BRIEF NOTES ON DESIGNING PROTECTION SYSTEMS AGAINST ROCKS FALLING DOWN SLOPES

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1 INTRODUCTION

In many cliff-line situations it is not feasible to carry out comprehensive stabilisation of all slabs and blocks of rock that may slide or topple from the face. It is often necessary to design protection systems for whatever structure happens to be in the path of possible falling boulders. In order to do so it is necessary to estimate the energy of the boulders that may fall down the slope and then to design a suitable structure that may either absorb or redirect this energy. This note sets out a procedure for carrying out this design process. However, it must be emphasised that the approach set out contains much subjective judgement on the part of the author although wherever possible the procedures have been checked against actual experience and recorded data (scarce though this is).

2 SOME NEWTONIAN PHYSICS

Because the reader may have forgotten his or her school physics the following equations for falling and rolling are given -

Velocity after t seconds $v = at$
Displacement during first t seconds $s = at^2$

Velocity in terms of distance $v = \sqrt{2as}$
Angular velocity at radius r with tangential velocity v $\omega = v/r$
Potential energy $= mgh$
Kinetic energy $= mv^2/2$
Rotational kinetic energy $= \omega^2 I/2$
(where ω = angular velocity and I is the rotational inertia).

The frictional resistance is proportional to the mass of the sliding block. Thus energy loss is proportional to slope height. Thus the percentage energy loss is independent of height.

Also since frictional loss is proportional to weight and the work done is proportional to weight the percentage energy loss is independent of weight.

3 ESTIMATION OF IMPACT ENERGY

From the design fall height (see Figure 1) the free fall kinetic energies of different design boulder masses are estimated. There are then two cases that need to be considered - namely steep cliffs (slope angle $> 60^{\circ}$) and conventional slopes (slope angle $< 60^{\circ}$).

For steep slopes up to 80m or so in height, Ritchie (1963) provides evidence that a large falling boulder will strike the face only once. Thus in order to determine the energy conditions when the boulder reaches the base of the cliff one adopts the following procedure -

(i) Assume that the boulder will strike a 45° ledge after falling some chosen distance (this may be an arbitrary 5 metres or may be judged from the particular cliff geometry).
(ii) Calculate the theoretical trajectory.
(iii) Determine the impact angle at the base of the slope.
(iv) Apply the energy correction from Figure 2 to determine the impact vertical and horizontal velocities at the base of the cliff.

For flat slopes the assumption is made that there will be multiple bounces with rolling and sliding down the slope face. Thus at the base of the slope the direction of travel will be parallel to the slope and the horizontal and vertical velocities can be determined using the energy corrections in Figure 2.

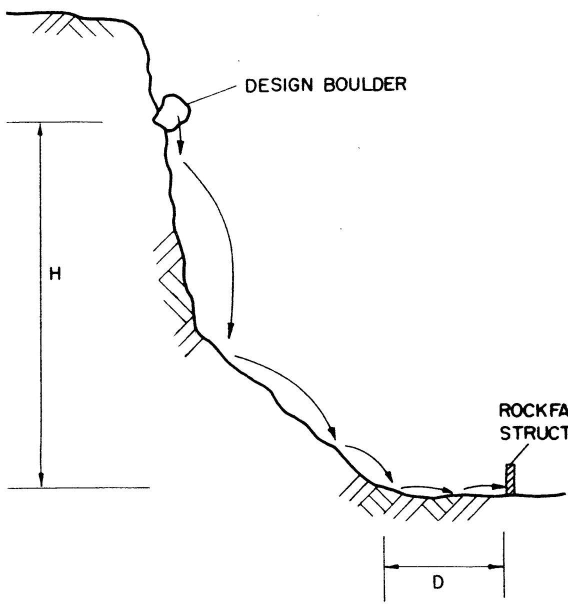

Fig 1: Rockfall Protection Design Idealised Problem

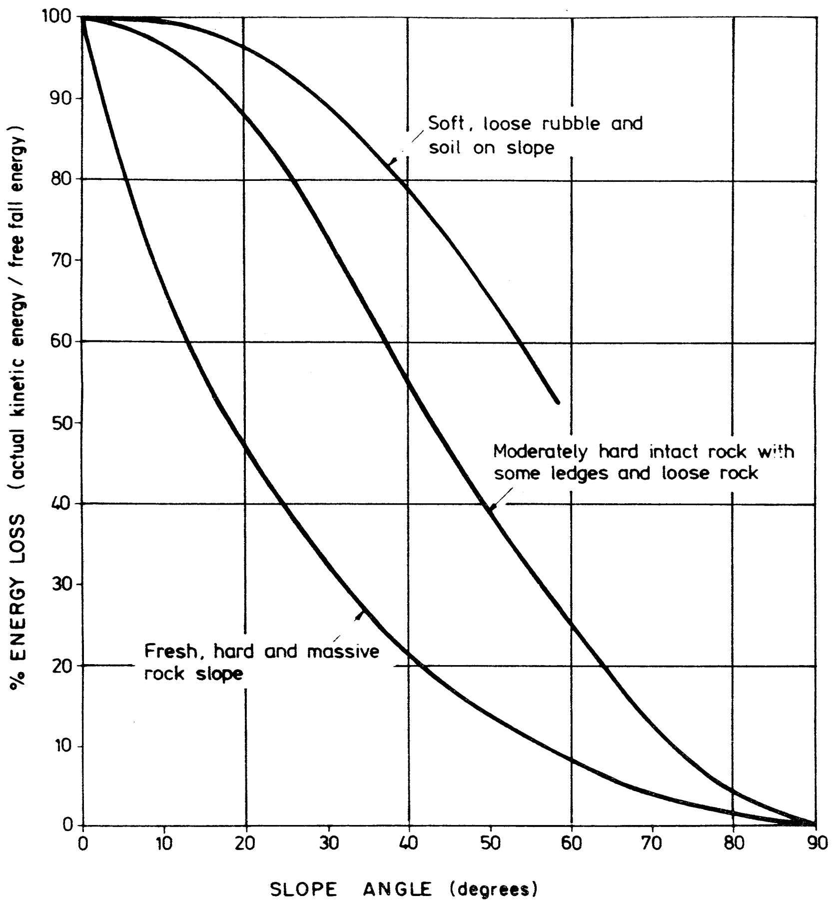

Fig 2: Rockfall Protection Design - Energy Loss on Slope

In the case of a boulder falling freely and then hitting a near horizontal surface at the foot of the cliff, Figure 3 gives an idea of the percentage of vertical momentum that will be destroyed on impact. The remaining vertical momentum will be translated into horizontal velocity and rotational energy. For ease of computation only horizontal velocity is considered - zero rotation is assumed. Hence one can compute horizontal kinetic energies at the base of the cliff for the different design boulder sizes.

Assuming the foot of the cliff to be reasonably close to horizontal, Figure 4 allows estimation of the horizontal stopping distance as a function of the initial horizontal kinetic energy. If the energy absorbing structure is located within this stopping distance the impact energy can be determined by direct proportion.

In the case of a uniform slope where the rockfall protection structure is placed on the slope one has only to consider the reduced energy, obtained using Figure 2, in order to determine the impact energy.

4 THE ENERGY ABSORBING STRUCTURE

At the outset it should be noted that the maximum energy that can be absorbed with a practical rockfall protection fence is of the order of 1000 KNm. This is equivalent to a 100 tonne boulder moving at about 4.5 m/sec. This is not very fast considering that it represents the free fall velocity from a height of 1 metre ! The point is that very large boulders cannot be easily stopped and in general it is much better to deflect these boulders rather than trying to stop them.

Secondly, it should be noted that earth and rock structures such as embankments and boulder mounds are far more efficient energy absorbers than steel or concrete beams and columns or steel cables. However, in certain cases a heavy, specially designed fence may provide a satisfactory solution and the design approach is set out in the next section.

5 DESIGN OF A ROCKFALL FENCE

The main energy absorption capacity in a fence lies in the plastic distortion of the fence posts. In the case of cantilever posts this energy absorption per post is given by -

$$E = M_p \theta$$

where

θ = angle through which post is rotated

M_p = plastic moment of resistance

Because a free standing universal section or rail section will tend to twist and collapse out of the plane in which the impact force is applied a reduction must be applied to the above energy absorption unless such twisting is prevented.

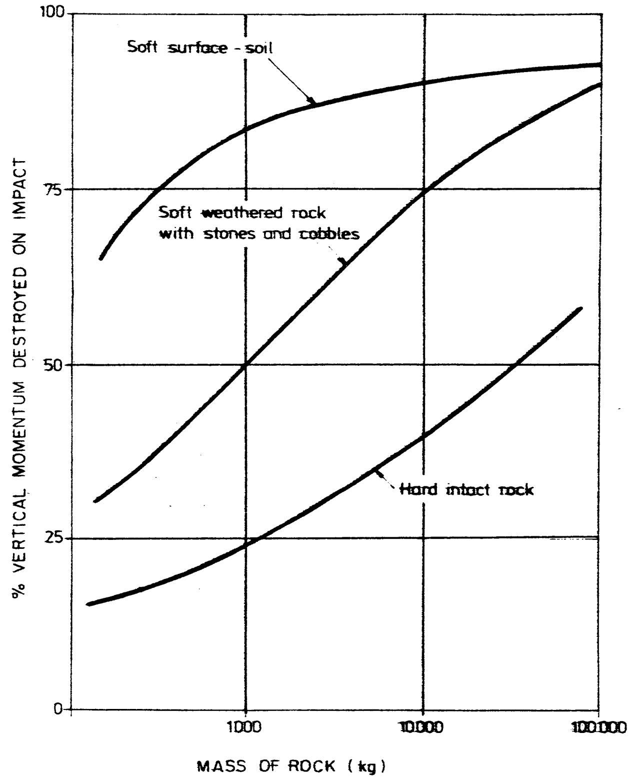

Fig 3: Rockfall Protection Design - Destruction of Vertical Momentum on Impact

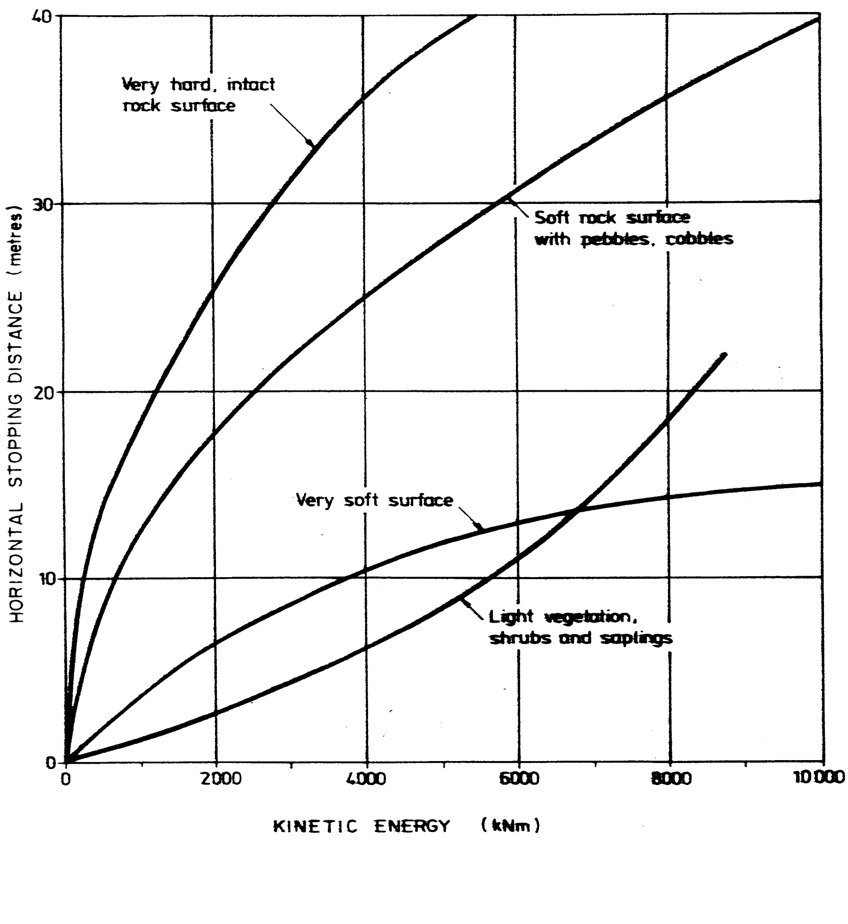

Fig 4: Rockfall Protection Design - Attentuation Along Horizontal Surface at Foot of Cliff

Assuming a single 150 UC 37 post is knocked through 70° we have the maximum energy absorbed as:-

$$E = 79.5 \times 70/180 \times \pi$$
$$= 97 \text{ kNm}$$

Thus to absorb an impact energy of 1000 kNm it would be necessary to collapse 10 posts.

For a 43 kg tram rail section

$$E = 31.8 \times 70/180 \times \pi$$
$$= 39 \text{ kNm}$$

Thus would require 26 posts to fail.

An alternative is to make use of a propped cantilever as illustrated in Figure 5.

On the basis of calculations conducted at Sydney University for 150 UC 37 sections it is estimated that for the force applied at position 1 (Figure 5) the energy absorption would be about 200 kNm and in position 2 would be about 180 kNm. Thus one would require between five and six of these propped posts to collapse. Because of the difficulty in constructing these propped posts and the fact that they have to be linked by much heavier cables than the cantilevers it is proposed that simple cantilevers be adopted wherever possible.

5.1 Design of Cables

The cables that connect the posts must be strong enough to ensure that the posts are pulled over when a large boulder strikes the fence between the posts. The cables can be analysed using the program CABLE written by H. Harrison of Sydney University.

For a fence composed of 150 UC 37 posts such analyses indicated that with the posts at 2.5 metre centres, 13mm diameter wire rope had sufficient strength that, if struck by a boulder, plastic hinges would form in the posts before the cable broke. In other words, the fence would collapse rather than the boulder passing through the fence.

5.2 Spacing of Posts

The design approach adopted is typically as follows:

A 100 tonne boulder may be expected to have the dimensions of about 3m × 3m × 3m. In order to be certain that a rock of this size will hit at least two posts simultaneously the posts should be at about 1.5 metres centre to centre. However, it is considered that with a spacing of 1.75 metres centre to centre the probability remains high that two posts will be struck simulataneously.

5.3 Height of Posts

The height of posts must be such that:-

(i) Boulders are unlikely to bounce clear over the fence
(ii) When struck by the design boulder the collapse of the required number of posts will occur, i.e. with short posts it would be possible for say four posts to be flattened without there being enough deflection of the cables to pull down further posts.

5.4 Cyclone Mesh

The fence is usually covered with heavy duty cyclone mesh which is manufactured in a width of 1830mm. An overlap of at least 250mm should be allowed, thus giving the following possibilities:-

Number of widths of cyclone mesh	Fence height (metres)
2	3.41
3	4.99
4	6.57

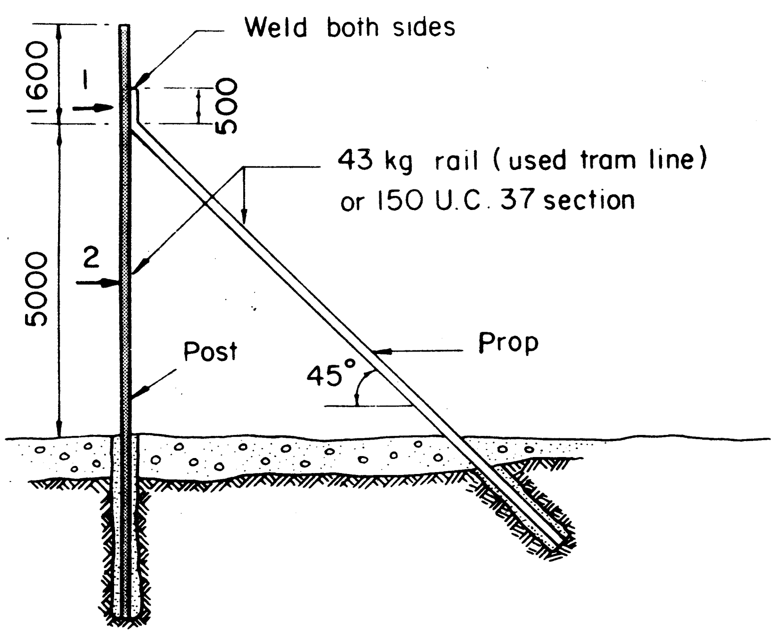

Fig 5: Typical Rock Fall Fence Post

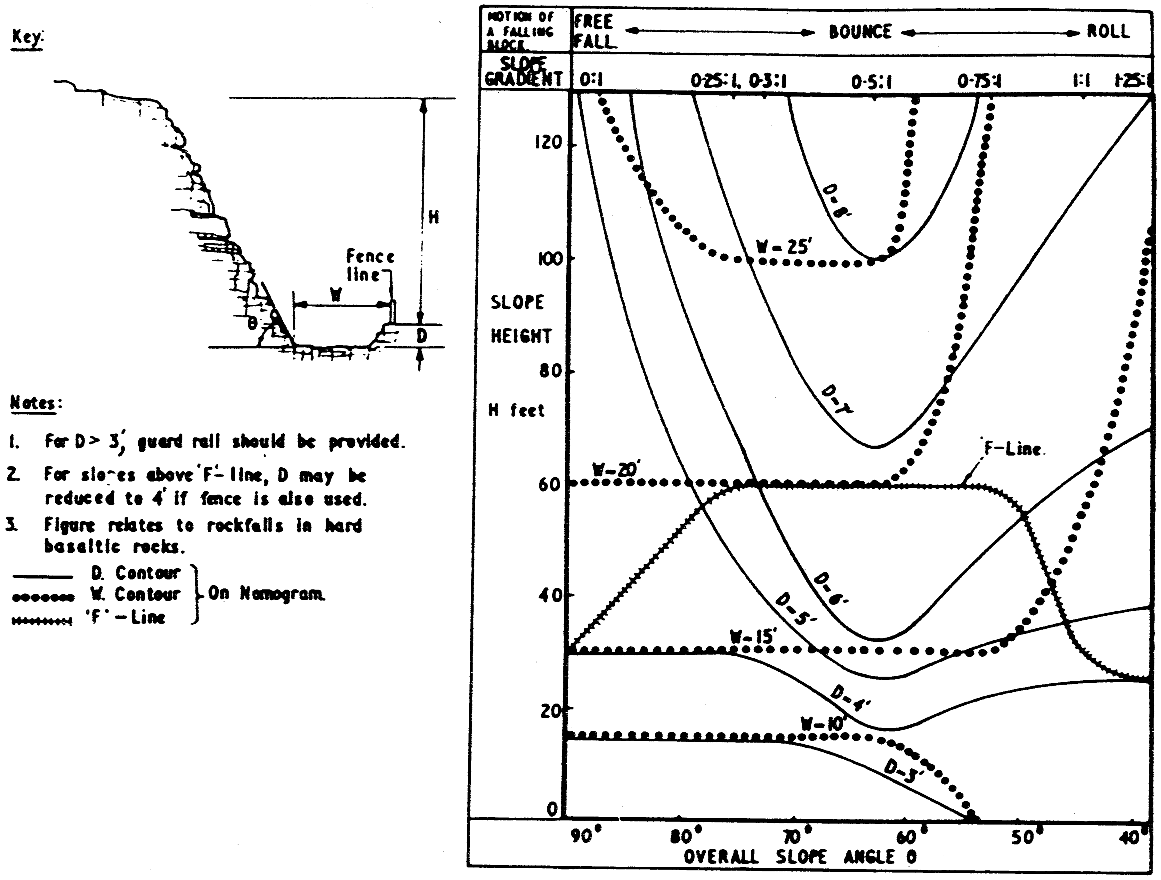

Fig 6: Rock Fall Ditch Design (after Fookes and Sweeny 1976, and Ritchie 1963)