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EARTH STRUCTURES IN TRANSPORT ENGINEERING – SUSTAINABLE APPROACH AND TECHNICAL SOLUTION

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Требования к качеству земляных сооружений для транспортной инженерии (автомагистралей, высокоскоростных железных дорог, аэропортов) растут в результате увеличения транспортной нагрузки, скорости транспорта, а также в связи с тем, что экологические аспекты играют все более важную роль. Прежде всего, в статье рассматриваются экологические аспекты, а также тот факт, что подобного рода новые земляные сооружения располагаются в более сложных грунтовых условиях. Закрепление грунта играет очень важную роль и в случае использования менее свойственных материалов и в случае увеличения уклона склона для уменьшения площади, которую занимает транспортная инфраструктура. С этой точки зрения внимание уделяется подпорным стенам из бетонных блоков. В статье будет показан особый подход к определению разных предельных состояний таких подпорных стен, в особенности внешней и внутренней устойчивости. Расчет устойчивости основан на собственных компьютерных расчетах с учетом закрепления, как дополнительной горизонтальной силы между отдельными полосами.

Demands on the quality of earth structures of transport engineering (motorways, high speed railways, airports) are increasing as a result of increasing transport loading, transport speed and also that environmental aspects are playing more important role. First of all environmental as-

pects are discussed in the paper as well as the fact that these new earths structures are situated on more complicated subsoil. Soil reinforcement is playing very important role either how to use less appropriate materials or to increase slope inclination for limitation of the land which is occupied by transport infrastructure. From this point of view the attention is devoted to retaining walls from segmental concrete blocks. Specific approach, how to solve the different limit states of such retaining wall will be shown, especially external and internal stability. Stability calculation is based on own software counting with reinforcement as with additional horizontal force between individual strips.

1 INTRODUCTION – BASIC ASPECTS

Transport engineering is currently undergoing relatively rapid development. This is foremost indicated by the development of an international highway network and by the construction of many new airports and these moreover in very difficult circumstances. Also at the same time there is a reconstruction of the railway network for higher speeds and entirely new construction of routes for high speed trains. As well the amount and area of dedicated car park space grows. At the same time the philosophy of "Sustainable Construction" has been getting primary attention in recent years, Vaníček (2011). This new approach shows that an excellent technical solution is a necessary precondition, but not a sufficient one. Other aspects to which the modern project must apply itself to, are the environmental, sociological and architectural ones, and of course also an economic perspective, because the final solution should be economically competitive, (Vaníček, Kuráž & Chamra 2005).

From the point of view of general principles of transport engineering we can identify the following specific points:

- The total area for construction of transport infrastructure has a pronounced tendency to grow and impacts significantly on land appropriation, especially land already marked as greenfields sites, and this can be considered as a negative factor.
- Earth structures in nowadays construction of transport infrastructure present a significant potential for using various secondary materials, waste, by-products in the process of construction.

- In response to a growing concern for environmental protection the requirements placed on earth structures in constructions of transport infrastructure are increasing with special regard for possible crashes by different transport methods and the escape of any transported dangerous substances into a surrounding area. This, however, also relates to common products involved in any operation, be it oil drops, fuels, vehicle engine products etc.

These specific points go on to influence conceptual approaches to the design of new, and the reconstruction of existing transport infrastructure.

2 SITUATION OF TRAFFIC NETWORK, LONGITUDINAL SECTION

The above mentioned specific points influence the total approach to construction of transport infrastructure, and for linear projects it manifests itself in situating their route, or respectively this fact can come up in longitudinal profile. Land protection changes a perspective on situating the route even when it may significantly complicate the actual design of earth structure. It involves:

- Greater utilization of brownfields for situating new routes.
- Situating of a route of transport infrastructure to an area with difficult foundation conditions – it involves especially territory with very soft subsoil, with subsoil structurally unstable or territory that is sliding.
- Situating the route away from the areas with significant supplies of drinking water or with a detailed specification of its protection.

With new approaches this also changes perspectives on the longitudinal profile of the route. In the classical interpretation a balance between embankments and cuttings was in favour. From the present point of view it is obvious, that generally there exists a surplus of materials, which could be used for embankments and that is why the condition of balanced capacities loses its significance. At present with urban development the surplus of mined soils increases, for example as a result of underground construction, tunnels, enlarged capacities of excavations of construction pits for the use of building land also under the terrain level etc. The next area is production of a significant volume of waste rock in the mining and processing of raw materials, recycled materials from construction demolitions, products created from processing and utilization of raw materials – for example power station and heating plant fly ash from coal burning. And so we could continue in this elaboration, because it is possible to anticipate continually new suggestions.

3 APPROACHES TO CROSS-SECTIONS

During the design of earth structure cross-section (mainly for motorway) two main points are the most significant. First one is connected with land acquisition, when nowadays the land is more valuable and hence the footprint is minimised. The second one is the technical solution of slope stability for such steepened structures. In this case the technical solution uses mainly soil reinforcement in its two main concepts, reinforcement by geosynthetics for embankments and soil nailing for cuttings. However the high demand for protection against surface erosion has to be accounted for. The details of all these problems of earth structures are described in more detail by (Vaníček & Vaníček 2008). Reinforced slope allows steeper slopes and hence reduction of the amount of soil required for the construction of the embankment or utilization of soils that would otherwise be categorised as potentially suitable or unsuitable. The use of reinforcement is reducing the amount of fill material, which is sustainable for the case of reduction of the transport requirements. Roughly the same applies to cuttings where reinforcement by soil nailing is decreasing the amount of soil that otherwise would be excavated and transported elsewhere. Another alternative shows the construction of the road in mountainous area, when one lane is made with the help of soil nailing and the other lane is constructed from soil reinforced embankment in which the soil from cutting for the first line is used, Fig. 1.

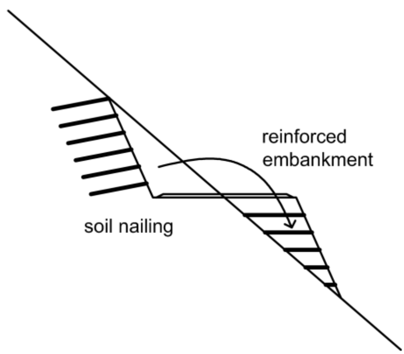

Fig. 1. Construction of the road in mountainous area – combination of reinforced soil embankment and soil nailed cutting

4 REINFORCED SOIL WITH SEGMENTAL CONCRETE BLOCK

Small prefabricated blocks have different shapes as patented by different producers, but are mostly similar to hollow brick. Weight is around 20 kg, so that the block is easily transported by one man. Connection between individual blocks and the reinforcing element (geogrid sheet) is realized by way of friction. Detail of such a connection is shown in Fig. 2 where gravel grains filling the inner space in the block are partly sunk between a mesh of grids, so the size should be in a certain ratio to meshes. Facing can be vertical or graded (stepped) and for the first case the connection can be improved e.g. by a vertical steel bar. For the graded wall, a small buttress ensures stability of the blocks during the compaction of a new layer and also after completing the whole wall, increases inner stability, especially against bulging. Typical examples of external and internal stability which have to be checked are shown in Fig. 3. To improve the aesthetic aspect producers can create a face to look like natural stone. Special blocks, called concrete planter boxes, are a little bit wider and the front part is filled by top soil for better planting.

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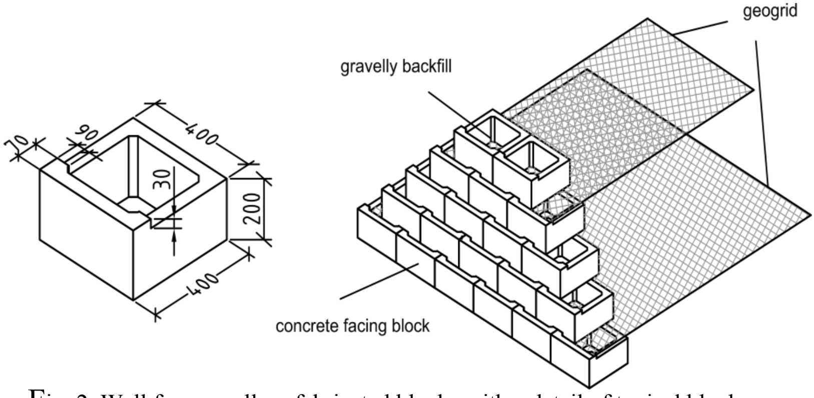

Fig. 2. Wall from small prefabricated blocks with a detail of typical block

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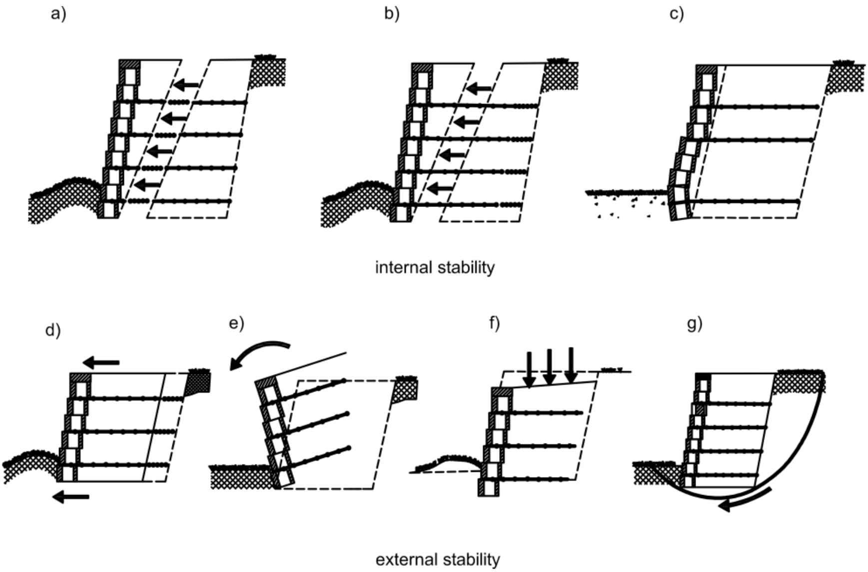

Fig. 3. Assumed failure mode under a centrally loaded surface strip foundation on geogrid-reinforced soil

5 IMPLEMENTATION OF REINFORCING ELEMENT EFFECT INTO SLOPE STABILITY CALCULATION METHOD

Let us suppose a simple case of slope reinforced with one reinforcing element, see Fig. 4 and observe how this element contributes to the increase of slope stability for individual assumptions. According to the assumption ad a) the reinforcing element, its design tensile strength, reacts in the horizontal direction. This additional effect from the reinforcing element is additional moment acting on cantilever y, which is the distance of the reinforcing element from the centre of the circular slip surface. This assumption is the recommended one in BS 8006:1995. It is obvious that in the upper part of slope the positive influence is lower than for the same element situated in the lower part of the slope. This approach assumes the maximum engagement of the reinforcing element without any deformation.

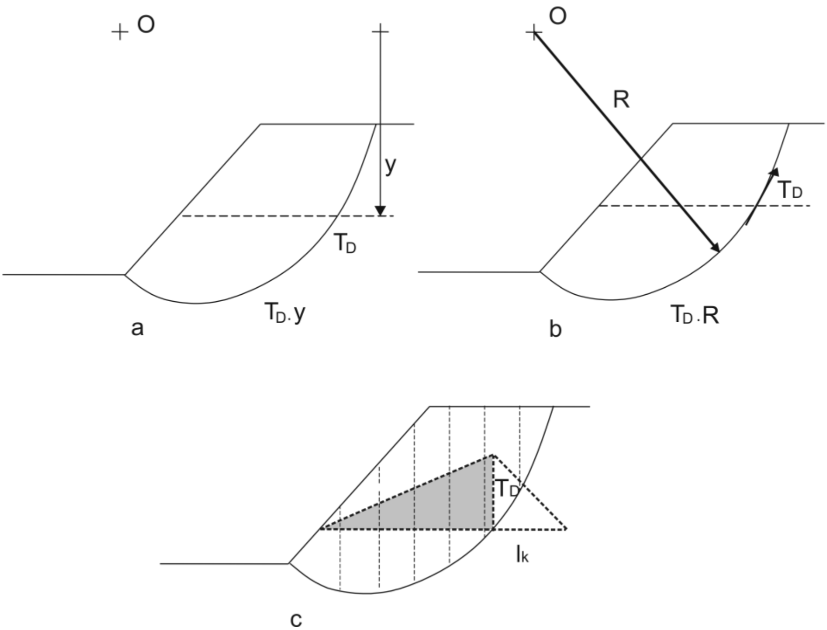

Fig. 4. Main options how to incorporate the reinforcing element into slope stability analysis

In the second case ad b) the influence of reinforcing element is reflected as additional moment acting on cantilever R, which is the radius of circular slip surface. In principle this approach assumes that due to the development of shear plane accompanied by shear strain along the circumference of the circular slip surface the tensile force in the reinforcing element is mobilized also along this circumference. The influence of the reinforcing element is constant, independent of its position in the slope.

This assumption represents another extreme; tensile force is activated after a significant shear strain in soil.

The third case ad c) reinforcing element is acting as additional horizontal force, the maximum of which is in the point of intersection with slip surface. This horizontal force is decreasing on both sides, in the direction of slope face side or in the direction of anchoring. The difference on inter-slice boundary is this additional force. In principle it is prestressing force between individual slices. The effect is variable, depending on the position in the slope, and is increasing with increasing area of the triangle which is bordered by design tensile force T_D and by length of reinforcement to the slope surface. Generally the highest effect is in the place where the tangent line parallel to the slope is touching slip surface; roughly in the lower third of the slope. The author prefers this approach also for easier application with general shape of the slip surface.

Due to this assumption the method of (Janbu 1973) was used for the calculation of the reinforced slope (Vaníček & Škopek 1989), (Vaníček 2000). Janbu's method, which is adopted uses on each slice, to which the whole slope is divided, equilibrium equation in horizontal and vertical directions and momentum one.

Due to the fact that the calculation of this way modified Janbu's method is rather long for hand calculations and for the determination of the most dangerous slip surface with minimum factor of safety, a computer program SVARG (Slope Reinforced by Geosynthetics) was developed, see (Vaníček & Vaníček 2000). The program can almost immediately solve factor of safety for selected slip surface or in a very short time find the worst slip surface. The slip surface can be general. This program also automatically checks the anchorage length of the reinforcement with the expression:

$$L_k = \frac{\gamma_L \cdot T_d}{2 \cdot (\gamma \cdot h \cdot tg\varphi_{gs} + a)} \tag{1}$$

where φ_{gs} – angle of internal friction between soil and reinforcing element; a – adhesion between soil and reinforcing element; h – depth of the reinforcing element below the surface; T_d – design tensile strength of the reinforcing element; γ_L – partial factor for anchorage length, e.g. = 3 based on Czech requirements.

6 CONCLUSIONS

This paper refers to the new demands on earth structures. Two main aspects that are defining the requirements are environmental ones and design ones. Within the environmental aspects we count the situation of route though complicated areas (brownfields, highly compressible and landslide prone areas), use of waste or by-product materials for the actual construction (e.g. fly ash, slug) and contamination from these materials as well as from oil drops, accidents, etc. Into the design aspects we count recommendation of Eurocode 7 – Geotechnical design and two basic limit states – ultimate limit state and serviceability limit state, for which the first one was specified in more details.

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