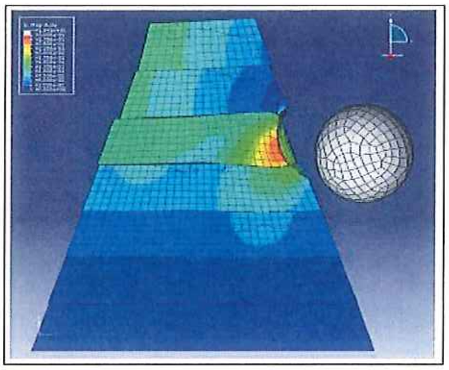
4) Design Philosophy



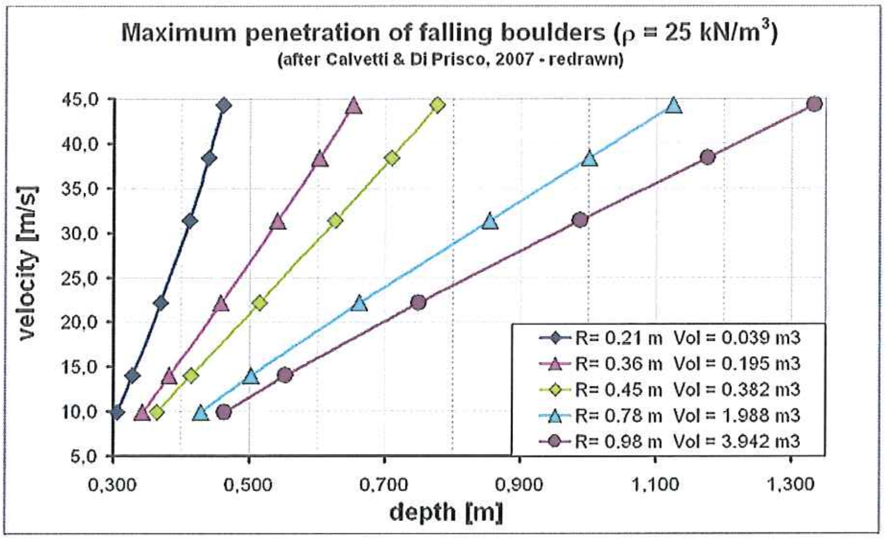
For many years Maccaferri has been developing a scientific design methodology to enable designers and engineers to easily design and specify reinforced soil embankments for protection from rockfall and also debris flows. Reinforced soil techniques and the structures being constructed have been employed for many years now. These structures are well known for their versatility and great ability to absorb energy especially during the earthquakes. This was proven in major earthquakes in Japan, Taiwan and also Christchurch. It therefore also makes sense that this high energy absorption characteristic is use in resisting the rockfall impact. Maccaferri has worked with a number of experienced and highly respected technical institutions to fine tune the Maccaferri GTM Bund system.

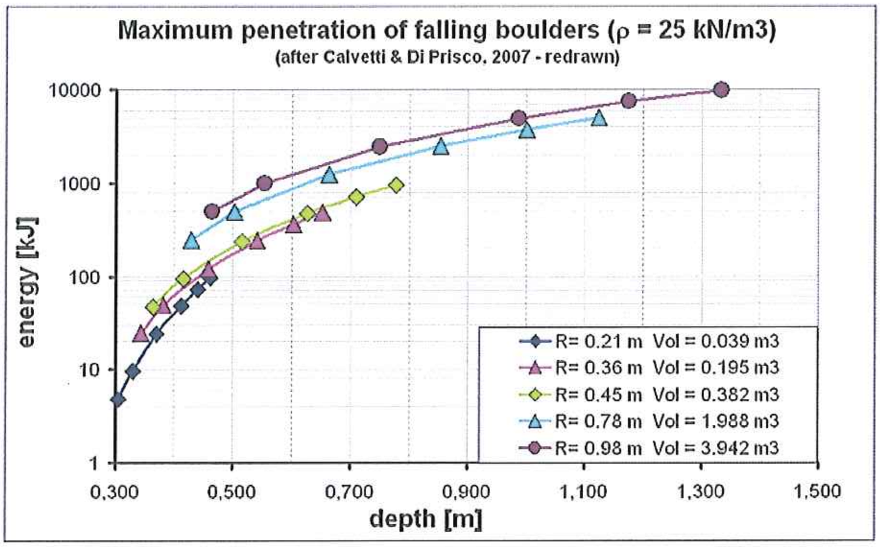
The Green Terramesh reinforced soil bund system has many key benefits including extremely long design life, relatively low per-linear-meter cost* and simple maintenance methods. A particular advantage of the bund is the essentially unlimited energy capacity. (*Compared to mesh or fence systems and depending on site specific factors.)

The photograph (right) shows boulder impact with a Green Terramesh Bund. The boulder was estimated, through back analysis, to have had impact energy in excess of 5000kJ and the embankment required only relatively minor cosmetic repairs to be returned to a fully serviceable condition. More importantly, the embankment continued to remain in a serviceable condition after three other large falls, each of approximately 3000 tonnes. Maintenance was recently carried out on these embankments and the works comprised removal of accumulated fallen material and the cosmetic (plus very minor structural) repairs to the surficial portion of the embankment.

The embankment design methodology is based around FEM and analogue modeling along with calibration with actual full scale impact tests. From this work a series of technical tools were developed to enable the prediction of various characteristics and develop a proportioning system to enable successful specification of embankments for rock fall protection purposes.

The graphs below are taken from the design methodology and illustrate the likely penetration of impacting boulders (of various diameters) into the face of a reinforced soil embankment. The graphs are developed on the basis of impact or velocity and energy respectively.





For an embankment to work effectively, the design assumption should take into consideration the following aspects:

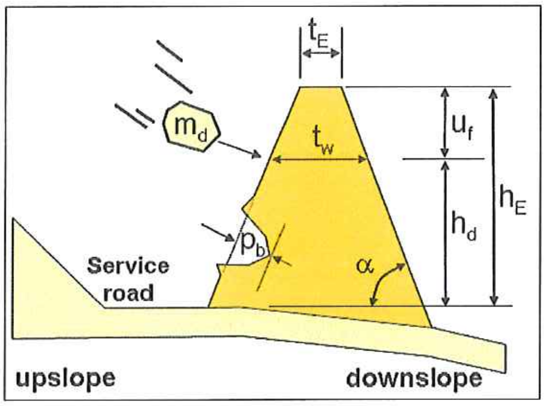
a) The embankment height shall be sufficient to intercept the rock trajectory

b) The area directly upslope of the embankment must provide sufficient space to accumulate fallen rocks

c) The embankment must have sufficient thickness and density in order to prevent the rocks from penetrating the embankment

d) The embankment must be self stable under its own weight (internal stability)

e) The stability of the slope on which the embankment is founding on shall be stable (global stability)



Point a) to c) shall determine the basic geometry of the Green Terramesh bund. Rockfall trajectory analysis performed will provide the essential data on the expected energy and maximum height during impact. This is then use for the sizing of the bund.

Point d) to e) deals with the stability analysis of the embankment internally and externally. Conventional slope stability software can be used to perform the stability checks. In this case, MacStars-W software is used.

4.1 Determination of Green Terramesh embankment geometry

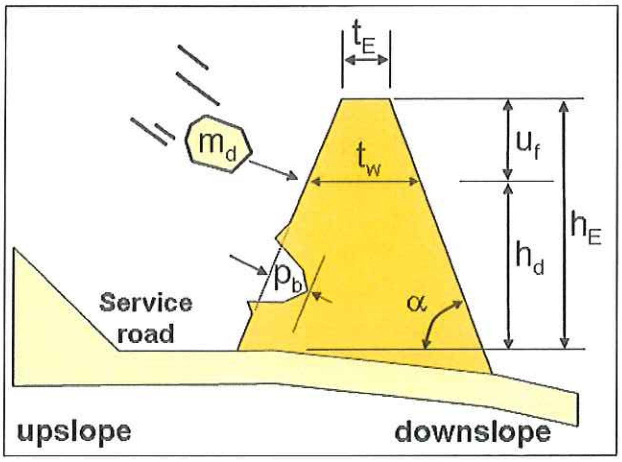
From the available data made available to us, the Green Terramesh embankment geometry can be determine based on the design philosophy above.

- Maximum penetration depth in relation to the impact energy of 557kJ from Charts= 0.45m (approximately)

- Minimum thickness of the embankment (t_w) at the height of impact required (i.e h_d=1.6m) = 2 x 0.45m =0.9m

- The upper portion beyond the impact height (u_f) should be at least equal to or exceeds the diameter of the block considered (i.e 2.2m)

- The minimum height and the top crest width of the Green Terramesh embankment can then be determined from simple geometrical calculation.



Bounce height, h_d = 1.6 m
GTM face inclination = 70 degree

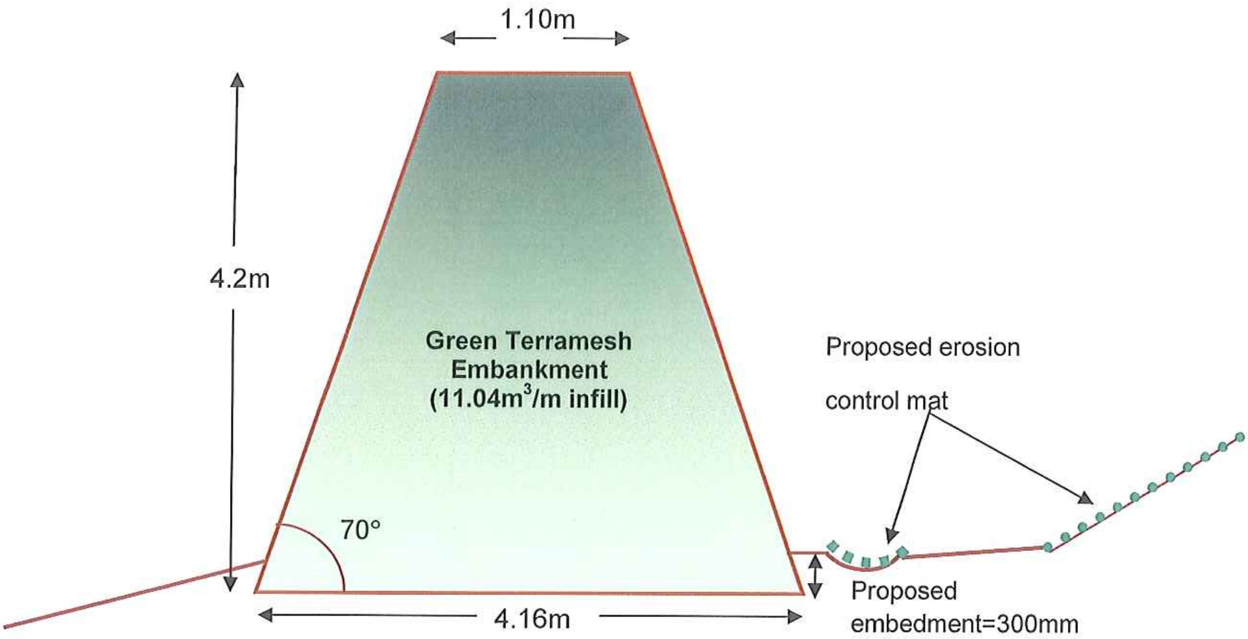
Boulder diameter (m)	Boulder Vol (m^3)	Minimum height (m), h_E	Minimum base width (m), B	Minimum thickness at impact (m), t_w	$t_w > 2 * P_B$?
2.2	5.5	3.8m	3.87	2.70	OK

Considerations:

1. Thickness of GTM embankment at point of impact, $t_w \geq 2$ times penetration depth, P_b
2. Upper section of the embankment above point of impact, U_f = diameter of the boulder (minimum)
3. Minimum GTM embankment top crest width, t_E fixed at 1.10m

The final geometry of the Green Terramesh embankment after considering actual GTM unit dimension and minimum height >3.8m is obtained as follows:

Bounce height, hd at 1.6m



4.2 Stability Analysis Results

The results of the stability analysis for the GTM bund on the most critical section are summarized below:

	Calculated		Design Criteria		
	Static	**Seismic**	**Static**	**Seismic**	**Remark**
FOS Internal	**2.689**	**1.365**	**1.5**	**1.1**	**OK**
FOS Global	**2.370**	**1.174**	**1.5**	**1.1**	**OK**

Note: Additional geogrid reinforcement Tensar RE540 is required only at the base level of the GTM bund for improvement of the global stability failure during seismic load case

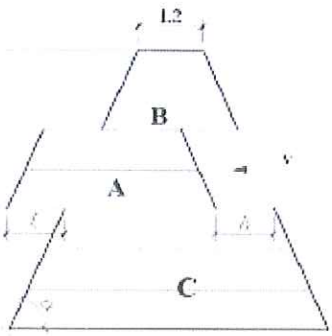
4.2 GTM Bund Energy Capacity

The impact energy of Green Terramesh bund and their relationship with the bounce height with boulder size can be estimated based on the charts developed by Calvetti & Di Prisco. However, the state of the GTM bund after the impact if it is fit for another impact or requires the re-construction (at that particular impacted section only) requires another stability checks.

Three-dimensional numerical models are usually difficult to calibrate in the dynamic field; a great deal of computational time are necessary using numerical analysis software such as ABAQUS needs to be employed and not considered a usual design tools for engineers. A simplified analytical approach has been suggested that could permit a simple evaluation of GTM reinforced soil bund to be used for rockfall protection.

The design can be done at Ultimate Limit State (**ULS**) or at Serviceability Limit State (**SLS**) to define the geometry of the structure able to stop the design rock masses. **ULS** is determined by evaluating the static stability of the structure after the deformation, by simple equilibrium evaluation: the projection of Block A centre of mass has to be inside the front support of Block C (see Fig. below), or the projection of the Block B (see Fig. 13) centre of mass has to stay in equilibrium with Block A. The design at Ultimate Limit State does not allow the embankment to stop subsequent rock impacts with the designed energy level. **SLS** conditions have to permit an easy maintenance of the structure, the mountain side penetration and the valley side displacement have to be imposed. In this way, the embankment will be able to stop multiple design blocks impacts. Generally, the parameters mentioned above should not exceed the following values:

- upslope penetration: lower than 20% of the embankment thickness at the impact height and not higher than 50-70 cm. For larger displacement it is difficult to repair the structure
- downslope sliding: lower than 30-40 cm.



Based on these simplified criteria, the maximum impact energy of the GTM bund for the ULS and SLS conditions can be estimated for the GTM bunds:

	SLS Condition	ULS Condition
Impact Energy	**2,000kJ**	**>10,000kJ**