



## WATER, ENVIRONMENT AND MANAGEMENT

### Design of hill irrigation in Chirang, Bhutan

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#### INTRODUCTION

The aim of this paper is to describe and explain some innovative designs adopted on the Chirang Hill Irrigation Project in Bhutan in the eastern Himalayas. The project aimed to improve about 80 farmer built canals during the period 1986-90, with financial assistance from the Asian Development Bank. These improvements were undertaken with extensive farmer participation, following standard designs. Some of these designs are similar to those used widely elsewhere, but this paper concentrates on others which are less common.

#### SETTING

Chirang District in southern Bhutan is dominated by steep hills consisting of mica, schists, gneiss, phyllite, quartzite and limestone, and valleys with streambed slopes from 5 to 25°. This results in flashy stream flows with high suspended sediment and bed loads of gravel and boulders during the monsoon. Catchment areas at the canal intakes are relatively small, so that there is generally a shortage of water for the irrigated area, except during the middle of the monsoon.

The farmers have constructed numerous small canals from these rivers across the steep valley sides (cross-slopes generally steeper than 35°), often in unstable weathered material. There are frequent landslide problems along the canal lines. The irrigated areas are flatter valley slopes where narrow bench terraces have been formed in the shallow clayey silt soils. These are found at altitudes from about 600 to 1400 m.

The area has a monsoon climate with about 80% of the annual rainfall occurring between June and September. Mean annual rainfall is about 1400 mm (ADB, 1985). The main irrigated crop is wetland rice, which is transplanted in June to July. Some farmers also grow wheat under irrigation in the dry season (November to May). The area has good road access and canals are generally less than 1 hour's walk from the road.

#### Previous irrigation systems

The earthen canals in this area are similar to those built by farmers elsewhere in the Himalayan region, with simple structures built of stone, earth and timber. From the river source, each canal runs by gravity along the river valley for about 1 or 2 km to the irrigated area. The poor soil banks, steep slopes and rudimentary structures result in high transit losses from the canals.

As well as conveying water from the river, the canal also collects water from the numerous springs, drainage channels and small streams which flow across it. The use of this water is agreed between the farmers, and when water is available, it is diverted into the canal, up to the limit of the canal's capacity.

Command areas vary up to about 70 hectares, but a typical canal supplies some 10 hectares of land belonging to about 10 farming families, who are often related. On each canal the water is generally taken by the farmers in turn, and distribution is by field-to-field flow. Under the project, a water user association was set up on each canal being improved, and the farmers elected a chairman, secretary/treasurer and water guard.

#### DESIGN APPROACH

##### Consultation

The project adopted a participative approach, as described elsewhere (van Bentum et al 1989 and Smout 1990). The intention was to maintain and strengthen existing patterns of responsibility, operation and maintenance. A canal was chosen only after a request from the farmers that their canal should be improved, and they participated in the selection of works and the construction, providing the unskilled labour without pay. The project provided skilled labour (masons), materials such as cement and pipe, and technical supervision. The farmers remained responsible for operation and maintenance.

##### Standard designs

Standard designs were developed for the project to simplify the design, quantity estimation and construction of the works. Each structure was designed in four sizes, to cover standard nominal discharges of 26 l/s, 56 l/s, 104 l/s and 164 l/s. These corresponded to four different lined canal sizes (0.3 to 0.6 m bedwidth) at a 1 per cent slope.

##### Problem areas

The work which could be undertaken to improve each canal was limited by the budget and by labour availability. The budget for materials and skilled labour was set at \$450 per hectare in 1986, which was the average cost used at appraisal of the project. The construction work had to be fitted in with the other demands on the time of the small number of farmers on each canal. As a result, work was concentrated on those problem sections of the canal which limited its overall conveyance capacity, for example unstable areas (often damaged by landslides) or seepage areas. The aim of the designs was to overcome the major problems

and seepage losses, so that water was conveyed reliably to the command area, within the constraints of budget and labour availability, rather than to produce canals which were fully engineered along their whole length.

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## SOLUTIONS

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A full description of the design procedures and structures can be found in the project Irrigation Manual (RGOB 1990). The designs adopted on the project included: a gated intake, with spillway and sand trap, to exclude floods and sediment from the canal; rectangular section cement masonry lining to reduce seepage losses; and aqueducts or culverts (superpassages) for cross drainage. Such structures are widely used on hill irrigation schemes, and they are not described further in this paper. A particular feature however was the emphasis on creating a stable bench for the foundations. This is detailed below, followed by descriptions of more unusual solutions adopted on the project: pipelines for conveying water across problem areas, level crossings for cross drainage, and offtake and footbridge structures within unlined canals.

### Construction of a stable bench

Frequently the existing earth canal was located within material which was either highly weathered debris on the rock face, or soil built up on a foundation of loosely stacked stone. Such material would settle and might fail at a later date, causing the failure of lined canal, pipeline or structures built on such foundations. Therefore this material had to be cleared and a stable bench formed on which to build the canal. This could usually be done where rock was exposed, or soil slopes were less steep and there was no evidence of earlier slope failure either above or below the canal alignment.

Rock ranging from good to moderately weathered would provide a good stable bench. A rock face could be distinguished by its common pattern of bedding or cracks, though joints might be filled with soil. Before cutting the bench, loose soil, rocks and trees were cleared from above the canal alignment. Drilling and blasting proceeded by cutting a step into the rock at the upstream end, and moving downstream parallel to the rock face to lengthen the bench. All rock loosened by blasting was removed, and the back slope cut back to less than vertical. The bench width was kept to the minimum required for the canal (Photograph 1).

Where slopes were easier and there was no evidence of slumping or slope failure, a stable bench could be formed by cutting back into the slope. If the excavated face appeared undisturbed and high seepage flows were not present then it should be stable. Where lining was to be constructed the back slope was cut back to prevent material falling into the canal. If falling debris or a steep back slope could not be avoided concrete pipe was installed and covered with soil, instead of lined open canal.

### Pipelines

Concrete pipeline was widely adopted in problem areas, for example on steep slopes where minor landslides had damaged earlier canals and in places where the canal width was restricted or where excess seepage would occur from an unlined canal. HDPE pipeline was also used, but this was

more than twice the cost of concrete pipe and therefore was limited to areas where a stable bench could not be formed and only a flexible pipeline would survive.

A concrete pipeline has the following advantages over cement masonry lining for crossing problem areas:

- requires a narrower bench cut in the hillside
- safe from material falling from above (if covered)
- if land movement occurs, and the pipe is displaced, it can be moved back into position and rejoined
- low labour requirements for installation
- uses less material (cement, sand, stone) than cement masonry, which partly offsets the transport requirements
- cheaper in some circumstances, especially if cement masonry lining would require a slab to cover the canal, or a retaining wall

Many lengths of concrete pipeline were installed on the project using pipes up to 300 mm internal diameter in lengths of 1.25m which could be carried to site (Photograph 2). Plain-ended pipes were used, which were obtained from a selected pipe factory, with quality control of materials and manufacture. The pipes were laid at a design slope to overcome the estimated friction and inlet/outlet losses at 1.25 x design discharge. Twin pipes were used if the head was limited, and for the larger canals. At design discharge the maximum velocity through the pipe was less than 1.6 m/s.

On site, a bench was cut to give a stable foundation for the pipe, and careful attention was given to pipe laying and jointing using collars and mortar (1 part cement to 4 parts sand). The farmers provided the unskilled construction labour, and so became familiar with the techniques. The pipelines were covered with earth or stones, to reduce temperature variation and to protect them from falling material. Inlet boxes were provided with a screen (50 mm opening - smaller sizes clogged too quickly) set away from the pipe to allow cleaning. In later designs a stone slab was added on top to prevent people putting things in the pipe. An outlet box was used to still the flow. The pipeline lengths were normally about 15 to 30 m, but for longer pipelines intermediate boxes were installed at maximum 30 m intervals to allow access.

The farmers' water guard was trained to clear the sand deposited in the inlet box and the trash collected on the screen. Pipe blockages were cleaned by pulling through a wooden disk slightly smaller than the pipe diameter, using two 30 m long ropes, each fixed to one side of the disk.

The pipelines are reported to have been used for four years to the farmers' satisfaction. Some pipes were damaged by falling material from above and repaired by the project masons during the construction period. It remains to be seen how frequently problems occur and whether farmers can repair them satisfactorily. This would be facilitated by making a stock of spare pipes available to the farmers.

The widespread use of pipelines was queried by some practitioners working elsewhere when case studies from the project were presented earlier (Smout et al, 1992). This solution was adopted with the farmers' agreement for problem areas, often across steep slopes where the previous canal had failed. The command areas were relatively small, allowing design discharges to be carried (with the 25% safety margin) by reasonable sized pipes. Also the pipe was factory made and installed under technical supervision, overcoming the quality problems which can occur with

manufacture on site and unsupervised construction. From the points of view of both the project and the farmers, the reduced labour requirement of pipelines was a major advantage.

### Level crossings

During inspection of the canal by the project staff and farmers, a cross drainage structure was located wherever a stream or drain crossed the existing canal. The level crossing was the selected type of cross drainage structure for small perennial streams with a low debris load where the stream could contribute to the canal flow. It was not used for large flashy streams which carried a lot of sediment in the wet season - in such cases the canal was passed under the stream in a culvert, or over it in an aqueduct.

In a level crossing the canal crosses a stream at the same level and flows into the canal so that at low flows the stream augments the flow in the canal, but high stream flows overtop the outer bank of the canal and continue down the water course. Compared to an aqueduct or culvert, the level crossing enables all the water in the stream to be used for irrigation, but the stream also carries sand into the canal, increasing the risks of blockage and overtopping downstream of the structure. Like other cross drainage structures, damage can also result during flood flows.

The standard design of the level crossing had the following features:

- an apron on the upslope side of the canal to collect water from the stream
- a spillway on the downslope side of the canal, to discharge excess water
- an orifice in the canal downstream, to prevent flood flows passing down the canal and to divert them over the spillway.

Both dry stone masonry and cement masonry were used in the structure, and the farmers could repair these fairly easily. They also needed to clear out material deposited in the canal.

Structure dimensions were agreed jointly on site. The width ranged from 1 to 3m and must be sufficient that the upslope collection apron can contain all the stream flow or seepage zone. The spillway crest level was set at the design water level in the canal, with the soffit of the orifice 0.05 m above this. In the case of large streams, the masonry orifice block was supplemented by a rock filled gabion or dry stone walling to prevent flood flows passing around the structure and along the canal alignment.

Where the level crossing was built on a hard rockbench, then the upstream apron comprised dry stone for erosion protection, with no downstream protection required in the stream. Otherwise on less resistant material, rock filled gabions were used to maintain the downstream bed level of the stream and trap sediment to support vegetation after construction.

In stream crossings where the contribution of flow was considered valuable but debris loads were too high for a level crossing, the canal crossed below the stream in a culvert and a side stream diversion was used at low flows, discharging into the canal upstream of a spillway and orifice block.

### Offtakes and footbridges

On the existing canals the farmers made offtakes by cutting

a hole in the earth bank through which water could flow to the fields. Clods of earth were used to open and close the gap. This was simple but had the disadvantage of scouring the canal and weakening the bank, leading to problems of leakage, overtopping of the bank and breaching of the canal at this point. Similarly, the farmers rarely built footbridges over the canals, as people and their animals could cross without serious difficulty. However this also tended to damage the bank, leading to the same problems.

To prevent the loss of water and risks of canal failure which result from these problems, offtakes and footbridges were installed along the whole length of the canals which were selected for improvement under the project, in sections which remained as earth canal as well as in lined sections. The position of the structures was agreed with the farmers during the survey and selection of works.

### Offtake

The offtake structure was a cement masonry structure with a standard 0.3 m wide opening, dropping onto large stones at ground level in the field, to prevent scour and erosion of the base of the structure. In earth canals a minimum 1 m length of cement masonry lining was provided upstream and downstream of the offtake. Grooves were provided in the opening and in the main canal downstream to assist the farmers in placing stones, earth, vegetation or timber to control the offtake.

This offtake is operated in the same way as the farmers' existing cut in the bank. They do not normally divide the canal flow, but distribute it by rotation, especially during land preparation for rice, and during winter cropping. It may be noted that proportional weirs are not used in this area, and the importance of reusing drainage water would make it very difficult to agree appropriate fixed divisions of the canal flow.

### Footbridge

The footbridge comprised a 0.10 m thick concrete slab, reinforced with wire mesh, resting on a 1.5 m length of rectangular lined canal. Initially, bamboo or timber was used instead of the reinforced concrete slab, but these had only a short life so the design was changed to concrete, which was generally preferred by the villagers.

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## CONCLUSIONS

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The project adopted a number of innovative solutions: benches cut in the rock to give stable foundations, pipelines to cross problem areas, level crossings for streams across the canal, and minor structures (offtakes and footbridges) to prevent damage to earth canals. These have all proved acceptable to the farmers, and they are proposed for consideration on other hill irrigation projects.

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## ACKNOWLEDGEMENTS

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Thanks for permission to publish this material are expressed to the Department of Agriculture, Royal Government of Bhutan and to the project consultants Booker Tate and Mott MacDonald.

**Photograph 1.**  
Construction of a bench and concrete pipeline



**Photograph 2.**  
Carrying concrete pipe to site

