Bulletin of Geography. Physical Geography Series, No. 12 (2017): 83–91
http://dx.doi.org/10.1515/bgeo-2017-0007

The role of geological conditions in the disintegration of historical structures on the escarpment of the Lower Vistula Valley, on the example of Chełmno (Poland)

ISSN 2080-7686

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Abstract. Chełmno is a town in the north-western part of the Chełmno Lakeland. It is one of few towns in Poland to have fully preserved its medieval defensive walls. Its touristic and natural environs make it a popular tourist destination. The town's location near the escarpment of the Vistula valley mean that the preserved historical structures (including the defensive walls) are under threat. A few years ago a buttress became detached and two sections of the defensive walls collapsed. One part was rebuilt (the site where the studies were conducted), while the second part remains unrestored. Bricks are also progressively coming away. This situation may be the result of several factors, although the authors claim that the most important are the geological structure and the wall foundations (which are shallow, at a depth of 1–2 m, with the wall having been built up higher in the 16th century).

Key words:
stability of defensive walls,
sediments load capacity
cultural heritage,
medieval town walls
Chełmno
Poland

Introduction

Chełmno is located in the north-western part of the Chełmno Lakeland (Niewiarowski 1968). The study area, which includes the old town, is delimited to the north and west by the edge of the Vistula river valley, and to the south by an approximately 40-metre-high escarpment which descends to the Browina river valley and joins the remaining part of the till plain from the north-east. Long ago this topography was advantageous for its excellent natural defensive value. That is why such a site was conducive to the founding of a medieval town, whose boundary was fitted to the topography by surrounding the entire area with defensive walls. Because of the lesser height differences on the eastern and western sides of the town, water-filled moats were constructed (Czacharowski 1999).

Until 1267, Chełmno was surrounded by an earthen rampart (Góra, webpage). After this year a brick wall was built, reinforced with about 30 towers. Almost three hundred years later the walls were built up higher, to their current height (Czacharowski 1999). Unfortunately, a few years ago two fragments of the historical fortifications collapsed (a stretch of wall and a buttress). Additionally, other parts of the walls have for some years been systematically repaired due to brickwork coming away. Figure 2 shows the place where the but-

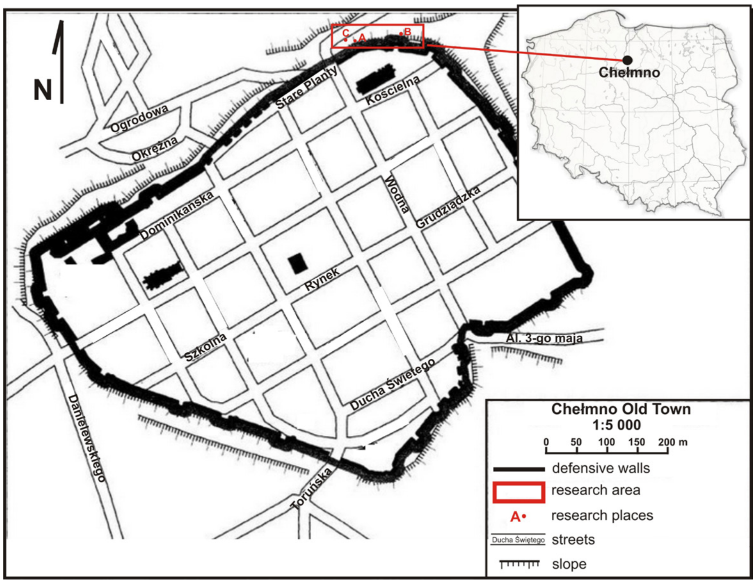

Fig. 1. Location of the study area (map by decree of the President of the Republic of Poland 2004)

tress and brickwork came away from the wall, and indicates the points at which bores were drilled.

Both its architectural and touristic value prompted the authors to conduct a geo-engineering analysis at the site of the damage in question. Selected research methods were used for direct identification of the subsoil under the displaced wall sections. This research was intended to determine the geological boundaries, type of ground, predicted spatial layout, water content and signs of groundwaters in the undergound (by drilling), and to determine the degree of ground compaction (by probing using a DPL light dynamic probe at occurrences of sand), as well as taking geo-radar measurements and elaborating geo-radar profiles.

Studies to date along the defensive wall consist of those conducted in 2012 by a private company commissioned by the Office of Monument Documentation. The aim of these studies was to determine the groundwater conditions in the foundation zone of sections of the walls.

Geological and hydrogeological settings

The medieval area of Chełmno surrounded by defensive walls is located on an isolated fragment of till plain. It is composed of sediments from the Saalian glaciation, the Eemian interglacial and the Weichselian glaciation (Fig. 3).

Fig. 2. Location of study boreholes in designated places

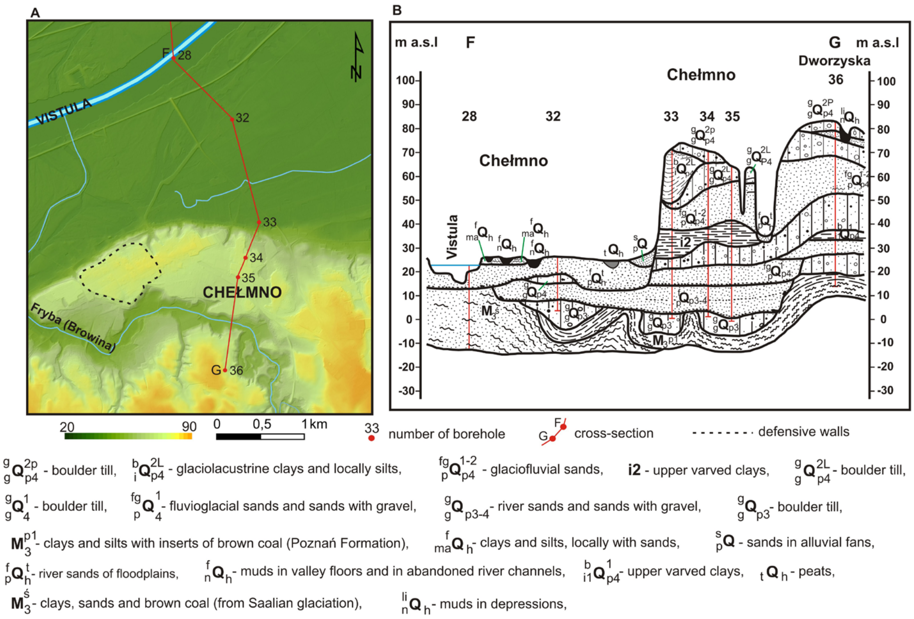

Fig. 3. Surface relief of the study area (A) and geological-engineering cross-section (B) (Butrymowicz 1981)

The escarpment in Chełmno is located at a height of 75 a.s.l. The full geological structure was presented on an archaeological geological cross-section (Fig. 3) and described based on an explanatory map (Butrymowicz 1981). On the surface of the till plains there are boulder tills whose occurrence is probably related to the maximum extent and recessive moraines of the Poznań phase of the last glaciation (${}^{g}_{g}Q^{2P}_{P4}$). The thickness of these sediments varies from 2 to 12 m. Directly below these deposits there are deposits from the Leszno phase. There are grey, grey-black or grey-brown varved sediments. These consist of layers of dark clay and lighter silt or fine sand (${}^{b}_{i}Q^{2L}_{P4}$). The varved sediments' thickness ranges from 1 to several metres. Next to these sediments are grey and grey-brown sandy till, clayey till or silty till (${}^{g}_{g}Q^{2L}_{P4}$). Under the layers of clay from different phases of the main stadial of the Weichselian glaciation are glaciofluvial sands (${}^{fg}_{p}Q^{1-2}_{P4}$; ${}^{f}_{p}Q_{P3-4}$; ${}^{fg}_{p}Q^{1}_{P4}$) They are fine-grained, and somewhat silty. In places, thin interbeddings of silts and clays occur, up to a few centimetres thick. After the layer of glaciofluvial sediments, there are varved deposits, boulder till, sand and gravels. Below clays and mud with inserts of brown coal (Poznań Formation M_3^{P1}) there are lenses of boulder tills (${}^{g}_{g}Q_{P3}$). These clays are the lowest level of glacial sediments that occur below the fluvial sediments from the Eemian interglacial.

Chełmno lies on a moraine hillock and within the confines of its defensive walls. The geological structures which significantly influence man-made constructions are Quaternary deposits. In the study area, mainly tills have been recognised (Masiota and Myszkiewicz 2011). Clays are interlayered with sands, gravels and silts. These were deposited by meltwaters during the Weichselian glaciation (Niewiarowski 1968). Manual drilling (to a depth of approximately 4 m) identified a sloping layers of Quaternary deposits. The points at which drilling was conducted and the lines of geological cross-sections and geo-radar profiles are indicated on Fig. 4. Pleistocene deposits are represented by the glacial deposits of the Vistulian glaciation (sandy clays and clays) with lenses of fine sand and sandy silt (Fig. 5). These clays are hard plastic with typical plasticity index values of IL = 0.25. The drilled sandy silt has a typical plasticity index value of IL = 0.20 (Przyborowski 2002).

In this area the Holocene is mainly represented by man-made embankments composed of clays, sands, silts and brick debris. These embankments are found mainly on the Old Town side and are of varied thickness. On the external side of the walls the presence of a soil layer of approximately 0.3 m thick was identified.

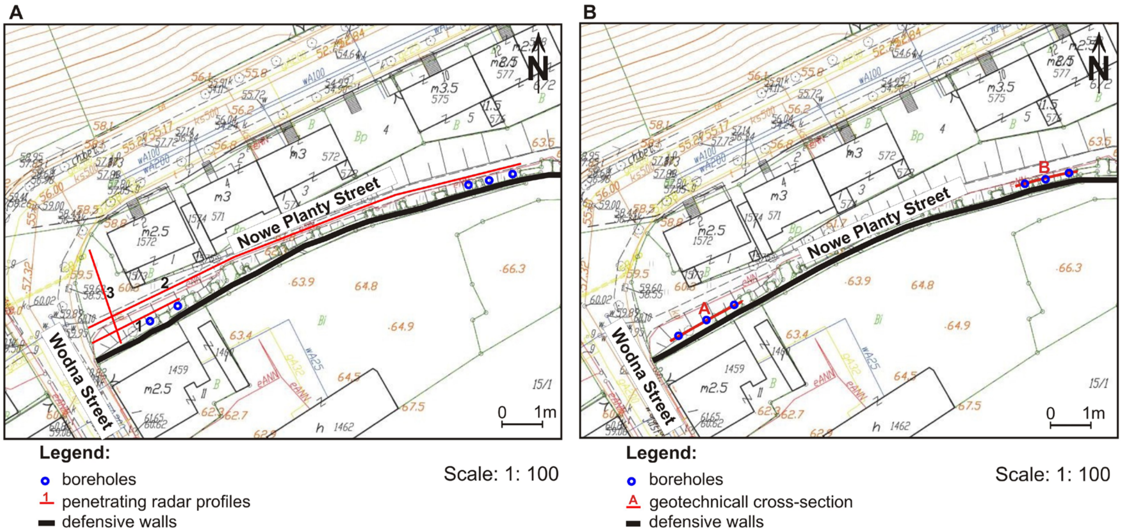

Fig. 4. Location of boreholes, line of geological cross-section and geo-radar profiles

There are three aquifers here, sandwiched between clays aquitards (Masiota and Walkowiak 2012). The level of the groundwater table depends on climate conditions (quantity of rainfall) and topography.

Chełmno sheet area is characterized by varied and highly changeable hydrogeological conditions. Quaternary sediments do not have a constant aquifer. Locally occurring aquifers, with the exception of the Eemian interglacial and Holocene river settlements are not sufficiently water-rich. Pleistocene aquifers have unfavourable water permeability or limited infiltration conditions. Certain possibilities are created by high-altitude-Palaeozoic aquifers that are poorly recognised. A significant amount of salt in these waters will limit their usefulness (Butrymowicz 1981). The main usable level of groundwaters is the Quaternary level; it is well isolated from the surface, and well developed in sandy deposits of varied coarseness (from coarse sands to multi-grained sands with gravel). The first aquifer occurs at a depth of 4–7 m, and the second at 12–17 m (sub-clay), while the third level lies at a depth of between 25 and 78 m (Masiota and Walkowiak 2012). Stratigraphicall this is the is the oldest aquifer, and it has good water permeability. Due to the depth, the capture of these groundwaters is inefficient (Butrymowicz 1981). The flow of groundwaters is north-westerly, towards the Vistula River, which is the local base for drainage.

The main reason for the threat to slope stability is usually the occurrence of water in the slope. Reducing the strength of the soil also causes water saturation at the bottom of the slope, moisture with surface water, and saturation of the cracks with water (Wysokiński 2006).

Methods

The geological studies were carried out at 9 places by drillings (including a locations on the Old Town side and on the external side of the walls). During the drillings macroscopic analyses were performed (colour, humidity, granulation), including by piston penetrometer, VT cross probe and rotary cutter (VT – vane test). Probing was also conducted using a DPL light dynamic probe.

The authors selected study locations in places where the walls are suffering damage such as vertical and diagonal cracks running the full height of the wall. These points did not coincide with the locations of previous studies, but were in their vicinity. Due to the fact that the defensive walls are historical, only non-invasive studies were conducted. In order to determine the geology, manual drillings were done (at 5 points). Then, dynamic probing was conducted in places where drilling had yielded sand. The final stage was to conduct geo-radar

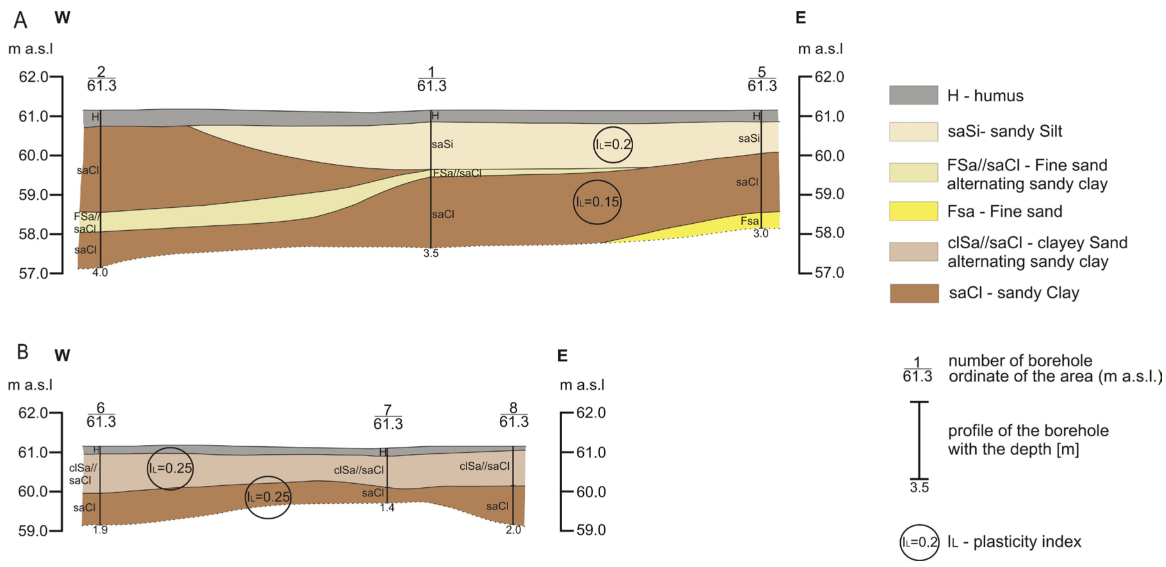

Fig. 5. Geotechnical cross-sections (A and B) of the indicated study area (location in the Fig. 4B)

profiling. The studies were conducted with the aim of determining the causes of the walls' subsidence and the detachment of an entire buttress at Wodna street and Nowe Planty.

Then, probing with a DPL light dynamic probe was done. This research was solely for the purpose of determining the quality of the ground's condition. Along the walls a geo-radar profile was also made, determining the depth of non-bearing, low-permeability ground. Geo-radar studies were performed with a GCB-300 shielded antenna (manufactured by Geoscanners AB). It has a centre frequency of 300 MHz; the antenna emits a spectrum of about 150 to 600 MHz but the central portion is 300 MHz. The maximum listening time of the antenna is 120 ns, which with dielectric permittivity of the ground at 9 penetrates to a depth of 6 metres. Such ground dampens the emitted waves, which makes visible the boundary between cohesive and loose ground. As a result, it is unknown what deposits lie below the cohesive soils. The condition and consistency of soils was determined in the field by manual manipulation.

Geological and hydrogeological properties of the ground under the walls of Chełmno

Chełmno has 2 main geological-engineering divisions. The first is a region with favourable geological-engineering conditions, and the other is a region that impedes construction. The analyzed area in which the medieval defensive walls are located lies in both the first and the second division (Fig. 6). Land areas favourable to construction include areas of loose, compact, semi-hard and hard plastics, medium-density ground with no geodynamic phenomena, and groundwater table depth of the water is more than 2 m. The defensive walls were built on the till plain.

Objects located on the escarpment are located in the impact zone of the escarpment. This is an area where there are displacements of terrain points (damage to objects on and near the slope) without loss of stability. The long-term build-up of these displacements can lead to the destruction or damage of buildings, in the absence of landslides. Cracks in the ground may cause rainwater to penetrate. This lowers the soil strength parameters due to increased moisture, hydrostatic pressure and hydrodynamic water. This also causes cracks to grow rapidly and expand.

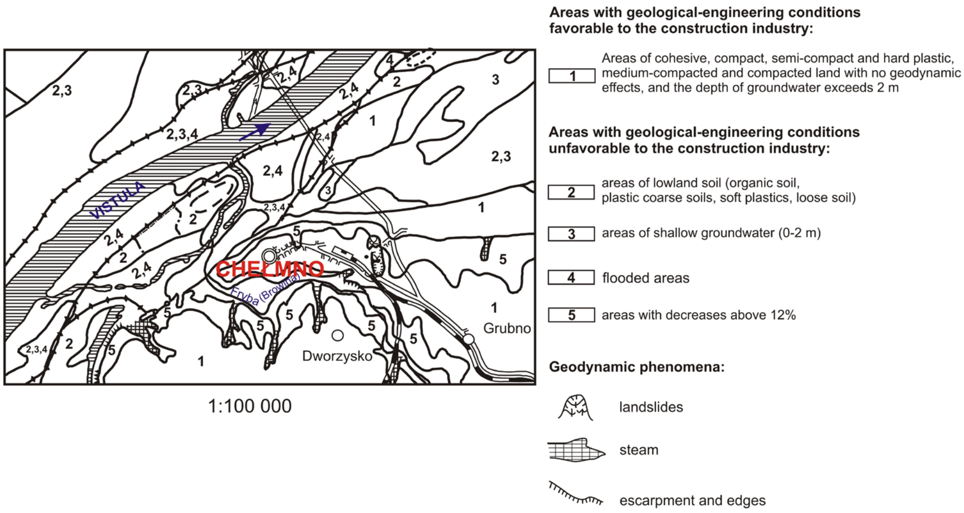

Fig. 6. Archival geological-engineering sketch (Butrymowicz 1981)

The study was conducted by authors on both sides of the buttress on the corner of Wodna Street and Nowe Planty (Fig. 2 – place A). The drilling was done to a depth of 3.5 m (borehole 1) and 3.7 m (borehole 2). The ground to the right of the buttress (borehole 1) is dry, and the bored out sandy silts and clays are stiff. On the left of the buttress (borehole 2) the bored out soils are moist; these are clays and sandy silts which, below 2.2 m, have a soft consistency. After analysis of the ground around the wall it is unclear why such differing groundwater conditions occur over such a small stretch. It may be the loose, uncompressed and moist slope of the escarpment having been covered with younger soils or embankments. This area requires further examination in order to determine the cause of the differences in conditions.

In the vicinity of the studies, the results of slow mass movements are visible (creeping soil). Opposite the fortifications (on the external side) there is a building which is supported by a special wooden constructions (Fig. 7), because the building wall shows small cracks.

The base of the skeleton construction is secured in a concrete slab. It was therefore not possible to conduct direct analysis of its subsoil. Manual drilling was only conducted to a depth of 0.9 m next to the support and at a distance of approximately 2 m, because drilling was made impossible by large brick fragments. The underground analysis was therefore of the unbuilt-upon embankment (unmonitored). In this area a geo-radar profile was also made. This profile clearly shows a structural boundary (at a depth of approximately 1 m). This is probably associated with a layer of glacial till. It is associated with the occurrence of clear horizons at this depth in the geo-radar profile.

The second study area was located on Nowe Planty street (near the wooden tower), where individual bricks or fragments thereof had fallen away from the defensive walls. These studies were conducted to a depth of 2.0 m. The bored out earth was stiff, dry clay.

Fig. 7. Wooden supports for a residential side wall

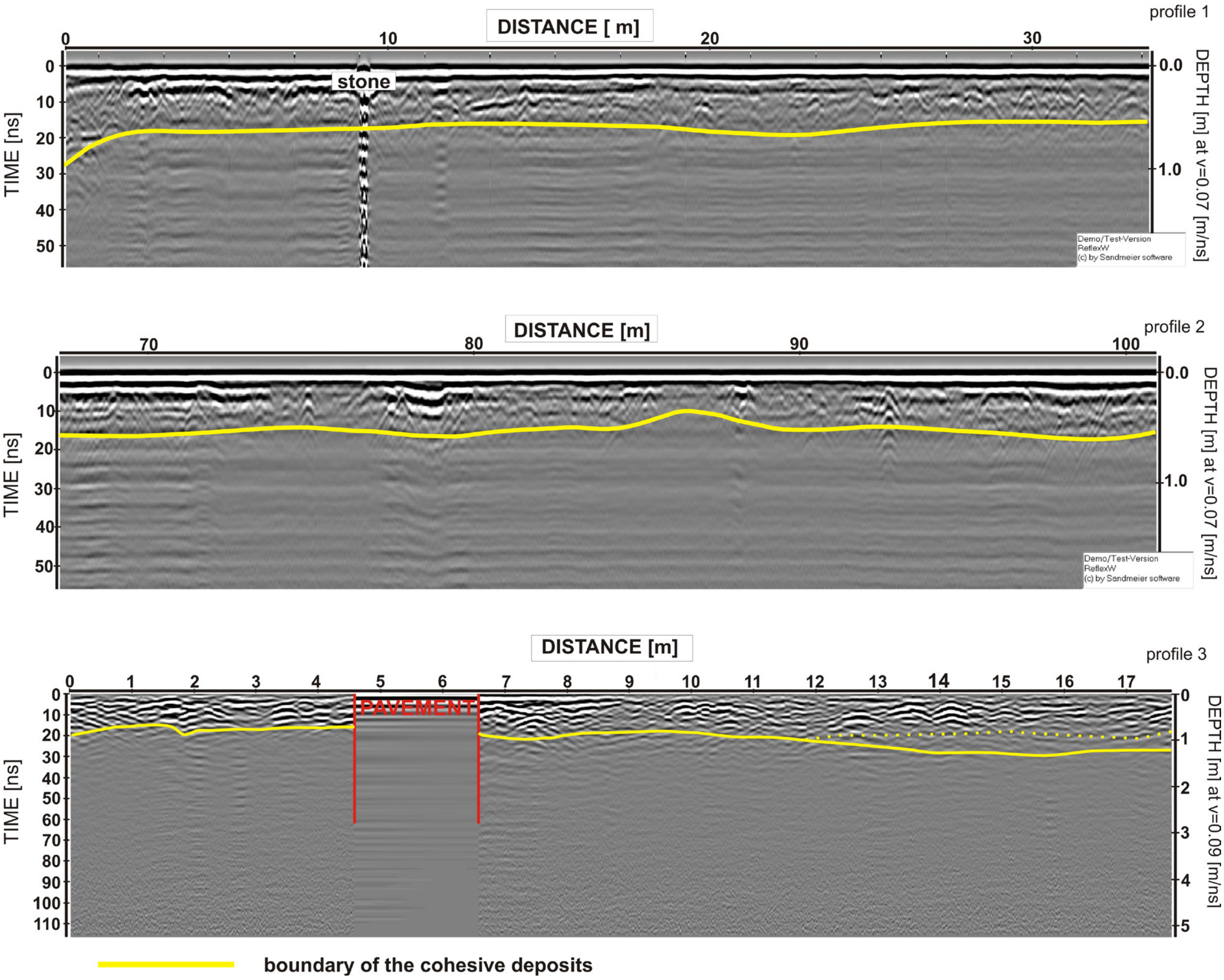

Fig. 8. Penetrating radar profiles (location in Fig. 4)

The soils of the analysed subsoil (by the detached buttress) were loose and cohesive sediments represented by: stiff sandy silts; fine sands interbedded by layers of sandy and stiff clay (borehole 1); and medium stiff and soft sandy clays (borehole 2). During the analysis, the occurrence of groundwaters was not recorded to a depth of approximately 4 m. The load-bearing subsoil to the area in question is of fine sands and sandy silts. Clays were found at a depth of 0.3 m, which is confirmed by the geo-radar profiles. In the second area (where the brickwork came away) boring yielded stiff sandy clay interlayered with clayey sand and sandy clays. In both cases no non-construction embankments were identified. On the external side of the walls (Fig. 2) there is soil (to a depth of 0.3 m).

Discussion

The easiest way to protect the stability of buildings located near a slope is to shift the object away from the upper edge of the slope. Structural safeguards must be applied or slopes should be appropriately profiled. A groundwater belt drainage system is a good option for objects that are at the escarpment and are on impermeable or poorly permeable soils (Wysokiński 2006). This involves digging a system of perforated drainage pipes into the ground around the building. As a result, the water flows into the pipes and is discharged to a safe distance from the object.

Results of geological research indicate that the main threat to the walls is probably as much from the geological structure as from the shallowness of their foundations. The best ground for building foundations is native mineral soils (Pisarczyk 2001). For the area in question these are represented by medium-density fine sands. Unfortunately, these exist only as lenses occurring between layers of clay. Moreover, these deposits occur at depths ranging from 2.5 to 3.5 m, so significantly deeper than the wall foundations (foundation depth is 1–2 m). At the depth of the wall foundations there are sandy silts and clays (sometimes interbedded with fine sands), which are usually firm and can bear high loads. It is only at borehole 2 that the clays found at a depth of approximately 3 m are soft. Clays are found at a depth of as little as 0.3 m. The shallow position of these deposits means that long-lying rainfall can result in pockets of standing groundwater between the base of the foundations and the native ground. In the long term this leads to a decrease in strength parameters. Repeated deep freezing of the wet subsoil on the escarpment slope leads in the long term to solifluction movement of the surface and building layer. Water stored in clays expands under the effects of low temperatures (the active layer of the study area is 1 m deep). This leads to a weakening of the walls and their buttresses, which caused the detachment of the buttress.

The damage to defensive walls cannot be related to brick corrosion at foundation level resulting from permanent contact with ground water or capillary action because some bricks have fallen off about 2 m above the ground. It is more likely that the walls are being damaged because they are tilting. In addition, it is clear from field observations that the area around the wall is not marshy, so groundwater should not affect the escarpment.

Tyszkowski has studied the mass movements in the Lower Vistula Valley. He analyzed landslides in the Morsk and Wiąg region. This area has a similar geological structure to that of the analyzed area in Chełmno. In that region, settlements older than paleogean are located at elevations of approximately 90 m a.s.l. Sandy formations formed in the Early Vistulian are found in the Miocene layer (Wysota 2002). The landslides there developed mainly in areas of clay and sandy loam and in deluvial sediments (Tyszkowski 2014).

In the present area of study (Fig. 1), the loosening of bricks from walls cannot have been caused by mass movements such as landslides. It may have, however, been caused by river flow, through direct undercutting of the slope and ground changes, mainly in loose sands and silts. This may be due to the influence of fluctuations in soil moisture and the ground water table associated with the Vistula river water table (Tyszkowski 2014).

Downhill creep is one of the elements that can be used to determine if there is mass movement on an escarpment. It manifests in the characteristic bend of trees. The trunk deforms convexly in the direction of movement (Wysokiński 1999). At the study sites in the area, the slope is wooded. During observation, there were no signs of downhill creep. The only element that proves some slow mass movement is a house supported by wooden buttresses (Fig. 7). Another negative element affecting the facilities located on the slopes is groundwater or water from the water supply network or from local drainage and rainwater. Damp in walls is unfavourable for buildings. Rain water can penetrate the walls of buildings due to lack of moisture insulation (Wysokiński 1999). The problem with the walls in Chełmno is the lack of drainage (rain water is not drained from the walls).

Conclusions

The geological studies carried out aimed to produce an initial description of the geological conditions with regard to their potential influence on the observed damage to defensive structures. The observed damage may have diverse causes. Among them, the following should be considered:

Mass surface movements: the defensive walls are founded on a rise, with ground pressure from the town side – the ground level (of the non-construction embankment) is higher from the Old Town side, by as much as approximately 2 m.

Cracking and subsidence of the walls may be caused by disintegration (degradation) of bricks and mortar due to freezing of the damp walls. Freeze activity in the external zone subjects it to powerful external stresses, which may lead to cracking and loosening of bricks.

Standing groundwater in the foundation zone of the walls may lead to deterioration of the ground condition and loss of bearing capacity, causing the onset of mass surface movements.

The extension upwards of the defensive walls in the 16th century: they had been initially somewhat lower, and the increase in load on the defensive wall construction on the crown of the escarpment had a negative impact on its stability.

References

BUTRYMOWICZ N., 1981, Szczegółowa Mapa Geologiczna Polski w skali 1:50,000, arkusz Chełmno. Wydawnictwo Geologiczne, Warszawa.

BUTRYMOWICZ N., 1981, Objaśnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50,000, arkusz Chełmno. Wydawnictwo Geologiczne, Warszawa.

CZACHAROWSKI A., 1999, Atlas historyczny miast polskich. Chełmno, 1 (3), Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika, Toruń.

GÓRA G., Mury obronne, baszty i bramy, www.moje-chelmno.pl/mury-obronne/mury.

MASIOTA J., MYSZKIEWICZ M., 2011, Program Ochrony Środowiska dla Gminy Chełmno do roku 2011 z perspektywą na lata 2012–2015. Green Key, Mełno.

MASIOTA J., WALKOWIAK J., 2012, Aktualizacja Programu Ochrony Środowiska dla miasta Chełmna na lata 2012–2015 z perspektywą do roku 2019. Green Key, Mełno.

MIKLASZEWSKI S., MODRZEJEWSKI S., 1977, Mury miejskie – odcinek V, Chełmno. Dokumentacja techniczna – rozpoznanie stanu i opinia techniczna. Toruń.

NIEWIAROWSKI W., 1968, Dzieje Chełmna i jego regionu. Środowisko geograficzne powiatu i miasta Chełmna. Państwowe Wydawnictwo Naukowe, Poznań: 9–38.

PISARCZYK S., 2001, Gruntoznawstwo inżynierskie.Wydawnictwo Naukowe PWN S.A, Warszawa.

PRZYBOROWSKI P., PARADOWSKA U., 2002, Dokumentacja geotechniczna dla wzmocnienia wybranych odcinków murów obronnych miasta Chełmna. Toruń.

REPUBLIC OF POLAND PRESIDENTIAL DECREE OF 13 APRIL 2005 concerning recognition as historical monument. 2005, Journal of Laws, 64.

TYSZKOWSKI S., 2014, Rozmieszczenie i geneza współczesnych osuwisk nizinnych w strefie bezpośredniego oddziaływania rzeki na przykładzie zbocza Doliny Dolnej Wisły między Morskiem a Wiągiem. Landform Analysis, 25: 159–167.

WYSOKIŃSKI L., 1999, Warszawska skarpa Śródmiejska, od Al. Jerozolimskich do ul. Sanguszki. Warszawa.

WYSOKIŃSKI L., 2006, Ocena stateczności skarp i zboczy. Instytut Techniki Budowlanej, Dział Wydawniczy, Warszawa.

WYSOTA W., 2002, Stratygrafia i środowiska sedymentacji zlodowacenia wisły w południowej części dolnego Powiśla. Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika, Toruń.

Received 18 February 2017
Accepted 15 May 2017