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Dumping of rock on geotextiles

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ABSTRACT : A geotextile within a hydraulic structure should not only meet hydraulic filter criteria but should also meet specific mechanical criteria, amongst other things with respect to the dumping of rock. Large scale dumping tests have been performed to understand the most important parameters in the failure mechanism of the geotextile. In this paper the most important results of a study concerning the dumping of rock on geotextiles including some calculation models will be given. However, more research is needed.

1. INTRODUCTION

Geotextiles, covered with rock or gravel, are often applied in dike, bank or bed protection structures to prevent the erosion of the subsoil. Examples of these hydraulic structures are given in figure 1. During placement of the rock geotextiles are subjected to high impact stresses. Therefore a geotextile should be strong enough to withstand the mechanical impact due to the dumping of rock on it. The geotextile fabric should be able to absorb this mechanical impact without deformation or damage to such an extent that its function will be lost. However, in the daily practice a, lot of damage cases have been reported which are the result of unadequate placement of rock on geotextiles.

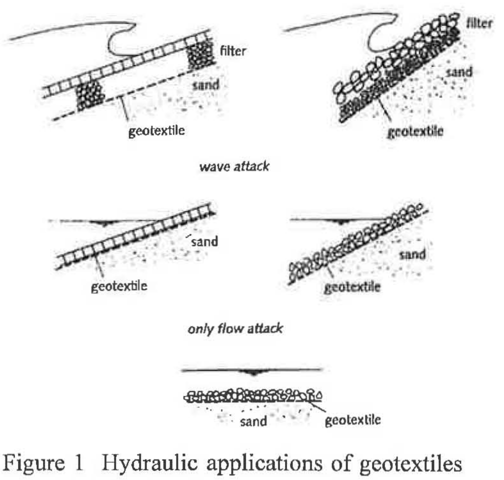

Figure 1 Hydraulic applications of geotextiles

There is a lack of adequate standards and directives concerning the dumping of rock on geotextiles, as well as adequate criteria for the determination of the appropiate dump height. In the scope of the CUR committee C80, a study with respect to the dumping of rock on geotextiles has been carried out by the Road and Hydraulic Engineering Division of Rijkswaterstaat (Berendsen, 1994). In this study the results of large scale tests, executed by Rijkswaterstaat, have been evaluated and compared to other available results and criteria. Also the dumping of rock into water has been considered. Beside that, a calculation model concerning the dumping of rock on geotextiles, has been worked out. The most important results of this study will be given in the following paragraphs.

2. GENERAL

Rock or gravel can be dumped on the geotextile stone by stone or in bulk. In this process the drop energy developed by the stones (kinetic energy) is converted into deformation energy of the geotextile (plastic elongation) and the subsoil, which finally can lead to the failure of the geotextile fibres.

The following mechanisms of geotextile failure can be distinguished due to dumping of rock on it:

- the tensile strength of the geotextile, at the impact area of the stone, is exceeded. The yield value of the geotextile fibres is reached or exceeded at places (puncture mechanism).
- the tensile strength of the geotextile between different stones is exceeded which leads to tear of the geotextile fabric (tear mechanism).

In the study carried out by the Road and Hydraulic Engineering Division of Rijkswaterstaat, the influence of the following factors on the damage of the geotextile fabric has been investigated:

- the drop height of the stones;
- the weight and shape of the stones;
- the type and strenght of the geotextile;
- bulk or not in bulk dumping of the stones;
- the extent of compression of the subsoil;
- the extent of saturation of the subsoil.

Increase of the drop height, as well as weight increase of the stone, results in more damage to the geotextile. The two parameters can be combined into a new parameter, the drop energy. It appears from experiments in practice that a single falling stone causes less damage than a larger quantity of stones released in one operation (bulk dumping).

It appears also that non-woven fabrics in general show more damage than wovens. Wovens are able to absorb forces into two directions and are therefore consequently stronger than non-wovens. Sharp edged stones cause more damage to the geotextile fabric than blunt stones. The influence of the extent of saturation and compression of the sandy subsoil was in our case found to be negligible.

In relation to the other factors, the influence of the shape of the stone, the type of geotextile and the extent of compression and saturation of the subsoil otherwise are small and to such an extent that these, in practice, may be neglected.

3. DESIGN CRITERIA

On the basis of the study carried out by Rijkswaterstaat it appeared that up to now only two practical criteria, concerning the dumping of rock on geotextiles, are available.

Lawson (1992) investigated 45 existing revetments in which rock in bulk is used on geotextiles, woven as well non-woven fabrics. In the relation deducted by him the in-situ impact resistance of a geotextile depends on its mass per unit area.

$$m_g \geq c_s D_{85} \sqrt{H} \qquad (1)$$

where m_g = the mass per unit area of the geotextile fabric (gr/m^2); c_s = a damage factor, depending on the percentage damaged surface area to be accepted (gr/m$^{3.5}$); H = the drop height of the bulk dumped rock (m) and D_{85} = the characteristic diameter of the rock grading, corresponding to 85 % by weight of the finer rocks (m).

The damage factor c_s depends on the percentage damaged surface area to be accepted in the hydraulic structure. If no construction damage is accepted at all (0 % damaged surface area) for c_s a value of 1200 should be taken into account. For a damaged surface area of about 10 % a c_s value of 750 is recommended. The damaged surface area hereby is related to the number of stones which cause damage and is defined as the geotextile surface area covered by these stones. Only the stones which are in direct contact with the geotextile are to be considered here.

The definition "damage" is generally defined as damages which have the result that the geotextile cannot fulfil its functions adequately anymore. Lawson's starting point, however, is damage to the geotextile fibres. In that case probably the tensile strength and the filter function of the geotextile are substantially reduced.

On the bases of the drop ram test of the Bundesanstalt für Wasserbau (BAW) in figure 2 a design relation is presented in which the critical drop

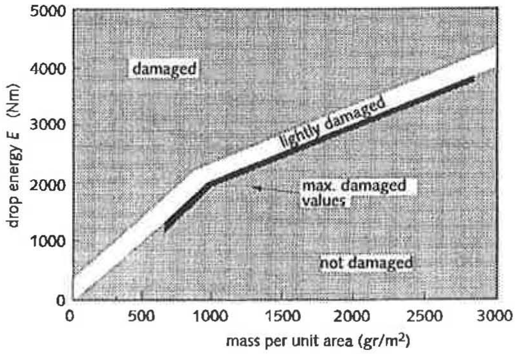

Figure 2 Critical drop energy as a function of m_g

energy of a single stone in bulk dumped rock is a function of the mass per unit area (Hall, 1993).

$$E_{cr} = 2m_g \qquad 0 \leq m_g \leq 1000 \qquad (2)$$

$$E_{cr} = m_g + 1000 \qquad 1000 \leq m_g \leq 2500 \qquad (3)$$

where m_g = the mass per unit area of the geotextile fabric (gr/m^2) and E_{cr} = the critical drop energy of a single stone in bulk dumped rock (kgm^2/s).

The critical drop energy E_{cr} is the energy which just not causes damage to the geotextile. Starting point with respect to damage is again damage of the geotextile fibres. The drop energy of a single stone is hereby defined to be the product of the weight of the stone M, the acceleration of gravity g en the drop height H of the stone (E = MgH).

The geotextile damage due to the dumping of rock in bulk is mainly determined by the largest stones in the rock grading. The largest stones in the rock grading are here characterized by the M_{85} or D_{85}.

In figure 3 the critical drop height as function of the mass per unit area of the geotextile is given for the rock gradings 10/60 kg, 30/130 kg and 60/300 kg respectively. Concerning Lawson, it was started from equation (1) and 0 % damaged surface area (c_s = 1200). Concerning BAW, it was started from equation (2). Beside that, a number of results of dumping tests, carried out by Rijkswaterstaat and Antoine (1990), is added. The characteristic diameter D_{85} of the rock grading, on the basis of the mass distribution, hereby was determined by the rule of thumb $M_{85} = \rho_s(D_{n,85})^3 = 0.60\rho_s(D_{85})^3$. For the above mentioned rock gradings and a rock density ρ_s of 2600 kg/m^3, these amount to 0.34 m, 0.44 m and 0.58 m respectively.

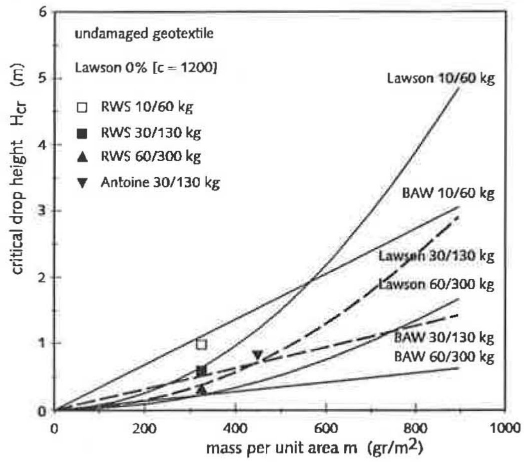

Figure 3 Critical drop height bulk dumped rock

For small values of the mass per unit area it appears that the Lawson relation results systematically in lower critical drop heights than those calculated on the BAW relation. For large values of the mass per unit area this effect is exactly opposite. The transitional area is, depending on the applied rock grading, between 300 and 600 gr/m^2.

In practice, Lawson seems to be a safe lower limit with respect to the design of geotextiles with a low mass per unit area while BAW must be considered to be an absolute upper limit in this case. On the contrary, for geotextiles having a high mass per unit area, BAW seems a safe lower limit with respect to the design, while Lawson should be considered to be an upper limit.

In the foregoing it has been clarified that damage to geotextiles can be originated by dumping coarse rock on it. Consequently, this does not mean that the whole construction, from which the geotextile forms part, will fail. Failing of the construction is also depending on the forces which come into existence and on the residual strenght. As long as the riprap protection will not be removed most stones seal the damages they have caused.

4. DUMPING INTO WATER

Beside the dry dumping of rock, frequently the dumping is carried out in water. The velocity of the stones in water will, due to frictional losses, in comparable situations, be smaller than the velocity developed in air. Consequently, the critical drop height in water will be greater than this height in air. The energy, as well as the velocity, at the moment of the impact in the geotextile, should not exceed the critical energy as well as the critical velocity, both in the dry and in the wet situation.

The velocity U_z of an individual stone, falling over a distance z in the dry situation, is described by:

$$U_z = \sqrt{2gz} \qquad (4)$$

where U_z = the velocity of the stone at a distance z (m/s); g = acceleration of gravity (m/s²); z = the drop distance of the stone (m)

The velocity of an individual stone, released from a height H_0 above the water and hitting the water surface with a velocity U_0 ($\surd\,2gH_0$) is described for $z > H_0$ by (see also example given in figure 4):

$$U_z = \sqrt{U_e^2 + (U_0^2 - U_e^2)e^{-2c_1(z - H_0)}} \quad \textbf{(5)}$$

$$U_e = \sqrt{\frac{c_2}{c_1}} = \sqrt{\frac{5}{3}\frac{\rho_s - \rho_w}{\rho_w}\frac{gD_x}{C_d}} \quad \textbf{(6)}$$

$$c_1 = \frac{3}{5}\frac{\rho_w}{\rho_s}\frac{C_d}{D_x} \quad \textbf{(7)}$$

$$c_2 = [\frac{\rho_s - \rho_w}{\rho_s}]g \quad \textbf{(8)}$$

where U_e = the equilibrium velocity of the stone in the water (m/s); U_0 = the velocity of the stone when hitting the water (m/s); H_0 = the drop height of the stone above the water (m), ρ_s = the density of rock (kg/m³); ρ_w = the density of water (kg/m³); C_d = the drag coefficient of the stone (-) and D_x = the characteristic diameter of the grading, corresponding to x % by weight of the finer rocks (m).

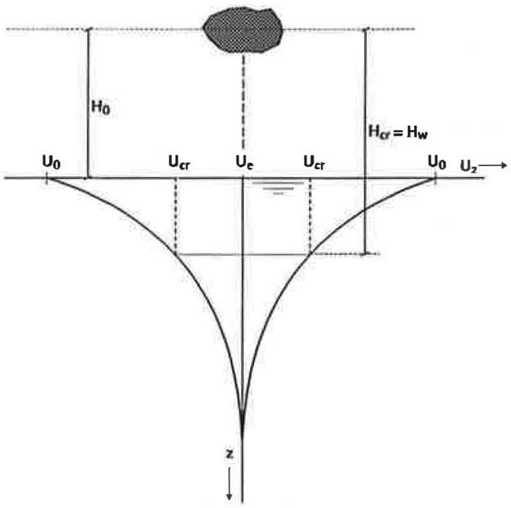

Figure 4 Drop velocity U_z of a stone in water

In figure 4 an example of the velocity U_z as a function of the drop distance z of a stone falling in water is given.

The above mentioned formulaes are developed for stones having a shape factor of about 0.60. This generally means that $M_x = \rho_s(D_{n,x})^3 = 0.60\rho_s(D_x)^3$.

On the basis of the velocity development of a stone falling in water, hitting the water surface with a velocity U_0, it can be concluded that the stone, if the water is sufficiently deep, finally always reaches its equilibrium velocity U_e. The impact velocity U_z of the stone should not exceed the critical drop velocity U_{cr}, both in the dry and the wet situation. The critical drop velocity U_{cr} can be found from the criteria of Lawson and BAW.

Substitution of the critical drop velocity U_{cr} in formula (5) leads to an expression for the critical drop height of the stone in the wet situation. The critical drop height H_w of a stone, released at a height H_0 above the water surface and having a critical drop velocity U_{cr}, will in the wet situation described by:

$$H_w = H_0 - \frac{1}{2c_1}\ln[\frac{U_{cr}^2 - U_e^2}{U_0^2 - U_e^2}] \quad \textbf{(9)}$$

where H_w = the critical drop height in wet condition, U_{cr} = the maximum permisseble drop velocity

The following situations can be devided now:

1. $U_0 \leq U_e$ and $U_{cr} < U_0$: not any wet drop height satisfies; the velocity U_z of the stone in the water is from the moment of hitting the water already larger than the critical velocity U_{cr}

2. $U_0 \leq U_e$ and $U_0 \leq U_{cr} < U_e$: only drop heights smaller than the critical drop height H_w statisfie; for drop heights larger than the critical drop height the critical velocity U_{cr} is exceeded

3. $U_0 \leq U_e$ and $U_{cr} \geq U_e$: every wet drop height satisfies; the velocity U_z of the stone in water is always smaller than the critical velocity U_{cr}; the equilibrium velocity U_e is never exceeded

4. $U_0 \geq U_e$ and $U_{cr} < U_e$: not any wet drop height satisfies; the velocity U_z of the stone in water is always larger than the critical velocity U_{cr}; the equilibrium velocity U_e is always exceeded

5. $U_0 \geq U_e$ and $U_e \leq U_{cr} < U_0$: only drop heights larger than the critical drop height H_w statisfie; for drop heights smaller than the critical drop height the critical velocity U_{cr} is exceeded

6. $U_0 \geq U_e$ and $U_{cr} \geq U_0$: every wet drop height satisfies; the velocity U_z of the stone in the water is from the moment of hitting the water already smaller than the critical velocity U_{cr}

5. CALCULATION MODEL

In this paragraph a model is given for the calculation of the maximum permitted drop height of the rock gradings 5/40 kg, 10/60 kg and 40/200 kg for a geotextile having a mass per unit area of 400 g/m^2. This is done for both the dry and wet situation. In case of the wet situation two heights of discharge H_0, respectively 0 and 1.0 m above the water level, have been employed. The density ρ_s of the rock amounts to 2600 kg/m^3. The characteristic diameter D_{85} of the above mentioned rock grading amounts respectively to 0.29 m, 0.34 m and 0.50 m. For the drag coefficient C_d a value of 1.0 is used. All calculations have been carried out according to the Lawson relation, which, in this case, may be seen as an absolute lower limit (c_s = 1200).

For the gradings 5/40 kg, 10/60 kg and 40/200 kg maximum permissible drop heights of 1.32 m, 0.96 m and 0.44 m respectively are found in case of the dry situation. The critical velocities U_{cr} ($\surd 2gH_{cr}$) belonging to these drop heights are 5.1 m/s, 4.3 m/s and 3.0 m/s respectively. These maximum permittable velocities are also relevant for the geotextile in case of dumping rock into water. The calculation results concerning the wet situation for drop heigts (H_0) of 0 and 1.0 m above the water surface are given in the following tables (1 and 2).

Table 1 Results critical wet drop height, H_0 = 0 m

H_0 = 0 m	Critical "wet" drop height and velocity		
Grading	5/40 kg	10/60 kg	40/200 kg
U_0 (m/s)	0	0	0
U_e (m/s)	2.8	3.0	3.6
U_{cr} (m/s)	5.1	4.3	3.0
H_w (m)	≥ 0 [1]	≥ 0 [1]	≤ 1.3 [2]

Table 2 Results critical wet drop height, H_0 = 1 m

H_0 = 1 m	Critical "wet" drop height and velocity		
Grading	5/40 kg	10/60 kg	40/200 kg
U_0 (m/s)	4.4	4.4	4.4
U_e (m/s)	2.8	3.0	3.6
U_{cr} (m/s)	5.1	4.3	3.0
H_w (m)	≥ 0 [1]	≥ 1.1 [3]	n.v. [4]

[1] any wet drop height satisfies in this situation; the velocity of the stone in water is always smaller than the maximum permisseble velocity U_{cr}.

[2] the wet drop height should not be larger than the calculated value because otherwise the maximum permissible drop velocity U_{cr} will be exceeded.

[3] the wet drop height should not be smaller than the calculated value because otherwise the maximum permissible velocity U_{cr} will be exceeded.

[4] not any wet drop height satisfies in this situation; the velocity of the stone in water always exceeds the maximum permisseble drop velocity U_{cr}.

6. CONCLUSIONS

With reference to the study carried out by Rijkswaterstaat concerning the dumping of rock on geotextiles it can be concluded that both criteria (according to Lawson and BAW) in the daily design practice are most useful for the determination of the critical drop height of in bulk dumped rock on geotextiles. The criterion of Lawson is a safe lower limit for geotextiles having a low mass per unit area, while the criterion of BAW should be considered to be an upper limit. For geotextiles having a high mass per unit area this is just the other way round. The transition between the two criteria depends on the used rock grading and lies between about 300 and 600 gr/m^2. The test results found by Rijkswaterstaat agree with the results found by Lawson and BAW. In practice, the critical drop height of rock in water appears to determine very well. Due to the differences between the criteria of Lawson and BAW, however, more detailed research in determining the exact criteria is needed in the near future.

7. REFERENCES

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