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Use of geogrids in stability problems and lateral earth pressure relieve in historical retaining structures

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ABSTRACT: A problem of deterioration or a new function and greater load acting on an old retaining structure, which is usually connected with development of modern cities or road network can, be easily solved when old construction is replaced by a new one, as it is often done in enginnering practice. Use of geogrid reinforced earth can solve this problem in other way saving both original, historical look of the retaining wall and costs of the works.

1 INTRODUCTION

With development of modern cities some old structures, retaining walls included, have to be able to fulfill a new function without losing their historical look. It is often combined with different problems like necessity to withstand new, bigger loading to be in accordance with todays rules concerning stability or problems with old, deteriorated parts of the construction itself and its foundation. Suggested solutions, based on long engineers' experiences with reinforced concrete structures, usually propose replacement of old retaining wall by a new one, not taking into consideration the possibility of saving historical value of engineering works from XIXth century or even older. Utilization of geogrid reinforced earth retaining wall can not only relieve loading acting on an old structure, thus prolonging its serviceability, but it has positive effects on costs of the works very often leading to their considerable reduction.

2 TYPICAL PROBLEMS ENCOUNTERED. IN OLD RETAINIG STRUCTURES

The most common problems, which one can face, when old retaining wall has to be incorporated in a new ifrastructure of the town, are following:

- the state of the structure doesn't allow for further exploitation (Fig. 1a)
- deterioration of the foundation system reduced its bearing capacity or stability of the structure (Fig. 1b)
- new function imposed and bigger loading, then before, exceeds actual bearing capacity of the construction itself or its foundation or dangerously diminish structure's stability (Fig. 1c).

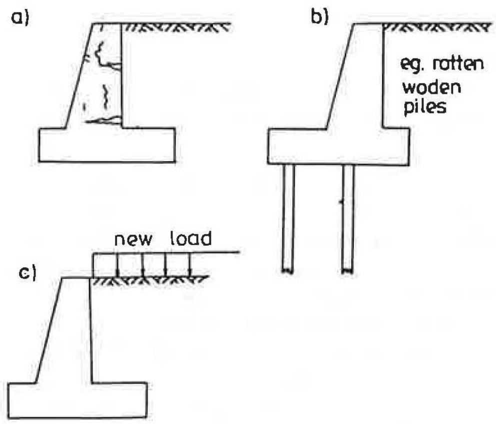

Fig. 1 Typical problems encountered in old retaining structures

Possible solutions of the problems presented above were divided into 3 groups:

1. demolition of the old retaining structure and replacement by a new one (Fig. 2a, 2b)
2. relief of old structure and taking part or whole loading by a new construction (Fig. 2c,2d)
3. adding some elements to the old structures to strengthen it, prolong its servicibility or to adapt it for a new, bigger loading (Fig. 2e, 2f).

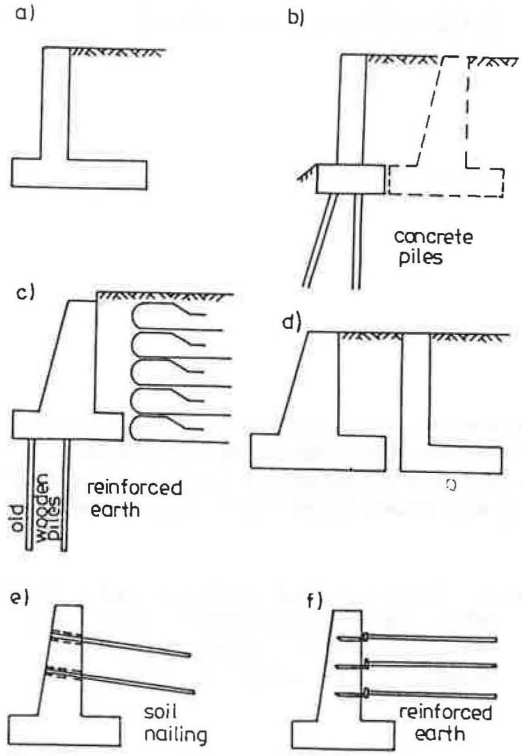

Fig. 2 Possible solutions of problems with old retaining walls presented on Fig. 1.

Each solution has its adventages and disadventages. The choice of quite new construction (1) make the planning much easier. Without difficulties one can fullfill all current requirements. There is no problem with usuful load - its value is not limited by parameters of existing construction.
The old structure must be dismentled, which is not acceptable for people, who really value see in original and are not satisfied by a replica or simulation of the historical look of the outer parts of the wall. The solution is efficient and safe, but very often expensive, too.
Solution 2 can save the old structure in its original form. It is relieved from actual loading or new loads are taken by a relief structure, so even if the condition of the wall or its foundation is bad it can be easily repaired to withstand at least its dead weight.
The new construction hidden behind the old one is not seen. A relief system can be made as traditional concrete retaining wall or reinforced earth can be used eg. with synthetic geogrid reinforcement and soil from the site as a filling. Relief structure can take over all new functions and loads (Delmas 1988). There is no such freedom of forming the construction and taking loads as in case 1.
In solution 3 the old structure became a part of a new system. By adding some elements to the old wall one can increase its bearing capacity, improve stability or prolong its service life. When the state of the old structure is bad the use of this method can be problematical and/or very expensive (Brzeski 1991, Gudehaus, Schwing 1987)
The choice of the solution should be made after thorough consideration of all factors like technical condition of the construction, planned loading, stability, historical value, costs, equipment possibilities of the contractor. An example of such discussion and final realization of relief construction made of geogrid reinforced earth for old embankment wall is presented in chapter 3.

3 ODER RIVER OLD EMBANKMENT WALL - - A CASE HISTORY OF ITS REPAIR (Parylak and others 1992)

3.1 Description of the construction

The embankment stone wall with brick facing was probably made in 1861. It surronds Piasek Island on Oder river. The cross-section of the wall is presented on Fig. 3. The construction is 3,2 - 3,8 m heigh above the top of wooden piles' cap made of stones. There is a wooden sheet pile wall in front of the cap, which could carry some horizontal forces caused by lateral earth pressure. The upper part of the sheeting has suffered destruction. The analysis has shown, that, as a result of this, the wooden piles in the external, river side raw are overloaded (calculated force was 205 kN, bearing capacity because of the pile's material - 200 kN). The piles in the first land-side raw were pulled-out withe the force - 19 kN and theirs joint with the cap was not designed to carry tension forces. Because of progressive destruction of the wooden sheeting there was a danger, that the embankment wall will start to tilt increasing the loading of the external raw of piles and leading to collapse. It was decided to build a new, reinforced concrete wall in front of the old one.

3.2 First, suggested solution of the problem

Design office, which has got the contract, has prepared the project of a new embankment wall. It was founded on two raws of Wolfsholtz piles connected by a reinforced concrete cap. On this base a new, reinforced concrete embankment wall was to be made. The solution provided sure and long term protection of the river's bank, unused old structure

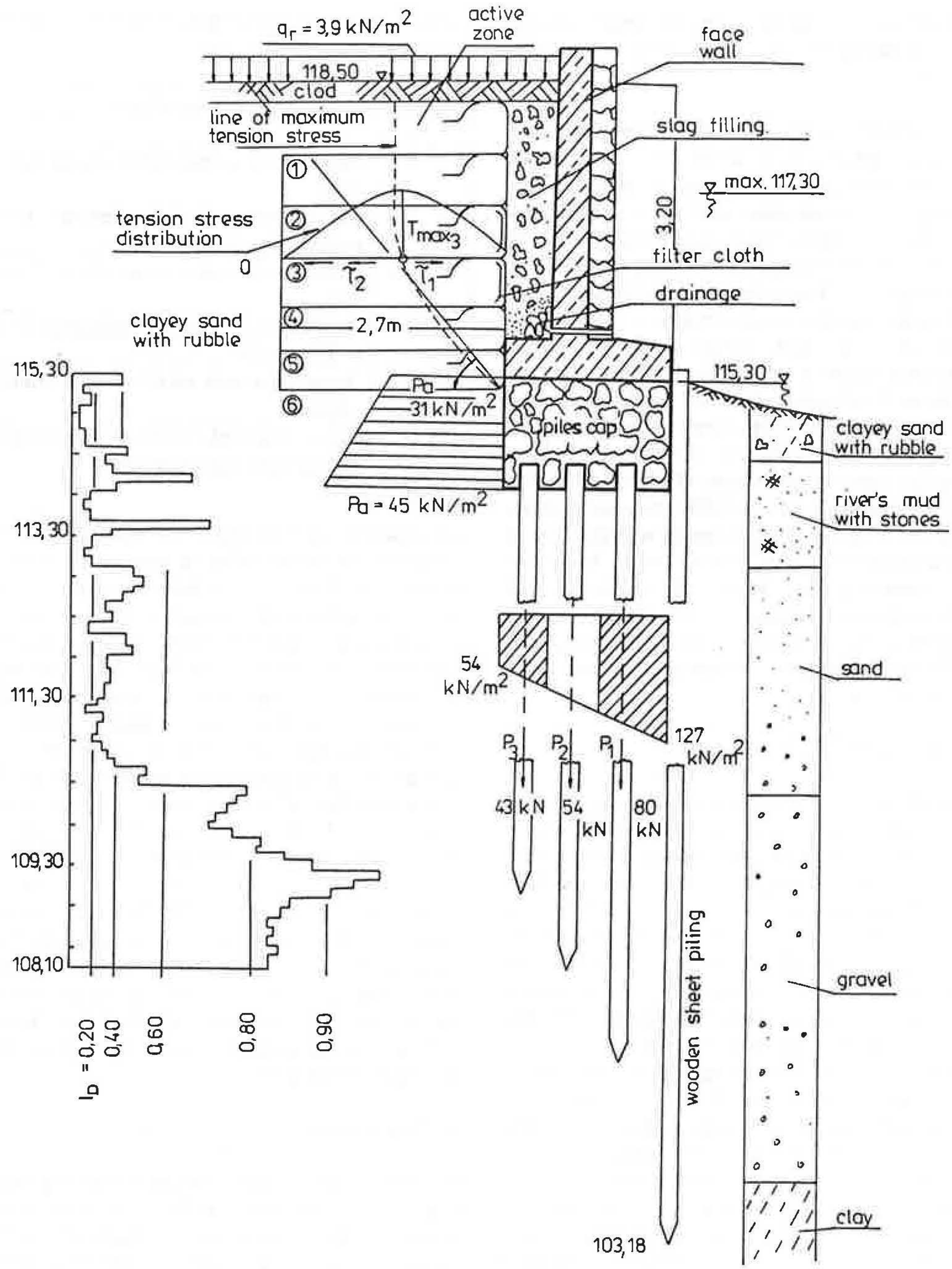

Fig. 3 Cross-section of the embankment wall with reinfarced earth relief structure

was to be dismentled. The works have been started and 20 m of the new construction was realized prooving to be very expensive. Inspection of the uncovered parts of old piles' cap and upper parts of old wooden piles made during the works confirmed theirs good technical condition and investor started to look for more sparing solution.

3.3 Relief construction from geogrid reinforced earth as an alternative for a new, reinforced concrete system

It was evident, that the old embankment foundation can serve longer, if it could be relieved from horizontal loading caused by lateral earth pressure charging the embankment wall. As a result much more uniform piles load distribution could be obtained and the damaged sheet piling would be no more necessary. Two solutions could be considered - soil nailing or reinforced earth as it is shown on Fig.2c and 2e. Soil nailing was not further investigated because of expensive equipment and complicated technology both not available by most contractors in the area. The compacting equipment is in more common use in almost all building enterprises. Also the technology of reinforced earth is easier to introduce by unskillful personnel of the contractor, who has no expierience with this type of retaining wall (Delmas and others 1986b). It was one of the most important factors, why reinforced earth has been choosen in this case . The solution is known in Poland, there is a polish standard concerning static calculation, but this type of construction is not widely used in building practise.

3.4 Soil profile

Under about 0,2 m thick humus layer there is, till the depth of ca. 4,5 m, an anthropogenic soil with clayey sand granulation. It contains up to 5 % of clay particles , up to 3 % organic matter and about 10 % of buildings rubble (crushed bricks and mortar). Detailed soil profile is presented in table 1.The strength parameters of the soil were determined on laboratory compacted samples in triaxial apparatus in CU tests with pore pressure measurment. The effective angle of internal friction was $\Phi' = 22\,^{\circ}$ and cohesion $c' = 7$ kPa for samples compacted to the same density as in situ and $\Phi' = 33{,}7\,^{\circ}$ and $c' = 7$ kPa for soil compacted to relative density $I_s = 0{,}95$ (according to Proctor's test). Dry density of the in situ soil was $\rho_d = 1{,}47$ t/m^3. For calculation of earth pressure behind the reinforced earth retaining structure density $\rho = 1{,}73$ t/m^3 was used taking into account moisture content at the most wet season of the year. The soil compacted by optimum moisture content ($w_{opt} = 13{,}5$ %) to relative density $I_s = 0{,}95$ has $\rho_d = 1{,}67$ t/m^3 and $\rho = 1{,}83$ t/m^3. Deeper layers are presented on Fig . 3. Some average parameters of these layers used for calculation are specificated in table 2.

Table 1. Detailed soil profile behind the wall (0 - ca.4,5 m below ground level)

Depth	Type of soil
m	
0,0 - 0,2	humus layer accumulated during last 50 years
0,2 - 0,6	building rubble with big quantities of brick and roofing tiles debris
0,6 - 0,8	humus accumulated more then 50 years ago
0,8 - 2,0	clayey sand with many inclusions of old building rubble
2,0 - 2,8	clayey sand with small traces of building rubble
> 2,8	clayey sand with traces of crushed bricks and medium sand inclusions

According to the data from 1909 and later work of Chrąchol and others (1978) underneath 4,5 m below ground level there is a 2 m thick layer of river mud with estimated strength parameters - $\Phi = 15\,^{\circ}$ and $c = 10$ kPa and from 6,5 m depth - medium sand with density index $I_D = 0{,}20 - 0{,}50$. Made in situ sounding has prooved, that supposed river mud layer should have higher strength parameters, then it results from archival materials. The analysis of particle size distribution of samples taken from this layer has shown, that the soil can be classified between clayey sand with 5 % of clay and ca. 2,5 % of organic matter and clayey gravel with 2 % of clay, 30 % gravel and 9 % of organic matter. The mud with clayey gravel grading had following strength parameters: $\Phi' = 31{,}8\,^{\circ}$ and $c' = 12$ kPa, mud with clayey sand grading had $\Phi' = 25{,}8\,^{\circ}$ and $c' = 14$ kPa. The strength characteristics were determined in CU triaxial tests. For calculation of the subsoil bearing capacity the parameters of mud with clayey sand grading had been used.

3.5 Dimensioning

Reinforced earth retaining structure relieving the old embankment wall was calculated according to the polish standard, which has adopted the method recommended by Laboratoire Central de s Ponts et Chaussées (Delmas and others, 1986a). Reinforced massif is divided into 2 zones by a two part slip line. Active zone is restained from sliping by reinforcement (e.g. geogrid) anchored in the passive zone. Reinforcement must have enough strength to resist tension forces. Vertical stress distribution on the level of every reinforcement layer is a Mayerhof

Table 2. Average soil profile and geotechnical characteristics used in calculation

Depth	Type of soil	Content of organic matter	ρ_d	w (water content)	ρ	Φ'	c'	Remarks
m		%	t/m^3	%	t/m^3	deg	kPa	
0,0-4,5	clayey sand with buildings rubble	up to 3	1,47	18	1,73	22	7	parameters for soil behind reinforced earth construction
0,0-4,5	clayey sand with buildings rubble	up to 5	1,67	13,5	1,83	31,7	7	parameters for filling compacted to relative density I_s=0,95
4,5-6,5	clayey sand	2,5 - 9	1,19	42	1,69	25,8	14	
> 6,5	fine sand /medium sand			26,5	1,9	30	0	I_D= 0,2 - 0,5

type. Coefficient of earth pressure is taken equal K_o at surface level and is progressivly reduced reaching the value of K_a at depth 6 m and from this point stays constant. Because the terrains adjacent to the river are used for walking, a live load of 3,9 kN/m^2 was taken into account in calculations.

There was a discussion, if local, anthropogenic soil can be used as a filling or non-cohesive soil with high shear strength should be transported from outside. After triaxial tests, because of good strength characteristics, local soil had been choosen. Because of relativly high content of organic matter, only a material with a high chemical resistance could be used as reinforcement. Geogrid made of synthetic complied with such requirements offering besides long servicibility, high tensile strength and good collaboration even with cohesive soils. The producer guaranteed 120 years working time, if determined level of stresses in reinforcement will not be exceeded.

According to the calculation, a reduction of load on piles in external raw from 205 kN to 80 kN is obtained as a result of using reinforced earth relief structure. Design office responsible for the project decided to close the embankment by a new reinforced concrete wall with a facing imitating old brick wall, though, in authors' opinion, original old brick wall could be left after some repairs had been made. Neverthless suggested solution let to do the work by much less cost, then if new, Wolfsholtz piles foundation had to be done. Some parts of the old construction could be saved and further used together with the new relief structure.

4 CONCLUSIONS

- Many design offices in Poland, because of their long experience, prefers traditional solutions based on reinforced concrete. Even if they know about new techniques or materials used in retaining structures, like e.g. reinforced earth, geotextiles, geogrids, they are very distrustful and reluctant to introduce them, having no design practise and very few information about behaviour of such structures .
- As it was shown on the example presented in the paper, the use of geogrid reinforced earth, as a relief structure for old embankment wall, can be both economical and simple solution. It should be always considered, as alternative or supplement for reinforced concrete structure, when old retaining wall has to be relieved or charged with a new, bigger loading. It allows to save historical walls and to utilize safely theirs bearing capacity eliminating necessity to replce them by a new structure.
- Presented solution can be effective and economical by designing of new walls founded on piles, where considerable reduction of lateral earth pressure would be desirable (Wichter, 1985).

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