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Geotechnical Failures Caused by Human Errors

Marek Tarnawski
West Pomeranian Technical University, Szczecin, Poland

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Marek Tarnawski
West Pomeranian Technical University
Szczecin, POLAND 70-311

ABSTRACT

The West Pomeranian Technical University holds conferences on building failures. It usually takes place every other year and it is well known and respected in Poland. The jubilee, 25th conference took place in 2011. With intent to honor it the author prepared a monograph entitled "Geotechnical reasons of building failures". It was based, almost solely, on the contents of 225 case studies presented in the former conference proceedings. As with every conference based so much on case histories it presents in its papers a mosaic of various cases. Although each describes and explains the reality in its own way, systematic analysis allows us to find their common properties. This, in turn, enables to categorize them and finally to present ways to prevent such damages in the future. These are the key issues of this paper. Even though most described cases are local to Poland, many findings would surely prove applicable in many other countries, as well. Poland is situated in central part of Europe with sea coast on the north and mountains down south. The majority of the middle is built of glacial (Pleistocene) and post glacial (Holocene) deposits while older formations, like Tertiary marine clays occur on the surface in places as well. A similar picture of superficial geology is common in Europe in the wide belt from France to Russia as well as for remarkable parts of the United States and Canada. Therefore, results presented in this paper may be interesting for a number of readers.

PREFACE

Proceedings of 24 conferences on building failures held since 1974 by West Pomeranian University of Technology in Szczecin (Poland) contain a collection of case histories. They specify reasons and courses of those events as well as remedial measures taken. Geotechnical aspects of building failures were indicated in at least a few papers of every conference edition. The author had analyzed that rich and diverse material and he found it reasonable to collect them in a book publication. It was published on the occasion of the jubilee, 25th conference (Tarnawski 2011; Fig. 1).

The analysis covers as many as 225 cases so it encouraged to generalizations and recapitulations. Still, it was hard to assess whether the descriptions regard extreme cases (being interesting because of that) or, on the contrary, they are typical. Therefore the author also analyzed various statistic specifications within the richest Polish database on building failures created by Building Research Institute in Warsaw. A comparable analysis enabled to define basic reasons of the failures of geotechnical type which took place in Poland in the period of last forty years and to illustrate them by appropriate examples. The present paper tries to summarize that work shortly. It is important to note here that the article is concerned solely with building failures due to reasons with geotechnical background and it naturally leaves aside all the cases not applicable for geotechnical discussion.

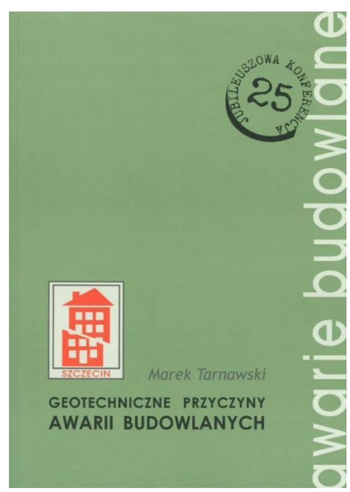

Fig. 1. Cover of the author's book: "Geotechnical reasons of building failures".

ANALYSIS OF THE STATISTIC DATA

Building Research Institute in Warsaw (ITB) has been collecting data on building risks, failures and disasters in Poland since 1992. The data up to 2006 are available at present. There have been documented 3351 cases altogether within this period. Data collections are provided with a number of defined parameters which make statistic processing easy. However the system is not perfect. Not all values are filled in for every case. One can find an enigmatic description "other" in many places. Sometimes many aspects of an event are presented, but the deciding factor is not indicated. Statistic analysis may be hampered or inaccurate then. Reducing the reasons of failures to simple classification of mistakes which took place at the stage of designing, construction or operation of a building makes it difficult to find their actual background (cause) and picking out the ones where failures were connected with foundation or – wider – with geotechnical conditions. Fortunately, there is an extra data field in the database where a short description of the failure can usually be found (non-empty in 2220 out of 3351 cases). It seems that little importance was attached to this data – for instance this field was not taken into consideration in statistic specifications elaborated yearly by ITB. There are 210 cases where one can find there information connected with foundations, settlement, soil etc. These positions were found related to geotechnical reasons of building failures and they have been analyzed thoroughly.

The first step of the analysis (Tarnawski 2009) consisted of comparing the frequency of a given kind of failure in general to such failures caused solely by geotechnical reasons – with reference to (among others) the kinds and features of construction objects. Four technical parameters of objects were considered: kind of foundation, object's purpose, building material and technical state. Surprisingly, no connection was found in one case: it turned out that no kind of foundation predestinate an object to a state of failure because of geotechnical reasons. Considering their functions, the largest number of failures relates to dwelling and public houses as well as to industrial buildings because they are simply most common. The same with failures caused by geotechnical reasons, but a percentage share of these reason is distinctly higher for the first two, whereas much lower for industrial buildings. Severe technological requirements and more careful investor supervision in the case of industrial buildings or such special structures like chimneys or bridges may explain that. On the other hand competition on developer market (houses, apartments) and unlimited tenders for public building construction may be the reasons of looking for savings at the stage of site investigations, designing as well as earth and foundation works. Geotechnical reasons of failures are more frequent than the others in the cases of structures built of a rigid material (structures made of reinforced concrete and bricks), and especially so for structures built of prefabricated elements – highly sensitive to displacement. The number of failures because of geotechnical reasons is negligible in the cases of steel structures and equal to zero in the cases of wooden buildings. Geotechnical reasons of the failure are of external character, no matter if human fault or force majeure is finally to blame, hence there is little or no connection with previous technical state of the structure. To the contrary: new buildings, in a good technical state, suffer failures of this kind quite often.

Eleven groups of failure reasons (among those with geotechnical background) have been separated on the grounds of the analysis of the descriptive field contents. They are compiled on Fig 2 and described in the following chapters.

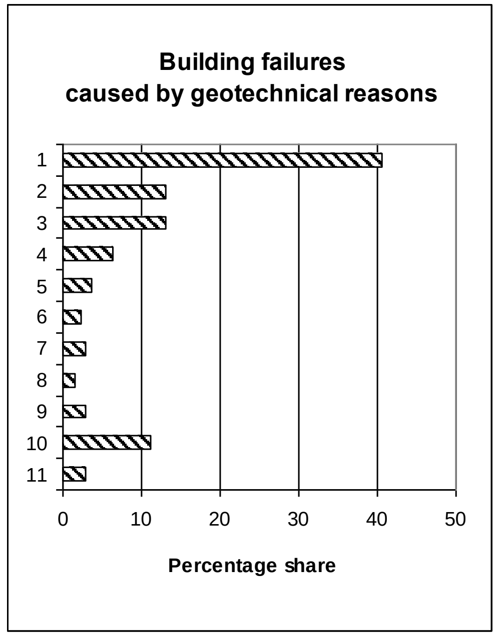

Fig. 2. Geotechnical reasons of the building failures according to ITB data.

1. *Errors in design*
2. *Errors in construction works*
3. *Excavations made nearby*
4. *Leaks in water-sewage system*
5. *Drop of ground water level*
6. *Washing by river or sea water*
7. *Mining damages, vibrations, earthquakes*
8. *Landslide processes*
9. *Shrinkage and swelling of expansive soil*
10. *Karst and other geological threats*
11. *Quasi-geotechnical failures.*

ERRORS IN DESIGN AND CONSTRUCTION WORKS

Errors in designing are definitely at the first place (> 40%). Adding (inappropriately secured) excavations carried out nearby to the mistakes in „our own" construction works (both are contractor errors, in fact) as well as leaks in water-sewage system and dewatering works we will obtain more than 36 % altogether and the second place among the reasons of building disasters and failures of geotechnical base.

Foundation on too weak native or artificial substratum dominates definitely (55%) among design errors being a source of failures. Construction defects are on the second place (almost 22%), then poor protection against water (13%) and insufficient subsoil reconnaissance (11% of failures). There are two major groups of reasons among construction work errors: foundation breach (> 60%) and poor subsoil treatment (30%). Human factor was always the failing factor.

Why does one permit foundation on too weak substratum (if insufficient reconnaissance is not the case)? Review of the papers gives a numerous collection of assorted answers. So it happens that:

- the influence of differentiated thickness of the weak soil is underestimated and the building is founded after a partial soil exchange only with differentiated settlement and inclination of the building as a result (Trojnar, Pietrzyk 2003) or soil exchange is done carelessly, often in presence of ground water (Kmieć, Sękowski 1994, Marcinkowski 1987),
- poor or well compacted gravelly – sandy fill is built on weak (organic) substratum and construction works start before it is consolidated; further settlement is mostly caused by the fill load (Gaszyński, Motak 1996, Świeca, Walczak 2009),
- the structure is founded on loose fill (Bartnik, Bukowski 2007) sometimes underlain by organic soils (Kujawiński 2001; Fig. 3) or straight on such soils (Wojtasik, Troć 2001), or at too shallow depth (Mikołajczak et al. 1979, Pająk et al. 1994),
- too short piles, wells or jet-grouting is designed (Puła et al. 2001) or gravel columns are arranged too far one from another (Gajewski 2007, Gryczmański 1997, Meyer, Stopa 1994),
- the problems of floors, partition walls and other devices situated inside of the building or even whole secondary structures as well as building cranes are neglected and they are founded on weak fill or organic soil (Bartoszewicz et al. 1991, Łukasik, Kotlicki 2009, Sękowski 1987, Szkwarek et al. 1980),
- native but loose sands are treated as bearing substratum (Adamczyk et al. 1987),
- loads corresponding to the strength of bearing soils are adopted even though distinctly weaker soils occur not much deeper (Kawalec B., Kawalec J. 1997),
- bearing capacity of soil is overestimated (Kujawiński, Rybak 1987),

that is, recapitulating: soil conditions are assessed in an inappropriate way (Kawalec 2007).

Lack of or poor quality reinforcement, especially ring beams and too narrow or blocked dilatations should be listed as construction errors discussed most often (Ajdukiewicz et al. 1995, Szkwarek et al. 1980).

Failure situations connected with groundwater often take place as early as during earthworks. Ignorance of designers should be recognized as their basic reason. (Bartnik, Bukowski 2007, Młynarek et al. 2005). Engineers even use the name "quicksand" (a rare natural phenomenon) to "quicksands" produced by themselves to mask their own incompetence. Underestimation of buoyancy causes rise of underground tanks (Barycz 1989, Szeloch, Dyszak 1989) and whole structures (Glinicki, Nowara 1976). Investing in deep cut river valleys one should take into account the possibility of artesian waters occurrence. Self-outflows are difficult to control. High pressure may cause large scale quicksand phenomena and finally destroy the area (caves, spring niches, "artificial" streams) and structures built there (Damicz et al. 2007) or at least make construction works (of bridge pillars for example) much more difficult (Świeca, Walczak 2007).

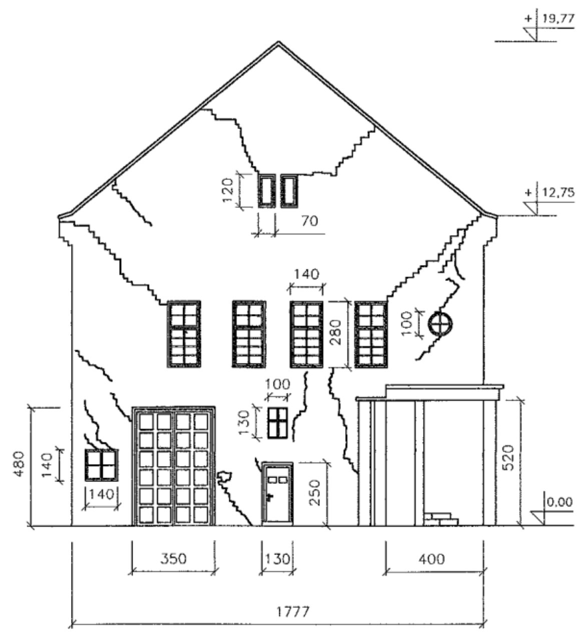

Fig. 3. Cracks seen in a gable wall of industrial building founded on a weak substratum (Kujawiński 2001).

"Usual" rain water can be a serious opponent, too. Saturated gravelly fill will moisten underlain cohesive soils, worsen their geotechnical parameters and finally cause settlement larger than assumed (Górecki, Kuchler 1989), not to mention cellar moistening. Neglect of technical state of dewatering devices results in moistening of the substratum or embankments and in deformations or landslides of plasticized soil (Biedrowski, Sobkowiak 1999, Kawalec 1999, Łukasik, Wysokiński 2001, Pająk et al. 1994, Sołowczuk et al. 1996).

Complexity of soil conditions and of phenomena taking place in the substratum and influencing stability of a structure is not always discovered by routine geotechnical investigations (Jeż et al. 1996, Kwarciński 2007, Sękowski, Sternik 2007, Zieliński, Kubicki 1991). It happens, not too often of course, that design is made without any soil investigations … (Buczkowski, Niedzielski 2007).

Errors in building's substratum reconnaissance can be listed as follows (Gryczmański 1999):

- lack of test points in structure projection,
- improper location or sparse net of test points,
- insufficient reconnaissance depth,
- mistakes in kind and state of soil description,
- improper geotechnical division of substratum,
- lack or incorrect estimation of mechanical parameters of soils,
- omission of unfavorable phenomena which may occur in substratum,
- insufficient hydrogeological observations.

A total lack of site investigations is a rarity, also because of formal and legal reasons. However it happens that after a major location change no complementary investigations are carried out. Extrapolation of geological data may fail if stratigraphy is irregular (not horizontal). More frequent case of improper location of test points poses a threat of omitting (especially: lens-shaped) weak soils. Too shallow reconnaissance threatens with underestimation of settlement or improper identification of bearing soils for indirect foundation purposes. Mistakes in kind and especially in state of soil determination are frequent. They result from lacking or inexperienced geological supervision on site and from basing on drilling results only, without in situ and laboratory tests. Error may grow because of improper geological structure interpretation followed by inappropriate synthesis of geotechnical picture of the substratum. Mechanical soil properties are commonly estimated on the grounds of correlations. This may lead to dangerous mistakes, but the basic problem is estimation of strength properties and compressibility of anthropogenic and organic soils. Failures can occur if such phenomena like:

- swelling and shrinkage of expansive soils,
- freezing of heave soils,
- drop settlement (of loess),
- karst,
- liquefaction, tixotrophy,
- underground excavations.

are not taken into account.

Hydrogeological reconnaissance means the necessity of proper determination of depth and character of ground water horizons and also prognosis of their oscillations. It is important considering both its rise (questions of dewatering, isolation etc.) and drop that may cause additional settlement. The quality of geotechnical reconnaissance can be improved by using modern investigation tools with CPTU penetrometer at the head. Unlike other building materials soil is characterized by remarkable heterogeneity but its identification (before the actual excavation is made) is made only from point to point. Various test methods often give different results (parameter values) and geotechnicians' experience with apparently similar soils are also different. This may result in differences even in several hundred percent in parameter value estimation (Wysokiński 2007). Using different assumptions (parameters) one will come to different conclusions (Gryczmański 2007).

The most frequent contractor's mistake is disturbance (undermining) of the (existing) foundations. This can take place during reconstruction or renovation works (Misztal S., Misztal G. 1995, Pieczyrak et al. 2005, Puła et al. 2001, Radzikowski 1979) and concern a building or a pipeline nearby (Cios et al. 1999, Kania et al. 2009, Misztal S., Misztal G. 1995, Radzikowski 1979, Suwalski et al. 2001, Trojnar, Pietrzyk 2003) or "just" an excavation wall and neighboring area (Horodecki, Dembicki 2009, Wysokiński 2005, Wysokiński, Kotlicki 2001). There are examples (Bojanowski 1991, Kawulok, Wuwer 2005, Mikołajczak et al. 1979, Radzikowski 1979) of poor preparation or breach of the substratum as well as of hasty commencement of earthworks (Kozłowski, Bednarek 2001). The bottom of an excavation which was waiting from Autumn to Spring must become degraded because of unloading, rain water impact, freezing and heave processes (Kiereś 1976, Sękowski 1987, Sobkowiak, Filipowicz 2007).

DYNAMIC WATER IMPACT

An interesting case took place when a breakwater of retaining wall type was built. Such a construction is typical for medium and small ports of Polish Baltic coast, with the average water depth of a few meters. The substratum is usually built of non-cohesive soils (Haurykiewicz 1980). Breakwater is built section by section (Fig 4a) with vertical chambers made of steel sheet wall piling (3) joined by a tie rod (5) and filled with stones (6). A slab made of reinforced concrete (7) rests on the walls.

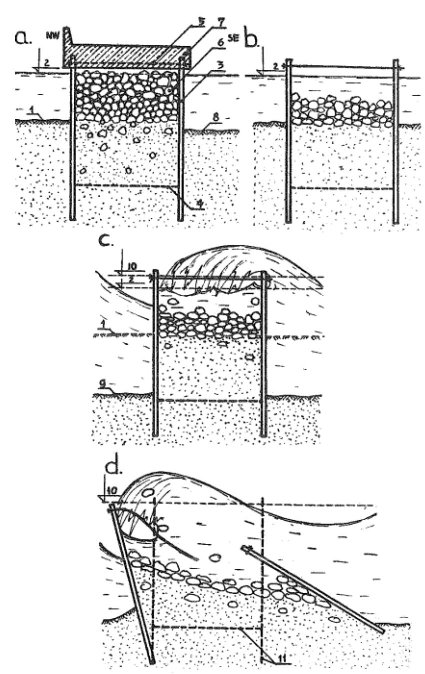

Fig. 4. A breakwater of retaining wall type: a finished structure (a), structure under construction described in the text (b) and the mechanism of the failure (c, d) (Haurykiewicz 1980).

Breakwater is an alien in marine environment. Taking this into consideration means, among others, assessment of possible depth to which the sea bottom (1) can be washed away by breakwater's walls and rational evaluation of the possible working periods (without a storm). As storms are random phenomena one should take into account their possible effects not only when the structure is ready but also when it is under construction. This example shows a connection of unfavorable weather conditions and too optimistic design assumptions. The result is a disaster of one section under construction (Fig. 4b). Storm waves washed out soil 2 m deeper than it was assumed (9) and much deeper than the designed bottom of harbor dock (8). Soil resistance diminished then and the waves, filling easily the section (as sea condition rose from the average "2" to the stormy "10", in Beaufort terms), increased water pressure from inside. Together with stone layer pressure it overcame the diminished resistance (Fig. 4c). The waves attacking upper parts of walls caused a bilateral level effect. Both walls leaned coastward. The tie tore off and the breakwater section had been destroyed (Fig. 4d). A sudden water accumulation in a limited area and the failure of sheet wall piling under construction is also described in another paper (Mazurkiewicz 1999). Flood tides or changes in current arrangement may wash the bases of bridge pillars and their tilt or catastrophe (Łączkowski, Podhorecki 1988). There are known (Mazurkiewicz 1996) destructive results of currents produced by driving devices (propellers) of modern ships or ferries, specially the ones designed for quick mooring and leaving a quay and a harbor without tugboat assistance. They cause erosion of the bottom and destroy normal protection (mattresses, concrete slabs etc.). Structures situated on the beach are exposed to damages or destruction by storm waves (Ostapiuk, Wichtowski 1989). A common denominator for all of the described cases is a maladjustment of structure protections to extreme impacts which may happen in sea or river environment.

EARTHQUAKES, VIBRATIONS, MINING DAMAGES

Dangerous earthquakes are a rare phenomenon in Poland, although it would be an oversimplification to state that it is a non-seismic area. For example, two intense earthquakes (magnitudes 4,8 – 4,9 in Richter's scale, epicentrum beyond north Polish border) took place on September 21, 2004. As a result damages of more than 100 structures were reported in NE Poland (Cholewicki et al. 2005). However the majority concerned secondary, finishing elements. Two structures (church and vicarage in Ciche Miętustwo) among 35 recorded were seriously damaged (cracked walls) in southern Poland after an earthquake near Czarny Dunajec (4,6) on November 30, 2004. Their further serviceability had been questioned (Gwóźdź 2005).

Mining damages occur in the areas of underground mineral exploitation: Upper Silesia and Legnica – Głogów cuprum district. In the former, the exploitation has lasted several hundred years. Underground mining activity bears a considerable danger for structures existing on the surface. Its destructive results are a rewarding subject for scientists. Several papers deal with linear structures (roads, pipelines, energetic lines and streams) and underline the necessity of special care while designing them, especially motorways (Gryczmański, Sternik 2005, Kliszczewicz 2005, Strycharz et al. 2005, Żak et al. 1995) on the areas threatened with mining damages (Fig. 5).

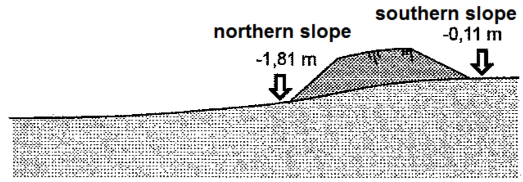

Fig. 5. A sketch showing results of mining exploitation on motorway embankment (Gryczmański, Sternik 2005).

Building damages can be caused by three main factors being results of mining exploitation, namely (Ciesielski et al. 1997):

- continuous or discontinuous surface deformations caused by exploitation with gallery roof collapse,
- surface deformations caused by dewatering of the substratum,
- vibrations of building substratum caused by mining shocks.

The first reason is the most important one. Its source is presented on Fig. 6. A post-mining basin as wide as the exploitation front is a typical result of mining activity which influences building structures.

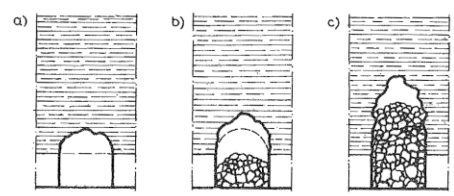

Fig. 6. A growing emptiness and loosened zone in an abandoned gallery.

It has to be emphasized that structures built on mining areas should be protected as in the case of seismic zones. Review of the papers presented in the author's book (Tarnawski 2011) indicates, that excessive building damages brought about by post-mining surface deformations are caused by design or construction errors. One classical example is presented in (Pająk, Jaśniok 2009). A large shopping center of reinforced concrete, prefabricated, skeleton structure got serious damages and its further use was impossible. Extension gaps made at the foundation level only, without wall and roof segmentation was its essential defect. As vertical wall joints had been filled with styrofoam and poliuretane foam, the 110 m long object behaved as a one-segment structure. The tie-rod system used, which should have assured geometrical stability of columns and their foundations in horizontal plane was improper considering undetermined run of substratum deformations.

Columns' foundations were tied in one direction only. Hence, both foundations and columns could move almost freely perpendicularly, as rigidity of long tie-rods is slight in that direction. Diagonal rods, typical in such cases, had not been designed. Construction damage character indicated great compression deformation in longitudinal direction. The outside foundation feet were pushed in towards inside the object. The columns propped against floor shield, rotating and inclining outside. This movement cased dangerous shortening of purlin's support, destruction of joints as well as cracks of columns and walls. In addition, the object was founded relatively deep (about 2,5 m below the surface) in postindustrial, loose anthropogene soils which continued down to the depth of approximately 5 m. The soil around the walls was well compacted because it was occupied by parking and maneuver areas. This gave additional creep pressure against underground walls. As future coal mining activities were planned underground and the structure was badly damaged the owner decided to pull down the object and to built another one, well protected against the deformations. It included dividing up the whole building by vertical gaps into eight statically independent segments. Relatively rigid ferroconcrete foundation grate of each segment was to bear the influence of curvature and horizontal deformations. There was adopted a light, steel roof and reinforced construction was left for columns, foundations and some walls only.

As a new object, such as the one described above (admittedly – poorly designed) reacted that way, one should expect more extensive damages in buildings being advanced in their technical age (Bryt – Nitarska 2007). Materials or constructions not rigid enough produce weakened or overburdened parts, where damages accumulate. Successive descriptions of failures of structures founded in mining areas (Kawulok, Wuwer 2005, Kawulok, Cempiel 1999, Kawulok, Kliszczewicz 1999, Ajdukiewicz et al. 2001, Barycz, Kocot 1997, Kania et al. 1988) indicate the following, most often met, imperfections:

- location of a structure in the zone of extremely unfavorable mining influences,
- subsoil prepared improperly,
- improper extension gaps (to narrow gaps, gaps with a material like cement or styrofoam left incidently, gaps liquidated by concrete, incomplete gaps),
- low spatial rigidity of foundations and cellars, lack of monolithic connections of load-bearing walls (often non-reinforced) with foundation and slab, savings on reinforcement around openings in cellar walls,
- improper tie-rods and ring beams or lack of them, lack of reinforced pivots connecting floor and wall slabs with slab ring beams,
- continuity of roof construction or lack of hipper roof bracing in roof construction,
- not sufficient fastening of external protective plates, low quality of wall element assembly,
- the choice of precast construction system which is not adjusted to bear underground exploitation impacts,
- poor damp proof course,

that is to say: poor adaptation of a structure construction to bear mining exploitation impact.

Mining damages are common where a large scale underground exploitation of mineral resources is carried on. Hence a lot of various methods protecting (and repairing) structures have been developed. Typical damages of buildings presented schematically on Fig. 7 are repaired by wall extension as high as necessary to eliminate tensile stress zones. Reinforced, wall supporting frames or rectangle nets made of steel profiles can be used as well (Kawulok 2009).

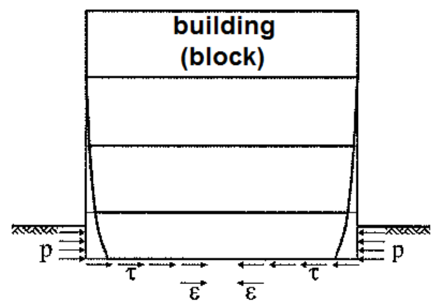

Fig. 7. A scheme of building damages caused by horizontal terrain deformations (Kawulok 2009).

Tilt of building structures is obviously an often phenomenon in the areas of mining exploitation. Strong structures may not be damaged then, but when inclination exceeds 25 mm/m their further use is impossible both due to reduction of their serviceability and overall safety. However, tilt can be eliminated. Rectification can be carried out by removing soil from under higher positioned part of the structure (Fig. 8a) or by lifting the lower part by lifts (Fig. 8b).

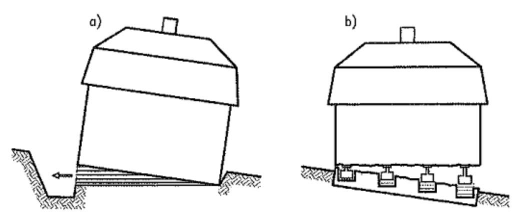

Fig. 8. Schemes pf basic methods of inclined structures rectification (Gromysz, Niemiec 2007).

Sometimes a mining damage effect aggregates with results of other geological phenomena. For example (Fedorowicz L., Fedorowicz J. 1997) a building tilt caused by a passage of mining may sum up unfavorably with uneven settlement caused by differentiated compressibility of the substratum and give values higher than anticipated. A crater-shaped deformation of 50 m in diameter was noticed on a mining area. It was a threat for buildings standing there. Measurements proved a 1,5 m drop in the center of the crater. According to geological data analysis the subsidence lies over a karst crater. It came into being after Tertiary gypsum rocks dissolved. The crater had been filled with Quaternary deposits.

It became active because of intensification of suffosion, most probably as an effect of human activity. Either deep well influence or mining underground excavations are possibly to blame (Kawulok et al. 1997). A serious surface destruction took place as a result of disastrous (almost 150 thousand m3) water with clayey material outflow to an excavation of 800 years old salt mine in Wieliczka (Janowski 1996). Karst and other geological threads are responsible for approximately 11% of building failures caused by geotechnical reasons (see. Fig. 2).

LANDSLIDE PROCESSES

Landslide processes belong undoubtedly to the phenomena of geological nature, but they are usually treated (and described) separately. In Poland, they constituted a small percentage (to 2%) of failures not long ago, but this situation seems to trend adversely nowadays. Mass movements as well as such phenomena like volcanism, earthquakes or hurricanes attacking sea coasts are usually treated as natural processes, independent on human will. Analysis of a few cases gives a chance to assess whether such an approach is appropriate.

In August 2006 a building disaster took place in Wisła when a ski-jump (named from Adam Małysz, the citizen of that town) was being reconstructed (enlarged). A landslide arose at the landing area. Approximately 6500 m3 of rock debris slipped down destroying a part of a ready embankment. The slope is built of typical flysh deposits. They are sandstones and slates occurring alternately. Layers sink against the slope. Then, stability conditions of landing area were apparently better than in the case of consequent slopes. But detailed studies revealed a small fault in the ski-jump axis. Hence the cause of the landslide occurrence lied not only in cutting the lower part of the slope and loading its upper part to increase the steepness of landing area, but also in:

- undetected fault and corresponding big thickness of colluvium increasing landslide predisposition,
- ground water outflow from the slope,
- heavy rainfalls that saturated weathered rocks and soils relocated on the slope.

The analyzed natural slope has been in an unstable balance, for many years. A safety margin was narrow. Hot summer, then heavy rain and not ready drainage were a direct impulse for the landslide (Wysokiński, Świeca 2009).

Warta River valley slope in Poznań is built of tills and clays. It had been leveled by brick and soil fill. In connection with unregulated water conditions above this caused a rise of ground water level. Lower parts of fill had been saturated and upper parts of native cohesive soils – plasticized. Then landslide movements took place. A disaster of a workshop building which stood on the top of the slope was one of the results (Biedrowski, Troć 1997).

A loss of slope balance caused a landslide. It was the reason of a warehouse disaster. And the reasons of the landslide formation were as follows (Grabiec, Przystański 1980):

- the design of both warehouse itself and slope profile was worked out on the grounds of geological data from the neighborhood featuring non-cohesive soils only, but at the actual location there occurred a 1 m thick layer of organic mud in sands,
- high water level states changed unfavorably slope stability conditions,
- fills forming the slope were made carelessly, using mixed soils.

Calculations gave a high safety factor ($F > 2$) if the slope was built of sands, no matter how high ground water level was. The presence of mud (f = 10o, c = 5 kPa) changed the result to F = 1,15 in average water states and F = 0,98 when the ground water state was high. It is interesting that the building itself, most probably, did not affect the slope's stability.

A multi-storey dwelling house was built on top of a slope of a river valley. A parking lot had been designed as well. To save room for it the slope had been built up. Cracks on the surface appeared a few months later. After that, a 0,3 m fault arose and the landslide process began. A waste-pipe ran below the parking lot. It started to leak. Wastes outflow turned the parking lot failure into ecological catastrophe (Borowczak et al. 2005). The valley is cut in a massif of Tertiary clays and boulder clays. Their top (covered by fills) declines towards the river. Investigations prove remarkably lower mechanical parameters of native soils on the contact with fill than deeper. It is typical as the top of low permeable soils is „lubricated" by rain water infiltrating from the surface. Slope instability was caused by overloading due to the new fill.

Mass movements can occur not only on natural or modified slopes. They accompany earth structures as well. A section of the western Gorzów Wielkopolski beltway was opened for operation not a long time ago. The route runs across Warta River valley, where it was designed on high embankment and through a highland – in relatively deep excavation. Numerous superficial landslides were found right after the earthworks had been finished, on the slopes of both embankment and excavation (Wojtasik, Różański 2009). The highland is built of glacial and fluvioglacial deposits (tills and sands). River deposits of riverbed facies (sand) and flood facies (mud) dominate in the valley, together with deposits of plant origin: peat. As the embankments were high (locally to 20 m), remarkably steep (1:1,5) and without any reinforcement or dewatering, their stability was doubtful. Calculations and analyzes carried out confirmed these doubts. As many as 62 failure fields have been described at a 5 km section of the beltway. Damages such as erosional gullies, superficial slips, ground water seepages were caused not only by a risky geometry adopted, but also lack of any protection of the slopes against erosional activity of rain water (rain ablation). The most serious damages were observed in bottom parts of the slopes. The embankments were made of a local material using the soils from excavations, also cohesive ones. The earthworks were being done in Autumn, Winter and Spring. Weather conditions were difficult because of heavy rainfalls. The parameters adopted by the designer were unrealistically high. CPTU penetrations were carried out to check the state of the embankment. “Weak” soils were recorded in 12% of the profi les (Wysokiński 2009) and they should not have been there at all. The fill was mostly sand (approximately 80%) which was surprising, because a bigger share of cohesive soils was expected considering landslide niches observation results. Penetrometer profiles proved a remarkable changeability of soil density. A proper, acceptable quality of compaction and the material itself had been documented only in one whole profile. As many as 40% of the fill profiles contained thin weak layers, usually impermeable. They gathered water. It should be emphasized that the weakest places decide on stability loss.

Once upon a time an excavation down to 8 – 10 m was performed. Pleistocene, stiff silts, sandy and silty clays, hard and stiff decomposed Carboniferous rocks and Carboniferous sandstones, mudstones and claystones (soft rocks) occurred in the substratum. Excavation slopes were primarily designed of the steepness 1:1, but it was changed later on. A 2 m wide shelf was shaped in the middle and the slope above was protected with slabs of ferroconcrete. The slope appeared unstable. There arose a 20 m wide and 6,0 – 6,5 m deep landslide. It had been controlled by an earth buttress. However the buttress had to be dismantled to make foundations. A Berlin retaining wall was designed to be used to support the slope. Even though the landslide proved instability of the slope, favorable geotechnical parameters from site investigation report were adopted for calculations. I-beam sections of the wall had been fixed 1,5 m below the designed excavation bottom. They were tied by 6 - 10 m nails. Two levels of nails were made when three of them tore off. Only after this failure supplementary geotechnical investigations had been carried out. They revealed, among others, a 1 m coal layer among Carboniferous deposits. It turned out to be the skid layer. The failure happened because of insufficient identification of substratum conditions and disregard for possible discrepancy between the conditions described in site investigation report and the real ones, after the landslide had taken place (Łukasik 2007).

One of the most spectacular building disasters caused by geotechnical reasons took place at a construction site in Warsaw in 1998. It consisted of breaking a cavity wall protecting an excavation and a landslide to the excavation. It was 14 m deep. A street 22 m wide was destroyed together with underground installations. The catastrophe was preceded by a successive movement of the wall towards the excavation. Protection of the excavation was designed on the grounds of an engineering – geological report, where calculated values of mechanical properties of soils were determined on the grounds of direct shear tests and triaxial tests as well as on the grounds of instructions given in PN-81/B-03020 Polish Standard. These values were conservative. Basing on them three levels of anchors keeping the cavity walls had been designed among the others. On the grounds of higher parameter values proposed by a foreign consultant the idea of soil anchors was abandoned. There were major discrepancies in determination of soil pressure against the wall between the foreign report (the smallest values) and estimations given by Polish specialists (three or four times higher). The cavity walls were calculated taking into account too low pressure forces. Hence they were poorly (and improperly) reinforced and they were too short. It was the basic reason of the catastrophe (Wysokiński 1999).

A local slope stability loss took place in a thirty years old deep railway passage. Soil buried the track. Calculations basing on cylindrical slip surface proved stability of the slope. But the slip took place along a shallow, almost flat plane. Less cohesive soils slid down on the top of clays, which was inclined almost parallel to the slope. Site observations revealed that the slope failure took place at the only section not covered by plants where some earlier earthworks (for a fence and a cable) were carried out. Disturbed soil enabled water to penetrate into sandy clays which then migrated on the top of (pure) clays. It was confirmed by firm in places consistency of sandy clays in a stiff background. The slope was made mobile because of a diminishing friction (Kawalec 1999). Somewhere else a section of railway track got wet and the slopes of the excavation slid down. It appeared (Sołowczuk et al. 1996), that a blockage of drainage system caused the loss of slope stability in Pleistocene highland environment. Another case. Water seepages and landslide phenomena were observed on a slope cut by railway track. Efforts were made to overcome them but they helped for a short time only. It was noticed that:

- intensive slope degradation took place only near buildings,
- destructive processes were active in wet years.

Investigations and observations (Jeż, Kostrzewski 1997) proved that unfavorable changes of water conditions were caused by:

- devastation of farming drainage,
- letting gutter water out straight on the surface and leaking septic tanks,
- watering plants,
- damming shallow underground water by building foundation walls,
- supplying the slope by water migrating from an old opencast pit,
- blockage of trenches and drains by the railroad track.

Geological structure was also an important factor for slope stability. The top of clays was inclined in conformity with the slope decrease and it was covered by saturated sands. Finally the following factors have been recognized guilty of the failure state of the slope:

- topographic factors (gradient of the slope determining water movement and setting a component of gravitation in motion),
- climatic factors (rainfalls intensifying failure states in wet years),
- edaphic factors (geological structure favoring landslides),
- biotic factors (influence of human and his incorrect decisions, ignorance and negligence, changes in plant cover).

These factors make a whole in nature. It is called ecosystem. Change of any of them results in certain effects and in a change of remaining components. Such an approach is defined as environmental determinism.

EXPANSIVE SOILS

Possibilities of worsening of soil conditions by carefree contractors have been presented in the chapter describing errors committed during earth and foundation works. However unfavorable changes may also occur in the substratum after a long time. They usually lie in changes of moisture of cohesive soils. The soils which react noticeably by shrinking or swelling are called expansive soils.

Tertiary clays which occur in many places in Poland are usually bearing soils of stiff or hard consistency. But these expansive soils change their volume under influence of drying up or getting wet. Shrinkage or swelling processes often start as a consequence of human errors. Differentiated settlement may be the result of foundation of the structure on both local peaks of top of clays and in sandy (ie. less compressible) background. When shrinkage is added, the differences grow (Fig. 9).

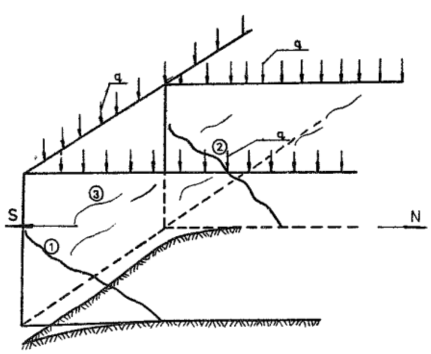

Fig. 9. A characteristic layout of cracks of suspended wall. The reason: shrinkage of dried up clays (Klin 1978).

It happens, that water gathers in local hollows. It causes swelling of clays moistening them. At the same time dried up (with the participation of tree roots) clays from local peaks – shrink. The effect: the growth of differences in settlement and building damages. Indentation of building foundation in clays creates a barrier for shallow ground water draining away. The opposite side of this building may be destructed because of local settlement caused by shrinkage of dried up clay. A handsome tree left near a newly built structure (like in patio), with its root system isolated from rain water supply, is forced to draw water from deeper clay layers. The clay dries up and shrinks causing settlement and building damages. And vice versa. The use of sand pillows indented in the top of clays causes gathering of water in there, the grow of moisture content in impermeable clays and swelling. The results are failure states. (Zawalski A., Woziwodzki Z. 1996).

To end with probably the most astonishing case let us present this one. Three-storey outbuilding broke more or less in half soon after it had been built. A vertical rift (Fig. 10a) with an opening widening upwards extended from the cellar as high as to the roof (Jeż J., Jeż T. 2001). Tilt of the right side of the building stabilized after some time. The building was repaired and populated. Fifty years later the gable right side of the building separated from the whole and leaned. Another crack appeared a few years later. The damages looked similar when the elevation view was considered (Fig. 10b). However they appeared different in horizontal projection. The first crack was more or less perpendicular to longer walls of the outbuilding. The subsequent ones formed larger and smaller circular arcs with the centre of this circle occupied by … a black locust (Robinia pseudoacacia). Geotechnical investigations carried out afterwards(!) revealed that slightly wet, medium dense sands (not much compressible soil) occurred under the left side of the building and compressible peat under the right side. This was the reason of differentiated settlement and breaking of the building. The later stability period followed the end of peat consolidation process. As time was passing by the root system of black locust was increasing. It absorbed moisture from peat during dry periods. Peat was shrinking. When the tree influence zone reached the building substratum the settlement process was resumed and the successive cracks were the consequence of it. Peat shrinkage tests confirmed this hypothesis.

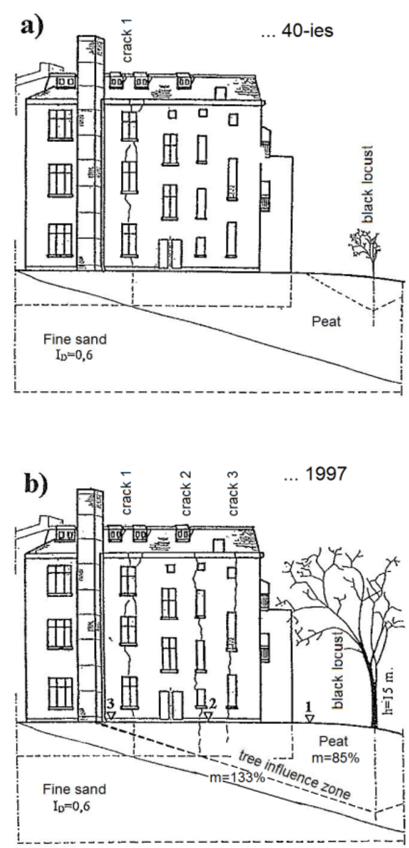

Fig. 10. The development of damages (cracks) of the building desctibed in the text (Jeż J., Jeż T. 2001).

Natural processes which can be described as „grass-roots" forced additional peat consolidation and overlapped the result of a building art error: direct foundation on differentiated in respect of compressibility substratum without its identification and without any strengthening of subsoil or construction.

SUMMARY

Selected examples of building failures and disasters in Poland – all caused by geotechnical reasons – covering the time span of several dozen years have been presented in this paper. Such events are usually divided into caused by natural reasons, willful human acts as well as being the result of both factors (e.g. Wardhana, Hadipriono 2003). At first glance this classification seems to be supported by the list of failure reasons compiled on Fig. 2. However, the analysis of particular cases indicates that even those natural reasons should have been anticipated by participants of construction process and appropriate remedial measures should be taken up. Sometimes a man "helps" the nature to destroy his own work. It is hard to find failure examples indicating their mechanism to be unknown or unidentified by science. On the contrary. The analyses show incompetence and lack of necessary knowledge not exceeding the level of BSc or MSc – usual/required for designers or construction management personnel (Van Baars 2011). The times when foundation on weak soils was risky had passed long ago. Today such failures are usually caused by failing to comply with one or a combination of factors which include planning, analysis, design, construction control and supervision, which all-in-all means that they are avoidable. (Gue, Tan 2004). We come closer to the thesis that in all failures caused by geotechnical reasons a man is to blame.

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