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Classification of reinforced soil structures based on their possible failure mode

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ABSTRACT: Proposed is a kind of a general classification of reinforced soil retaining walls, to take into account their internal structure and most probable failure mode. Such classification, however imperfect, makes more clear the problems arising when attempts are made to describe reinforced soil walls theoretically.

1 GENERAL CLASSIFICATION

There are many ways of using reinforcement to improve mechanical properties of soils. Some typical examples of reinforced slopes and embankments are shown in Fig.1. This figure presents at the same time the general classification of reinforced soil structures, accepted in the paper.

The classification refers to the soil nailing and other techniques used to construct steep slopes and embankments (called generally reinforced soil).

It is based on a structural uniformity or non-uniformity of reinforcements as well as uniformity or non-uniformity of reinforced soil structures itself.

Uniform reinforcement is defined, after Schlosser at al (1983), as "an uniform inclusion, where the soil-reinforcement interaction can develop in any point along the inclusion". In contrary, if an inclusion is reinforced itself in some particular points, where the soil-reinforcement interaction is concentrated, non-uniform (or "composite") reinforcement is concerned. In accordance with this definition, a plain nail belongs to uniform reinforcements, and an anchor to non-uniform ones.

As a result two categories of reinforced soil structures, being reinforced with both kinds of reinforcements, can be separated. In Fig.1 only in case of structure G reinforcements are non-uniform. The rest of the structures shown in Fig.1 have uniform reinforcements. In one case (I) it is an isolated single layer of uniform reinforcement, in all the remaining cases (A, B, C, D, E, F, H) multiple reinforcement is applied. Among the last group of structures there are some with reinforcements placed uniformly within the part of the structure adjacent to its face (Fig.1 A, E, F, G, H). This kind of structures, having regularly spaced uniform reinforcements distributed along the whole height of a structure, will be called structurally uniform. The other walls from Fig.1 are not structurally uniform - B and D because their reinforcements are not parallel, C due to reinforcements localized only on the part of structure's height, G due to non-uniform reinforcements.

2 MECHANICALLY UNIFORM STRUCTURES

Those reinforced soil structures which are structurally uniform, show, under certain conditions, the mechanical uniformity, what allows to describe them as ones built from a composite material (Sawicki at al, 1989).

An exact definition of mechanical uniformity would be difficult at the present state of knowledge, so it will be introduced only on some examples. In general a certain reinforced soil slope will be considered as mechanically uniform if it is structurally uniform and can be homogenized as a whole (Fig.2). Soil reinforced with some other material should be referred as at least two-component discrete medium. Homogenization means that such a medium is modelled by some continuous, analogous one (for example the rigid-plastic anisotropic composite, Sawicki at al, 1989). The advantage of using homogeneous models is that they allow to solve easily problems of some importance for a practice, like for example the problem of bearing capacity of reinforced soil slope

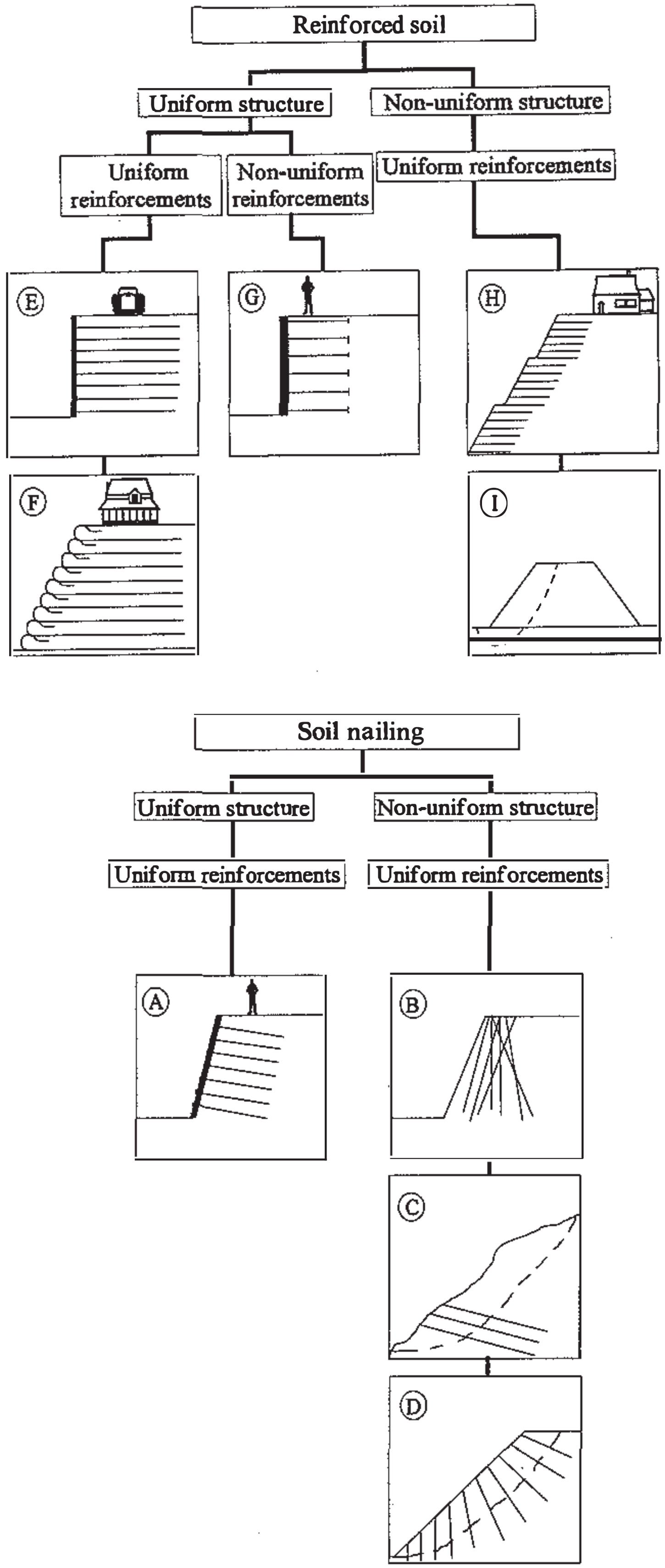


Fig. 1. Some types of reinforced soil structures

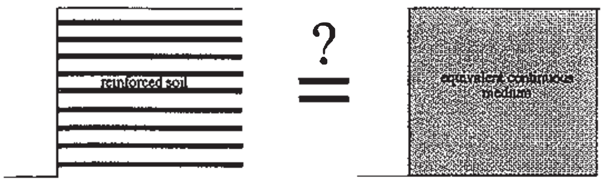


Fig.2. Homogenization of a simple reinforced soil structure

(Leśniewska, 1993). To apply those solutions in practice one needs however to define what kinds of structures do they refer to? There are two main assumptions of continuum models, which can help to answer this question: first that dimensions of the smallest volume, containing both r.s. components in the same proportion like in the whole reinforced mass must be significantly smaller then a height of a wall H and an extent of a surcharge d (Fig.3), second that the lengths of reinforcements overlaps an area where any changes caused by internal and external loads are expected. Transformed for real structure it means that following factors have to be examined: location and magnitude of the expected external loads, ratio of a vertical reinforcement spacing to the external load extent s_v/d, (Fig.3), ratio of external load extent a height of a wall d/H, ratio of a vertical reinforcement spacing to a height of a wall s_v/H, the most probable expected failure mechanism, lengths of reinforcements in relation to a failure mechanism. There is no enough space in this paper to discuss more detaily all above mentioned factors. Let us assume then, that the ratios s_v/d and s_v/H are small enough for the homogenization purposes and let us focus on the remaining factors.

2.1. Internal and external failure mechanisms

To discuss some factors having an influence on failure mechanisms of r.s. slopes or walls, Fig.4 was prepared on the base of a number of model and full-scale tests, performed on structurally uniform r.s. walls (see References). In this figure some basic types of failure are presented, without preserving real layout of any particular experiment. There were more complex types of failure found in the experiments either, but they could be in most cases composed from basic ones shown in Fig.4.

The general conclusion drawn from majority of tests quoted in References is that the failure of reinforced soil steep slopes is accompanied by a presence of failing soil "wedge", like in a case of a plain soil.

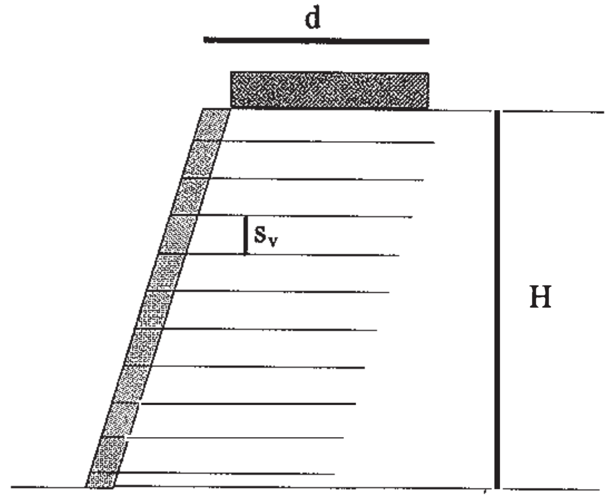


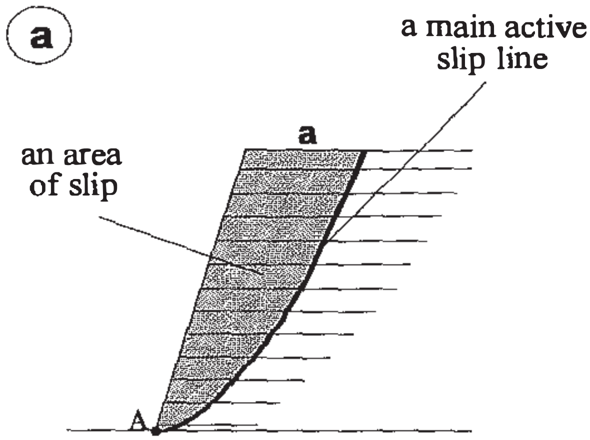
Fig.3. Characteristic dimensions of reinforced soil structure loaded at a top.

If this wedge is included totally within reinforced area of a given structure, such kind of failure is called an internal one. In contrary if the failing soil wedge partly exceeds the reinforced area, the failure mechanism is called an external type of failure.

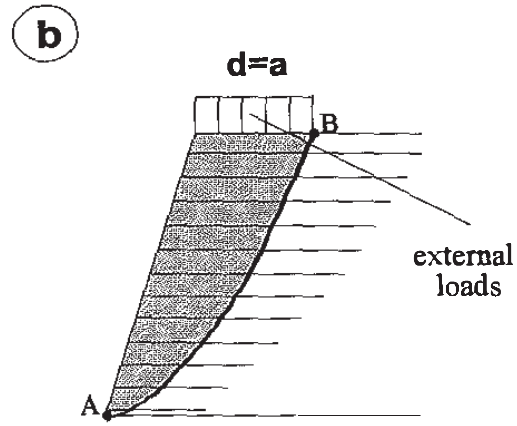
Structures which failed in the second way should be regarded as non-uniform ones - they can not be mechanically uniform, because they consist of two different materials - reinforced soil and a plain soil.

Their failure mechanism can not be predicted on the base of continuum model either. Fig.4a shows an example of failure which can occur without any surcharge due to a soil self weight. For long enough reinforcements it is an internal failure. Characteristic for this kind of failure is that the main slip line passes through the slope's toe (point A in Fig.4). The distance cut by a soil wedge in this case is indicated as a. If an additional surcharge is added at the top of r.s. wall, more complex behaviour may be expected (Fig.4b-f). It depends on location of loads and lengths of reinforcement. Fig.4b shows an example of a structure loaded externally in such a way that the extent of loading $d=a$. Generally the distance d is different then a and different slip lines may be activated. When the surcharge is big enough in comparison with the stresses caused in point A by a self weight, the main slip line passes rather through point B than point A (it is usual situation in most of model tests - in real structures a self weight causes much bigger stresses then a surcharge).

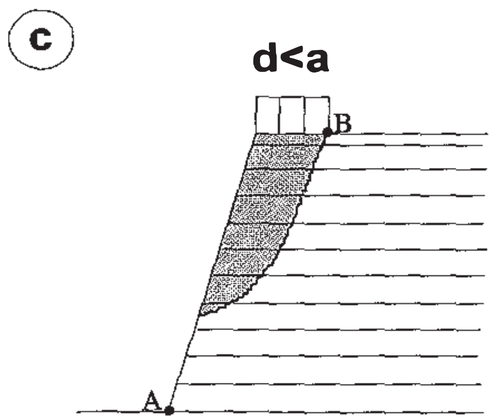
As a result following failures may be created: totally internal failure for $d<a$ and reinforcements longer then d (Fig.4c), external failure for reinforcements shorter then d and external load



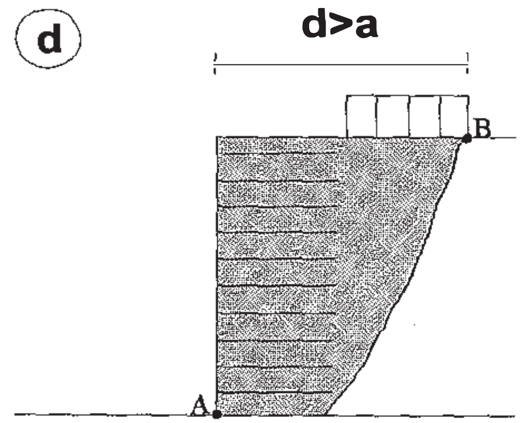
A limit case of an internal slip failure mechanism caused by a self-weight.



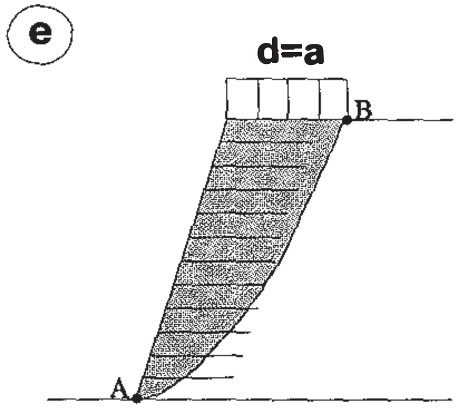
A limit case of an internal slip failure mechanism caused by a self-weight and an external load.



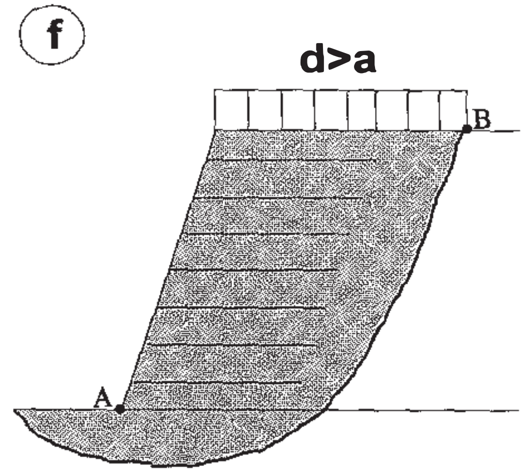
A case of an internal slip failure mechanism caused mainly by an external load.



A case of an external slip failure mechanism caused by a self-weight and an external load.

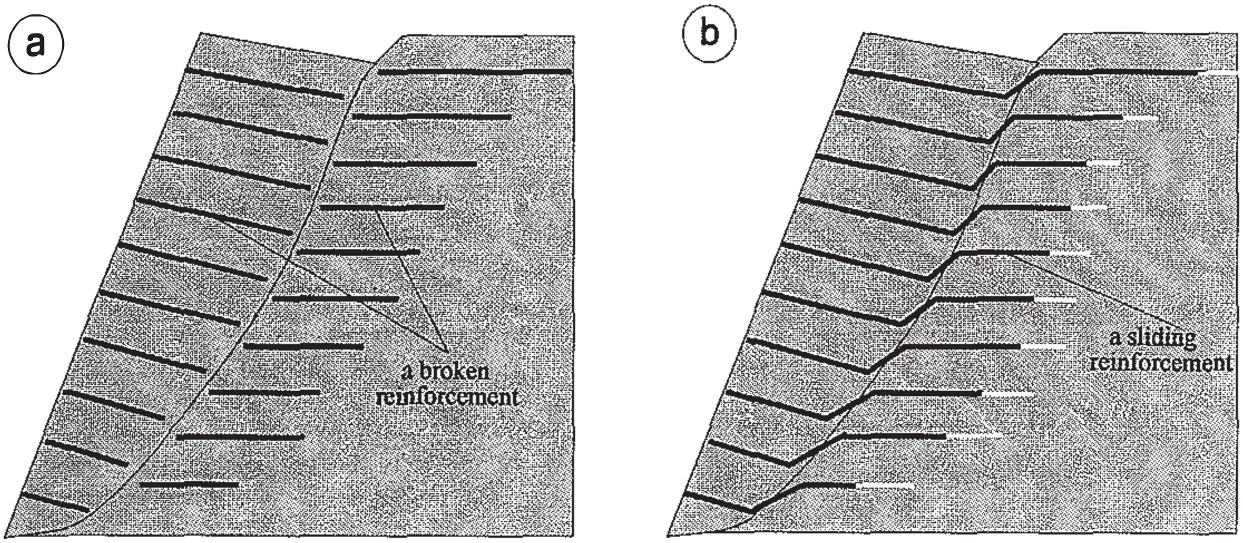


A case of an external slip failure mechanism caused by a self-weight and an external load.



A case of an external slip failure mechanism caused by a self-weight and an external load.

Fig.4 A case stady



Internal failure due to rupture of reinforcements   Internal failure due to reinforcements' slip

Fig.5. Two modes of uniform internal failure.

located behind reinforced soil area (Fig.4d), external failure for $d=a$ and reinforcements lengths shorter then d (Fig.4e), external failure for $d>a$ and reinforcements' lengths shorter than d, including failure of a subgrade. In the last case some part of the subgrade should be regarded as a part of the structure in a wider sense. Any structure loaded in such a way that strong interaction with a foundation can be expected can not be considered as mechanically uniform. Coming back to Fig.1 it should be assumed then, that structures A, E and F would show most probably an internal failure, when H an external one. It is clear that any changes in position of load or reinforcement layout may change a failure type. If the distance d in Fig.4f would be shorter, the failure could occur like in Fig.4 b or c. In Fig.4f the distance d is comparable with the slope height. So for example structure shown in Fig.4b, if loaded on longer distance, could show similar behaviour like f. It is possible that two ore more slip lines may appear in the structure - often one activated by a surcharge and the other by a self weight. The conclusion from the above is that only structures with an internal type of failure can preserve mechanical uniformity. There must be one more condition fulfilled however - the mode of reinforcements failure for mechanically uniform structure must be the same.

2.2. Uniform internal failure

As it was stated before, any reinforced soil structure can be mechanically uniform only when its most probable failure mechanism is an internal one. This is not satisfactory condition, however, because in case of an internal failure of structure as a whole there are two possible ways of reinforcements failure - they can be cut by a sliding soil wedge or they can be pulled-out by it. Those two possible situations are presented in Fig.5. It is clear that in the first mode (Fig.5a), the value of friction, anchoring any particular reinforcement within the soil mass behind the failing soil wedge is greater then the tensile force responsible for rupture of reinforcement. There is opposite relation for the second mode (Fig.5b). Both cases showed in Fig.5 represent the uniform mechanisms, when all reinforcements experience rupture or sliding. In reality the most of existing structures and models described in literature usually have upper reinforcements shorter than appropriate anchorage distance and lower reinforcements much longer than this distance. This makes all those structures' failure mechanisms non uniform - the uppermost reinforcements usually experience pull-out, when the rest of them are broken (Sawicki at al, 1987). Such structures, even if they are structurally uniform, can not be described with a help of continuous models with sufficient accuracy. Continuous reinforced soil models however, such like the one presented by Sawicki at al 1989 and Leśniewska 1993 may help to classify structures as uniform or even to construct such structures. With a help of solutions of boundary value problems discussed in both papers it is possible to predict with some accuracy the most probable active slip line for them. With this line it is possible to calculate length of reinforcement

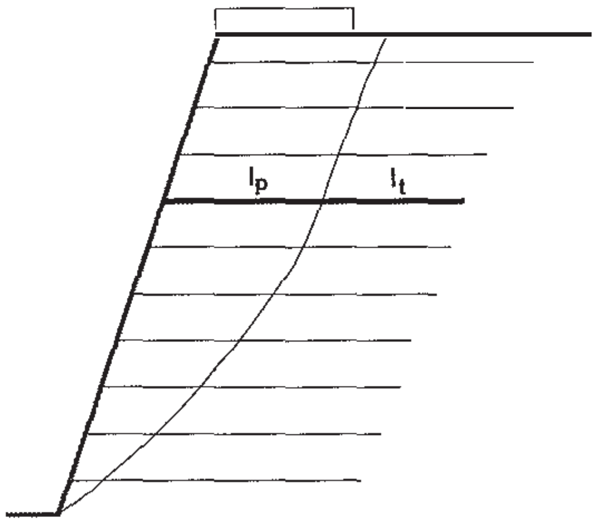


Fig.6. Division of reinforcement's length by the theoretical slip line.

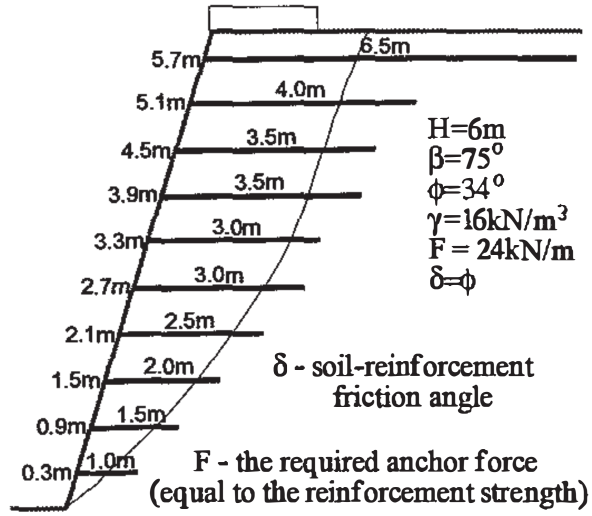


Fig.7. An example of uniform reinforced soil wall

within the soil wedge l_p, Fig.6, and the additional length l_t which is necessary to anchor each of reinforcements with desired value of anchor force.

Fig.7 shows what should be the reinforcement layout to create the mechanically uniform reinforced soil slope, for which the value of anchoring force (the same for each reinforcement) is equal to its rupture strength. The slip line were calculated numerically with a help of program RES (Leśniewska, 1993).

CONCLUSION

More attention should be payed on lack of mechanical uniformity of many reinforced soil structures, which is of great importance for their appropriate theoretical description.

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