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Use of geosynthetics for erosion control as decisive element in retaining construction of steep erosive slopes

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Abstract
Retaining steep rock or loose rock slopes is often a technical task which requires a combination of solid civil engineering with biologic ways of construction as well as erosion control. Especially rock that is easily weathered such as sandstone produces a fine material of small grain sizes which is likely to be eroded from the top of slopes. If erosion of material is not prevented, new stability problems will arise within a few years and planting of vegetation on the slope will become delayed or impossible. Moreover mud could collect on top of the slope, which could overflow drainage installations and adjacent areas/roads. Such situations require a special design of the slope surface further to the construction of retaining elements. Erosion of easily weathered rock leads to a loss of contact between the anchor plates of soil nails and the covering steel mesh. Material transport in the slope can be immediately prevented by using special erosion control blankets made of geosynthetics. Weathered material remains at place and the process of planting vegetation is speeded up. The growing of grass and herbs as well as trees later on is supported. In special cases the blankets together with steel mesh have to be prestressed on the slope.
This paper describes complex practical experience and may not seem very spectacular at first sight. Nevertheless it is very important and helpful to show how easy and cost-efficient rock or loose rock (soil) slopes can be stabilized by using geosynthetics. The topic belongs to the disciplines of bioengineering and is of interest where erosion problems occur and where ecologic design of stable steep rock slopes form challenges for engineers. Dimensioning approaches and technical details for realization are demonstrated with examples. The paper is therefore of interest for clients and consulting engineers as well.

1. INTRODUCTION

Weathering and erosion of soil and rock are processes that always occur. In the best case the timing of both can technically be influenced so that a well-designed and long-term stable construction can be established. The following paper considers aspects in relation to rock slopes but can also be used for considerations regarding soil slopes, too. From a technical, engineering geological and bioengineering point of view it is during retaining and realization of rock slopes with inclinations of more than 45° up to about 80 … 90° in most cases dealing with two separate processes. The process of constructing a rock slope is compared to its life time only a short moment. The rock is in this phase fresh and unweathered. Also the mechanical efforts comply with the solidity of the geological formation (jointing, layering) which are found during rock loosening and slope construction. Further to conventional excavation methods also blasting and milling or other techniques could become necessary. Erosion in this phase is negligible. However decomposition processes of several rock types can often already occur within the construction phase owing to the mineral composition and tectonic stress and are induced by rain, wind or in combination with changing frost-thaw-periods. Weathered material is then eroded from the slope. Similar problems occur with soil slopes, too, if these are steeply inclined and the protecting effect of vegetation is lost. All retaining measures that are built into the rock slope (and steep soil slope) must include a surface facing. When applying soil nails and anchoring techniques, the surface must be suitable of transmitting forces. This paper considers open cut slopes with different kinds of facings and connections between anchors/soil nails. Closed steel or concrete facings are not considered.

Figure 1…3: Claw mats of polypropylene as mazy laid structure and in combination with a grid net

Stability and usability/strength of shape is depending on the grade of erosion of the weathered material from the slope. Therefore erosion protection of the slope surface is firstly a technical task of granting slope stability. Different kinds of synthetic claw mats of extruded polymer fibers have proven especially effective. Application of these mats will be further described in the following. Figures 1 to 3 show the different aspects of a claw mat of extruded polypropylene fibers.

While biologic products of straw, jute, sisal etc. have proven reliable for slopes with an inclination of up to 30 … 40° during one vegetation period, erosion protection of steeper slopes – especially rock slopes – requires constructional support over longer time periods, often more than 3 … 5 vegetation periods. Purely biological products are then not effective anymore. The effectiveness of erosion protection however is technologically required. If open cut methods are applied, the surface must not be eroded as anchor heads, e.g. soil nails, could become uncovered. Force transmitting between rock/soil and the anchoring system of soil nails and steel net is then kinematically disturbed. If soil movements occur at the surface, retention by the linking can only become effective after further soil movement. These processes are schematically shown in Fig. 4…5.

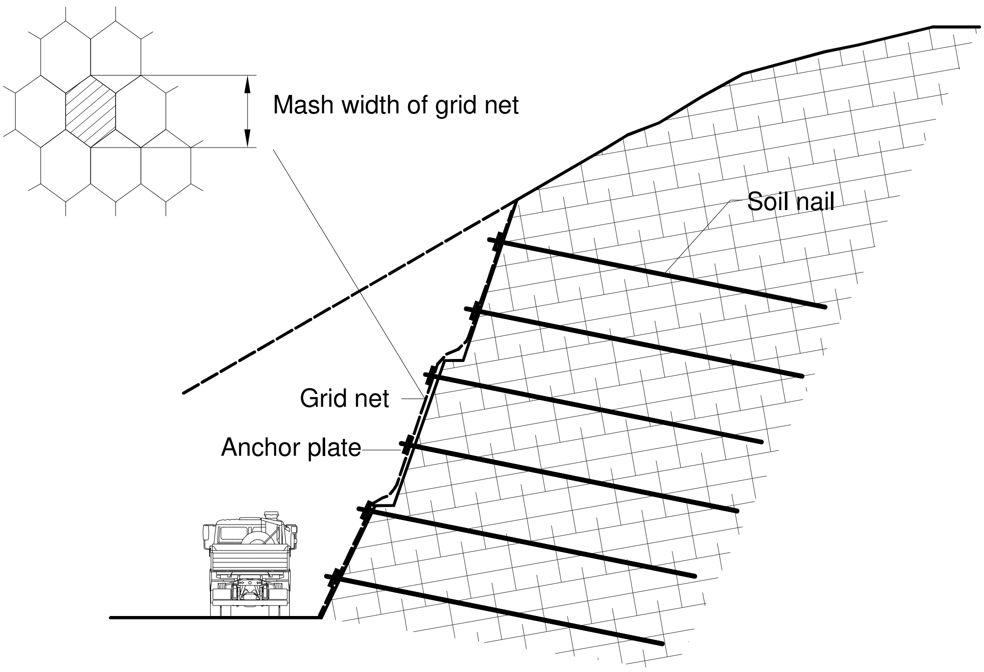

Figure 4: “Fresh” retaining rock slope after retention installations without erosion protection

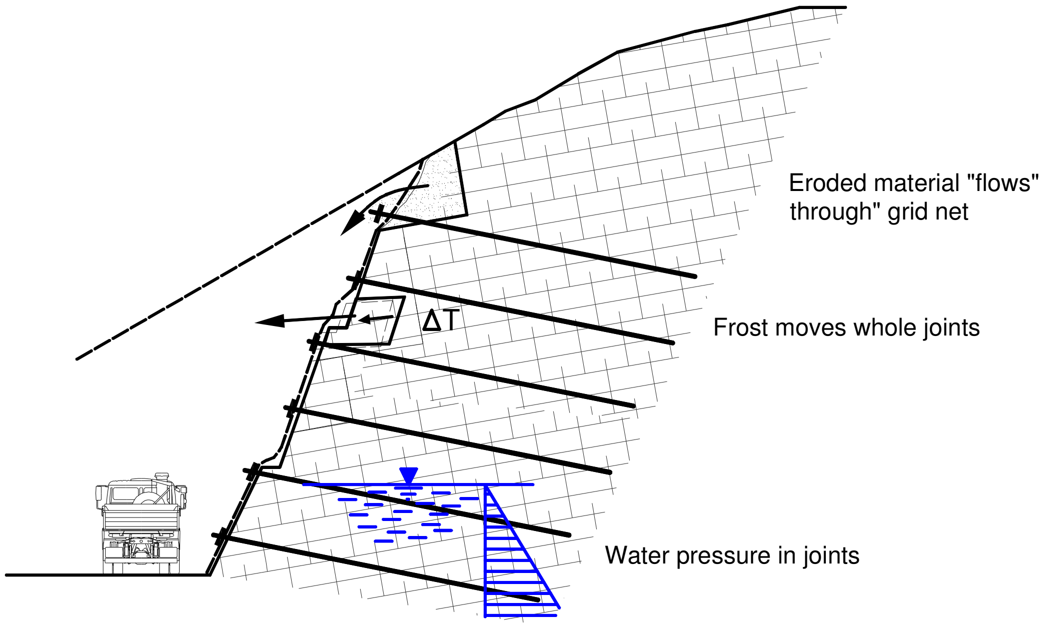

Figure 5: Destruction of retaining slope installations by erosion (Water, Temperature, Wind, Gravity)

Due to the great range of geotechnical variants the technological function of erosion mats are explained using different engineering geological examples.

2. RETAINING MEASURES IN SANDSTONES

Which retaining measure is applied in sandstone depends on the mineral binders being responsible for the stability of the sandstone as well as on the grade and time of the process which erodes single sand grains of the sandstone from the binder. Calcitic binders can cause great solidity; clayey binders lead in most cases to a deep reaching softening of the sandstone after only a few frost-thaw-periods. Slopes of this kind quickly erode to soil. If soil nails are here to be applied in an open cut system, erosion protection measures must be considered during slope design. Otherwise eroded sandstone material will rapidly be removed from the slope leaving the anchor heads uncovered.

Figure 6: two views of a Sandstone-slope before the start of construction

Erosion at slopes of this kind will leave an inclination of 30 … 40°. To avoid this process, the sandstone or the generated loosened material has to remain in place. Figures 6 and 8 to 10 show examples of applications at a sandstone slope.

Already during construction some odd rain showers eroded great sand masses off the slope. The lower part of the construction was designed as a shotcrete retaining wall. The upper part of the sandstone slope was designed with an average inclination of about 50 … 70°. Observations at the slope before the start of construction clearly showed that it was urgently necessary to design an erosion protection above the retaining wall. The slope shown is of sandstone that is mainly solidified by a calcitic binder. With this material the sandstone does not completely decompose but sand is only eroded in thin single layers by wind, temperature changes and water. A typical grain size distribution curve of weathered sandstone material is shown in fig 7.

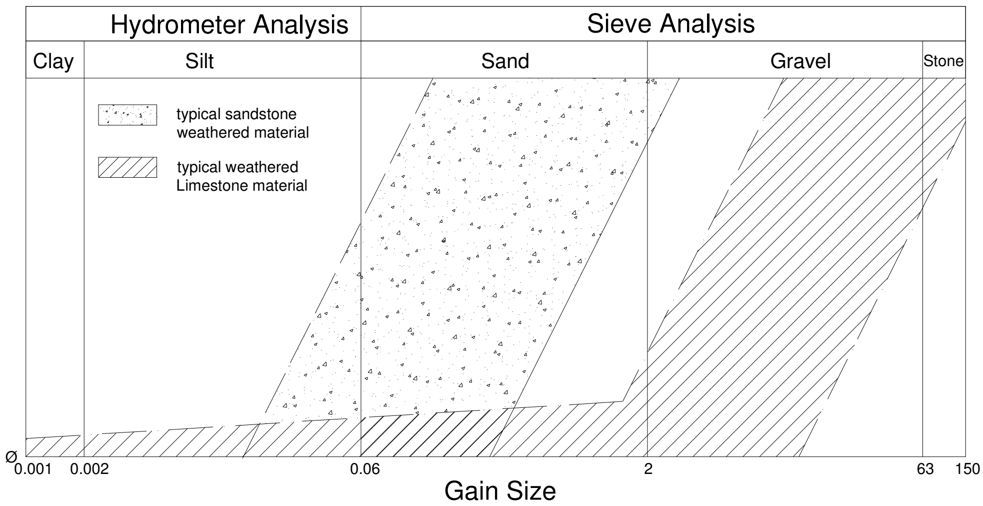

Figure 7: Grain size distribution curve of weathered sandstone and weathered limestone materials

If a claw mat is tightly fixed on the slope surface, sand transport will occur directly at the slope surface. However, the extruded claw fibres shorten the transport of single sand particles from a few cm to maximum some decimeters. The claw mat becomes filled with sand from the slope from the bottom to the top. Weathered material was also partly filled in when it leaks from the slope above the construction site. Planting vegetation was not required.

Figure 8…10: Construction moments and the growing vegetation over a time period of 8 months

The weathered material from the sandstone contains sufficient mineral nutrients so that vegetation started to grow due to natural succession. Figures 8 to 10 show the construction moments and the growing vegetation over a time period of 8 months. After the claw mat had been completely filled with weathered material it provided enough room for rooting of first vegetation.

Erosion was practically stopped after the claw mat had been filled with eroded material. The gutters at the bottom of the rock slope have never shown larger amounts of sand after finalizing the construction works. The soil nails have also never been uncovered, so that the covering net remained tightly at the rock surface during the whole lifetime of the structure.

The same design approach was used for the open rock slope with the system of erosion protection as for soil nails with a shotcrete wall. The design soil pressure on the surface (steel plating) was determined using a model for the open system considering rock jointing. The design included a proof for a punching of the nails through the covering net. Such a design approach is only feasible if the slope remains in a stable form.

3. RETAINING MEASURES IN THE INTERBEDDING OF SANDSTONE-MUDSTONE

Mudstone and sandstone with clayey binders belong to the changeable solid rocks and are also referred to as *soft* rock. The following example deals with the erection of a retaining wall which was constructed as a combination of soil nails with shotcrete and natural stones and an open system with soil nails on the upper rock slope. Mudstone and sandstone are interlayered with gypsum that is mostly subroded. Single gypsum beds were still present. Several fossile depression structures were already filled with eroded materials of mudstone and sandstone in form of clayey and silty sand. Within the depth which was being affected by the structure the interbedding strata of mudstone and sandstone possessed very low compressive strengths of 0.5 … 10 MN/m². It was known that the material will quickly loosen after being uncovered and becomes mobile during weathering and erosion. In contrast to the harder sandstone there is no slow removal of thin particle layers which are only slowly removed from the minerally bound rock complex. However within shortest time – during frost even after few frost-thaw-periods – a deep reaching softening of the rock appears with a complex transitions to soil. If intense rain fall occurs the material can literally fluidize in single layers of 30 … >50cm thickness. Figure 11 shows several stages for the weathering of mudstone.

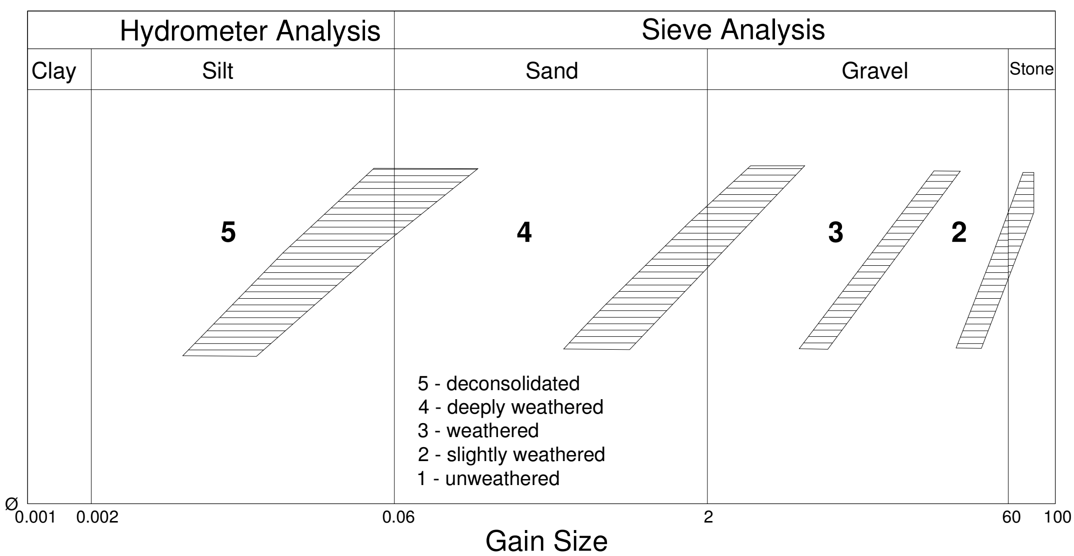

Figure 11: Several stages for the weathering of mudstone (Wallrauch 1969)

Soil nails in an open system and without erosion protection are as well absolutely not feasible here because common wire grid nets that must be applied for force transmitting between soil nails and surface have mesh sizes of 6 … 10 cm and the loosened mobile soil could be transported through the grid. Consequently a rapid transformation of the slope surface would occur, the anchor heads would be uncovered, the wire grid net would lie loose and unprotected on the surface, local slides within the slope surface could move unhindered below the net. Again, the same process is shown here. The erosion protection mat slowly fills from the bottom to the top. In the special case of fig. 13 the gridstructure is filled with crushed straw from the hydroseed.

Figure 12…14: construction moments in a slope of mudstone; in figure 12..13 the surface starts to cover with the erosion protection mat

Figure 15: The slope under construction / placing the erosion protection mat

4. MISSING RETAINING MEASURES IN MARINE LIMESTONE – A BAD EXAMPLE

As contrast example a rock retaining at Muschelkalk (shell limestone) rock should be described here which was discovered by the author close to his office and which shows clearly how a wall behaves

without any erosion protection measures. Fig 16 shows the overall retaining measure. Over the total height a formation of Muschelkalk – the so-called Wellenkalk – was secured.
Fig 16 to 18 were taken less than 6 months after completion of the construction works. After only one autumn and winter material transports within the slope and through the wire grid occurred. With a slope height of about 5 … 8 m material masses of about 50 … 100 kg per m became mobile within the slope.

Figure 16…18. A bad example: Details of slope retaining in Muschelkalk WITHOUT erosion protection 6 months after completion

The Limestone (Wellenkalk) is characterized through its high tectonic stress and through the fact that it quickly weathers into cubic pieces of a few cm due to its bedding and jointing. The fine joints are usually covered by very thin clay layers that gather a lot of water and start soaking very quickly. Due to this circumstance the Wellenkalk rapidly weathers into a clayey-gravelly matrix. A typical grain bound of weathered Muschelkalk material is shown in Fig. 7. The construction site picture 17 shows how single gravel grains can fall through the mesh unhindered.
Fig.18 shows the process how the anchor head becomes uncovered despite the forces in the stressed grid net at the anchor head plate. Parts of several cm to dm size are loosened from the rocks and transported through gravity. On comparing these pictures with the figures above it becomes obvious that an erosion protection design in the slope could have prevented material transport and geometric slope changes thoroughly. Efforts (and costs) for slope maintenance would also have decreased significantly.

5. EROSION PROTECTION IN THE SALT – AN EXTREME APPLICATION

As last example a slope retaining during a highway project in Germany is shown. The more than 20 m high highway slope had to be constructed within the tailings pile of a potash mine.

Figure 19…20: Erosion protection on a potash tailings pile (during construction)

Fig. 19 shows that the solidity of the pile was so great that the slope could only be cut by heavy roadwork milling devices (see stairs in the Figure). Although the salt in its minerally bound form is mainly crystalline it can easily be removed by rainwater and generates partly very deep erosion channels on the slope surface. Erosion protection with claw mats was constructed on a larger slope surface, which could later on not be overbuilt anymore. In this special case the claw mats are filled with crushed grains of size 1 to 3 mm in a second step; Fig. 21.

Figure 20…21: Claw mat placed on the slope (unfilled) and a filled with crushed grains of size 1 to 3 mm

Further grain sizes within narrow limitations of up to maximum 2 to 4 mm are also appropriate. The function of the grit is to prevent the rainwater from flowing concentrated in single channels and as such create erosion channels but to drain laminar. Moreover the surface of the grit filling provides a preferred opportunity of storing seeds from the air or of hydroseeding. Deformation of the salt slope could be extremely slowed down and homogenized. The poor conditions for planting vegetation on such slopes were remarkably improved.

6. CONTRUCTIONAL CONSEQUENCES

Soil and rock mechanical changes of the geological body must be considered during construction and design of rock slopes in changeable solid rock.

Rock that is solid during loosening and which can only be treated with heavy devices may transform to soil slowly and layer-wise or quickly and deep-reaching depending on their mineralogical composition after removing the geological load and on immediate erosion impacts (water, frost, wind, gravity …). Erosion products are in clay-silt-fractions up to sand and gravel. If open systems of slope protection are constructed with grid nets, erosion products may flow out of the slope, alter the geometric slope form and as such change the structural system, compare fig. 5. In most such cases the design conditions for rock slopes are not appropriate. Due to erosion processes slopes of this kind must be treated as soil slopes. For proving the outer and inner slope stability the whole geometric body is modeled as soil. Failure mechanisms that result in soil pressure on the surface must be investigated. A typical design tool is presented in Fig. 22. Nevertheless this design tool can only be used if the geometric stability of the slope may be assumed. Furthermore it must be granted from a structural point of view that soil pressure is actually acting on the surface and is not reduced by erosion.

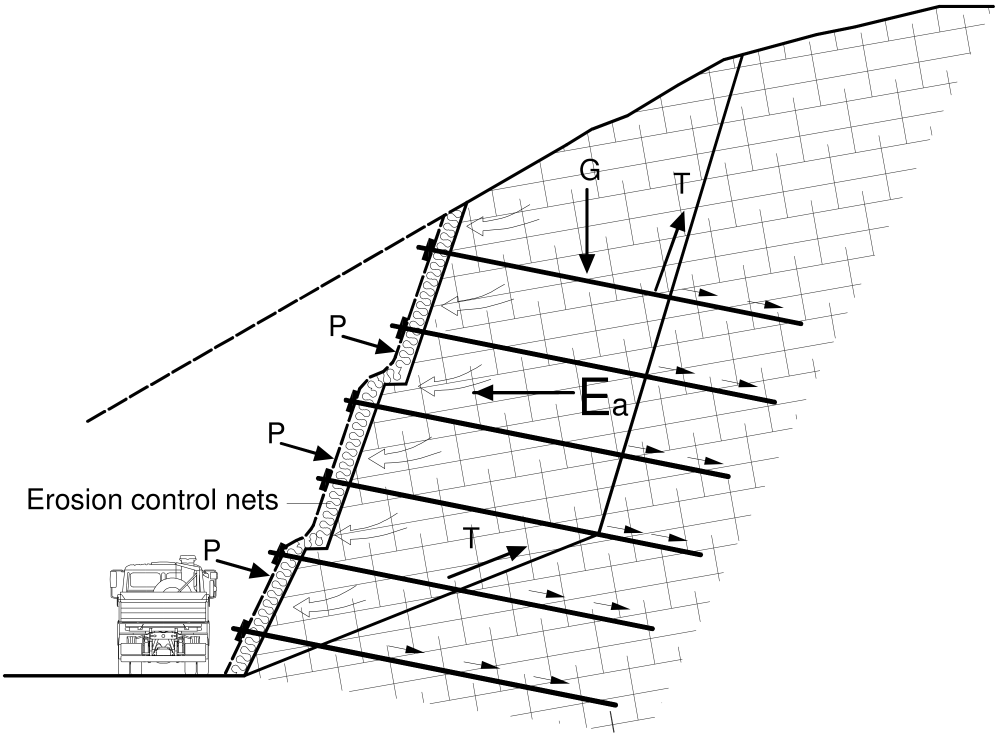

Figure 22: Design considerations for slope restraint with erosion protection

Furthermore these slopes suffer from shrinking after long dry periods. This can result in shrink cuts within the slope surface. Monitoring of slopes indicate that rain water which flows into the cuts after rainfall, causes hydrostatic pressures within the slope. In this case the design has to include an extreme load case, where single local parts of the slope can fail.

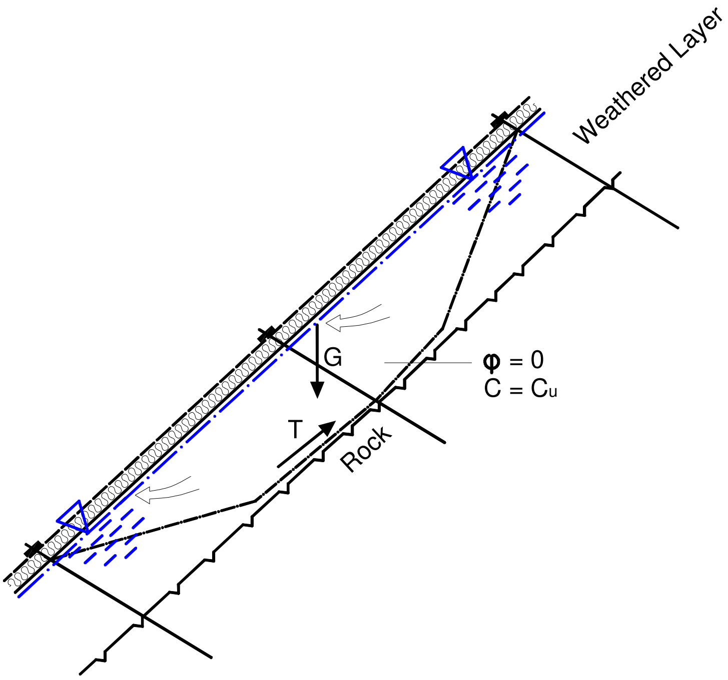

Figure 23 Hydraulic slope failure

Material loosened by erosion can become very soft and tends to flow out of the slope. We call this process “hydraulic slope failure” . Hydraulic slope failures only occur locally, where the material was loosened the most, and always in connection with water moving in the slope surface (e.g. after intense rainfalls). To avoid these processes a sufficiently stable erosion protection element must be present below the wire grid net as otherwise an areal bearing of the soil pressure by soil nails, anchor plates and wire grid net may not be assumed. The design scheme for the load case of a local hydraulic slope is shown in Fig. 23 This simple scheme can be used for determining the pressure on the grid net as a special load case which results from the effects of the outflowing masses. The soil is modeled under buoyancy and with undrained shear strength.

7. SUMMARY AND PERSPECTIVE

The very cost effective extruded erosion polymer protection mats are a significant design element of structures for challenging slope protection. On one hand they almost completely prevent erosion processes in the slope. The regressive erosion of material in the slope is as such stopped. The overall structure of the slope protection with soil nails and steel wire grids remains geometrically stable and can therefore be designed as a structure. Design assumptions such as soil pressure load or hydraulic slope failure can be applied with retaining structures of this kind, only in combination with long-term effective erosion protection elements as part of the overall structure. An especial importance lies with erosion protection mats for pre-stressed slope anchors about which will be reported in future papers.

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