

Boulder Treatment in Hong Kong

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INTRODUCTION

Hong Kong is situated on the southern coastline of China and has a land area of only 1 075 km². The terrain is hilly, with upper slopes steeper than 35° and footslopes about 15°. To obtain flat land, reclamations along the coastal areas are commonplace. The population of nearly 6 million is concentrated in the urban areas of Hong Kong Island and Kowloon Peninsula and a few satellite towns in the New Territories. Being intensely developed, these areas are surrounded by or have extended into the steep hillsides. Inevitably most of the link roads in-between also cut into the very steep slopes.

Slope failures, including boulder falls, are a continual problem in Hong Kong. Over the years, significant loss of life and property damage have been caused. A great majority of the failures are directly associated with major rainstorms (Lumb, 1975, 1979; and Brand *et al*, 1984).

Though boulder falls are not uncommon in Hong Kong, there is a lack of publication on their problems and the treatment methods except for a few papers written recently by Brand *et al*, 1983; Threadgold & McNicholl, 1984; Beggs *et al*, 1985; Chan *et al*, 1986 and Grigg & Wong, 1987. It does not necessarily mean that boulder treatments are new to the local engineers. Indeed, there are old treatment works that can readily be seen in the Territory. Figure 1 shows an example where a granite boulder was propped by old brickwork columns. Figure 2 shows another, which is a terraced concrete blanket covering 12 000 m² of a colluvial boulder veneer in the Mid-levels of Hong Kong Island.

Before 1980, virtually no provision for boulder treatment was explicitly included in site formation packages, and the old treatment works described above were piecemeal and exceptional.

The aim of this paper is to make a short general review of boulder treatment practices in Hong Kong, with emphasis on both the design and construction problems.

GEOLOGY OF HONG KONG

A simplified geological map of Hong Kong is given in Figure 3. The main rock types can be broadly classified into granites and acidic volcanic rocks. They are by far the most important, as the urban areas, satellite towns and the link roads were built on them.



Figure 1. Boulder supported by old brickwork columns

These rocks have generally been subject to severe in situ weathering. The granitic rocks are younger but tend to be weathered more deeply. Mantles of decomposed granite can be up to 60 m thick, often containing corestones of relatively fresh rock. Volcanic rocks, however, have a thinner weathering profile and, except in some coarse-grained ash tuffs, corestones are very often absent. A profile which shows the typical weathering zones of granite is given in Figure 4. The same zones of weathering can be observed in some of the volcanic rocks but the features are not always as distinctive as those of the granites.

FORMATION OF SURFACE BOULDERS

In Hong Kong, surface boulders are derived largely from natural degradation of country rocks, erosion of overburden and site formation activities. The common forms of derivation are described below:



Figure 2. Concrete blanket in the form of terraces

- (a) The country rocks were subject to a series of tectonic movements, intrusions and unloading. These resulted in intense jointing of the rocks. Joint-bounded blocks from exposed location like natural cliff, when dislodged, give rise to rockfalls which become surface boulders downhill (Figure 5).
- (b) As mentioned earlier, corestones are present in the decomposed matrix of granites or some coarse-grained volcanic rocks. Should the soft mantle be eroded away, the corestones will be exposed and become perched on the ground surface (Figure 6).
- (c) Colluvium in Hong Kong, be it volcanic or granitic in origin, contains detrital boulders. Erosion in colluvial deposit, likewise, will expose the boulders. Figure 7 shows a small drainage line in a volcanic colluvial deposit. The concentration of boulders along the drainage line was a result of acute erosion due to high stream flow caused by torrential summer rains.
- (d) Cuttings associated with site formation for developments also create perched boulders on or close to the slope batter. Unstable boulders of this kind usually have a very high risk, as they pose a direct threat to the developments downslope. Figure 8 gives two examples.

In situ weathering starts primarily from the joint planes and eventually works into the rock mass under the action of groundwater and atmospheric gases (Ruxton & Berry, 1957). Corestones are left behind in areas where decomposition has yet to convert all the rock into soil. Due to the wider joint spacing in granites than in volcanic rocks, corestones occur more readily in granites and boulders of granitic origin are therefore generally much larger in size. Granitic boulders of about 5 - 25 m³ in size are common though some can be as large as a few hundred cubic meters, whereas boulders of volcanic rock origin are typically much smaller, being of the order of 0.5 - 2.5 m³.

Depending on how they were derived and positioned, boulders perch on the slope surface either in isolation or in clusters. The boulder veneer in the Mid-levels of Hong Kong Island, which covers a plan area of over 45 000 m², is an extreme example (Chan *et*

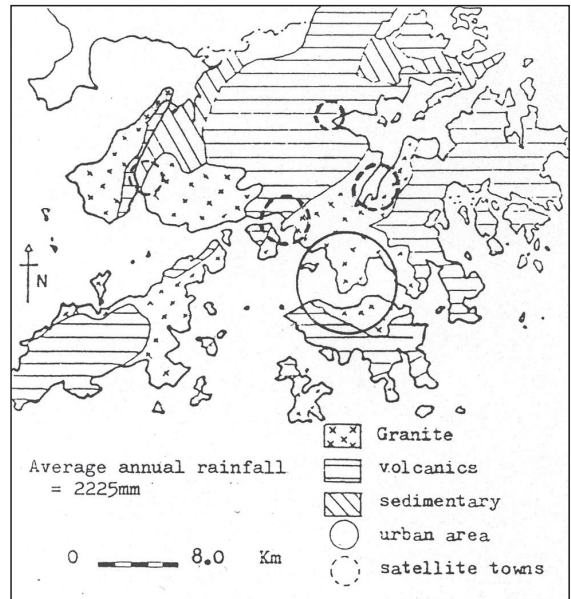


Figure 3. A simplified geological map of Hong Kong

al., 1986). Here, the boulder content, voids excluded, is as high as 70 to 100%. Surface boulders are naturally supported through surface friction, embedment into the soil or interlocking with other boulders.

DAMAGE AND CASUALTIES CAUSED BY BOULDER FALL

Boulder falls pose an appreciable threat to life and property in Hong Kong because developments are constructed extremely close to the natural hillslopes where surface boulders are produced. In 1926, a falling boulder, presumably of colluvial origin, was reported to have caused five fatalities at Elliot Pumping Station at Pok Fu Lam (GCO, 1987). Figure 9 shows the damage that may be caused by a boulder fall.

Some statistics of reported boulder falls for the years 1982-1988 are given in Table 1. Figures corresponding to other forms of slope failures, viz, failures of fill slope, cut slope, retaining wall, etc are also given for comparison. It can be seen that the occurrence of boulder falls is statistically not as serious a problem as the other failures. However, boulder falls can be damaging.

TREATMENT PHILOSOPHY

The movement of boulders on slope can be caused by:

- (a) External forces such as high overland water flow, landslips, vibration due to seismic or human activities (e.g. construction), etc.
- (b) Loss of support due to erosion or scouring

Zone Description		Zone Symbol	Weathering Profile	Zone Characteristics
Residual Soil		RS		Residual soil derived from insitu weathering; mass structure and material/fabric completely destroyed : 100% soil
Partially Weathered Rock	0/30% Rock	PW 0/30		Less than 30% rock Soil retains original mass structure and material texture/fabric (i.e. saprolite) Rock content does not affect shear behaviour of mass but relict discontinuities in soil may do so Rock content may be significant for investigation and construction
	30/50% Rock	PW 30/50		30% to 50% Both rock content and relict discontinuities may affect shear behaviour of mass
	50/90% Rock	PW 50/90		50% to 90% Interlocked structure
	90/100% Rock	PW 90/100		Greater than 90% rock Small amount of the material converted to soil along discontinuities
	Unweathered Rock	UW		100% rock May show slight discolouration along discontinuities

Figure 4. Rock weathering system for corestone forming rock mass (after GCO, 1988)



Figure 5. Surface boulders derived from rockfall



Figure 6. Corestones exposed due to erosion of matrix material

associated with torrential rain, removal of vegetation, etc.

- (c) Deterioration of the boulder itself by continued weathering.



Figure 7. Detrital boulders of a colluvial deposit along a drainage line



Figure 9. A car badly damaged by a boulder fall

appropriate boulder treatment works, apart from the properties of the boulder itself, the potential cause of its movement together with the physical constraints such as the space available, difficulty of access, proximity to developments, retention of mature trees, etc. need to be taken into consideration.

There are three approaches to remove or reduce the risk from a boulder fall. They can be used either in isolation or in combination:

- (a) Remove the item being threatened.
- (b) Remove the boulder or stabilize it insitu – preventive method.
- (c) Catch, arrest or deflect the moving boulder before it reaches the area of concern – protective method.

In Hong Kong, high land value usually prohibits the removal of the properties at risk. For piecemeal treatment or treatment of a relatively small scale, preventive methods are usually employed. For treatment covering a large area, it is economically more viable to adopt a combination of preventive and protective methods. The balance for which both methods could be suitably combined is dictated to a large extent by the size of the boulders and their distribution on hillside, as well as by the engineering constraints, such as topography, access, proximity to developments, etc.

PREVENTIVE METHODS

In many cases, the best solution is a sensible combination of the methods described below (e.g. see Figure 10(b), where splitting was coupled with buttressing). However, because the potential causes of movement are extremely difficult to determine (say, for example, the erosional/scouring effects of overland water flow due to a rainstorm) and individual boulder stability is hardly amenable to rigorous quantitative assessments, engineering judgement based on common sense, experience, and sound engineering principles (and sometimes suitable conservatism) are therefore of overriding importance for a decision.

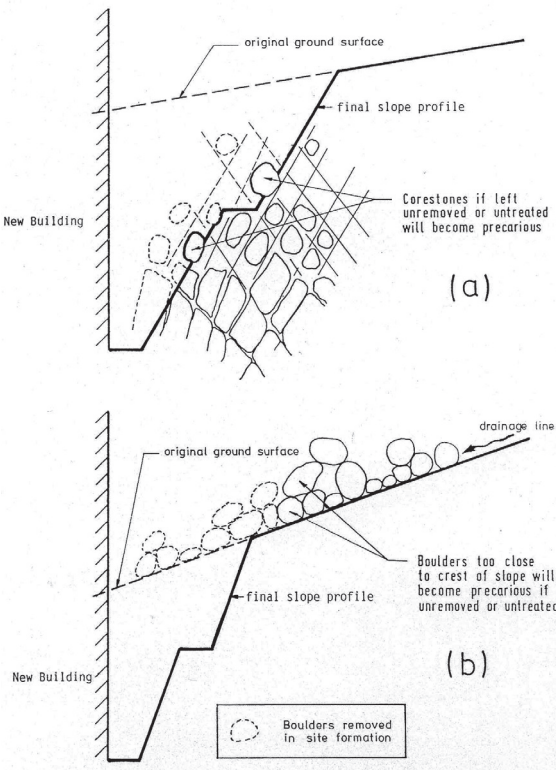


Figure 8. Creation of perched boulders by cutting

Intense rainstorms are common in Hong Kong (24-hour rainfall more than 250 mm and 1-hour intensities more than 50 mm are frequent), and boulder falls due to surface run-off concentration were by far the most common. In determining the most

Table 1. Number of incidents reported or known to GCO

Type of Landslip		May 1982*		Aug. 1982*		June 1983*		1984		1985		1986		1987		1988	
		no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Fill Slope Failure		30	6	12	6	19	12	14	12	13	5	18	8	14	4	15	10
Cut Slope Failure	Soil	183	34	105	51	72	45	62	52	118	46	93	40	165	54	61	39
	Soil/Rock	35	7	19	9	4	3	6	5	19	8	14	6	18	6	7	4
	Rock	16	3	8	4	8	5	2	2	8	3	8	3	10	3	5	3
Retaining Wall Failure		49	9	19	9	21	13	11	9	25	10	26	11	27	9	14	9
Natural Slope Failure		84	16	26	13	28	17	4	3	10	4	9	4	14	5	7	4
Rock or Boulder Fall		24	4	3	2	8	5	7	6	17	7	29	13	28	9	22	14
Other		115	21	12	6	0	0	14	11	44	17	36	15	31	10	26	17
Total		536	100	204	100	160	100	120	100	254	100	233	100	307	100	157	100

*Statistics of a single storm event

Splitting

This covers either wholesale or partial removal of a boulder. Splitting of a boulder can be achieved by pneumatic percussive drilling and wedging. Explosives may be used in areas sufficiently far away from the public. Expanding agents such as Bristar, have also been used with success, but a rock trap should be provided because it is not certain when the boulder would split apart and drop downhill. Figures 10(a) and 10(b) show a typical example of splitting work. This method is most cost-effective when the split rock fragments can be reused to form buttress or in filling up voids.¹

Indiscriminate or unplanned splitting may lead to serious problems if the boulder to be removed provides some form of support to other boulders, an example of which will be described later. Moreover, near the crest of high steep slopes, rock splitting should be carried out with caution. The dislodged rock fragments are dangerous and have caused accidents. A strong protective fence should be erected downslope if splitting is very close to and overlooking developments. Bamboo or timber fences are not effective for this purpose in most cases.

Surface Protection

Ground surface around the boulder can be covered or strengthened to prevent erosion which would otherwise undermine the boulder and cause instability. This can be in the form of a rock fill apron, chunam (a mixture of cement, lime and residual soil) layer or concrete paving. A surface channel is sometimes added uphill to divert the surface run-off away from the boulder. Figures 11 and 13 show examples of surface protection

work. This is a very cost-effective measure and useful in the heavy rainfall environment such as that in Hong Kong.

Buttressing

Boulder buttressing is versatile and is commonly



Figure 10(a). Splitting to remove overhang (before)



Figure 10(b). Splitting to remove overhang (after)

¹ Voids which would serve as a trap for uphill boulder falls should not be filled up.

used to improve the boulder stability. Masonry and concrete buttresses (Figures 12 & 13) are widely seen. Masonry buttress, though structurally less effective, can be readily built with split rock. This is especially cost-effective where concrete transportation or disposal of split rock is a problem.

For a long buttress, weepholes or drainholes should be installed to drain any water that may be intercepted from behind. The rock face to receive concrete should be scarified and cleaned to ensure a good bonding. Sometimes, dowels are also used. The terraces in Figure 2 are in fact a large scale buttressing work where unstable boulders were integrated to give a single stable mass.

Strut/tie beams

A potentially unstable boulder can be rendered stable through strutting it against or tying it to another stable boulder. Reinforced concrete beams or structural steel sections have been used for this purpose (Figures 14 & 24(b)). This method is particularly useful for treating boulders near the crest of high steep slopes where rock splitting or heavy surcharge are prohibited.

Sometimes, strut/tie beams can be used collectively to link or tie up a group of unstable boulders to give a stable unit. The grid-beam system on a slope in the Mid-levels area of Hong Kong Island typifies this extended application (see Figure 15). The area concerned contained numerous potentially unstable boulders overlooking highrise building blocks. The system was an approximately 3 x 3 m grid of reinforced concrete beams, 300 x 400 mm in cross-section, cast against the boulders in-situ with wire mesh infill whereby the potentially unstable boulders were held together. Boulders not intercepted directly by the beams were prevented from falling downhill by the wire mesh netting firmly secured onto the beams. To maximise the effectiveness of the system, the grid beams were aligned to intercept as many of the potentially unstable boulders as possible. On the other hand, the beams were also aligned to intercept those large but stable boulders to maximize the overall stability.

Anchorage

If the boulder is perched on competent rocks, sometimes dowels or rock bolts can be used effectively in securing the boulder where foundation space for buttressing is not available. Grout leakage through the possible gap between the boulder and the underlying rock can be overcome by double grouting whereby the primary grout will plug the leaks.

If the boulder sits on a thick mantle of soil, rock anchors or micropiles, though costly, can provide a solution. In a tension test on micropiles using Dywidag bar in a bouldery colluvial deposit in

the Mid-levels of Hong Kong Island, an average bond stress above 150 kPa between the pile and the soil/boulder was achieved. As a force as high as 1500 kN can readily be obtained from most anchors or micropiles, a few of them will therefore suffice in securing a very large boulder.



Figure 11. Surface protection



Figure 12. Masonry buttress



Figure 13. Mass concrete buttress (see also the surface protection)



Figure 14. Steel strut



Figure 15. Reinforced concrete grid-beam system with wire netting infill

Wire lashing/nets

Wire mesh nets are very often used to prevent rockfalls over rock slopes in Hong Kong. The mesh is usually made of galvanised wire with PVC coating, being woven into a hexagonal pattern with the joints formed by twisting each pair of wires through three half turns. The nets are secured by holding down bolts. The only application in boulder preventive works known to the authors, is that in the grid-beam system described earlier. There is,

however, obvious potential for a wider application in the future, especially where the boulders to be treated are in groups and of smaller sizes.

Where access is extremely difficult, galvanised steel wire ropes have been used to tie the potentially unstable boulders to the stable ones (Figure 16).

These methods differ from the others in the materials used. Since the wire nets and steel ropes are flexible materials, slight boulder movements, without necessarily leading to a failure, can occur after construction.

PROTECTIVE METHODS

Among the various protective methods employed in the other parts of the world (e.g. sterile zones, deflection barrier, retardation bund, catch or blocking fences, etc.), only the catch/blockade structures which require little space to build have been used in Hong Kong. This is not surprising as the land value is high and also there is always insufficient space to adopt the other solutions.

A number of structures of this kind have been built. They include a series of seven massive boulder barriers in the Northern Kowloon Peninsula below the eastern end of Lion Rock Ridge, a reinforced concrete rock trap ditch also in North Kowloon but below Beacon Hill and a collapsible fence on concrete foundation in the Mid-levels of Hong Kong Island. All these structures were built to intercept falling boulders below a certain size from reaching the areas of concern. Threadgold & McNicholl (1984) have described the first installation, Grigg & Wong (1987) the second and Chan *et al* (1986) the third. Figures 17 to 19 show the general appearance of these structures. Figures 20 to 22 give their respective details.

Like many preventive works, the design and construction of protective works are subject to physical constraints. For instance, access to the site is usually difficult and transportation of construction materials can by itself dictate the construction method. The massive boulder barriers aforementioned were gabion structures (Figure 20). All the components were transported to site with only little machinery. The light weight polymer geogrids (Netlon Tensor SR2 -- a uniaxial geogrid of high density polyethylene with 2.5% carbon black) gabion² needed only be fabricated on site and the rock infill placed by hand. Similarly, the collapsible fence was constructed of mild steel Square Hollow Section (SHS) posts (with in-situ weak

² Four of the seven massive barriers were badly damaged in a hillfire in 1989. The outer geogrid sheetings were burnt/melted and the retained rock infill collapsed as a result. The damaged barriers were replaced using Maccaferri gabions while the undamaged ones were covered with sprayed concrete as a protection against further hillfires.



Figure 16. Wire rope lashing



Figure 19. Boulder fence in Mid-levels



Figure 17. Boulder barrier below Lion Rock



Figure 18. Reinforced concrete rock trap ditch below Beacon Hill

concrete infill) which could be manually transported to site, and then connected together on site with steel wire ropes and wire mesh infill (Figure 22). The choice of this collapsible fence was also dictated by the steep topography. As the general slope angle of the site was as steep as 35° , a massive structure would unduly surcharge the slope. Therefore, to obviate the use of heavy members and foundations, the fence was made collapsible. By virtue of plastic deformation, the fence can absorb the energy of the moving boulder and catch it as if it were a massive structure.

As mentioned earlier, it is sometimes economical to combine the protective method with the preventive methods. The concept is based on typical size distributions of boulders on natural slopes in which the number of boulders tends to decrease exponentially with an increase in boulder size. The few large boulders can be more economically prevented from movement by insitu stabilisation. The majority of the average and smaller-sized boulders which may move can then be treated by the protective methods. In the North Kowloon sites, the massive polymer geogrid barriers and the rock trap ditch were designed to cater respectively for boulders not larger than 5 m and 3 m in diameter. Likewise, the SHS post-wire rope fence in Mid-levels could only cater for falling boulders with an impact not exceeding 100 kN-m (i.e. a 3-tonne boulder at a velocity of 7 m/s). Boulders of a larger size were stabilised insitu by preventive means.

INVESTIGATION

If the area requiring treatment is not covered with thick vegetation, aerial photograph interpretation usually provides an expeditious means of obtaining sufficient information for strategic planning and budgeting, e.g. ground profile, boulder density, boulder size and shape, etc. However, for areas covered with thick vegetation, other more tedious and time-consuming methods such as boulder mapping in strips over a predetermined grid have to be employed (Chan *et al*, 1986). The ground

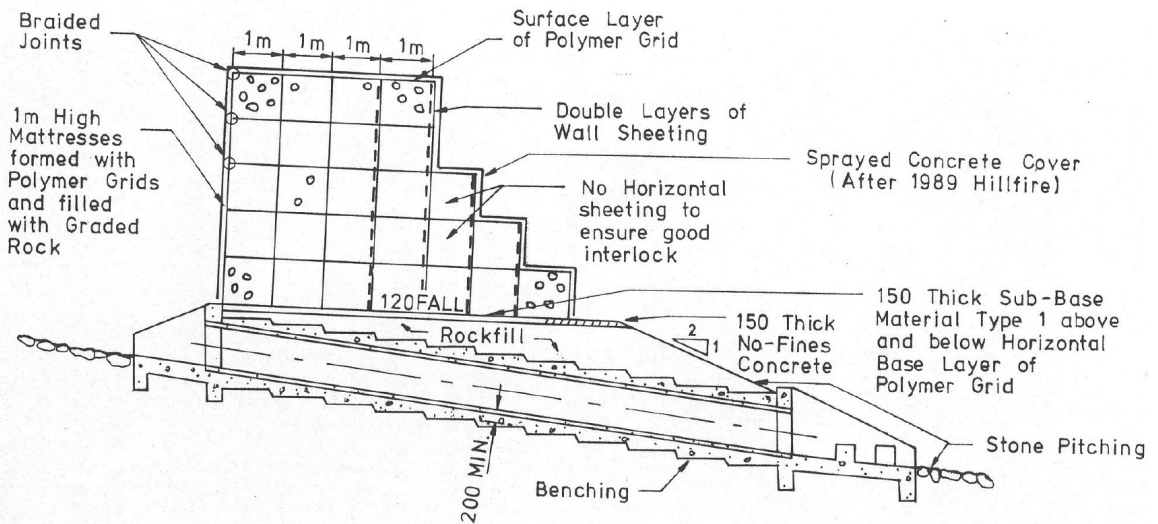


Figure 20. Boulder barrier details (after Threadgold & McNicholl, 1984)

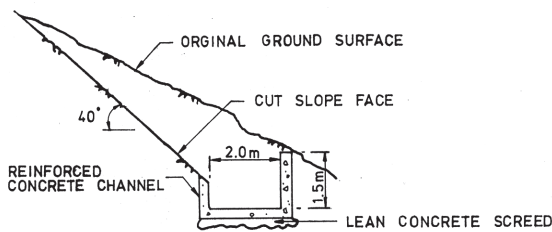


Figure 21. Rock trap ditch details (after Griggs & Wong, 1987)

condition and the boulders along the grid-strip are recorded, from which an overall boulder distribution is determined using statistical methods. This method enables the job to be kept within a manageable scale, and limits the undergrowth clearance, which may trigger instability.

For detailed design, visual inspection with simple tape measurements (with the help of a plumb bob) is the norm to determine the exposed dimensions of boulder. But for very large boulders, it is sometimes more convenient to employ survey methods using a theodolite.

However, to determine the stability of a surface boulder properly, it is not enough just to obtain the exposed dimensions. The geometry of the embedded portion should also be determined so that its centre of gravity with respect to the buried base under the most adverse loading/support condition can be ascertained. For small boulders, rigorous investigation is generally not justified. It is usually more practical and expedient to simply adopt conservatism in the design. This “err on the safe side” approach is not applicable to large boulders. To determine the embedment of a large boulder, pneumatic percussive drills are commonly

employed. This method is limited by the length of the drill rod which is typically not longer than 7 m. For very large boulders, drilling has to start closest to the “soil line”. Normally, with inclined holes, the drilling can reveal an embedment of 6 - 7 m in this manner. In most cases, this method can give adequate information for design purposes. Figure 23 gives some typical drilling rates of pneumatic percussive drilling through surface boulders, from which the position of their bases could be determined.

To obtain information about the bearing material for treatment structures, probing (e.g. GCO

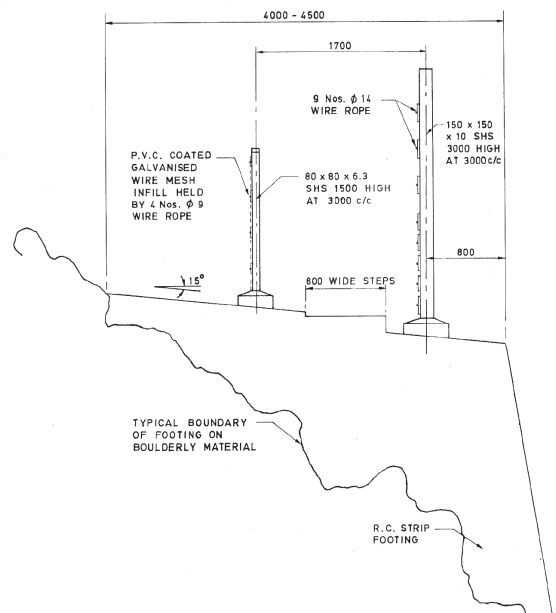


Figure 22. Boulder fence details

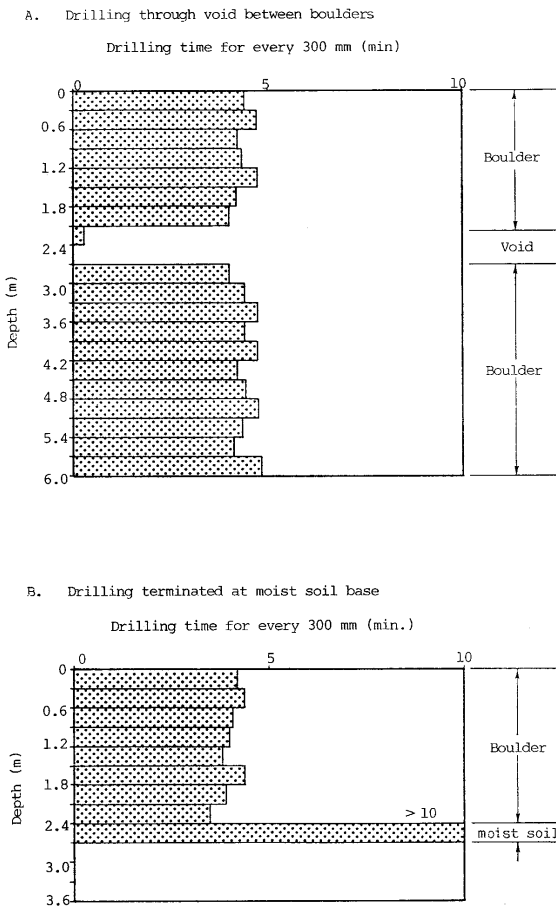


Figure 23. Pneumatic percussive drill – typical drilling rates

probe (Brand & Phillipson, 1984)) and trial pits are sometimes required to supplement the visual superficial inspections. Except where micropiles or anchors are used, boreholes are seldom necessary.

PROBLEMS IN DESIGN OF PREVENTIVE WORKS

There is no hard and fast rule about the choice of preventive works. Each boulder together with its setting is unique and treatment should invariably be based on individual merits. Engineering judgement as mentioned earlier is of paramount importance, not only because there are inherent imprecision and uncertainties associated with the determination of external effects and boulder characteristics, but also because boulder stability, being a complicated three-dimensional problem and involving an interaction between friction, embedment and interlocking, is difficult to analyse accurately. Because of the need for judgement in all cases both in the design of

stabilisation work and during construction, experience in boulder stabilization is essential. One should be aware that all engineering decisions are conditioned by desire (de Mello, 1977) and care should be taken to ensure that the engineering judgement will not be lightly turned into a desire. The following is an example in which inexperience (or a desire?) caused unnecessary delay and expenditure.

The work originally intended was the removal of a stack of interlocking boulders at the crest of a rock cut face overlooking a high density residential block. No specific instruction on the method of removal was given to the contractor, who naturally commenced by removing the top boulders first. After about five or six boulders had been removed, a workman reported that a large overhanging boulder below was shaking and work was stopped. (Figure 24(a) shows the situation just after the work was stopped.)

Investigation revealed that the overhanging boulder was in a state of “unstable equilibrium”, and any further loss of weight on top of it would inflict toppling. Due to its size, the consequence of any failure would be disastrous. Contrary to the original design, this large boulder was retained by stabilising it with a mass concrete buttress. Removal of the boulders on its top was then resumed. To provide for the buttress a firm foundation on the underlying rock, a layer of weak material immediately in front of the boulder had to be stripped off. To enable stripping of the material without jeopardising the stability of the boulder any further, a reinforced concrete strut plus two drive-wedge type rock bolts were installed to secure the boulder temporarily. Figure 24(b) shows a general view of the completed work. The job was delayed for two months for a contract period of only three months.

The preventive treatment works may appear to be simple. However, it can be tricky and should be handled by experienced personnel. The design engineer should always be aware of the possible consequence of failure. If a boulder fall is likely to give rise to a high risk to life or economic risk, a thorough investigation together with a conservative design are warranted.

PROBLEMS IN DESIGN OF PROTECTIVE WORKS

Boulder fall is a complex engineering problem and the speed and trajectory of fall depend on a wide range of variables such as boulder size, boulder shape, surface roughness of the slope, slope angle, etc.

Unfortunately, the existing literature on boulder falls is limited. Mathematical models have been developed by Ritchie (1963), Benitez *et al* (1977), Piteau (1978), Threadgold & McNicholl (1984) and Chan *et al* (1986) for simplified conditions. The boulder is taken to be a point mass in both the Ritchie

and Piteau's models, while in the others, it is taken to be a polygonal prism or a cylinder. Although mathematical models were used in the design of various large-scale boulder stabilization projects in Hong Kong (Threadgold & McNicholl, 1984; Chan *et al*, 1986 and Grigg & Wong, 1987), experience show that they were far from ideal and should only be used with caution. This is because many important factors in real-life situations cannot be accurately quantified by the models. For example, the shape, angularity and mass of the boulder, its possible movement paths before reaching the catch structure, the actual slope profile, deformability and roughness of the ground along the movement paths, the likelihood of the boulder being broken up during motion, etc can only be approximated and to some extent are guesswork. Though boulder fall is apparently not amenable to rigorous analysis, the models nevertheless provide a framework for understanding the fundamentals. They serve as a guide to the engineer in his design formulation.

To better understand the boulder fall and to facilitate design of the boulder fence in the Mid-levels of Hong Kong Island, Chan *et al* (1986) carried out a full-scale boulder fall experiment on two 30° slopes. The slopes were similar, one being a moderately decomposed rock outcrop with thin vegetation cover in

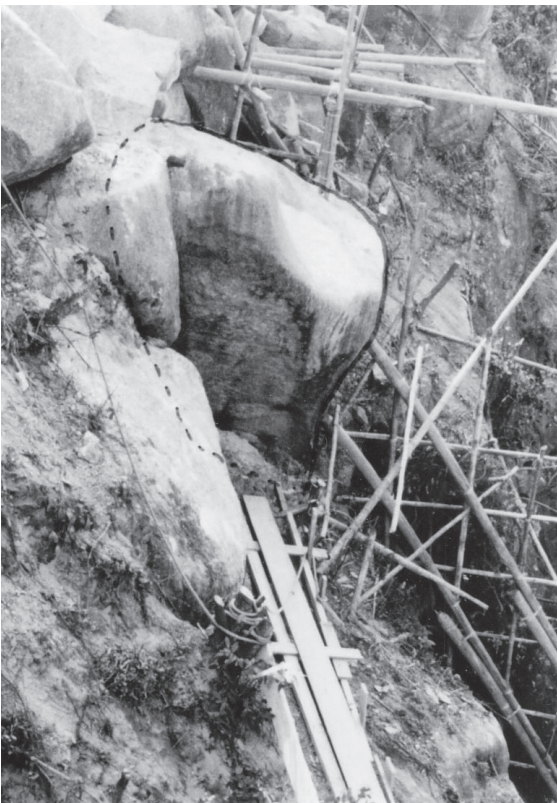


Figure 24(a). The shaking boulder (highlighted) (before treatment)

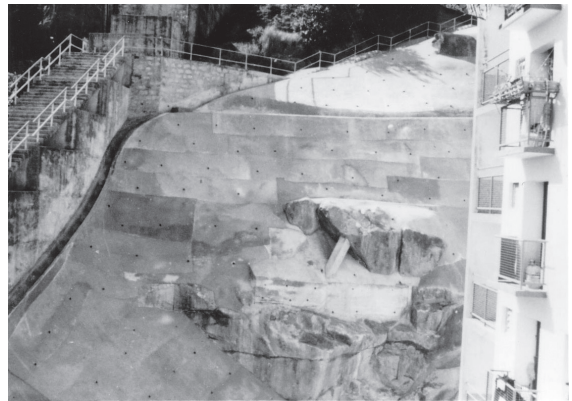


Figure 24(b). The shaking boulder (after treatment)

places (Slope I) and the other, a highly to completely decomposed rock slope with sparse vegetation and some surface boulder deposits (Slope II). A total of 70 boulders of sizes ranging from 30 kg to more than 1 tonne, and of differing angularity and shape, were rolled down the slopes. Boulder angularity, shape and size were found to have insignificant effect on the boulder velocities and the average velocities measured (Figure 25) were much lower than those predicted by the mathematical model (e.g. the predicted velocity of a 2 tonne subrounded boulder travelling a distance of 70 m on a 30° slope is about 10 m/sec as against the mean measured velocity of 4.9 m/sec). This is not unexpected as the lower velocity is attributed to many intangible factors which cannot be readily allowed for in the model, such as the uneven slope profile, vegetation cover, high ground deformability, humps created by the existing boulder deposits on slope, etc. Mak & Blomfield (1986) reported a similar experiment of rolling boulders down a number of steep presplit rock faces. The results are unfortunately limited to applications involving boulder falls on steep cutting batters like those illustrated in Figure 8. The majority of boulder falls in Hong Kong occurred on much gentler natural slopes.

There is also a lack of information in the existing literature on design concept and procedure for the catch structures. Most reported structures appear to have been based on empirical design methods (e.g. Bhandari & Sharma (1976), Mercer (1982)). Chan *et al* (1986) reported an effort to address the problem in a more analytical manner. In their design of the collapsible fence, a mathematical model was developed and various confirmatory laboratory tests were carried out to assist in the prediction of the fence performance.

CONSTRUCTION PROBLEMS

Difficult access is a problem for nearly all boulder treatment works in Hong Kong. Except for a site

which is very close to access road, sophisticated transportation methods employing heavy plant are invariably replaced by the more primitive means involving scaffolding, rails, chutes, etc. In a boulder treatment contract, if the contractor can develop a low-cost material transportation method, he is half way to a good profit.

Cost estimation for treatment works is, in most cases, very difficult. This is particularly true for preventive types of work since the unforeseen conditions are often only revealed as the work proceeds. The cost estimation should always be regarded as approximate only. Flexibility is required in the contract provisions to deal with contingencies and possible deviations which may arise.

Except where only a small area is treated, the most common situation faced by a designer is that boulders tend to be widely scattered. This, coupled with difficult access, requires the construction methods adopted to be mostly labour intensive. As the work and labour force are highly scattered, the control of output and workmanship is invariably difficult. The supervision level to be adopted to ensure a reasonable standard of workmanship should therefore be well thought out before the actual work starts.

In a combined treatment involving both preventive and protective methods, it is important to realise that the protective methods will only cater for boulders below a certain size. For boulders above this size preventive methods have to be chosen. It is therefore necessary to identify all the boulders above this threshold size. If a large number of boulders are to be

inspected, measured and assessed, the work should be carried out in a systematic manner to avoid oversight. An example is the Mid-Levels site on Hong Kong Island, where some 2 000 boulders were inspected over an area of 45 000 m². The site was divided into panels of about 500 m² each and the boulders to be assessed within each panel were individually numbered and their positions recorded on a plan. A standard procedure as indicated in the flow chart in Figure 26 was then followed through.

The preventive work required for individual boulders may differ widely in complexity. For simple and minor works, instructions to the contractor can be given directly after a visual inspection. However, for more complex and sizeable works, the more time-consuming surveying, drilling, stability calculation and design may have to be carried out. In many instances, due to the thick vegetation cover, the inspection, drilling, surveying, etc. could only be effectively carried out during the construction contract period. Thus, the contractor may find it difficult to plan his work in advance as late instructions for the more complex may prohibit simultaneous treatments of all boulders in close proximity (albeit of differing complexities) from carrying out. Good coordination between the engineer and the contractor is necessary to ensure that priorities in design and construction are properly worked out, otherwise serious delay and disruption to the agreed programme will result.

Mature trees are a rare asset to the Hong Kong community. Ruthless felling is unacceptable from both the environmental and geotechnical points of view.

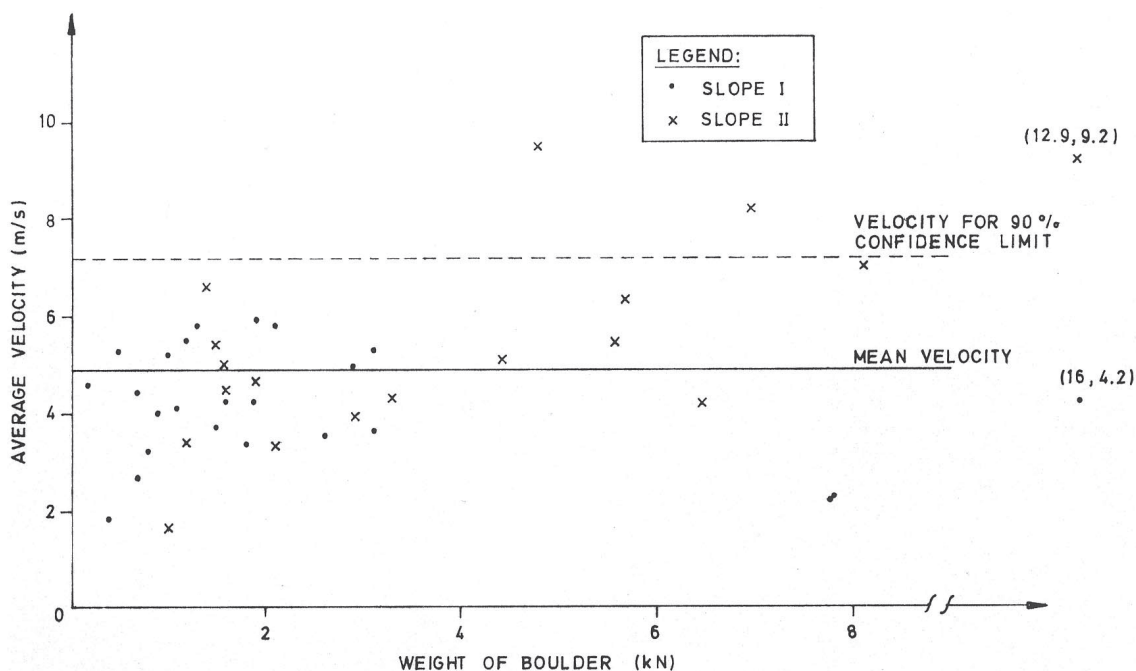


Figure 25. Full-scale boulder experiment: velocity versus boulder weight (after Chan *et al*, 1986)

Besides, trees can significantly reduce the velocity of boulder falls. With careful planning and a proper design, many trees can be retained. The message that tree felling should be avoided should be conveyed to the site staff and the contractor at the earliest possible opportunity, otherwise trees may have been felled during the undergrowth clearance, well ahead of any boulder inspection and design of treatment works. In fact, tree planting should be encouraged as part of the boulder treatments where conditions are favourable.

If pneumatic percussive drills are to be used over a long distance which is common especially in a large treatment works, head losses in the compressed air supply is another problem. A large capacity air compressor and large diameter air pipes (e.g. 50 mm) should be allowed for.

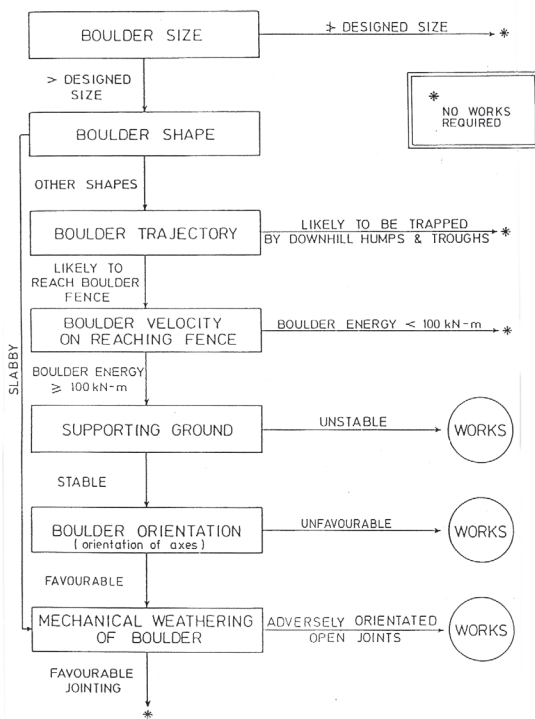


Figure 26. Flow-chart – identification of boulders for insitu stabilization.

CONCLUDING REMARKS

Despite that innumerable boulders exist over the hillslopes in Hong Kong, boulder falls, based on the reported incidents, generally constitute to no greater than 10% of the Territory's slope failure problem. Current Government policy is that a territory-wide programme for boulder treatment is impractical and that some elements of risk from boulder fall must be tolerated (Brand *et al*, 1983). Treatment works are

carried out where a boulder poses an immediate and obvious danger to life and property. Evaluations of boulder stability are undertaken where there have been persistent boulder falls or there is reason to believe that a dangerous situation could develop. This policy has been developed on the basis that the resources required for systematic inspection, undergrowth clearance and subsequent widespread treatment works to all existing boulder-strewn hillslopes in the Territory would be completely out of proportion to the risk the boulders may pose to the public. Nevertheless, apart from isolated piecemeal treatments associated with building development, large scale treatment works have been carried out. Some examples are the treatment works in North Kowloon and the Mid-levels area, as described in this paper.

Notwithstanding that boulder falls are not uncommon, their behaviour and related problems are only poorly understood. It is hoped that the gap will soon be narrowed down by more studies.

As boulder treatment works demand considerable engineering judgement, experienced personnel should be engaged in both design and construction. For large scale or high risk treatment works, effective site management and coordination are also of importance.

The treatment works described give a general picture of the local practices to handle the problem of boulder falls. Due to the complexity of the problem itself and the limited understanding of the mechanics of boulder movement, treatment works can only be regarded as reducing the likelihood of the boulder hazard. Even if conservatism is properly built-in, there is always a chance, slim though it may be, that the treatment works will fail to live up to our expectation.

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