Studia Geotechnica et Mechanica, Vol. XXVII, No. 1–2, 2005

GEOENGINEERING STRUCTURES IN SUSTAINABLE DEVELOPMENT OF CIVIL ENGINEERING

KRYSTYNA SZCZEŚNIAK

Civil Engineering Faculty, Wrocław University of Technology,
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland.
E-mail: krystyna.szczesniak@pwr.wroc.pl

Abstract: In a sustainable development of civil engineering, its numerous aspects should be taken into account. Environmental compatibility between the structures and structural materials, as a part of the sustainability, is limited neither to selected structural materials nor to selected type of structures. It is and it has to be associated with all structural materials, type of structures, structural technologies as well as their theoretical and practical aspects. Slopes necessarily occupy large areas and they are the parts of roads cuttings and embankments and a part of the bridge abutments. In this article, the considerations are limited to geoengineering structures, particularly to stabilising slope structures; the theory and principles of project and structure realization are not considered. Examples of the realizations described refer to recent engineering practice. The environmentally friendly soil nailing stabilization of road slope on inclined ground, deep excavation in urbanized area, mine waste slope, and the possibility of protecting location of historical monuments show the environmental compatibility of geoengineering structures.

1. INTRODUCTION. ENVIRONMENTAL CONSTRAINTS

The sustainability of geoengineering structures is considered to be a serious problem. In article, some of aspects of ground-improvement technology and case history from a recent practice are analysed. These case histories can show that in the domain of geotechnical engineering, engineers are aware of the urgent need to ensure environmental compatibility of the structures designed with the technology on one hand and of a reasonable reduction of energy consumption during the entire life-cycle and use of geoengineering structures on the other hand. The general principles of designing sustainable and environmentally compatible structures follow general requirements specified in Agenda 21 [1].

The slopes prone to sliding have to be stabilised according to well-thought-out plan and have to fulfil the multicriterion approach (figure 1).

Scheduling must be sensitive to the changes, such as operation of facilities, time required to order special material and equipment and weather. Although the stabilisation program may be well planned, its effectiveness may be adversely affected by delays in its implementation because of unexpected schedule constrains, such as legal problems, right of way acquisition, funding, political issues, or union problems.

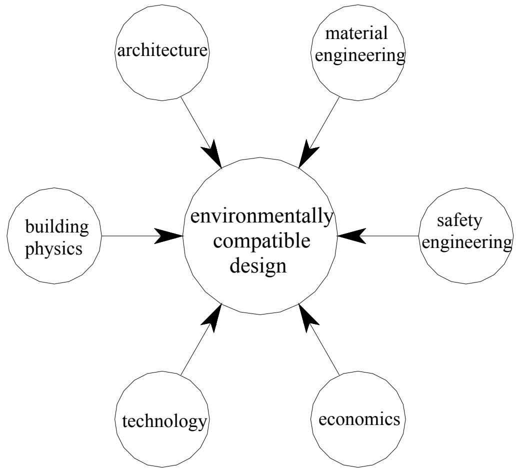

Fig. 1. Environmentally compatible design – multicriterion approach

When selecting the slope stabilisation work, we should consider its potential impact on environment during and after construction. The changes in groundwater flow can be potentially detrimental to the environment. Economical and functional slope stabilisation work has to be aesthetically pleasing. This aesthetic factor is important when the stabilisation work is to be made in natural habitats and forests, as well as in urban environments. Under these circumstances, attractive wall systems with vegetation, architectural treatments, and colouring are usually considered to improve aesthetics.

Economy of time and money are frequently the key factors in selection of stabilisation methods. This does not imply that complete or adequate engineering and geologic studies are to be waived in the interest of time and money, and within the time and emergency conditions that exist. The total cost of slope stabilisation work has many components, including the stabilisation system itself, right of way, temporary and permanent easements, disposal of unsuitable materials, and drainage. In general, the construction cost of nail/tieback walls is 60 percent less than conventional cost-in place concrete walls, and concrete cantilever walls become less economical for wall heights greater than 4 m. The statical analysis of earth reinforcement and geoengineering structures like soil nailing may benefit also from computer-aided design using software, for ex. SLIDE, STARS or TALREN, and it is favourable for project preparation time.

2. TECHNICAL CONSTRAINTS. SOIL NAILING

The stabilisation methods depends on engineered slopes. Technical constrains include those associated with:

- type of ground to be stabilised,
- strain compatibility,
- creep of in situ ground,
- soil corrosivity,
- durability,
- constructibility.

The type of ground base of constructed or stabilised slope, on which the stabilisation work will be carried out, has a major impact on its selection. The most important is the location of groundwater. Stabilisation work over soft ground requires either highly flexible systems that can tolerate settlement induced by imposed loads, or use of lightweight fill to minimise further shearing of unstable soil mass.

The slopes stabilised mechanically by, e.g., soil nailing are good examples of the systems influenced by the compatibility of strain of the system with the soil. The strains required to mobilise the full strength of the reinforcing elements are much smaller than those needed to mobilise the full strength of soil. Soil nailing as a technique of reinforcing soils is now well established and about 30-year old [5]. However, the majority of permanent nailed structures are more recent, and the total of up-to-date experience may not be conclusive. The longevity of the nailed system support depends on the durability of its individual components and on continuing ability to transfer force via bond from the soil to the nails.

Soil nailing system design involves spacing, size and length of the nails (figure 2). It must be determined based on the internal and external stability considerations (figure 3).

In comparison to conventional excavation and retaining systems, such as massive concrete walls, internal bracing systems and tieback walls, nailing presents the following main advantages:

- adaptability to different soil conditions,
- light construction equipment,
- flexibility: nailed soil-retaining structures are more flexible than classical cost-in-place reinforced concrete-retaining structures,
- reinforcement redundancy: if one nail becomes overstressed for any reason, it will not cause failure of the entire wall system, rather it will redistribute its overstress to the adjoining nails.

The basic characteristic of the nailed structure is the density of nails d:

$$d = \frac{t}{\gamma S_H S_V} = \frac{\pi D q_s}{\gamma S_H S_V},$$

where:

q_s – unitary limit shear stress,
t – the shear stress on the 1 m contact of nail–soil,
S_H, S_V – horizontal and vertical distances,

D – nail diameter,
γ – unit weight of soils.

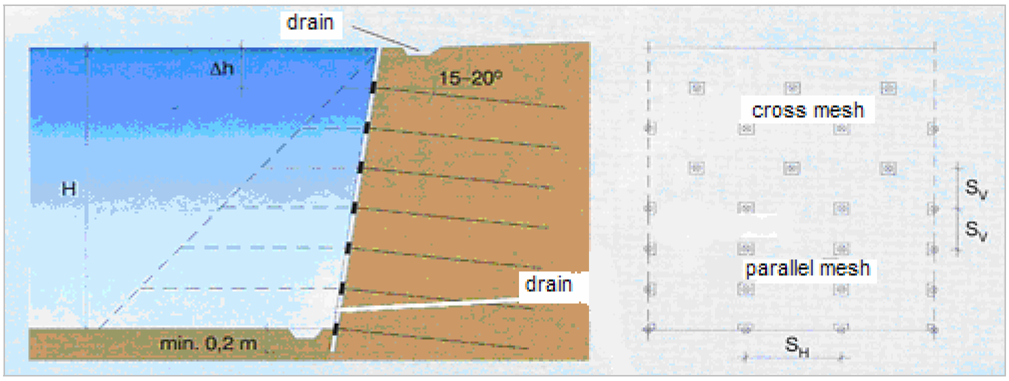

Fig. 2. Typical scheme of soil nailing [5]

Fig. 3. Local and global stability factor *F*

The design of nailed excavations and slopes generally is based on limit equilibrium analysis. The Eurocod 7 requirements proposed in [3] are similar to CLOUTERRE and ADDITIF1999 recommendations for concepts design, analysis, construction and monitoring [4].

3. CASE HISTORIES

The following case histories, from my own recent engineering practice, illustrate the application of soil nailing as environmentally compatible ground-improvement technology. In the mountainous regions, during building a road the waste of land utilised above and below was economically reduced by a steep dig for of cuts and slopes. The soil nailing slopes up to 60 degrees were constructed as green walls stabilised by geo-textile mesh without need for shotcrete. Settlement areas were consolidated permanently by soil nailing installed from the roadway. The road compatibility with the landscape due to utilisation of a local ground and rock for the architecture of borders is the advantages of this type of construction.

Fig. 4. Road in mountainous region. Typical stability analysis by program TALREN.
The successful design and aesthetic appearance (in the future) with vegetation on the facing

In order to ensure a stable and environmentally safe project, the global stability analyses were performed using the commercially available computer program TALREN (figure 4).

Another geoengineering structure is a 9 m high permanent nailed slope in urbanised area (figure 5). Its construction was an attractive and economical alternative to conventional retaining wall because the shape of the wall was irregular which allowed us to preserve the trees. The loose silty granular soil met the conditions for nailing technology.

a) b)

Fig. 5. Scheme of nailed slope (a) and a general view of its construction in urbanised area (b)

In all the countries closing down deep coal mines, the landscape "after the coal" is considered to be a troublesome problem. Technology of nailing which enables stabilisation of coal mine-waste slopes, can be solution in this case. A quick installation of relatively short nails often results in cost savings. The short, small-diameter drill holes typically used in soil nailing are suitable to mine spoil materials containing boulders, tree stumps and hard rocks. Light equipment and simple gravitational grouting procedures are well suited to the remote locations. Flexible geosynthetic facing material that promotes vegetation on the slope and assure the environmentally friendly architectural view can be used to assure local stability. The look of dumping overburdens, which are the history of coal mine industry, thanks to technology of stabilisation, can be environmentally friendly.

4. FINAL REMARKS

Because of the economy of excavating and transporting material as well as the expenditure on the land in urbanised and not urbanised areas all designs have to be created with a maximum tolerable slope, which is not often possible. This requires nicely balanced judgement based on thorough understanding of local shifts in precipitation, geomorphology and hydrology as well as localised soil properties.

There are many well tried and effective solutions to slope stability problems. National or local trade barriers and different influences sometimes affect the selection of stabilisation works and materials. Sustainable development and economic pressure enjoin continual search for more energy and cost-effective solutions, and this has led to a better understanding of the fundamental mechanisms. The total cost of slope stabilisation work has many components, including the stabilisation system itself, right of way, temporary and permanent easements, disposal of unsuitable materials, and drainage. Landslides and engineering structures, prevention and remedial works are discussed by many authorities responsible for education in geotechnics. Education of designers, contractors and site staff is fundamental to quality assurance in the sustainable engineering practice. The basic concepts of geoengineering structures like nailed slopes and the sensitivity of the design assumptions to construction practices must be understood by those responsible for the construction. Without this knowledge the technical and financial benefits offered by the use of a new technology of stabilised technique will not reach its full potential and will not fulfil the multicriterial approach to environmentally compatible design.

REFERENCES

[1] CIB – International Council for Research and Innovation in Building Constructions, 1998, Agenda 21 on Sustainable Constructions.

[2] STAWICKA-WAŁKOWSKA M., *Influence of civil engineering activities on environment in the scope of sustainable development* (*Wpływ działalności budowlanej na środowisko naturalne i człowieka w aspekcie zasad zrównoważonego rozwoju*), Izba Projektowania Budowlanego, Wiadomości, 2001, No. 10 (129), pp. 5–9.

[3] Geotechnical design – EUROCODE 7, Final Draft EN, 2002.

[4] SZCZEŚNIAK K., *Some remarks about soil nailing as an environmentally friendly technology for the stabilisation of slopes*, Proceed. of 2nd Int. Seminar on ECS, Prague, 2001.

[5] SZCZEŚNIAK K., *Soil reinforcement by nailing* (*Wzmacnianie gruntu metodą gwoździowania*), BIT, Budowlany Informator Techniczny, 2002, No. 3 (49), pp. 51–54.

[6] Proceedings of the First European Conference on Landslides, Prague, Czech Republic, June 24–26, 2002.