *quincha* wall in this location.

Nevertheless, the question of the resistance against wind pressure remains unanswered. An affirmative answer may render our hypothesis even more credible.

There are no accurate meteorological data for El Fuerte de Samaipata itself, but the data obtained for the town of Samaipata indicate the same tendency we observed on the top of the hill. The predominant winds are those from a NNW direction; thus, nearly perpendicular to the line of circular, drilled holes alongside the northern slope of the rock. The main problem, however, is wind speed. While in the town located in the valley 300 m below, the wind usually does not exceed 40 km/h (Fig. 13), it is much stronger on the top of Samaipata rock. When working on the top of the hill, we experienced considerable difficulties in

Fig. 10. A contemporary example of a terrace enlargement with a wooden wall and backfill (photo by J. Kościuk)

Fig. 11. El Mirador del Inkaraqay (Machu Picchu). Archaeological sounding showing the construction of the terrace on a steep slope of the rock. Visible blocks of split stone prevent the platform from slipping off the slope of the rock (photogrammetry: J. Kościuk)

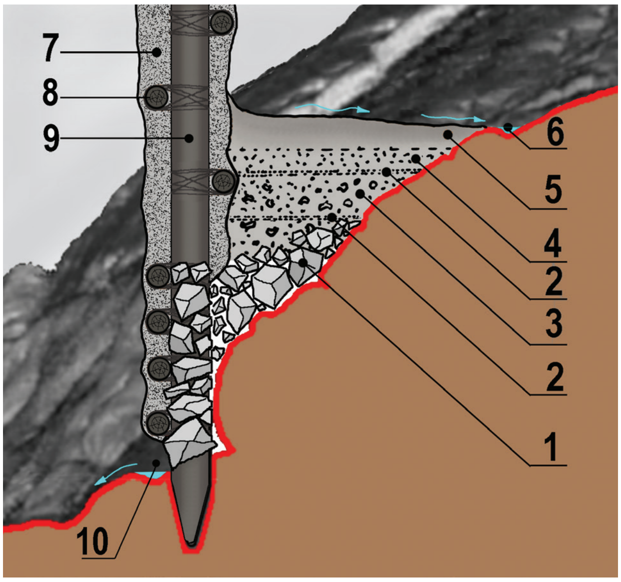

Fig. 12. Hypothetical reconstruction of the principle of enlarging the terrace behind the *quincha* wall: 1 – split stones; 2 – plant-fibre mats; 3 – crushed stone; 4 – compacted earth; 5 – compacted clay; 6 – rainwater drainage channel; 7 – compacted clay with chaff; 8 – drainage at the foot of the wall (elaborated by J. Kościuk)

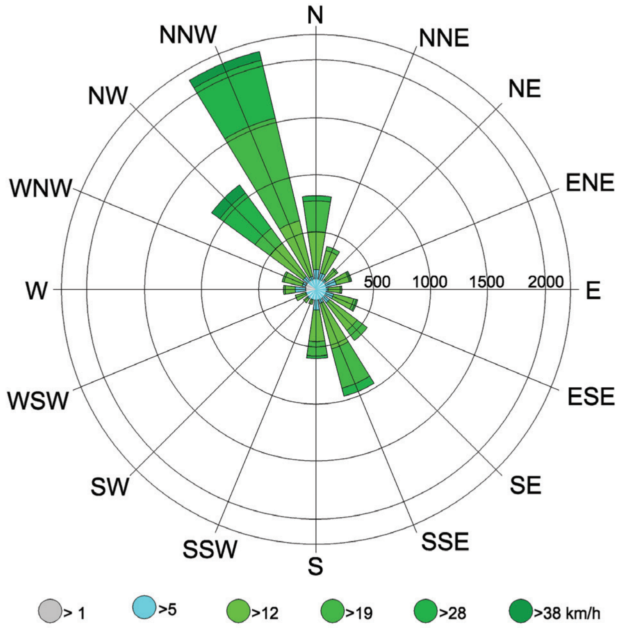

Fig. 13. The wind rose for Samaipata town (source: https://www.meteoblue.com/en/weather /forecast/ modelclimate/samaipata_bolivia_11494517 [accessed: 27.11.2017])

maintaining balance during the strongest winds. In a few cases, gusts of wind almost knocked down the heavy tripod holding our scanner (ca. 24 kg of total weight). Based on these experiences, wind speed can be estimated to be up to 90 km/h [16]. This is essential input data for subsequent numerical analyses that may ultimately verify our hypothesis

Numerical modeling of the quincha *wall – input data, material characteristics, and the simulation model*

The geometry of the rock was based on data from 3D laser scanning [17], [18] obtained during the 2016 fieldwork season with a Leica P40 scanner. In 2017, the holes in the rock were additionally documented with a handheld Artec Eva scanner, which gave precise data to model how the wooden posts could fit into the rock (Fig. 4). *Madera tornillo* (*Cedrelinga catenaeformis*) was chosen as the material for the vertical posts.

Since there are not any indications pointing to a particular type of *quincha* construction, the double-sided wall (Fig. 6D) was chosen with an infill of clay tempered with organic chaff. Despite this choice, we can only speculate how the horizontal elements and wattle work were arranged. Therefore, at this stage of research, it was decided to model these elements as regular truss elements in order to model horizontal bracing. The backfill that may have enlarged the platform behind the *quincha* wall was modeled with argillaceous gravel (clGr). The intervals between the posts were adopted in accordance with the results of 3D laser scanning as 45÷87 cm. Based on the same data, the diameters of the posts were 12 cm. The tops of the piles were 1.80 m above the ground on the leeward side – hence, due to differences in slope the posts differ in length.

The mechanical parameters used in our simulation (Table 1) were based on available literature [7], [19]–[21] and the authors' experience. The discrete model was built in the finite element package Midas [22] and consisted of 50 638 nodes and 228 797 spatial and truss elements resulting in 146 789 equations (Fig. 14). The rock part of the model was fixed at the bottom. The wind impact on the *quincha* wall was simulated as a uniform wind load from the NNW direction with a speed of 25 m/sec.

Table 1. Mechanical parameters of materials used in the numerical simulation (elaborated by J. Kogut)

Name	Young modulus E [MPa]	Poisson ratio [–]	Density [kN/m^3]	Internal friction angle [deg]	Cohesion [kPa]
Sandstone	10000.0	0.3	21.7	40	5000
Clay wall	20.0	0.3	20.0	20	20
Timber	7000.0	0.3	6.0	–	–
Infill (clGr)	20.0	0.3	20.0	30	20

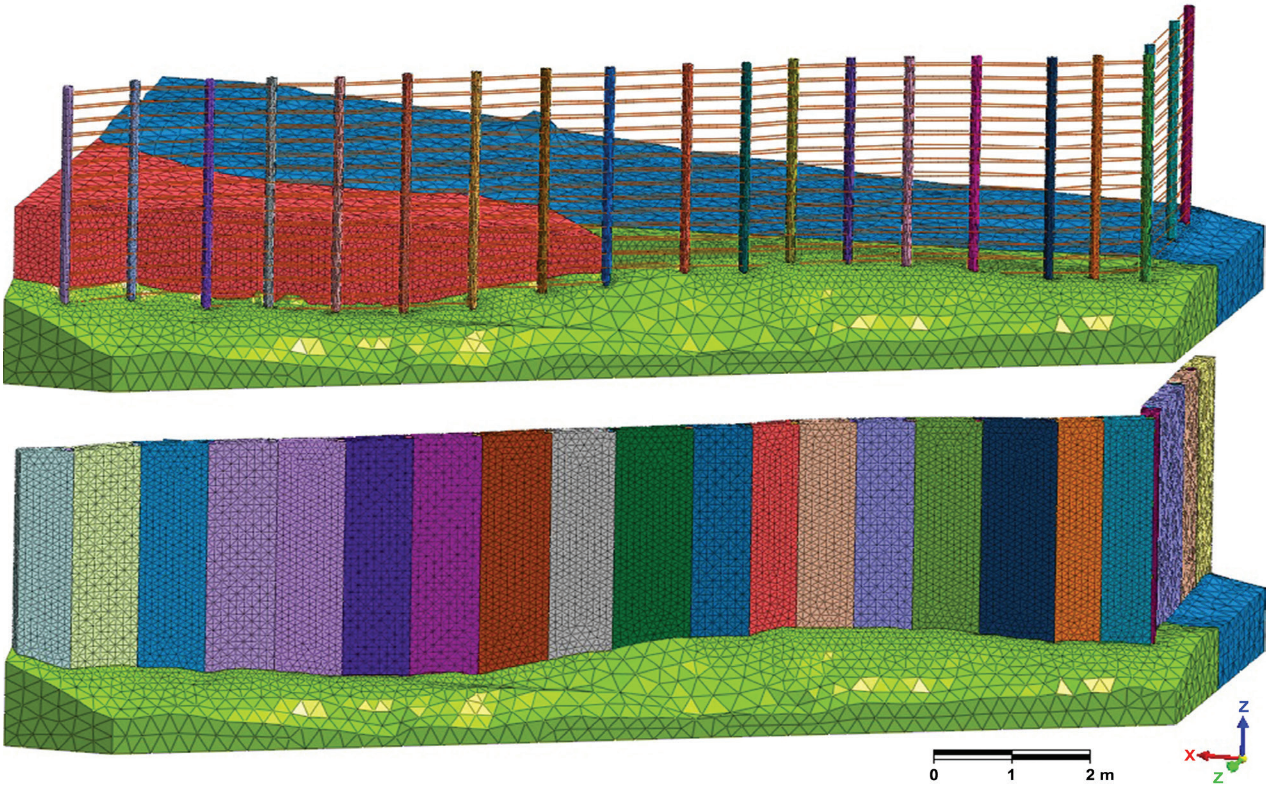

Fig. 14. 3D numerical model for FEM analysis (modelled by J. Kogut)

Discussion of results

The maximum value of the total displacements (Fig. 15) of the analysed wall scarcely exceeded 3 mm in the worst-case scenario. The displacements are presented as deformed models, separately for the wall, wooden posts, and the rock. The rock deformation did not exceed 0.09 mm. The simulated *quincha* wall construction proved to be so flexible that it could feasibly survive harsh winds. The maximum values of the total strains (Fig. 16) can be seen at the bottom of the *quincha* wall. The differences in the behaviour of the wall are due to the fact that the wall is

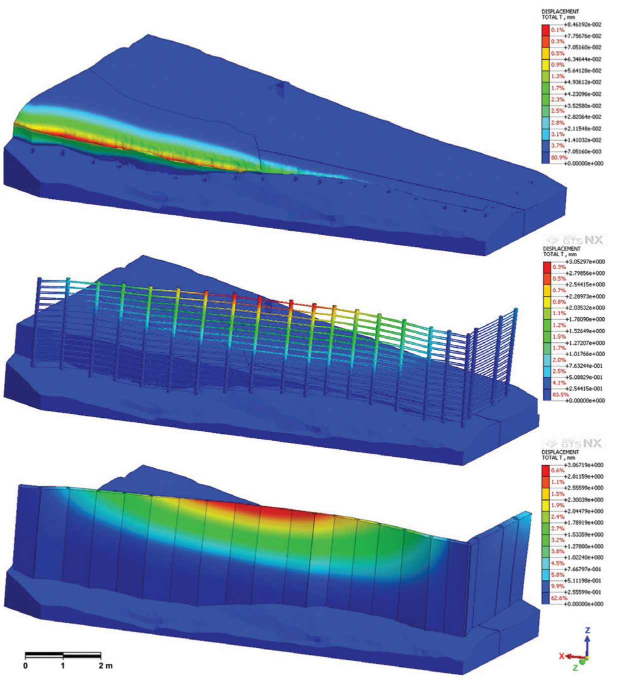

Fig. 15. Analyses of total displacements (FEM simulation: J. Kogut)

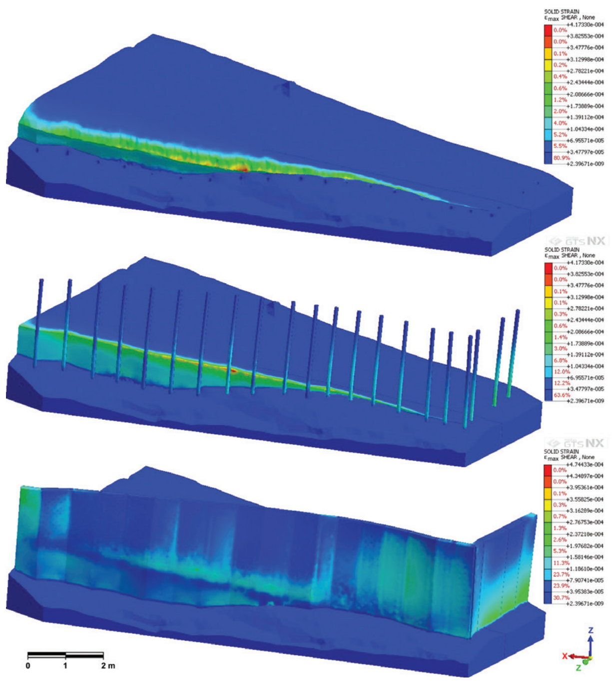

Fig. 16. Analyses of total strains (FEM simulation: J. Kogut)

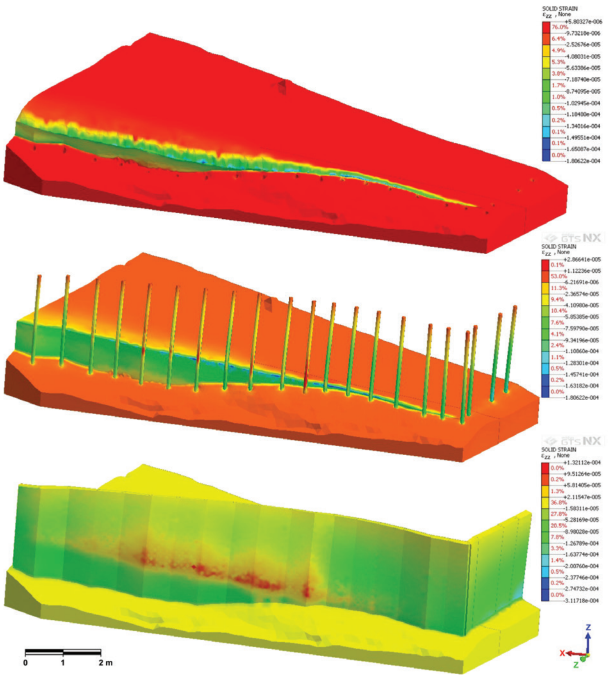

Fig. 17. Analyses of ε_{zz} strains (FEM simulation: J. Kogut)

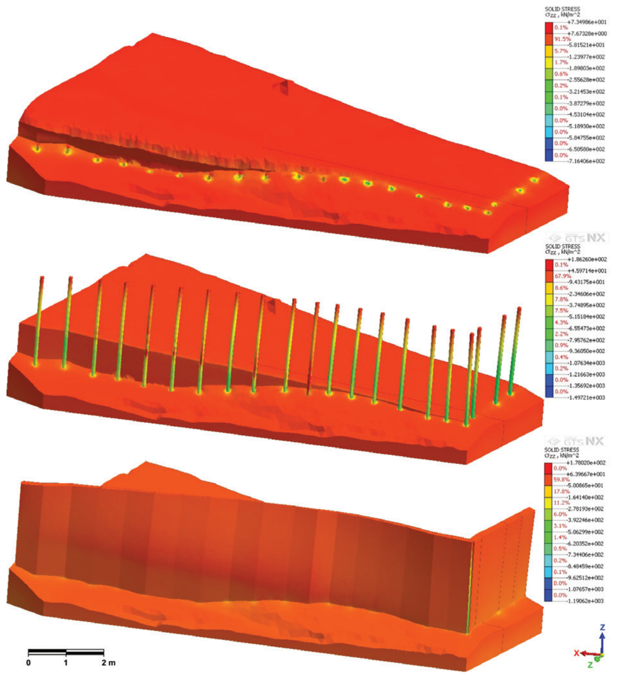

Fig. 18. Analyses of total σ_{zz} stresses (FEM simulation: J. Kogut)

a continuous structure, a part of which has backfill that enlarges the platform behind it. As expected, analyses of vertical ε_{zz} strains in the wooden posts (Fig. 17) showed that wooden fibre on the windward side experienced tension, while fibre on the leeward side was compressed. In the overall conditions, they were balanced.

It is evident (Figs. 18, 19) that the entire wall, as well as the rock, was subjected to small stresses, even in such harsh conditions. As for the rock itself, the maximum stress value can be seen in the post-holes, but it does not exceed the strength of the sandstone. The value of 0.5 MPa is well below the threshold value that may destroy the material around the holes.

A closer look at the internal behaviour of the *quincha* wall shows that the maximum shear stress is carried by the posts, and it is a stress level of 0.2 MPa in tension and 1.5 MPa when compressed. This is even more visible when the σ_{zz} stresses are analysed (Fig. 18). It should be noted that the compression strength of the wood was assumed to be equal to $R = 21$ MPa. Additionally, the horizontal elements of the wall reinforcement did not exceed a stress level of 0.3 MPa, and torque and bending moments were negligibly small.

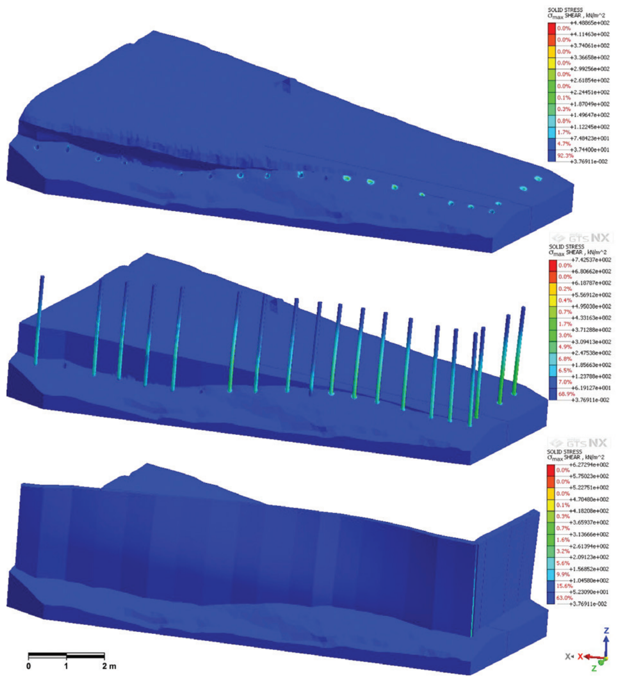

Fig. 19. Analyses of total Tresca stresses (FEM simulation: J. Kogut)

General conclusions

The results obtained on the basis of the FEM simulations allow us to state that the hypothetical *quincha* walls should have been able to withstand the assumed wind loads. The load capacity is so significant that, even after any changes in the strength parameters, taking into account the humidity status of wood and clay, the wall would still have been stable. It should also be noted that, in the simulation, a more advanced model was used in which horizontal elements reinforcing the wall were included. It can even be assumed that a lighter type of wall (for example, one-sided, Fig. 6C), would have also met the conditions.

The above text is an extended and rewritten version of our paper presented at the Structural Analysis of Historical Constructions 2018 Conference in Cusco [23].

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Abstract

El Fuerte de Samaipata, commonly known as Samaipata, is an archaeological site in Bolivia. It was inscribed on the UNESCO World Heritage List in 1998. The most characteristic feature of the site is a natural rock that served as a *wak'a* (sacred place) for several local, pre-Hispanic cultures, so its current condition is the result of at least 1200 years of development.

Towards the end of the 20th century and beginning of the 21st century, Samaipata was comprehensively studied and documented by German scholars. Due to the threat of progressing erosion, a new documentation project was executed by a Polish team. The main objective of the project was to document the vanishing site using 3D laser scanning.

Most of the research already published on Samaipata concentrates on the complex arrangement of niches and terraces, figural and geometrical petroglyphs, as well as canals and water reservoirs at the site. The long rows of small circular holes drilled into the rock attract less scholarly attention. They are commonly associated with the vertical posts used for traditional *quincha* walls. Since there are doubts about the ability of the *quincha* wall to resist the extremely strong winds on the top of the rock, the Authors conducted computer simulations to clarify these reservations. The 3D model was based on 3D laser scanning results, while FEM was used to solve structural analysis problems.

Key words: Fuerte de Samaipata, Bolivia, rock art, *quincha* walls, numerical modeling

Streszczenie

El Fuerte de Samaipata jest stanowiskiem archeologicznym w Boliwii wpisanym na Listę Światowego Dziedzictwa UNESCO w 1998 r. Najbardziej charakterystyczną cechą tego miejsca jest naturalna skała, która służyła jako *wak'a* (święte miejsce) dla kilku lokalnych kultur prehiszpańskich, więc jej obecna forma jest wynikiem co najmniej 1200 lat rozwoju.

Pod koniec XX w. i na początku XXI Samaipata była wszechstronnie badana i dokumentowana przez niemieckich uczonych. Ze względu na postępującą erozję polski zespół wykonał nowe pomiary, których głównym celem była precyzyjna rejestracja zagrożonych reliktów za pomocą laserowego skanowania 3D.

Większość dotychczas opublikowanych wyników badań na temat Samaipata koncentruje się na złożonym zespole nisz i tarasów, figuralnych i geometrycznych petroglifów, a także kanałów i zbiorników wodnych rzeźbionych w skale. Długie rzędy małych okrągłych wywierconych otworów przyciągają mniej uwagi naukowców. Są one powszechnie kojarzone z pionowymi słupkami stosowanymi do tradycyjnych ścianek *quincha*. Wątpliwości co do wytrzymałości ścianki *quincha* na ekstremalnie silne wiatry na szczycie skały skłoniły autorów tego artykułu do przeprowadzenia komputerowych symulacji w celu wyjaśnienia tych zastrzeżeń. Model 3D został oparty na wynikach skanowania laserowego 3D, a samą analizę przeprowadzono z wykorzystaniem metody elementów skończonych (MES).

Słowa kluczowe: Fuerte de Samaipata, Boliwia, sztuka naskalna, ścianki *quincha*, modelowanie numeryczne