Cylinder retaining walls

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Abstract – Design options for landslide toe support walls are limited in Nepal, where funds and expertise for sophisticated structures are generally not available. The article describes the background to an experiment to build a semi-rigid gravity wall of novel design, that incorporates mainly local materials and the use of hand labour for its construction. The wall consists of freestanding, cylindrical columns of cement-stabilised gravel. Its advantages are that it is easy to build, it releases ground water efficiently and it is capable of accepting differential settlement. The wall has supported an unstable slope for four monsoons so far, without appreciable deterioration.

A violent earthquake in eastern Nepal in August 1988 caused considerable damage to the Dharan-Dhankuta road and, it was feared, to a newly-constructed experimental slope retaining wall. In fact the wall was found to be intact and unaffected by a quake of magnitude 6.7 on the Richter scale, its stability being the first indication that the design could be proving a success. The wall is a prototype, built to demonstrate the feasibility of a new type of structure conceived by the Overseas Unit of the UK's Transport Research Laboratory. The Overseas Unit carries out research into road problems in developing countries for the Overseas Development Administration (ODA). The Dharan-Dhankuta road (Fig 1) was built under ODA's aid programme to Nepal and completed in 1982. Since 1984 the Overseas Unit has experimented with a number of slope stabilisation measures based on simple technology, of which the cylinder retaining wall is one.

The wall consists of a line of free-standing columns of sandy gravel, stabilised with 3 percent of cement by weight. The heavy, semi-rigid structure is an alternative to traditional masonry and gabion walls, which have shortcomings in Nepal's mountain environment. The Nepal government is expanding the road network into the foothills of the Himalayas, where the slopes are exceptionally unstable (Fig 2). Relief exceeds 1000m, and high temperatures and humidity weaken the rocks to produce a state of continual instability on slopes of 30-40°. The Dharan-Dhankuta road is constructed almost entirely in sidelong ground and is supported over most of its 52km length by gabion walls. In one or two places these are inadequate to retain wet debris masses and the cylinder wall was devised specifically for these very troublesome situations.

The requirement was for a gravity structure that could accept localised settlement without losing strength, but would not deform grossly under high lateral load – as does a gabion wall – nor crack like masonry. Good through-drainage was another essential feature. The structure would need to be simple to construct, in a country where engineering facilities are minimal. For example, the use of reinforced concrete in road construction is limited almost exclusively to bridge and culvert construction, the only areas where the high cost of steel and cement can be justified. The site chosen for the experimental wall was an ancient landslide which had overturned gabion walls on three previous occasions (Fig 3). While these walls were obviously built too small to retain the slide, it was clear that a gabion wall of sufficient strength would have to be substantial, and therefore that a different design might be appropriate.

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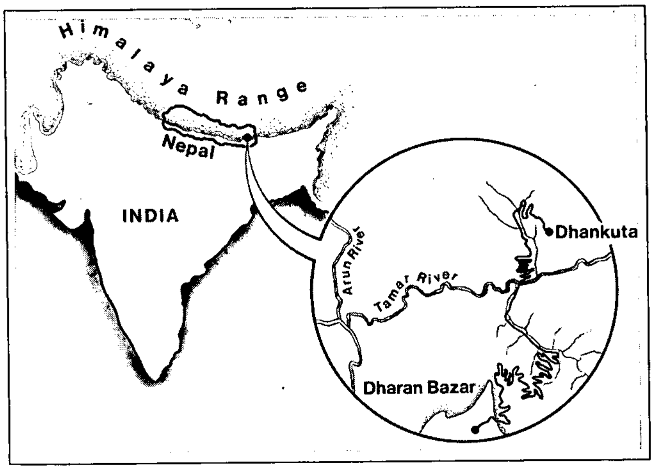

Fig 1 Nepal and the location of the Dharan-Dhankuta road

The first design

The initial design, built early in 1987, was based on that of a sandbag. Cylindrical columns of well-graded sandy gravel, 4m wide by 3m high, were compacted into a membranous skin, forcing it into hoop tension. The whole was expected to form a solid mass with a high resistance to shear. The skin consisted of sheets of 'Lotrak' geotextile to contain the fill, supported in a frame made of vertical reinforcing bars and horizontal hoops of gabion wire (Fig 4). Lotrak was used only because a quantity was available on site: the main aim at this point was to demonstrate the principles of design and construction. The cylinder was capped with 150mm of unreinforced concrete to maintain the shape. Holes in the cap allowed water to enter and make the fill as heavy as possible. A wall 37m in length, comprising nine cylinders placed 200mm apart, was constructed to this specification by Roughton and Partners International, the consultants responsible for maintenance of the road, with whom TRL are collaborating.

The wall withstood the landslide pressures for most of one monsoon season, but failed after a week of heavy rain during which 465mm fell (Fig 5). The wall failed by shearing of the fill. The skin was clearly not contributing to the shear strength of the cylinder, and once the skin had ruptured the fill poured out and the structure was destroyed within a few days by the slowly advancing debris mass. Despite this setback the design was felt to be intrinsically sound and potentially useful. The wall had resisted the forces of overturning and of basal sliding. It was also extremely freely-draining (between cylinders) and had been built efficiently by hand labour. It was decided that a full geotechnical analysis of the slope and the structure was justifiable, with a view to more accurately assessing the forces involved and producing a more balanced design.

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Fig 2 The foothills of the HImalayas are characterized by very deep valleys with highly erosive river systems. The hillslopes are near their limit of stability and periodic heavy storms trigger recurrent landsliding

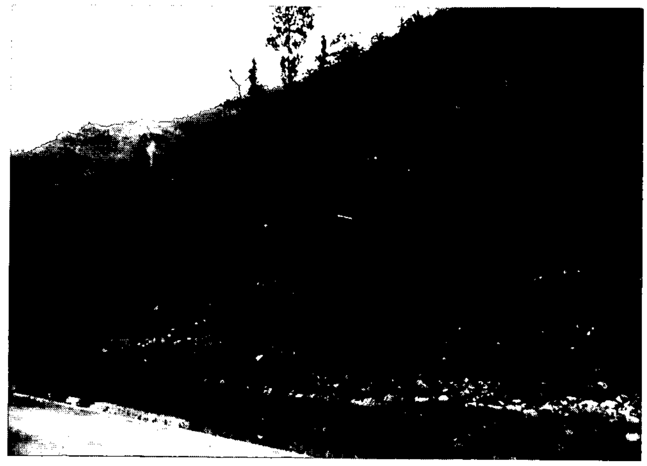

Fig 3 Landslide site and gabion wall close to failure, Nov 1985

The revised design

TRL appointed Babtie Geotechnical to investigate the failure and to design and construct a second prototype wall based on the concept of the first, if feasible. A large trial pit was excavated into the steep hillside behind the wall in January 1988. This revealed up to 3m of colluvium over weathered shale (Fig 6). The colluvium is a gravel, consisting of finely comminuted flakes of shale in a silty sand matrix (GF soil). At the interface between the colluvium and the rock is a thin band of grey micaceous and clayey completely weathered shale, dipping towards the road at 30°, parallel to the hillslope. Water seepages along the upper surface of the grey band show the layer to be relatively impermeable. All the ingredients were present for large landslide forces to be exerted on the

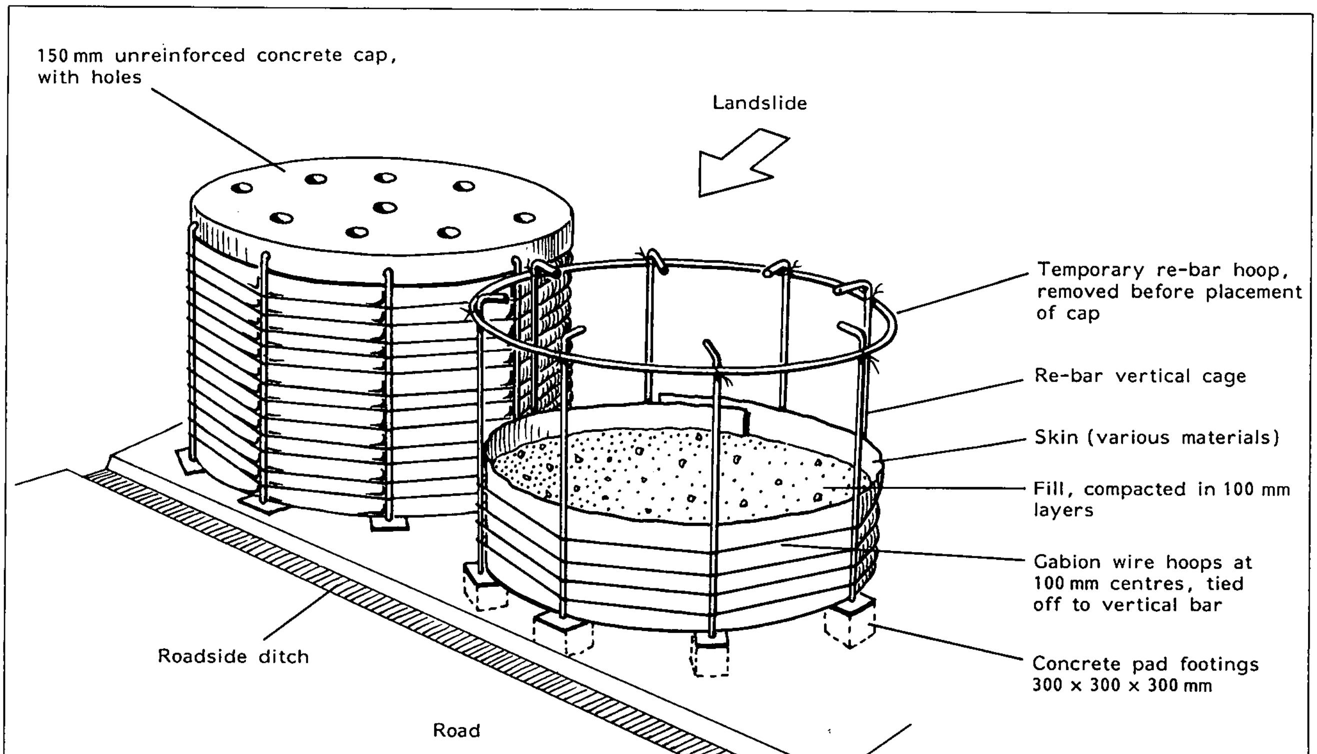

Fig 4 Schematic drawing of cylinder design and method of construction. The skin and fill are placed in lifts. In the revised design the structural concrete cap was replaced by a masonry weather capping

Fig 5 *The first cylinder wall in the early stages of failure, four months into the first monsoon season. During the following few days progressive movement of the landslide led to the destruction of the wall along half its length*

back of the wall. The micaceous band forms an adversely-dipping weak plane and would cause rapid build up of water pressure in the colluvium during the monsoon storms. Stability analyses confirmed that when the slope is wet the landslide forces would be greater than the internal fill of the wall could withstand, and that the wall would fail by internal shear (Fig 7).

Consideration was given to various methods of improving the resistance of the cylinders against internal shear. Stabilisation of the fill with cement was eventually selected as being the most practicable, although the choice was made somewhat reluctantly because cement is very expensive in Nepal. Even the small proportion specified doubled the total cost of construction. A proportion of 3 percent by weight was adopted, to give a 30-day unconfined compressive strength of at least 1 MN/m^2 and a tensile strength of at least 0.1 MN/m^2. A further disadvantage of cement stabilisation is that the permeability of the cylinder infill is greatly reduced, which would tend to allow water to accumulate behind the wall. The gap between cylinders had proved to be effective in releasing water, and this feature was retained as part of the design. However, to ensure that water is rapidly drawn to the gaps, a gravel drainage blanket was added behind the wall. This is held in at the gaps by a masonry plug with generous weepholes.

The size of the cylinders remained as before. Although the height of 3m was felt to be too low – in that if the slide moved the wall would be overtopped – it was thought that as the wall's efficacy had not been proved it would be better initially to adopt a conservative height to avoid the risk of overturning. Several types of outer skin were specified, in order to investigate the durability of local materials and the practicability of putting them up. As part of this study, some cylinders were provided with a weatherproof masonry capping while others were left unprotected.

A labour force of more than seventy men and women, including eight skilled masons, was assembled to construct the second prototype wall in May 1988. The workforce was spirited and keen and this contributed greatly to the success of the project. The work was set out and supervised by Babtie Geotechnical with the support of Roughton and Partners International. Simple on-site testing and monitoring was carried out to check the quality of construction of the cylinders. Before site work began, compaction tests were carried out in the laboratory to determine the optimum moisture content and maximum dry density of the mix. Stabilised soil cubes were prepared at optimum moisture content and tested at

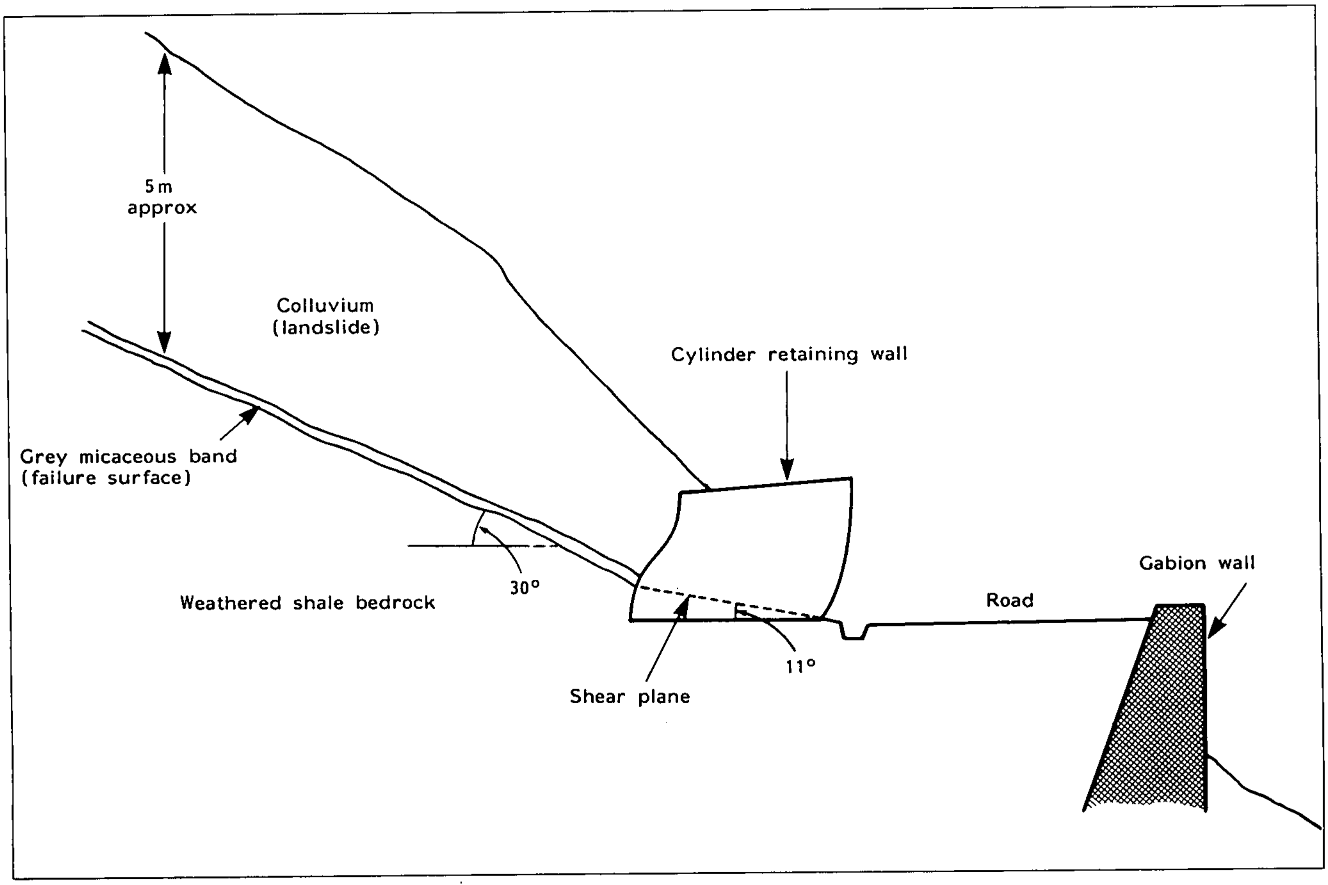

Fig 6 *Section through landslide and cylinder wall with unstabilized fill*

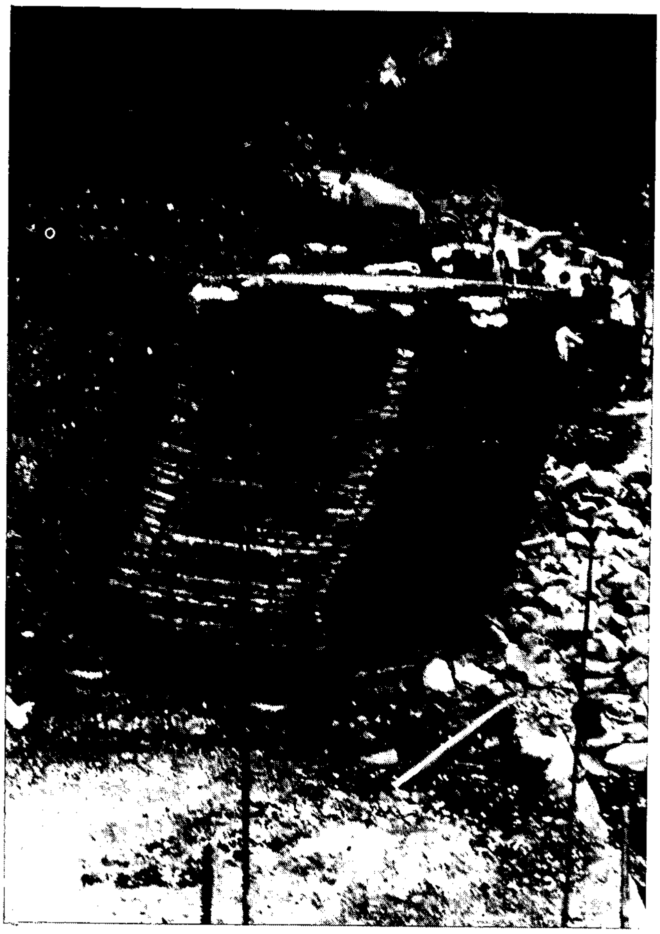

Fig 7 *Profile of failed cylinder wall during reconstruction*

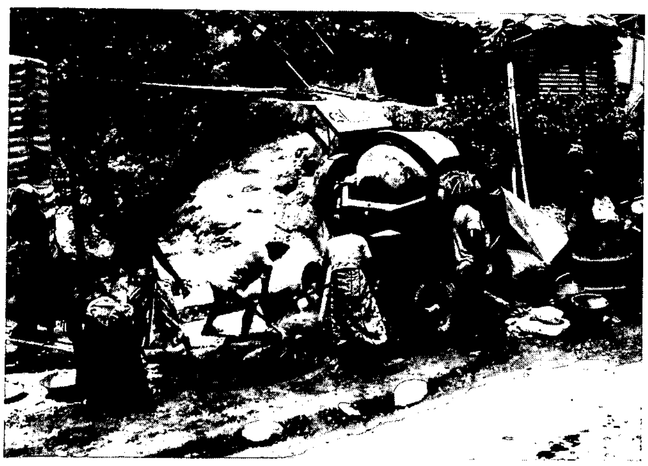

Fig 8 *Cement stabilized gravel being mixed and loaded into headpans*

3, 8, 10 and 30 days. The strengths obtained at 30 days confirmed the acceptability of 3 percent of cement. A Clegg impact hammer was used on the compacted samples to correlate impact values with dry density. These figures were then used to control the level of compaction in the cylinders, tested quickly and easily with the Clegg hammer as filling proceeded.

The site work was organised so that new cylinders were built one by one in place of the old, to maintain support to the hillside during construction. Most of the construction was labour intensive. Gravel fill and cement were delivered in batch

Fig 9 *Spreading and tamping cylinder fill material*

boxes to a mechanical cement mixer, then carried to the cylinders by head-pan (Fig 8) and compacted by hand tamper (Fig 9). A Caterpillar 950 front loader was used to remove old cylinders and prepare the site as this work was considered too dangerous for labourers. Construction of the 37m wall took a total of eight weeks, each cylinder taking about five days to build. The total cost of the wall was £11,000, which compared favourably with the cost of a gabion wall large enough to support the landslide. Such a wall would have to be 5m wide by 6m high and would have cost in the region of £17,500 to build.

Performance

The stabilised-fill cylinder wall has withstood four monsoon seasons without appreciable movement or deformation. Although the first two rainy seasons were not especially wet, the site was subjected to more than 150 mm of rain within one 24 hour period in 1988, shortly after the earthquake. Landslide debris has moved down and settled on top of the cylinders, reducing the angle of the toe slope, but not yet to a point where the surface is stable enough to allow vegetation to become established. Springs within the toe of the slide are still active, the fastest delivering about one litre of water per minute into the side drain during the monsoon.

Monitoring of movement of the wall and the degradation of the skins, and the condition of the landslide, will continue for several years to come. The question of the best skin type

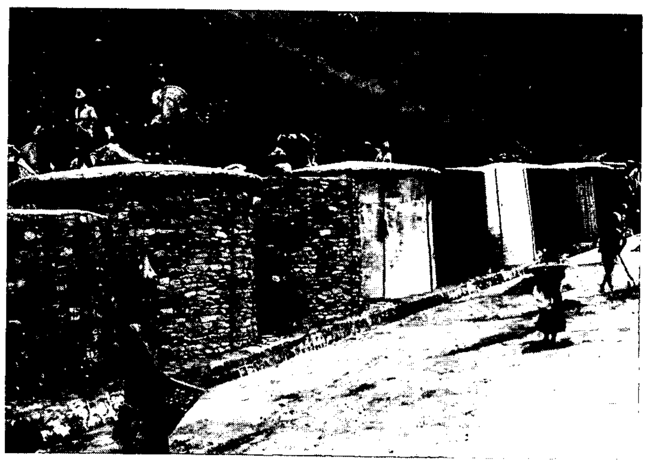

Fig 10 *The replacement cylinder wall nearing completion. From left to right the skin types are: two of dry stone masonry, three of galvanised steel sheet (one bitumenised), two of bamboo palisade (one bitumenised), and two without a skin (temporary polythene skin removed after curing). Caps on cylinders are made of mortared stone with a tile eave*

(see Fig 10) has yet to be settled. The skinless cylinder is the cheapest option but may in time suffer from degradation by surface weathering. The unprotected bamboo is already cracking and rotting. The sheet steel is expensive and may soon rust. The gabion-work skin is the most permanent and aesthetically the most pleasing. But it was the most expensive to build, and the length of time needed to put it up meant that horizontal construction joints had to be introduced into the fill, which could become planes of weakness under high earth pressures.

If the experimental wall continues to perform well consideration will be given to improving the design by such refinements as increasing the height-to-width ratio to enable it to support deeper debris, and utilising temporary shuttering for construction to minimise the steel components and reduce costs. If the application proves to be viable the cylinder retaining wall may become accepted as an additional design choice in situations where at present gabion and masonry walls are seen as the only alternatives.

Acknowledgements
The authors wish to pay tribute to the contribution made to the project by the late David M Brooks, Head of the Pavement Management Section of the Overseas Unit. His share in the conception, design and construction planning was equal to our own throughout.

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