CHAPTER 6

Conveyance Structures

A feature of most gravity irrigation systems in rolling topography is the considerable distance between the headworks and the command area. In some countries, this segment of the conveyance system is referred to as the "idle" canal since there are no outlets for irrigating fields. It is not surprising that most of the examples of structures in this section relate to problem areas in the "idle" segment of the conveyance system. Slopes are generally steep near the river or stream and the canal must often cross a series of difficult obstacles. Cross drains and unstable slopes are the most common problems.

Possibly the most difficult obstacle for farmers in constructing their own canals has been the need to traverse rock outcrops and cliffs. Though they have used ingenious methods such as heating rock faces with fire and cracking them by rapid cooling with water, labor-intensive methods using local technology have been a limiting factor for constructing canals in some communities.

Many of the examples in this chapter relate to the experience of improving structures in existing farmer-built systems. This usually means that the structure must fit with other components of the system that are not modified or improved. The modest nature of some of these structures is in keeping with the status of the remainder of the system. However, some examples are taken from the experience of constructing new systems and appear far more elaborate. It is important to recognize the difference in size among the systems in the examples. Access to resources for construction often relates to the size of the system, which has implications also for access to mechanical equipment, building materials not available locally, and skilled technicians for construction.

CONVEYANCE CANALS IN HILL AND MOUNTAIN SYSTEMS

Example 6.1 discusses the type of irrigation conveyance channel typically built by the Irrigation Department in the hilly areas of Uttar Pradesh. This is contrasted with some of the farmer-managed irrigation systems in Himachal Pradesh. This example gives an overview of problems that are discussed in greater detail in the remainder of the chapter. However, the experience with riverbed scouring and the method used to overcome the resulting problem of the canal at the headworks being higher than the riverbed are not mentioned in any of the other examples.

Example 6.2 illustrates a case where villagers had attempted and failed in constructing a difficult canal. With outside technical assistance and, particularly, using drilling and blasting equipment, it was possible to complete the canal.

An important issue discussed is the slope of the canal bed. The example indicates that agency staff had used canals with slopes steeper than the ones villagers traditionally used and that these canals had failed due to scouring. This must be understood in the context of the bed material. The section that is being referred to is unconsolidated scree. Local experience was clearly important in understanding acceptable flow velocities. However, engineers generally propose bed slopes that reflect their experience in lowland irrigation where topographic relief is limited. Lowland gradients are generally less than those traditionally used by farmers in mountainous terrain. Engineers also attempt to maintain a uniform gradient without drops for the entire length of the canal. In mountainous areas, farmers have learned to vary the slope to match the soil conditions. In rocky areas where cutting a large canal is difficult, they often use a steep gradient to minimize excavation and reduce the gradient when excavation is easy and high velocities would erode the canal. One method farmers frequently use in overcoming difficult sections, such as a rock outcrop, is to provide a drop in the canal to take advantage of an easier route. The loss of head may not be as important as reducing the cost of construction or maintenance that the drop allows.

STRUCTURES FOR CROSSING DRAINS

Cross drains are a major source of problems for irrigation systems in mountainous areas. Heavy rain causes small drains to become raging torrents for short periods but long enough to destroy the canal where it crosses the drain unless there is adequate protection. Unless precaution is taken, water from the drain will enter the canal and cause the canal to overtop and possibly erode an entire hillside causing enormous damage.

The level crossing discussed in Example 6.3 is a simple but effective structure in many situations when constructed properly. Figure 6.0.1 shows a level crossing with several defects. The sill level of the overflow is nearly at the same elevation as the downstream sidewalls. It should be lower and extend the entire length of the structure instead of being a small opening. In addition to improving the sill, discharge that enters the canal from the outlet end of the structure should be controlled. By adding a block in the canal at the downstream end of the structure with an orifice designed to limit the flow to no more than the canal design capacity, excess water will spill harmlessly over the overflow sill. Since cross drains are natural drainage ways, they should be utilized to dispose of all excess water in the canal.

A superpassage is a common and effective method for crossing drains with heavy bed loads. Example 6.4 illustrates several important points. The downslope side of the structure must be adequately protected or the structure will be undermined and will fail. A frequent mistake is made in the placement of superpassage structures. Figure 6.0.2 shows a superpassage built in Nepal that is set too far away from the hillside. The high velocity stream of water will excavate and eventually damage the upslope side of the structure. This also increases the drop on the downstream side making protection more difficult. The entire structure should have been shifted several meters toward the hillslope. This would have required additional excavation of the canal and structure but would have given better protection. Figure 6.0.3 shows a more satisfactory superpassage in Nepal where the structure is nestled against the rock. A trickle of water from the cross stream can be seen entering the canal through a small opening in the top of the masonry protection. During periods of high discharge the entire stream passes over the structure.

Figure 6.0.1. A level crossing in Nepal where the spillway crest is too high above the canal bed. The spillway should be wider and an orifice should be constructed to control drainage water entering the canal.

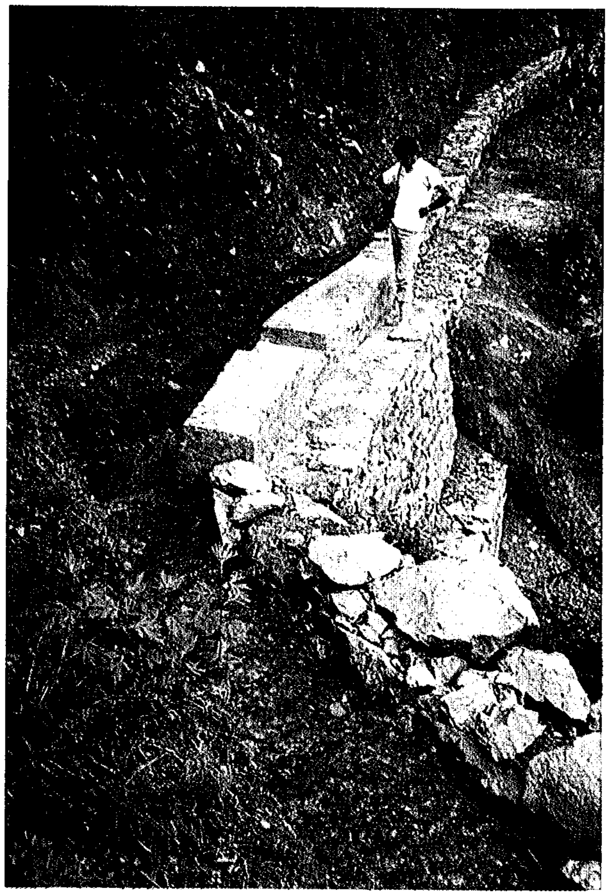
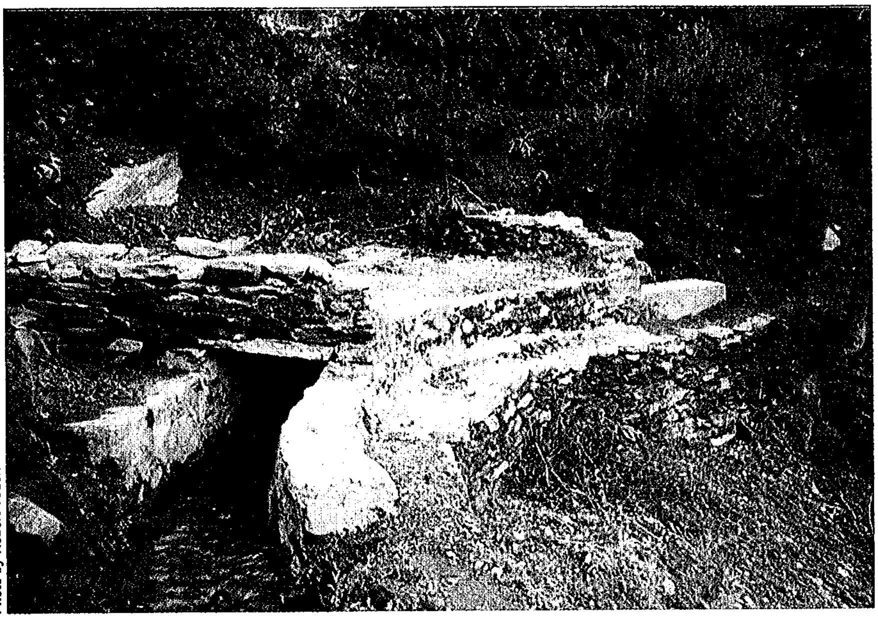


Photo by Robert Yoder.

Figure 6.0.2. Superpassage in Nepal that should have been shifted several meters toward the hillside.



Hollow logs have been used by farmers as aqueducts for centuries. Figure 6.0.4 shows a large log aqueduct being used in Nepal. This indigenous solution to crossing drains has been successful. Such log aqueducts are also frequently used as flow-limiting structures. All excess flow in the canal overtops the aqueduct and spills into the stream; a safe location for disposal of excess canal water. This factor must be remembered when new structures are built to replace traditional structures. However, deforestation is making it necessary to replace forest products with a viable alternative. Example 6.5 suggests a ferrocement option that needs to be explored further.

In Example 6.6, an inverted siphon was considered as an alternative to the suspended pipe aqueduct. Inverted siphons are frequently used to cross drains. If constructed properly and if maintenance can be undertaken regularly, inverted siphons are an important alternative to be considered. A note of caution, however is necessary. The high silt load of canals fed from mountain streams frequently settles in the siphon. If it is not cleaned regularly, the discharge will soon be reduced. If a valve is installed for cleaning, there must be provision for renewing the seals periodically or it will leak badly. A bolted cleanout cover on a tee section of pipe at the lowest point in the siphon is another alternative. However, bolts rust and wrenches of the correct size are seldom available in a remote area making routine cleaning difficult.

Figure 6.0.3. Superpassage in Nepal built against the hillslope.

Underpassages are sometimes easier to construct than superpassages but are not favored unless reliable information about the expected stream discharge is available. If an existing underpassage is being upgraded, and it has operated successfully

Figure 6.0.4. Hollow log used as an aqueduct in Nepal.

Photo by Robert Yoder.

for a long period of time, the size can be assumed to be adequate. If the catchment for a stream is small so that large errors are not likely in computing the runoff, designing an underpassage may be acceptable.

STRUCTURES FOR PROTECTING CANALS

The primary purpose of some structures in the conveyance system is to protect the canal from damage. While the siphon spillway of Example 6.8 has a singular purpose in limiting maximum discharge in the canal, other structures such as covered pipe and the bench flume serve several functions. They keep storm runoff and debris out of the canal while keeping the canal water from leaking out. In many cases, the protective action of lining, i.e., keeping the hillslope from becoming saturated which could result in slope failure, is more important than the improved efficiency that results from not losing water from the system by leakage. The structures described in Examples 6.8 through 6.12 all provide some measure of protection to the conveyance canal.

In many farmer-built systems, the farmers have learned by experience that it is useful to provide locations for diverting the entire canal discharge temporarily into a drain. If the canal has breached or temporary repairs need to be made without water in the canal, this saves the time necessary for traveling to the headworks several kilometers away to close the intake gate. Level crossings are frequently used for this purpose.

Controlling Discharge

The siphon spillway described in Example 6.8 is an ideal structure for larger canals. Several important factors need to be considered before selecting it for smaller canals. Experience in Indonesia with the same type of design indicated that it was useful in removing water at 2 to 20 m^3/s from canals. Scaling down the size would present difficult fabrication problems. Nonrigid material such as PVC pipe is not recommended. Reliable priming requires that a properly designed deflector be correctly placed.

Transition Structures

Transition structures such as the inlet box must include provision for blockages, which will inevitably occur. Particularly, this applies to structures that include a screen for preventing floating and suspended material from entering the next segment of the canal. When a structure blocks, the canal will fill and the entire discharge overflows. Unless provision is made for routing the overflow safely into a drain, the hillside could be seriously eroded and cause damage, even collapse of the canal. It is not reliable to depend only on regular cleaning to prevent blockage. The most likely time for blockage is during rainstorms when runoff carries leaves and other vegetative material and when access to the structure is difficult.

TUNNELS

Example 6.13 illustrates traditional tunnel technology employed by farmers in Bali, Indonesia for shortening their canal. In addition to being shorter, a tunnel has several other advantages. The stable situation of a tunnel generally reduces the seepage lost from the system. However, one of the greatest benefits is the reduced maintenance necessary since the tunnel is protected from damage by landslides and floods.

Farmers in many locations have recognized the value of having their canal underground. Figure 6.0.5 shows a canal in Nepal with segments that were moved underground. The purpose was not to shorten the canal but to protect it from damage by rocks falling from above and to reduce seepage from the canal. The canal is several hundred years old and has been repeatedly improved and enlarged. The present maximum discharge is about 350 l/s. The landslide-prone segments of the canal were difficult to maintain on the steep slope and so a tunnel was dug parallel to the surface about a meter underground. The holes in the cliff visible in the photo are openings into the tunnel which provided easy access while digging the tunnel and which are now used while desilting the canal.

Farmers managing the canal hired villagers with experience to do the tunneling for them. They were persons who in the past had worked with small-scale mining and were experienced in making and maintaining tools necessary for cutting and breaking rocks.

Figure 6.0.5. Canal in Palpa, Nepal with segments moved underground. Openings visible in hillside give access to the tunnel.

Photo by Robert Yoder.

CANAL LINING TO REDUCE SEEPAGE

Many types of lining are used to reduce seepage losses from canals. One concern is to save water that would otherwise be lost. Figure 6.0.6 shows farmers applying red clay lining to their canal as a temporary measure to reduce losses during a critical water-shortage period.

Figure 6.0.6. Red-clay lining applied by farmers as a temporary measure to reduce water losses from the canal during a critical water-shortage period.

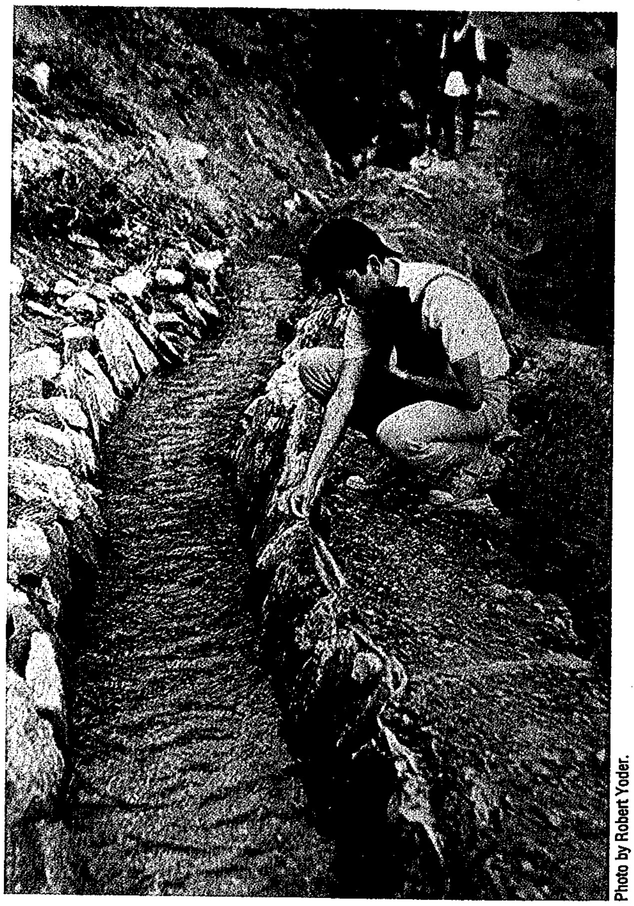
Another purpose of lining is to keep canal water from saturating unstable areas. Steep slopes that become saturated may slip due to the increased weight and lower internal friction. Some suggest that only flexible lining such as plastic sheet or high density polyethylene (HDPE) pipe should be used in areas where movement has occurred recently. The reason is that if rigid lining such as masonry or concrete pipe is placed through an unstable area and movement takes place, the canal will break and water will continue flowing causing serious damage before it can be shut off. After such a failure, broken masonry or concrete pipes are difficult to repair without suitable equipment and expertise. Although flexible lining may give little if any additional warning before failure, it may be easier to repair.

Consideration must be given to automatically shutting off the flow when the canal fails in a landslide. Using pipes that pull apart at a safe location for disposing the water down the slope away from the slide area should be examined.

Low-cost plastic sheet can be used as a temporary solution until a slope stabilizes. Figure 6.0.7 shows plastic sheet used to reduce seepage from a canal in a landslide area. The sheet is protected by earth covered with flat stones.

Soil cement, as described in Example 6.14, has been used with mixed success. Examples from the Philippines and Peru suggest that durability is a serious problem and use has been discontinued. The example from Nepal has not been proven

Figure 6.0.7. Plastic sheet used to reduce seepage from a canal in a landslide zone in Sindhupalchok, Nepal.



by years of use. It is included as an idea that needs further testing to identify under what conditions, if any, this low-cost lining method is effective.

STRUCTURES TO FACILITATE COMMUNITY LIFE

Irrigation design activities tend to neglect the nonagricultural use made of irrigation systems. In some communities, irrigation systems are the primary source of water for both human and animal consumption. In those same communities, bathing and washing clothes are additional uses.

Frequently, water buffalos are allowed to wallow in canals and cattle may stand in the water to avoid being bitten by flies. In other communities, irrigation canals are treated as sewers for waste disposal. In a similar fashion to the footbridge described in Example 6.18, other simple structures can be designed to facilitate community use of irrigation systems. Irrigation water cannot be recommended for human consumption, but lack of other alternatives will force continued use of irrigation water for many nonagricultural uses. Improving access will reduce damage caused to canal banks by animal and human traffic into the canal as well as making access more convenient.

EXAMPLES OF CONVEYANCE STRUCTURES

Example 6.1

Irrigation Canals in the Hills of North India

U.C. Pande[26]

Goal: *To convey water from steep streams to serve command areas of 10-50 hectares. Procedures used by the Irrigation Department and by the farmers are different; the Irrigation Department methods are based on the application of standard rules and criteria, and do not always satisfy farmers' practical needs, whereas farmers' design attitudes are more flexible and more innovative.*

The Setting

Before building a new system or improving an existing farmer-managed irrigation system, the Irrigation Department in Uttar Pradesh first investigates the quantity of water available in the source. There must be enough water available to irrigate a crop of wheat on part of the proposed command area in the winter. There must also be sufficient water during the dry season months of May-June to irrigate the rice nurseries. Having estimated the minimum assured quantity of water available in a stream, the Irrigation Department determines the area to be irrigated. This is based on standard water application spread uniformly over the command area.

The command areas in the hills of North India typically range from 10 to 50 ha. Because of the topography, the command areas are often long and narrow. The two main problems the Irrigation Department faces in operating such systems are conflicts over water rights and the damage caused to the canal by drainage crossings.

In the hill districts of Uttar Pradesh, in the past, villagers controlled irrigation water on the basis of prior rights. In 1975, the state took over all water rights. Even though rights now rest with the state,

26 Irrigation Consultant, New Delhi, India.

upstream villagers who use a system operated by the Irrigation Department often draw water without regard for the rest of the system. This violates the assumption of uniform benefits to users across a system.

In Himachal Pradesh, a complex web of water rights determines the size of the area served by a farmer-managed irrigation system. Some of the systems are very old. From experience, farmers have determined what areas can be irrigated with the available water and, in the past few decades, these systems have not been expanded. Knowledge of probable water availability at different times of the year has allowed them to develop a cropping pattern that is optimal in using the irrigation resource. This permits equity in sharing of water and ensures the best returns from land and water. When new area has been added by government-assisted improvements, only junior water rights are given to the newly irrigated land.

The Conveyance Canal

When a medium-sized stream is diverted into a canal, the canal must generally run for some distance in the flood plain of the stream. This length is exposed to damage by floods and the constant changes of the river course. On the smaller streams, this portion of canal is usually built using dry stone masonry both in farmer-constructed systems and in Irrigation Department systems. This can be easily repaired by the farmers when it is damaged. At times, the river-side parapet of the canal is raised to prevent flood waters from entering the canal. When larger streams or rivers are tapped, Irrigation Department-built systems are provided with expensive protection to reduce damage to the canal. Stream beds are easily scoured. This can lower the bed elevation below that of the canal at the diversion point and make it difficult to continue operation. To avert this situation, one of the practices adopted by the Irrigation Department is to provide a drop of 1 to 1.5 m somewhere in the first 300 m of canal. If the riverbed drops, the canal only needs to be cut lower in the section up to the drop to accommodate the change in the riverbed. If the scouring continues, it may be necessary to shift the diversion upstream.

Engineering staff in Uttar Pradesh usually assume that the maximum water requirement will be for growing rice and that 2 l/s/ha are sufficient unless the soil has a high infiltration rate or excessive slope. In such cases, the design discharge may be increased to a value between 2.5 and 3.5 l/s/ha. After allowing for seepage losses of 4.5 l/s/km in lined sections of the canal and 9 l/s/km in unlined sections, the design discharge can be determined.

A standard, uniform canal gradient is used. This is set at 4.5 m per km in the first kilometer followed by 3 m per km in the remaining length. In addition, a 1 to 1.5 m drop is placed near the diversion. Given the design discharge and gradient, the canal cross section can be calculated.

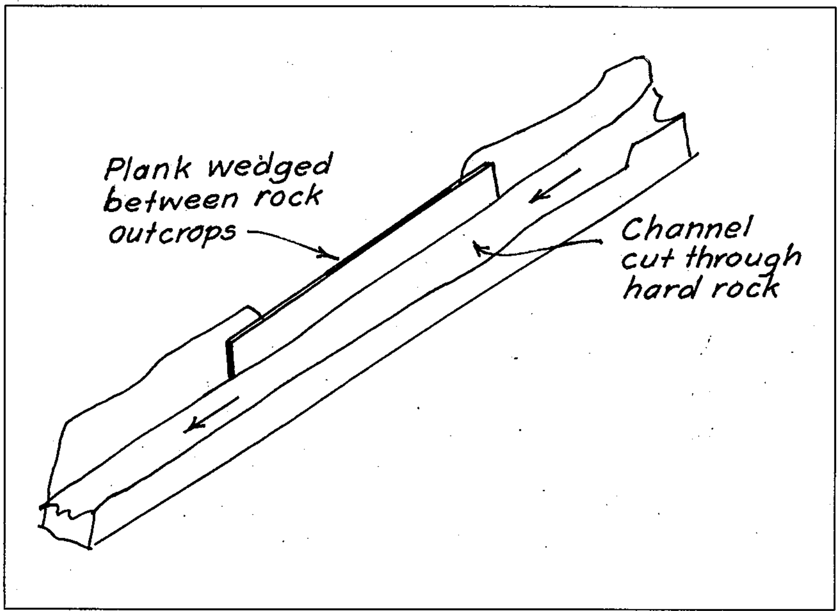
Canals operated by the Irrigation Department are usually lined with stone masonry or concrete. In some sections, pipes of cement concrete, asbestos cement, or mild steel are placed either at ground level or buried. The lined canals are designed to convey water in the most efficient manner. They are provided with 10-15 percent extra capacity for safety but since the cost is proportional to the size, they are built as small as possible.

This has caused a number of problems for the farmers. In cases where the command area is small, this approach has at times led to making the canal so narrow that farmers cannot use a shovel to clean the canal. The canal must be sized to accommodate the farmers' standard equipment.

More difficult is the problem of estimating water requirements for the crops. Farmers estimate water needs which exceed the amount the standard design of the Irrigation Department allows. If they want to divert excess water in the river to their fields, the canals designed by the Irrigation Department become a bottleneck. Frequently, the canals are damaged because farmers have tried to operate them above their design capacity.

Lined canals, if damaged, are expensive to repair. Repair of a masonry or concrete lined canal is an administrative burden which tends to be neglected by the Irrigation Department. The logistics of carrying out small quantities of work in scattered locations and controlling the quality of the work is often beyond the resources of the department.

Figure 6.1.1. Plank used as outside wall of channel to cross gap in rock.



Lining of some farmer-built canals has also proven to be counterproductive. In an unlined canal, the water velocity must be restricted to avoid scouring of the canal bed or large-scale erosion may result. This is accomplished by using a low gradient through erosive sections and correspondingly increasing the cross-sectional area. If department standards are used to determine the cross section for lining the canal, these segments become too small for the discharge that farmers are accustomed to using. Such systems deteriorate very quickly.

Farmer-built canals often reflect the innovativeness of the users. In the Himachal Pradesh District of Kullu, a canal was completely destroyed by a major flood in 1927. It had to be rebuilt as a half-tunnel section through difficult terrain in hard rock. In one section, it was not possible to build the outside wall of the canal. Figure 6.1.1 shows how a wooden plank was wedged between rocks to bridge the gap. By giving the canal a steep slope in this portion, the required cross-sectional area is reduced, decreasing leakage. The plank is still there and does not seem to have deteriorated in spite of long use.

Example 6.2

Aliabad Irrigation Channel, Hunza, Pakistan

Hussain Wali Khan[27]

Goal: *To convey 170 l/s of water from a glacier-melt flow across steep and loose terrain, to irrigate 700 ha of land, using low-cost methods appropriate for cooperative implementation by the labor of six benefiting villages.*

The Setting

The Aga Khan Rural Support Programme (AKRSP) follows an organizational approach for setting up sustainable village-level institutions called Village Organizations (VOs). AKRSP enters into a development partnership with the villagers. This is done through a series of dialogues between project staff and the villagers. The terms of partnership call for reciprocal obligations. The villagers must organize themselves into a VO, start a regular program of collective savings, and upgrade human skills. On its part, AKRSP offers a one-time grant to

27 Deputy General Manager, Aga Khan Rural Support Programme, Gilgit, Pakistan.

the VO for developing some type of productive physical infrastructure. Any type of physical infrastructure project is acceptable as long as there are equitable benefits to community members, and the VO is responsible for construction and maintenance.

In the example under discussion, the members of six VOs from Aliabad village had identified the need for a new irrigation channel. A channel already existed but was not adequate for irrigating all of the 650 ha of farmland already developed in the community. The new channel is to provide water for 60 ha of previously undeveloped land. The existing channel provided only 25 l/s of water. The new channel was to tap a new source of water.

Aliabad is located in the Hunza Valley of the Karakoram mountains about 100 km north of Gilgit town. The elevation is about 2,300 m. The area is in a rain shadow and receives minimal precipitation. All agriculture is dependant on irrigation. The climate is continental Mediterranean with cold winters and hot summers. December/January and June/July are the coldest and hottest months, respectively. Aliabad lies on the all-weather Karakoram Highway. Because of this, tourism-related businesses have developed rapidly, but the farmers realize that the local natural resources are their economic backbone, hence their desire for the irrigation channel.

Because of cold winters, only one major crop can be grown each year. Wheat, the predominant crop, is planted in March and harvested in August. Vegetables and fodder crops are also grown. After the wheat harvest, short-duration fodder crops are grown to utilize the remaining part of the growing season. There are strong crop-livestock interactions, with all farms keeping some livestock. On-farm forestry is also important.

The average household farm size is less than 0.4 ha. Generally, farmers have little agriculture surplus. However, some fresh and dried fruit along with vegetables and poultry surplus are marketed locally. There is a good market during the summer tourist season. Because of growing population pressures, Aliabad villagers gave preference for improving water availability for their existing lands, and development of some barren land in identifying a productive physical infrastructure project.

Figure 6.2.1 is a view from the channel looking down on the new land being developed. This land has been divided equally among the villagers. However, the process of land development is slow. The soil is sandy and full of stones and boulders. To build the soil, farmers plant alfalfa and nitrogen-fixing trees.

Figure 6.2.1. View of the undeveloped part of the command area from the new channel, Hunza Valley, Pakistan.

The Irrigation System

The water source for the new channel is the glacial melt from the Hassanabad *nullah* (ravine). The water available from the glacier ranges from about 150 l/s to over 1,000 l/s. The channel was built for a capacity of about 170 l/s. Figure 6.2.2 shows the relative location of the source and the command area.

Figure 6.2.2. Map showing the relative locations of the glacier, stream and command area of the Aliabad Irrigation Channel, Hunza, Pakistan.

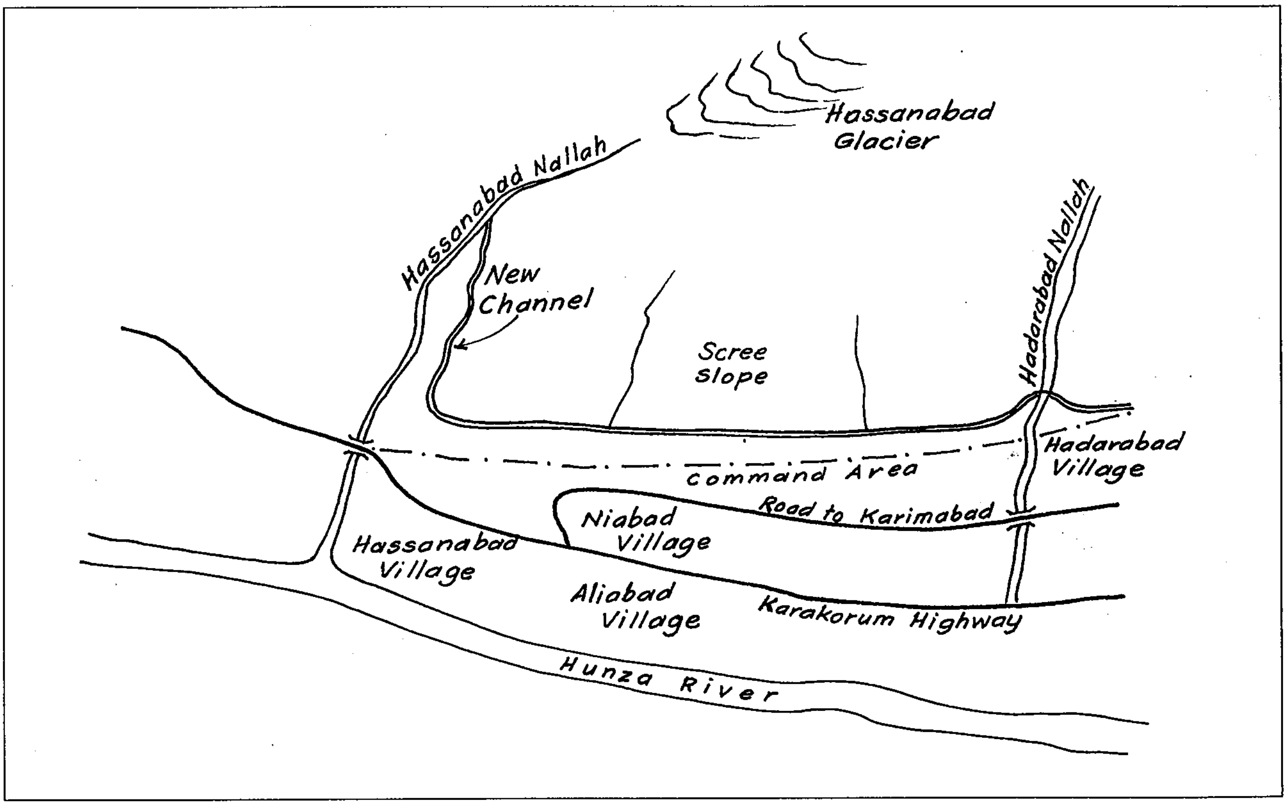
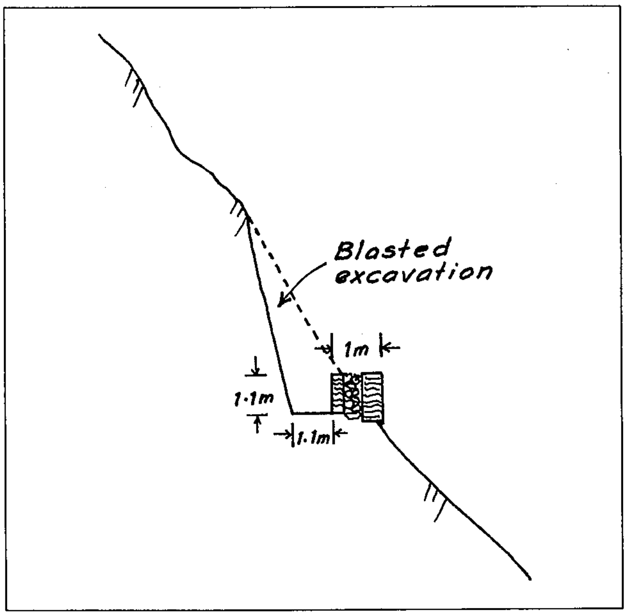


Figure 6.2.3. Profile of rock surface, blasted excavation for the channel and the channel embankment.



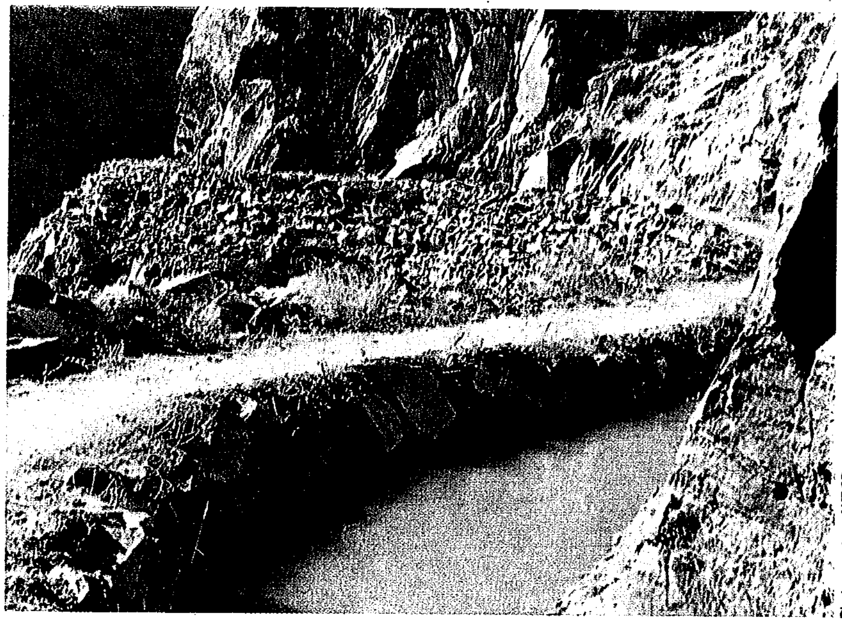
Work on the channel was initiated in 1984 and completed in 1988. With the completion of the new channel, the water available to local farmers has increased from about 25 l/s to nearly 200 l/s. The new water has been allocated to individual families within the system. A fixed rotational distribution, *warabundi*, was devised based on individual landholdings. Each household gets a turn after 18 days, with sufficient time to irrigate its fields.

The presidents and managers of the six VOs formed a committee to oversee the irrigation management system. The committee also solves local irrigation-related disputes. The six VOs have fully internalized the new irrigation structure. They are responsible for management, maintenance and repairs. The committee employs two watchmen, *chowkidars,* to look after the system from the diversion to the village. The committee pays the watchmen Rs 1,500 (US$88) per month.

The Irrigation Channel

Villagers joined AKRSP technicians in conducting an investigation of the project site. The joint team conducted a survey of the rocky area and decided that the project was feasible. While conducting a detailed survey, cross-sectional plans of locations

Figure 6.2.4. Completed channel in rocky area requiring blasting to create a bench for the channel, Hunza Valley, Pakistan.



Photo, courtesy AKRSP.

where blasting and masonry work would be required were drawn up. Figure 6.2.3 illustrates the rock cutting that needed to be done at some locations and Figures 6.2.4 and 6.2.5 show the completed work at two locations.

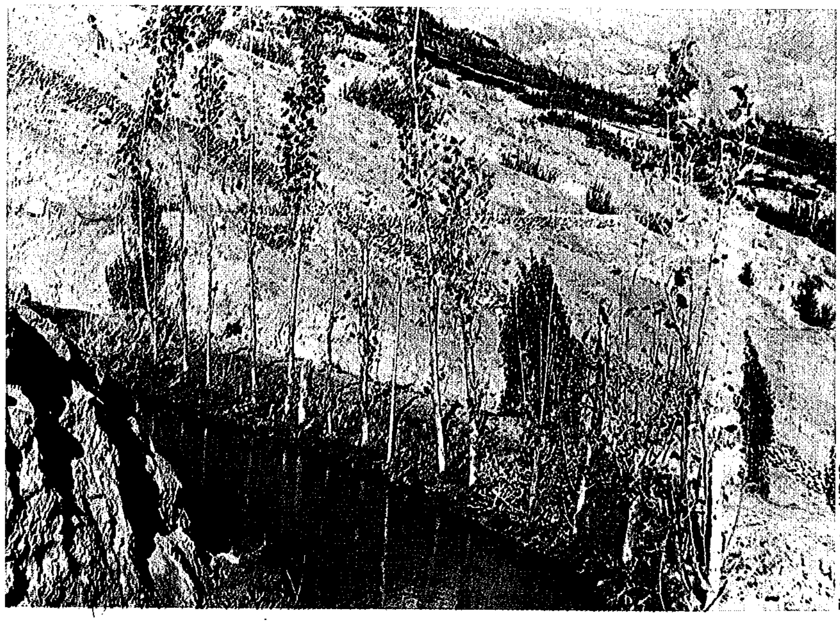
The total length of the channel is just over 9 km. Air compressors were used to drill holes for blasting. The work was difficult and dangerous; during construction three villagers died in accidents.

Local materials were used throughout the length of the channel. Because of the high costs of construction and maintenance an open, unlined channel was built. Masonry or concrete lining would be easily damaged in areas prone to slides and rock falls and it would be difficult and expensive for the villagers to maintain. To cross the Hadarabad nullah, stone slabs were used to cover the channel.

Selection of the appropriate bed slope and method for reducing seepage from the channel were two issues considered during design. Since the channel is only used in the summer months, there are no problems related to freezing.

Because the soil structure varies over short distances, "text-book" solutions were not applicable. There are several examples of irrigation channels constructed in the area by various state agencies that failed. They had a slope of 1/300. AKRSP engineers surveyed existing channel slopes in the area and found that the traditional practice was to have a slope of 1/1,000. While higher slopes are acceptable under certain conditions, they lead to rapid erosion in the scree area and destroy the channel. The traditional slope has a very low velocity. AKRSP engineers selected a slope of 1/600 as a middle option for the Aliabad channel. Figure 6.2.6 shows the channel crossing the scree.

Figure 6.2.5. Completed channel in rocky area with trees planted on the embankment, Hunza Valley, Pakistan.



Photo, courtesy AKRSP.

Figure 6.2.6. View of part of the previously developed command area with the channel visible as a line on the scree.

"biological cement" not only helps stabilize the channel, but also provides fodder and fuelwood. Though the seepage is not reduced, using it to grow a fodder crop means it is not entirely lost.

AKRSP provided a grant of about Rs 1.4 million (US$823,290) to the six VOs to complete the Aliabad Irrigation Channel. The scheme is operating successfully with clear benefit for the villagers. Combining traditional and engineering technologies in the approach followed by AKRSP engineers has been successful. Application of a "text-book" approach in the varied ecological and physical settings of the Karakoram mountains would have led to failure.

It would have been very expensive to construct and maintain lining necessary to control seepage. Since direct measures could not be taken, AKRSP engineers and experienced villagers decided that the channel embankment should be planted with forest trees and natural grasses (Figure 6.2.5). The

Example 6.3

Level Crossing for Channeling Drainage past the Canal in Chirang Hill Irrigation Project, Bhutan

Ian Smout[28], R.J. van Bentum[29] and Langa Dorji[30]

Goal: *To use low flows of lateral drainage streams to augment the canal flow, and pass higher flows across the canal; and to protect the canal against erosion, overtopping and sedimentation.*

The level crossing is a cross drainage structure where a canal crosses a stream at the same level. It is a traditional structure in which the stream flows into the canal so that the stream flow augments the flow in the canal, but high stream flows overtop the outer bank of the canal and continue down the hillside. This is the same project described in Example 5.8 and the details of the setting and irrigation systems are given in that example.

The structure was one of a number of works designed for the improvement of existing farmer-built canals. The farmers requested that their canal should be improved, and participated in the selection of works and the construction, providing the unskilled labor without pay. They remained responsible for operation and maintenance.

The Level-Crossing Structure

The level-crossing structure described here was designed for Bhutan's farmer-built canals which were being improved under the Chirang Hill Irrigation Project. The structure was intended to be built on improved canals where the stream was required to contribute to the channel flow, provided that it carried a low debris load. Compared to an aqueduct or culvert, the level crossing has a strong advantage in these circumstances because it enables the water in the stream to be used for irrigation. Also, there are no problems with pipes getting blocked. However, the stream carries sand into the canal, increasing the risks of overtopping. As in other cross drainage structures, damage can also result during flood flows.

The structure is shown in Figure 6.3.1. It has 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 downstream canal, to prevent flood flows from passing down the canal and divert them over the spillway.

The structure was designed to be built by masons and local farmers. Both dry stone masonry and cement masonry are used, and these can be repaired fairly easily.

Site investigation included walking the length of the existing canal with some of the farmers, identifying the problem areas, agreeing on the works to be carried out, and collecting information. The information included the length of the canal and the command area, which were used to decide the design discharge of the canal corresponding to one of the four standard canal sizes: 26 l/s, 56 l/s, 104 l/s and 164 l/s. A cross drainage structure was located wherever a stream or drain crossed the existing channel, and the required width for a level crossing was determined by inspection on site. The level crossing was the selected structure for small perennial streams whose flows could be utilized. It was not used for large flashy streams which carried

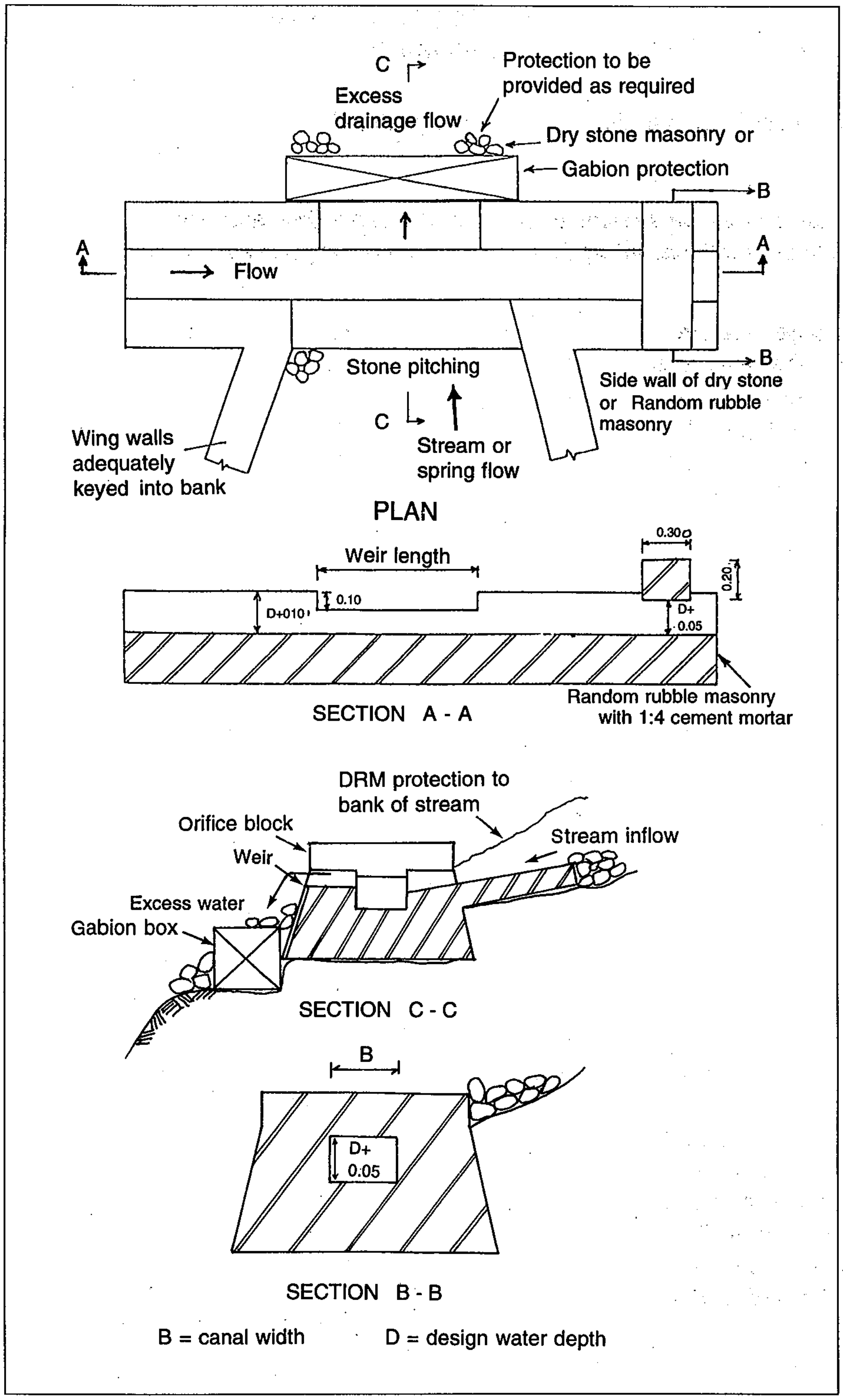
---

28 Lecturer, Water Engineering and Development Centre (WEDC), Loughborough University of Technology, UK.

29 Research Associate, WEDC, Loughborough University of Technology, UK.

30 Section Officer, Department of Agriculture, Royal Government of Bhutan.

Figure 6.3.1. Level crossing for drain, Chirang Hill Irrigation Project, Bhutan.



a lot of sediment in the wet season. In this situation, the canal was passed under the stream in a culvert.

The width of the level crossing must be sufficient to ensure that the upslope collection apron can contain all the stream flow or seepage. Low stream flows augment the canal flow; high flows pass over the spillway. The orifice block prevents the high discharge flows from passing down the canal. The spillway crest level is set at the design water level in the canal, and the height of the orifice gap between the canal bed and the block should equal the design water depth in the canal plus about 5 cm.

The farmers needed to clear out sand, gravel and trash which were deposited in the channel. The structure was successful in practice and could be valuable elsewhere for cross drainage in situations where there are shortages of flow in the canal.

Example 6.4

Superpassage Crossing for Side Stream, Kabhrepalanchok, Nepal

Christoph Morger[31]

Goal: To carry lateral drainage flows over a canal, in order to reduce maintenance and flow interruptions, and also to reduce losses due to seepage into the coarse material of the drainage stream bed. The solution used gabions, with stone-masonry for canal lining, and was implemented with farmers' own labor.

Irrigation canals in small hill irrigation systems usually follow the contour and cross many natural drains, i.e., gullies and streams. Each drain has different characteristics that must be considered in finding an appropriate way to allow the canal to pass safely. The example considered here is a superpassage consisting of a cement-stone masonry canal covered with reinforced concrete slabs. It is built on top of a gabion check dam across the drainage way. Stone masonry wing walls are provided to guide the side stream across the canal.

The Setting

Rice is the favorite crop of the farmers in Nepal. The typical crop rotation is rice during the monsoon with either wheat or potatoes in the winter from November to February followed by a pre-monsoon crop of maize or early rice in about half the area. The soils in the hills of Nepal usually lack the heavy texture and the low permeability of typical rice soils and additional irrigation is necessary to grow rice. The winter and pre-monsoon crops, at least during the important early growth stages, are entirely irrigated.

The superpassage described here was constructed in the Dhand Khola Irrigation System of Kabhrepalanchok District, Nepal. It is located at an elevation of about 750 m in the middle mountainous region of the Himalayan foothills. The climate is subtropical with a mean annual temperature of slightly above 20° C. The mean monthly maximum from April to September is around 30° C and the mean monthly minimum between December and February is approximately 5° C. The average annual rainfall is about 1,200 mm with high monthly variations. The Penman reference crop evapotranspiration is about 1,375 mm. Precipitation exceeds evaporation only during the monsoon period from June to September.

The Irrigation System

The irrigation canal was initially developed and operated by the farmers. The relatively steep gradient in the first 200 m of the canal and the lack of proper control structures caused scouring and frequent damage. Debris deposited during floods by two seasonal side streams often blocked and interrupted the canal flow. In 1987, the farmers asked the SINKALAMA Irrigation Programme for assistance to improve their system. This government project for rehabilitation and construction of hill irrigation schemes follows the policy that farmers organize the construction and participate in the work. The design, supervision, and part of the financing are provided by the program. The farmers using the canal are responsible for operation and maintenance of the irrigation system.

The catchment area of Dhand Khola is about 30 km^2 and the minimum flow during the dry season is between 150 and 200 l/s. Water is sufficient in the stream throughout the year with suitable land for irrigation being the limiting factor in

31 Irrigation Consultant, SINKALAMA Irrigation Programme, Kathmandu, Nepal.

expanding the system. The diversion is in the lower reach of the stream 2 km before its confluence with the Indrawati River. The bed slope in this reach of the river is approximately 5 percent. During the monsoon there are frequent floods carrying high bed loads. Because of this there is no permanent intake structure.

The head-reach canal is 450 m long serving a command area of 75 ha situated on a gently sloping alluvial fan. In the command area, the main canal follows the contour along the upper fan boundary. Soils are fertile and of medium texture. The major problems are in the head-reach segment of the canal where the soil is a sandy, gravel mix. This causes high seepage losses. Because of the slope the water velocities are high causing some scouring. Each of the seasonal side streams crossing the canal has a drainage area of about 100 ha.

The 75 ha command area is farmed by about 100 families. The village is served by a motorable gravel road. Local merchants purchase crop surpluses and market them in the Kathmandu Valley 60 km away. All decisions about production and marketing are made by the farmers. A water user group is in charge of operation and maintenance of the irrigation system. A committee organizes the necessary work and makes decisions about water distribution. Water allocation and maintenance obligation of individual families are usually on the basis of land area. No water use fee is collected. In the improvement project, farmers contributed 25 percent of the rehabilitation cost. This was done by paying 5 percent in cash and 20 percent in labor according to the rules for work supported by this assistance program. A government grant of 75 percent covers the rest of the costs.

The Superpassage Structure

An engineer and an overseer visited the site to collect information. They interviewed the farmers using a standard questionnaire. The canal was inspected together with a group of farmers and problems and possible solutions were discussed. Sketches of the longitudinal section of the canal and the cross drainage sites were made. The size of the command area was estimated and compared with the statements of the farmers.

The main problems of the canal were clearly the high velocities and the excessive seepage in the head-reach section and the two cross drains. Farmers suggested that if the canal were lined the high velocity would no longer be a problem and sufficient water would reach the command area in the pre-monsoon to extend the area of the spring crops.

It was decided to line the steep sections of the canal and to improve the two stream crossings by building two superpassages. Possible alternatives considered for the cross drains were passing the canal below the drainage using pipes and a canal with cement-stone masonry sidewalls covered with reinforced concrete slabs. Farmers in general have reservations about using pipes because their fixed cross section makes it difficult to increase the discharge and because they are difficult to clean if blocked. The side walls of an open channel can always be raised to increase the discharge capacity.

The head-reach canal was lined with stone masonry to reduce seepage losses. It was decided that the easiest solution for the cross drains was to provide cover-slabs at the crossings. The ancillary work required in each crossing was a gabion foundation for the canal and guide walls that confine the stream to the crossing point. Gabions were also used to protect the upstream side of the superpassage channel and to stabilize the bed level.

The design discharge was based on the peak water requirement for monsoon rice and the assumed percolation and system losses. The canal was designed for a 200 l/s discharge. The bed width of the canal is 0.5 m and the water depth varies from about 0.2 m to about 0.3 m for the lower gradient areas. The respective water velocities are 2.0 m/s and 1.3 m/s and thus permissible in a canal with stone masonry lining.

The superpassage channel was built entirely with stone masonry and directly on top of the gabion foundation (Figure 6.4.1). The design called for a masonry channel 0.5 m wide and 0.5 m high with the sidewall being 0.3 m thick. However, construction by farmers requires generous tolerances. They tend to make the canal somewhat larger than designed to allow increased discharge. In this case, the bed width turned out to be 0.6 m. The canal was covered with reinforced concrete slabs of 0.1 m thickness. The length of one crossing was 8 m and the other 6.5 m. Stone

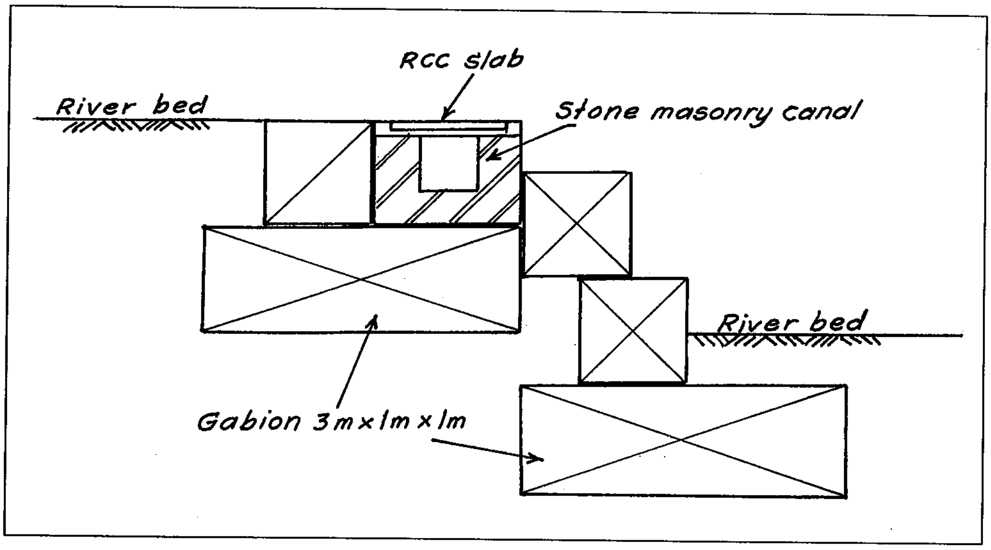


Figure 6.4.1. Cross section of superpassage used in the Dhand Khola Irrigation System, Kabhrepalanchok District, Nepal.

masonry guide walls were built to channel the water through the superpassage. Gabions were used to extend the sidewalls upstream (Figure 6.4.2).

Materials required for the 8 m long superpassage was 57 m^3 of gabions, 18 m^3 of cement-stone masonry and about 1 m^3 of reinforced concrete. The 6.5 m superpassage required 78 m^3 of gabions, 12 m^3 cement-stone masonry and 0.9 m^3 reinforced concrete. Total cost of the crossings was about US$2,400 each in 1988.

The structures require no special attention for operation. They are cleaned during routine maintenance. Since they were constructed, the interruptions in water delivery and emergency repairs have diminished considerably.

Figure 6.4.2. Completed superpassage in the Dhand Khola Irrigation System, Kabhrepalanchok District, Nepal.

Photo by S. K. Hyoju

Example 6.5

Ferrocement Flume in Syanja, Nepal

Dan Spare[32]

Goal: *To replace a traditional hollow-log aqueduct as a crossing for a ravine, because of increasing cost and difficulty of obtaining the traditional logs. The solution is an open parabolic flume of ferrocement, of 40 mm thickness, satisfying the farmers' constraint that it should be easy to clean and should not involve them in cash costs for maintenance.*

The Setting

The structure examined in this example is located in the Syanja District of Nepal. It is surrounded by the command area as in the project described in Example 6.14. A group of farmers have operated an old canal for many years to irrigate about 2 ha. Their source of water is a spring. The canal crosses a ravine before entering a 20 m long tunnel just before the irrigated area. The farmers have always had difficulty with the canal loop in the ravine because of a steep, and unstable cliff.

Ferrocement Flume

Originally a flume carved out of a large log was used to cross the ravine. This allowed runoff to pass under the aqueduct without harm. However, large trees are no longer readily available and have become very expensive. A few years ago the farmers had obtained some used 100 mm steel pipe sections and replaced the rotted wooden flume with them. However, the pipe limited the discharge and was sometimes blocked with debris. One larger-diameter steel pipe was considered for replacing the two smaller ones but this was found to be quite expensive considering the required size. Another alternative was a cable-supported HDPE pipe, but this also was considered to be too expensive without a suitable rock for anchorage. The ferrocement flume was suggested as an alternative, even though ferrocement construction methods were not known by local project staff apart from construction of buried drinking water tanks.

The solution to this situation was the construction of a 5.5 m long ferrocement flume with a parabolic cross section (Figure 6.5.1). A flume with a parabolic section was chosen for structural and hydraulic purposes. From the view of water conveyance, a parabolic section tends to be self-cleaning over a wide range of flows. Structurally, a parabolic section would give adequate strength with a minimum amount of cement plaster and reinforcement. The depth and top inside width of the flume were each 250 mm.

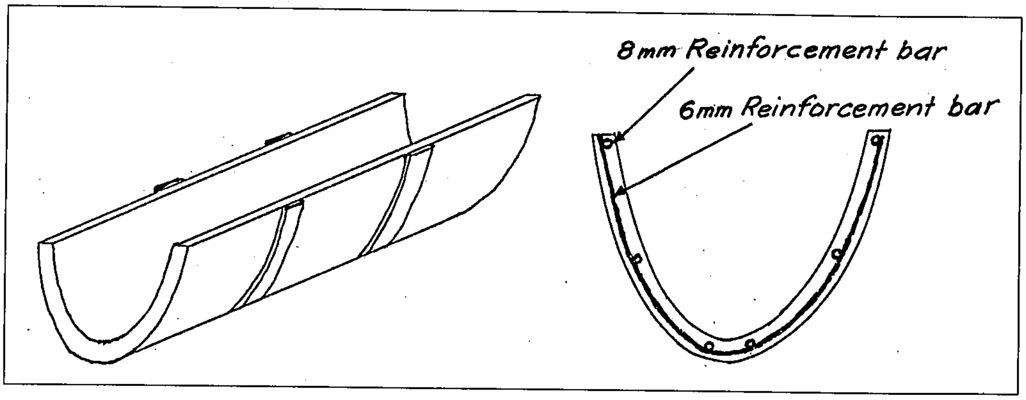
The primary "ferro" reinforcement used in this structure was six layers of fine chicken wire mesh tied to a framework of 6 mm and 8 mm reinforcement bars (Figure 6.5.1). The 6 mm and 8 mm diameter reinforcement rods were included in addition to the chicken wire in order to aid with construction and to reduce the possibility of buckling of the upper edges of the flume at the center. High quality sand was used to ensure integrity of the structure.

Construction of the flume was accomplished on the bed of the canal at a time when water was not flowing. A form was made out of soil so that the flume could be cast upside down. The steel bars and chicken wire mesh were laid over the soil form. Six layers of mesh were tied together and to the other reinforcement. This was quite tedious as chicken wire mesh does not easily lay flat and it was, therefore, not tied together as tightly as it should have been.

Cement plaster in a cement to sand volume ratio of 1:2 was applied and from the following day water was ponded on the structure for 10 days.

32 Irrigation Engineer, United Mission to Nepal, Kathmandu, Nepal.

Figure 6.5.1. Ferrocement flume in Syanja District, Nepal.



After this period of curing, a finishing coat of plaster was given to the inside of the flume.

After curing for five weeks, the flume was lifted into place by the farmers. Labor for delivering sand, cement, stone and other materials to the site was provided by the farmers. A mason was made available from the project to do the masonry work. Figure 6.5.2 shows the completed flume after it was set in place but before the ends were connected to the canal.

The flume was installed as a permanent, self-supporting structure on foundations at each end. A technician examined the site with the group of farmers using a level and a tape measure. Since this was an existing canal, it was simple to determine the necessary abutment elevations. The gradient between the abutments was greater than the slope of the canal because the original canal had looped all the way into the ravine.

The length of the structure could be shortened by building up an abutment on the upstream end. The downstream end already had a reasonable location for placement, and required only to be sealed with the canal, something the farmers had no difficulty dealing with.

This structure was permanently installed as part of the overall canal. The farmers clean and maintain the rest of the canal regularly and were prepared to include maintenance of this structure in their schedule. They were not interested in any structure that might require occasional financial inputs. They also preferred an open structure which would not be blocked with debris and which could be easily cleaned in case of blockage.

This structure has performed very well for the farmers. They have no complaints and a ferrocement flume appears to be a very practical technology. With refinement of construction methods and more detailed design, it is quite possible that it can be constructed with much less cement mortar, thus reducing the cost and weight. (Some literature advocates shell thicknesses of 15 mm.) Reduced weight would be advantageous, permitting ease of transportation. Most often, a good location for construction and curing is not

Figure 6.5.2. Ferrocement flume in Syanja, Nepal.

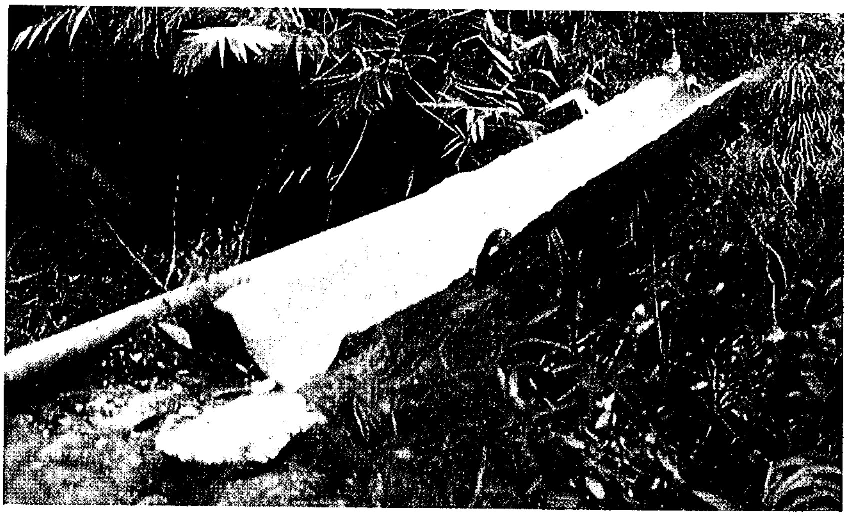


Photo by Dan Spare.

available near the site of installation. A light structure would also increase the ease of installation.

Flumes made later by the project in 1 m and 2 m lengths were constructed with one and two layers, respectively, of 14 gauge expanded steel mesh. This is a locally available product. For these, a steel frame was made and overlaid with a galvanized sheet to provide the inner surface of the form. This reduced labor considerably since it could be reused.

Example 6.6

Suspended Pipe Aqueduct for Crossing Ravine in Sindhupalchok, Nepal

Robert Yoder[33]

Goal: *To convey a small canal, supplying 33 ha of land, across a steep rocky ravine, using a direct crossing in order to eliminate 300 meters of the rock-cut canal bend which was difficult and dangerous for farmers to maintain. The solution used was to bridge the ravine with a 22 m plastic pipe suspended from a steel cable.*

The Setting

A gravity canal built in mountainous terrain must often cross streams in deep ravines. Open channel sections must loop deep into ravines in order to cross them at a uniform gradient. A ravine often has steep, unstable slopes making it difficult to maintain the canal. Frequently, the slopes are hard rock which is stable but which makes it difficult to excavate a bench for the canal. The canal segment crossing a stream is exposed to damage and siltation whenever it rains unless a structure is built to protect it. Alternatives to open channels that loop into the ravine are aqueducts at grade level supported by some type of bridge, or "inverted siphons" which are pipes that dip down and cross under the stream and then go up again to the level of the canal on the other side of the ravine.

This example describes a high density polyethylene (HDPE) pipe aqueduct used in a small irrigation system to pass the full discharge of the main canal over a stream in a ravine. The pipe was supported by a single suspended cable anchored to the rock cliff.

The irrigation system was originally built in 1972 by the farmers and has been operated and maintained by them without outside technical supervision. Steep rock walls in the ravine made it difficult for the farmers to maintain the open channel they had constructed as it looped deep into the ravine. When it rained, the stream frequently washed out a section of the canal. A government project for improving farmer-built irrigation systems assisted the farmers with the design and construction of an aqueduct to cross the ravine. The work was completed in 1989. The farmers have full responsibility for operation and maintenance of the entire system.

The Irrigation System

The structure being described is in an irrigation system located in the Himalayan foothills of Nepal at an elevation of about 1,000 m. In an average year, this area receives over 1,500 mm of rainfall. Most of the rain falls during the warm monsoon period from mid-June through mid-October. There are usually several light showers during December and January. This is the cold season when nighttime temperatures are near freezing. April and May are usually hot and dry.

33 Associate Specialist, International Irrigation Management Institute, Colombo, Sri Lanka.

In this part of Nepal, the preference is to grow irrigated rice during the monsoon. Because the farmers found it difficult to maintain this system during the rainy season, prior to system improvement, they grew rain-fed maize in the monsoon and only repaired the system to irrigate winter wheat and some potatoes. There was no road access to the command area until recently when a motorable road was completed. This road can be reached on foot within an hour. The farmers make all decisions regarding crops and carry inputs such as fertilizer from the nearby road.

The water source for irrigation is a small stream that has a discharge less than 50 l/s during the dry season but a base flow of 150-200 l/s during the rainy season. The stream has a steep gradient but is entirely fed by rain and spring water since there are no snowfields in its watershed. Floods cause frequent damage to the canal diversion and carry heavy silt loads. A canal about 3 km long conveys the water along steep mountain slopes and winds in and out of several deep ravines. Some areas that the canal passes through are unstable; landslides frequently break the canal. Other sections of canal had been cut into rocky cliffs. The command area is terraced and on a relatively steep slope with well-developed drainage throughout.

The irrigators live near their fields. As is typical in the hills of Nepal, the average landholding is less than one hectare. In addition to plots of land in the command area of the irrigation system, many farmers own small plots in other locations as well. Some of these plots are irrigated by other systems but much of the land is under rain-fed agriculture. Farmers of the command area have little if any surplus production to market.

With improvements made through government assistance, the command area is expected to increase from the present 13 ha to 33 ha and increase irrigation during the rainy season for two irrigated crops each year. Two methods were used for determining the size of the command area. Each farmer using water and every potential water user was asked to provide details of land he or she owned within the command area, and another estimate of the area was made using a 1:25,000 scale cadastral map. The design was based on the larger of the two results.

The area irrigated is constrained by the water available in the source. Several systems divert water from the same stream. Each system is entitled to all of the discharge in the stream at their respective diversions. Each system is dependent upon the water supplied by springs between system diversions and on excess flow not captured by the diversions upstream.

Within the system, water has been allocated to individual farms in proportion to the landholding of each family. Since the system improvements, water distribution is continuous to the twelve outlets from the main canal during the rainy season. Usually, the water is then distributed by rotation from one family's landholding to the next within the branch canal. During the dry season and when available discharge is low, the entire flow in the main canal is rotated from one branch canal to the next.

The farmers have formed a user organization and elected officials to manage the irrigation activities. Outside technical assistance and support were only for design and construction of improved structures and training in user organization; there is no continued support available for operation and maintenance. All resources for operation and maintenance must be mobilized from the users and they must manage conflicts on their own.

The Suspended Pipe Aqueduct

The farmer irrigators who built and operate the canal accompanied the technical staff during site investigation to select a site where an aqueduct could be constructed across the ravines. They pointed out the difficulties in cutting the canal into the rock cliff of the ravine and explained the experience they had in dealing with flood damage to the canal by the stream in the ravine.

The site was determined by choosing suitable locations for anchorage foundations on both sides of the ravine that minimized the span length. Sketches were made of the plan and cross section of the ravine, stream, and canal using a measuring tape and a level to provide accurate dimensions.

At the location most advantageous for an aqueduct, the loop of the canal could be shortened by 300 m. The first alternative considered was improving the canal section of the existing loop into the ravine and providing a superpassage for the stream to cross over the canal without damaging it. All 300 m of canal needed to be cut into the rock cliff for stability. The farmers were able to assist in estimating the time and labor required to improve the canal as it looped through the ravine and the technicians estimated the cost of the superpassage.

To span the ravine, a 22 m long aqueduct was required. Pillars to support a simple bridge to carry an open channel or pipe aqueduct were considered. However, the location of the foundation for pillars was susceptible to erosion by the stream and the depth of the ravine required pillars more than 4 m high, making this approach unacceptable. A truss bridge was considered but found to be far more expensive than improving the canal.

Since the canal carried a heavy silt load, a siphon would require a method for opening the pipe at its lowest point for cleaning. This was not considered manageable by the farmers with the resources available to them. The lowest-cost, low-maintenance solution proved to be an HDPE pipe aqueduct suspended from a single steel cable. The HDPE pipe sections could be permanently joined by heating the ends of the pipe to a specified temperature with a heat plate and then pressing the ends firmly together. The design called for anchoring the cable directly to the rock cliff on one side and using a gravity anchor block on the other.

The only hydraulic design consideration was selection of the appropriate pipe size. The design discharge, length of pipe, inlet and outlet losses, pipe friction loss, and available hydraulic head were the essential parameters. The design discharge was based on expected crop water requirements for the full development of the command area. Inlet and outlet losses were deducted from the available elevation difference between the inlet and outlet of the aqueduct to determine the hydraulic head available. The pipe size was then determined by using pipe flow equations and assumed friction losses. This process confirmed that a 250 mm diameter HDPE pipe was adequate for this application.

Factors considered in the structural design included the total load, point load, sag and stability during high winds. The loads and sag were considered in selecting a 1/2 inch diameter cable for supporting the pipe. On the upstream side, it was possible to anchor the cable with grouted anchor bolts directly to the cliff at the correct height. On the downstream side, a gravity anchor block and masonry tower were proposed. During excavation for the anchor block a massive boulder was encountered and the cable was anchored to it with grouted anchor bolts and a masonry tower constructed on the boulder to give the correct height to the cable. Guy wires were attached to keep the pipe from swaying in the wind. The inlet end of the pipe was fixed in masonry but the exit end was free to reduce stress caused by movement of the somewhat flexible structure (Figures 6.6.1 and 6.6.2).

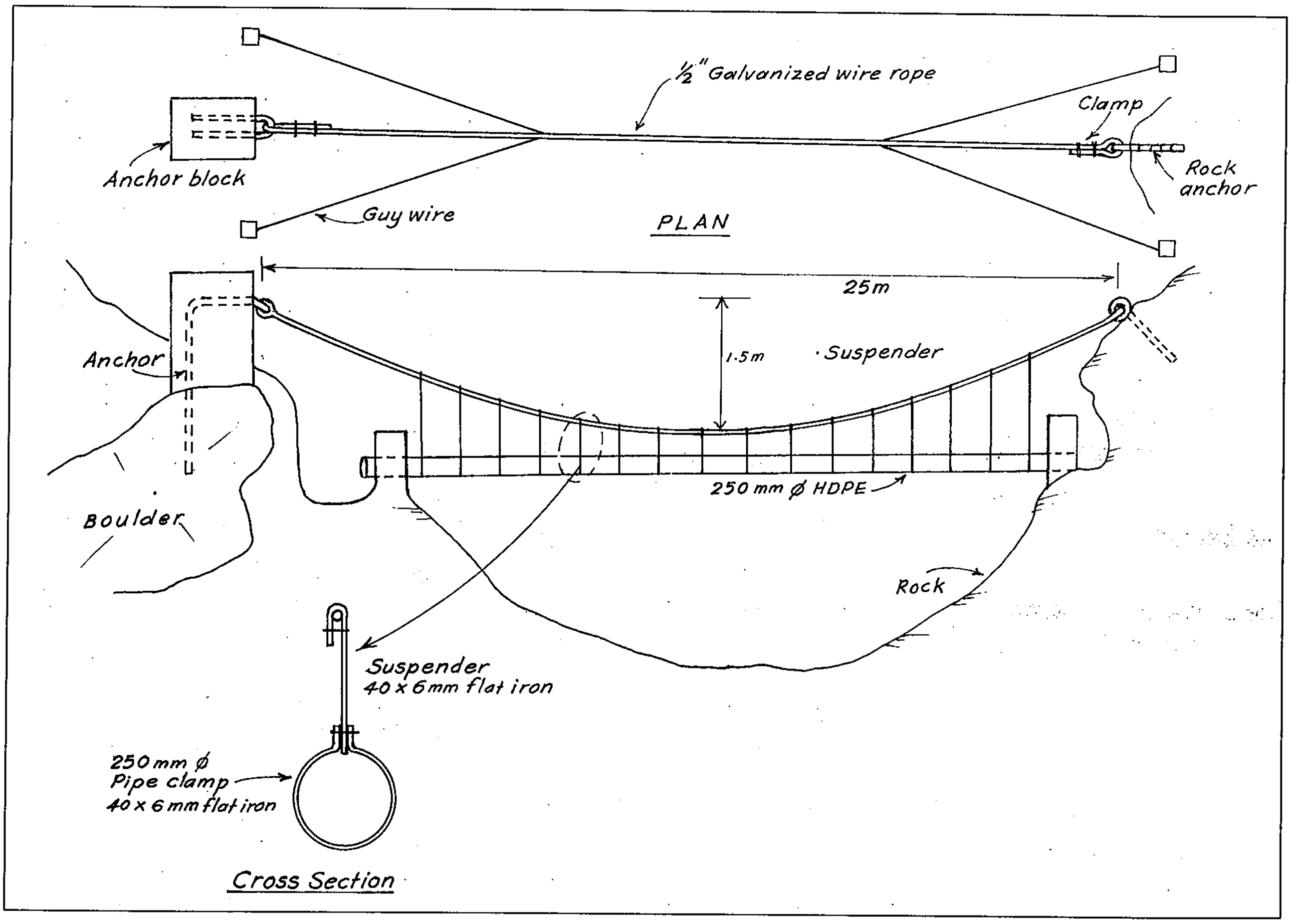
Though the suspended pipe aqueduct required skilled supervision of labor from outside the community for installation, the transport cost was low and erection time was short. The total cost of installation of the aqueduct including materials, supervision and labor was about US$1,000.

The existing canal was shortened by 300 m by using the aqueduct. This resulted in substantial elevation difference between the inlet and outlet ends of the aqueduct and allowed the pipe to

Figure 6.6.1. Suspended pipe aqueduct in Sindhupalchok, Nepal.

Photo by Robert Yoder.

Figure 6.6.2. Details of the suspended pipe aqueduct, Sindhupalchok, Nepal.



be placed at a relatively steep slope. This was beneficial in allowing a smaller diameter pipe which makes the structure lighter, reducing structural requirements and cost, and making it easier to install. It also prevents the deposition of silt in the pipe. However, the high velocity discharge at the outlet eroded the canal wall when operation began. This problem was solved by adding a simple outlet structure to dissipate the energy.

Though the aqueduct did not provide a convenient walkway, persons walking along the canal found it easier to cross on it than to climb down through the ravine. This caused the pipe to bounce and the fixed upstream end to develop a leak. Barriers were placed to discourage persons from using it as a bridge. Otherwise the structure has performed as expected and the irrigators are pleased with it.

Example 6.7

Reinforced Concrete Aqueduct with Collapsible Side Bunds, Sindhupalchok, Nepal

L. N. Bhattarai[34]

Goal: To convey a canal across one of its source streams, at a point where the available clearance above the stream is not enough to ensure that the bridge will not obstruct high stream floods. The chosen solution, to minimize the obstruction and to ensure maintainability by farmers, was to build only the base slab of the aqueduct as a permanent structure, with renewable masonry side walls which will collapse in the event of a high flood.

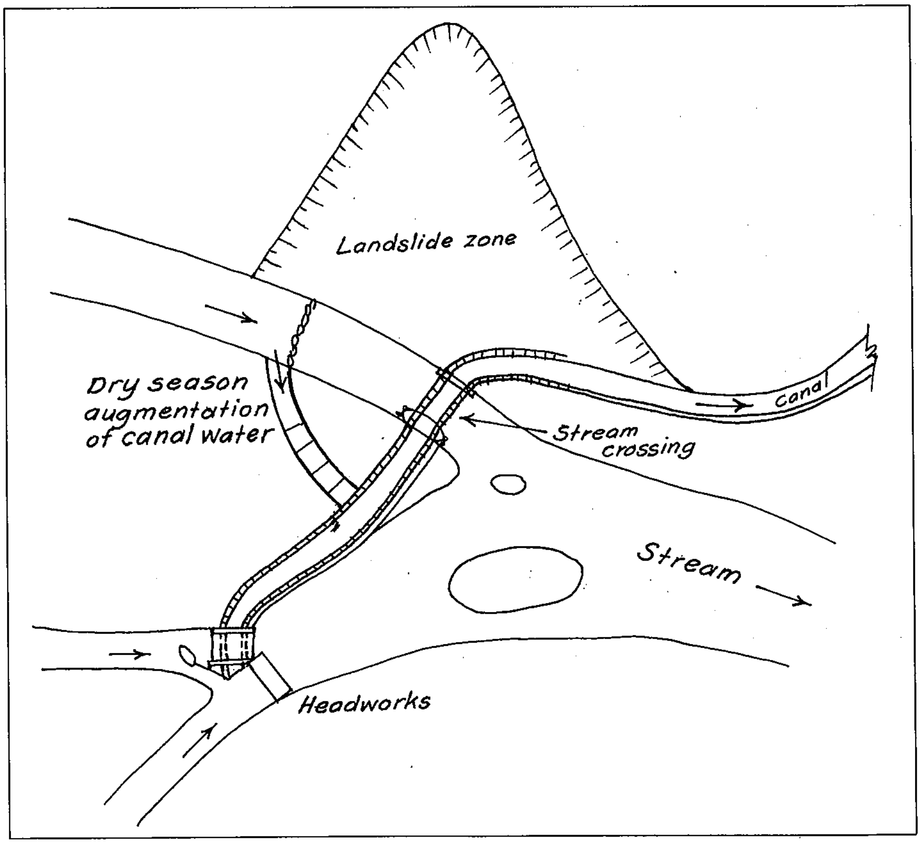
The Setting

The setting for this example is the irrigation system diverting water from the same source and immediately upstream of the one described in Example 6.6. The system was originally built by the irrigators and all operation and maintenance activities continue to be the responsibility of the farmers. The command area is 37 ha. The aqueduct described in this example was built at the same time and by the same project as the suspended pipe aqueduct described in Example 6.6.

The Reinforced Concrete Aqueduct

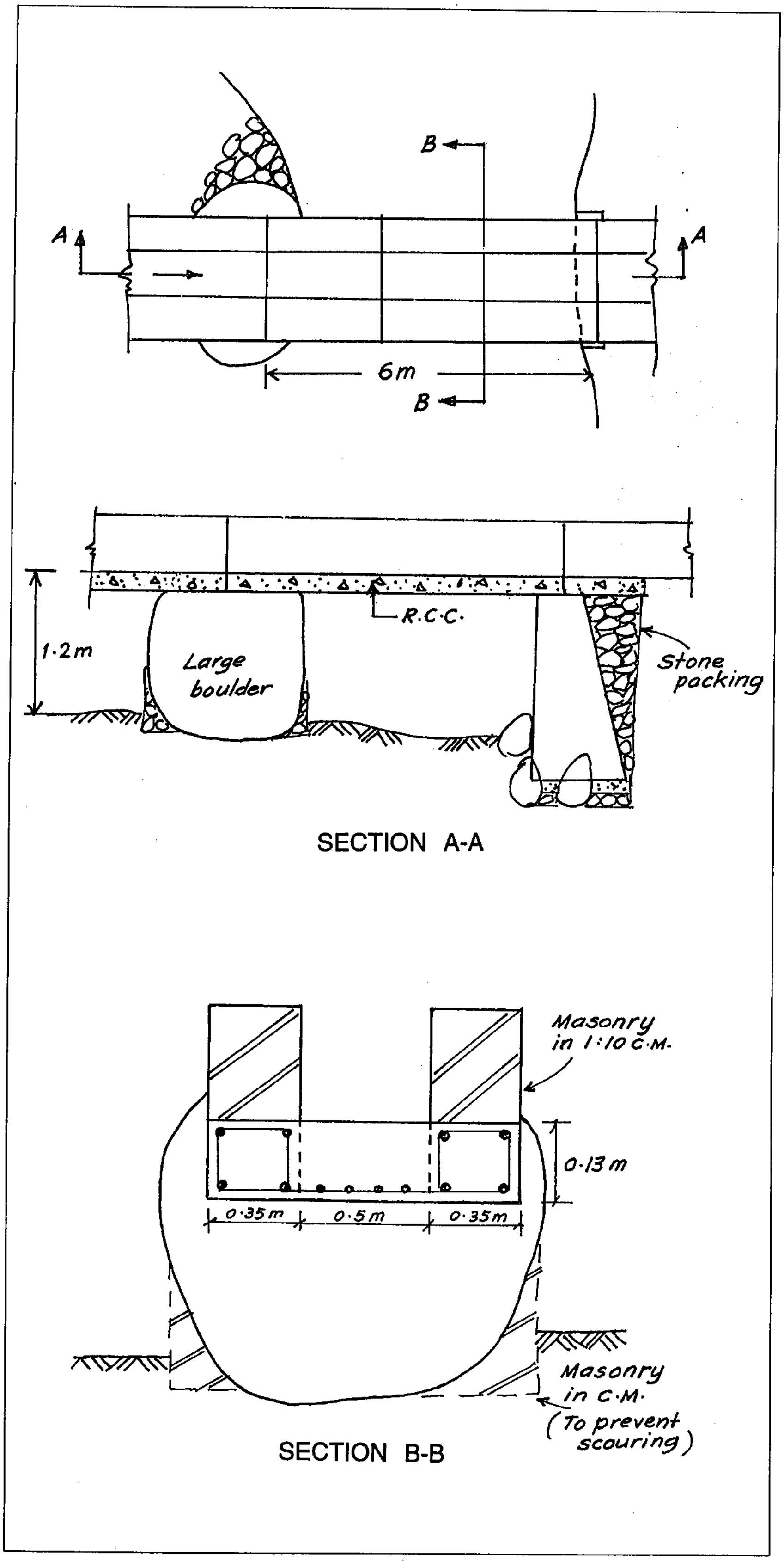
About 30 m down the canal from the intake, a small side stream crosses the canal. The farmers requested that the project assist them in building a structure to protect the canal from the frequent flood damage caused by this stream. The flood discharge was estimated to be in the order of 1.5 m^3/s according to the information given by the farmers and high water

Figure 6.7.1. Plan view of the headworks, stream crossing and landslide area, Sindhupalchok, Nepal.



34 Engineer, Hydro Engineering, Kathmandu, Nepal.

Figure 6.7.2. Details of the reinforced concrete aqueduct with collapsible side walls.



marks, but large boulders in the stream bed that are periodically moved by floods are evidence that the discharge may be much higher for short periods.

The design discharge for the canal was 150 l/s. However, dry season discharge in the primary source is very low and all the water available in the secondary sources is also tapped by the farmers.

Figure 6.7.1 shows the layout of the stream and canal. In addition to the danger from floods, there is evidence of land movement on the left bank of the stream. There is danger of a landslide damaging whatever structure constructed at this location. Danger of damage from a landslide encouraged consideration of a low-cost solution for the stream crossing. Because there is little clearance between the canal and the stream bed, any type of aqueduct is in danger of being damaged by a flood.

A level crossing was considered. A level crossing would make it easy to capture water from this source. However, several large boulders at the edge of the stream made it difficult to approach the stream with a protected level crossing. Blasting material was not available to the project for major rock removal necessary for this approach.

A suspended pipe aqueduct was considered too expensive since

Figure 6.7.3. Reinforced concrete aqueduct with collapsible side walls, Sindhupalchok, Nepal.

Photo by Naresh Pradhan.

anchorage blocks and towers were needed on both sides of the stream. A high density polyethylene (HDPE) pipe supported by a wooden beam was also considered. The farmers were concerned that a pipe would limit the discharge and indeed a large-diameter pipe would have been required given the low gradient of the canal. Inability to locate a suitable wooden beam was another reason for not selecting this approach.

A reinforced concrete trough aqueduct was considered. This called for the sidewalls to be cast as integral parts of the base. The sidewalls in such a case are considered as beams that support the structure. Since the sidewalls are directly in the path of floodwater, they are susceptible to damage. If they fail, the structure would collapse.

The alternative chosen was simply to cast a reinforced concrete base at the canal-bed level. The base rests on abutments on each side of the stream (Figure 6.7.2). Masonry side walls were then constructed on the base to complete the structure. The walls are not tied into the base and will collapse if submerged in a flood. Since the base without the walls has less area obstructing flow, it is expected to survive a flood. The farmers can then easily rebuild the sidewalls to repair the structure. In the first two years of operation, the structure has not been damaged and no maintenance has been required. Figure 6.7.3 shows the structure in operation.

Example 6.8

Siphon Spillway Escape Structure in Hubei Province, China

Liu Zhaoyi,[35] Chen Deliang[36] and Wang Changde[37]

Goal: *To protect a large, long canal, with a design discharge of 3.1 m³/s, whose flow is augmented along its route by capturing the waters of transverse streams. These additions of water are necessary to supply the command area, but involve risk of overlapping or erosion of the canal, and gated spills cannot always be operated during floods. The solution is a series of siphon spillways which function automatically when canal water level rises above the normal operating maximum.*

The Setting

This example describes a structure for safely releasing excess water from a canal. The Longmenchong Siphon Spillway is installed on the East Main Canal of the Meichuan Irrigation System. It spills the surplus water entering the canal during floods by siphonic action. It is located in Wuxue County, Hubei Province of China. This is a hilly area in the middle reach of the Yangtze River with rugged terrain.

Elevation of the command area is about 800 m in the north end and 20 m in the south. The Meichuan River passes through the command area and has an annual mean discharge of 0.5 m^3/s. The climate of this area is subtropical. The annual mean temperature is 16.8 °C. Annual mean sunshine is 1,914 hours and the annual mean rainfall 1,330 mm. About 40 percent of the annual precipitation is concentrated in the period from May to July. The area is predominated by granite and gneiss rock formations and the soil color is mostly brownish and brownish-red with medium fertility.

The area of cultivated land is about 8,500 ha including rice fields of 7,360 ha. A population of 11,500 people benefit from irrigation by this system. Rice and rape are main crops. In addition, wheat, cotton and cash crops are also grown. The cropping intensity is about 2.6. In 1989, the average grain yield of the command area was 9,200 kg/ha. The output of rape from the command area is as much as 6,700 tons. The crops planted depend upon the type of climate, soil composition, historical habits of the people, and marketing possibilities.

The annual runoff from the Meichuan watershed is about 15 million cubic meters while the water requirement for irrigated crops is about 56 million cubic meters when estimated with an irrigation dependability of 75 percent. The Meichuan Reservoir was built in the upper reaches of the Meichuan River to store irrigation water for the most effective delivery. In addition to the Meichuan Reservoir which was completed in 1959, 28 other small reservoirs and more than 6,000 ponds have been constructed to tap multiple water sources beyond the Meichuan watershed. The new water sources have increased the water supply to 60 million cubic meters, and the irrigated area has increased to 8,000 ha.

The Irrigation System

The water supply from Meichuan Reservoir is distributed in two main canals. The east main canal is 21.6 km long and the west main canal is 18.9 km long. More than 6,000 reservoirs and ponds are connected by the main, branch, lateral and field canals. The canal network with its reservoirs has the popular name "long vines with melons."

---

35 Professor and President, Wuhan University of Hydraulic and Electric Engineering, Wuhan, China.

36 Professor, Wuhan University of Hydraulic and Electric Engineering, Wuhan, China.

37 Professor, Wuhan University of Hydraulic and Electric Engineering, Wuhan, China.

The principle for planning the canal layout was to maximize the area irrigated by gravity. Based on topography, the east main canal follows the contour and its branch canals take off from one side. The west main canal follows the alignment of the watershed divide and its branch canals take off on both sides.

When the canal alignment was investigated, several alternate schemes were drawn on topographic maps. After the technicians discussed the alternatives with farmers, the best scheme was selected. A detailed topographic survey (1/2,000) was made along the preliminary canal route. Only after that was the final canal alignment and technical design determined. The slope of the east main canal ranges from 1/5,000 to 1/1,000 and the slope of the west main canal is 1/5,000.

The design discharge was based on the irrigated area, cropping pattern, irrigation schedule, and the type of irrigation delivery, i.e., mainly continuous irrigation. In the last 30 years, all the main canals were lined. This increased water use efficiency from 64 percent to 85 percent. The geological condition along the canals is weathered soils of granite. No serious leakage or landslides have occurred since the canals were put into operation.

The Siphon Spillway

The main canal of the irrigation system was built through a hilly area, and intercepts natural drains and streams. Storm water flows into the canal increasing the canal discharge. There is danger of this causing damage to the canal bank if the water level exceeds the maximum permissible level. In order to ensure the safety of the canal and its structures, nine gates were built in the 21.6 km length of the east main canal to release this flood water. However, it was recognized that there was a serious problem with the operation of these gates. A sudden storm could flood and breach the canal before the gates could be opened. So it was decided to install siphon spillways between the gates as a safety measure.

An important advantage of siphon spillways is that they operate automatically and release a large volume of water without manual manipulation. The second advantage is that they begin operating with only a small rise in the canal water level. In this case, the siphons were set to begin operation when the canal water level increased 10 cm above the design flow level. After the siphon begins operation, the discharge is nearly constant irrespective of the canal water elevation. This allows a lower canal freeboard, reducing the cost of the sidewalls. This was the factor that made the cost of the siphon spillways about 30 percent less for this canal than side spillway weirs operating under the same discharge to head relationship.

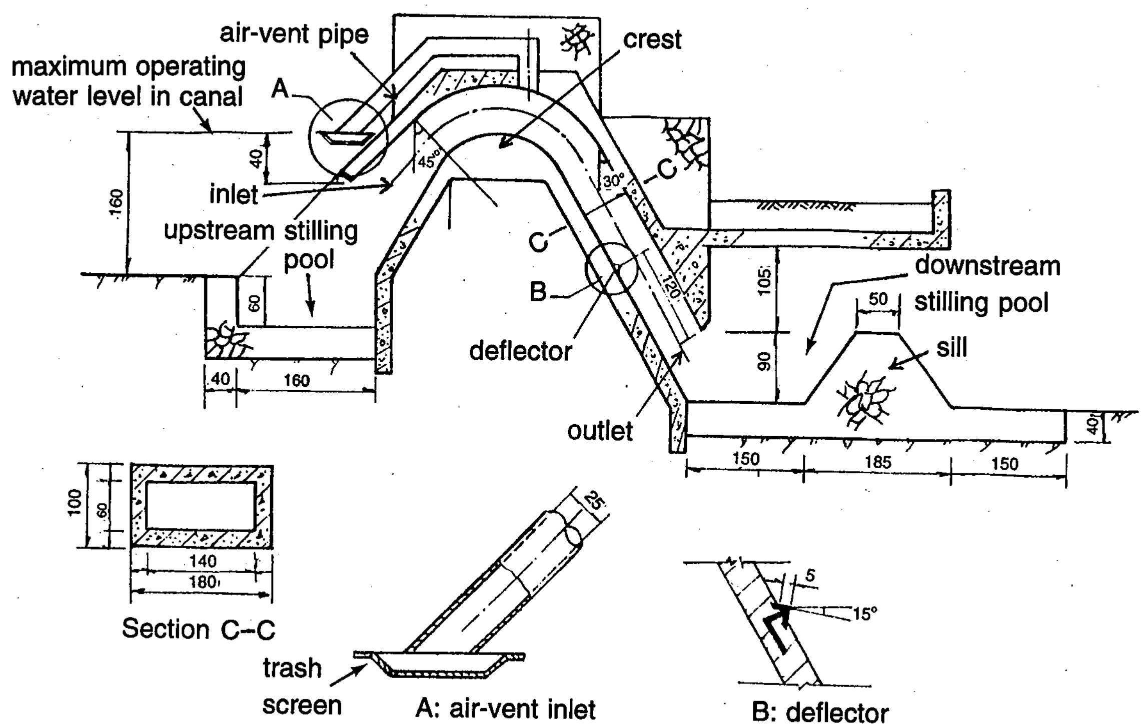
The siphon spillway consists of a closed inverted U-shaped conduit, an air-vent pipe and a stilling pool (Figure 6.8.1). The cross section of the conduit is rectangular. Just after the siphon crest, the conduit dimensions are 1.4 m x 0.6 m. The inlet is twice as large as the throat to reduce head loss at the entrance. The inlet is submerged 40 cm beneath the water surface in the canal. A deflector located in the conduit about 1.2 m from the outlet is necessary to seal the siphon passage as it begins to operate. A 25 cm diameter air-vent pipe is located on the top of the conduit. The inlet of the air-vent pipe is placed at the elevation of the normal water level in canal. The siphon discharges into a stilling pool. In addition to dissipating energy, the stilling pool seals the siphon outlet preventing air from entering into the conduit from the outlet. The working head of the siphon is 1.40 m and the designed maximum discharge is 2.65 m^3/s.

When the water level in the canal rises and exceeds the siphon crest, the initial discharge is that of a side spillway weir. The deflector and stilling pool seal the outlet side of the siphon so that no air can enter via the outlet. As the water level in the canal continues to rise, it covers the air-vent inlet and the flow of water through the siphon passage evacuates the air in the siphon tube. This primes the siphon and abruptly brings it to full discharge. When the canal water surface falls below the inlet elevation of the air-vent pipe, air enters and the siphonic action is broken, abruptly and automatically stopping full discharge.

The dimensions of the siphon conduit were determined by the discharge and working head. It must be large enough for a person to enter and carry out repairs. Design discharge for the siphon was selected by considering the area of water catchment and design discharge in the canal. Selection of the design water level of the siphon must consider not only the design water level and the water level of the maximum discharge in the canal, but also the actual water level during operation of the canal. The water surface just before the inlet drops when the siphon is operating.

The siphon spillway in this case has operated for 5 years and performed well. Experience from its operation shows that: 1) while a siphon spillway can prevent flood damage, gates are also needed to scour sand from the canal and prevent canal silting; 2) the siphon inlet must be located away from the canal sidewall and needs an upstream stilling pool to reduce turbulence for proper discharge regulation.

Figure 6.8.1. Cross section and details of the siphon spillway designed for the Meichuan Irrigation System, Hubei Province, China.



Dimensions in centimeters

Example 6.9

Temporary Pipe Made from Drums, Covered Canal, and Other Conveyance Structures in Bali, Indonesia

Yves Bellekens[38]

Goal: *To deal with the problems of canal failures and emergency maintenance in a 13 km canal conveying 760 l/s across very steep and unstable terrain with high risk of landslips, in the context that operation and maintenance must be performed by the farmers of a 380 ha system. Site access and material supplies are constraints. Solutions used include pipe crossings made from drums, coverage of the canal by stone slabs against debris falls, and superpassages.*

Figure 6.9.1. Pipes made from drums joined with bituminous-covered fabric which replaced a collapsed masonry wall, Bali, Indonesia.

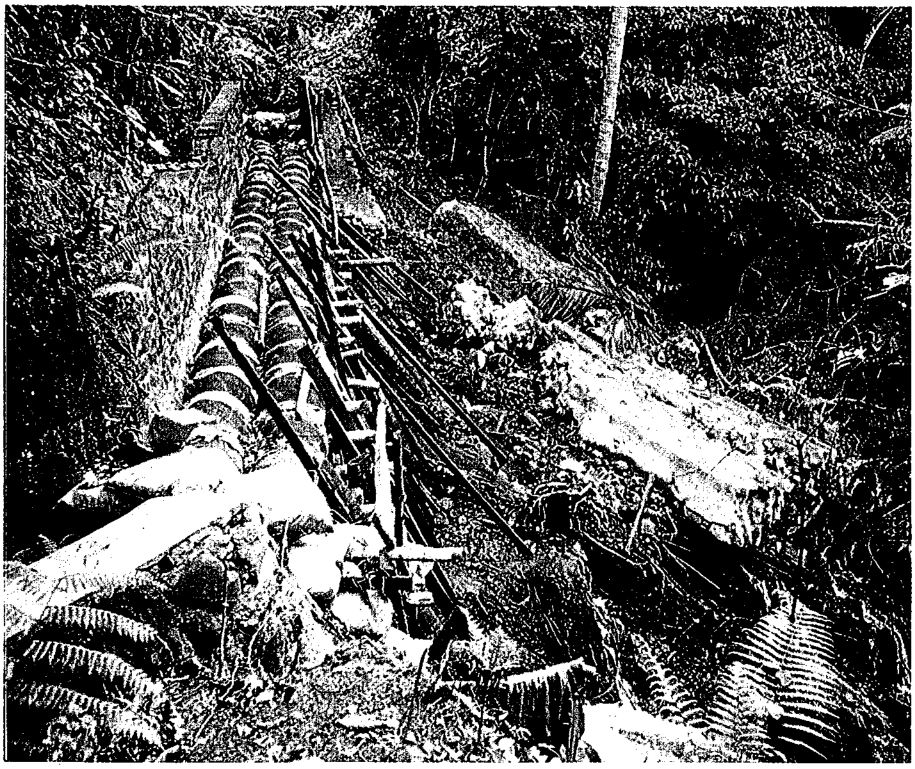


Photo by Y. Bellekens.

Hills and mountains present a distinctive environment calling for unique solutions in designing irrigation schemes. Beside the distinctive hydrology of mountain streams and the topography plus general remoteness of such areas, a number of other factors influence irrigation design. Perhaps the most important are: 1) the cost-effectiveness of the irrigation facilities, 2) the need to match local management skills and options, and 3) the ease and cost with which the structures can be operated and maintained in a sustained and reliable manner. The importance of self-reliant irrigators and irrigator-derived institutions cannot be overemphasized for effective irrigation in the hills and mountains. A gravity canal built in mountainous conditions follows the side of the mountain at a gradient less than that of the source stream. At times, it may be dug through a hill as a tunnel or along rocky or unstable areas of the mountain side.

38 Senior Evaluation Specialist, Asian Development Bank, Manila, the Philippines. The views expressed in this paper are those of the writer and not necessarily of the Asian Development Bank.

Figure 6.9.2. Concrete slabs used to cover masonry canal, Bali, Indonesia.

Photo by Y. Bellekens.

Figure 6.9.3. Excavation for masonry retaining wall foundation, Bali, Indonesia.

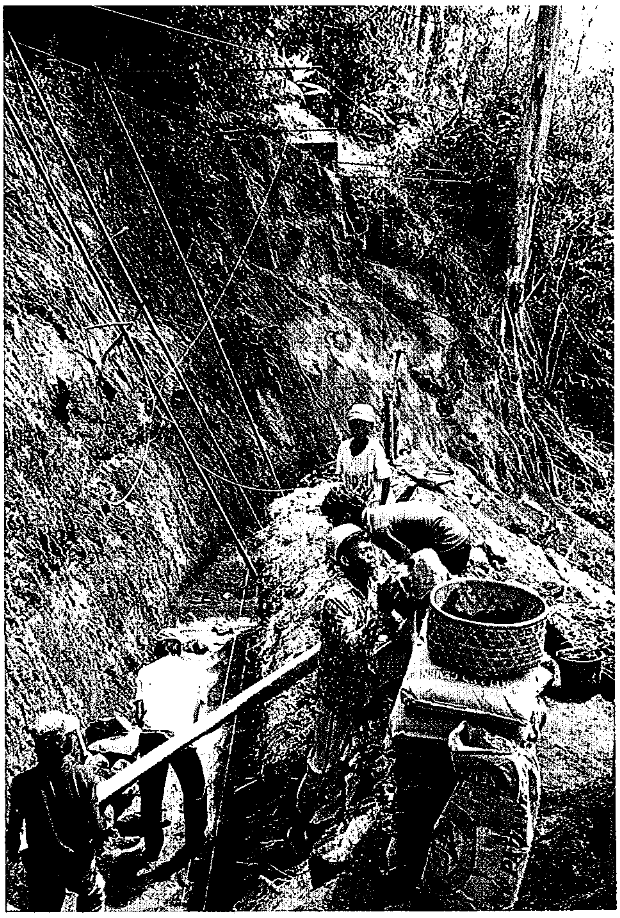


Photo by Y. Bellekens.

It may also require elevated flumes to cross depressions in order to shorten the canal which otherwise would follow the mountain contour over long distances. Pipes as well as various other structures may be required to protect the canal from falling debris such as soil, stones or rocks. Upslope drainage water, if in excessive quantities, must be channeled over or under the canal.

The Irrigation System

The setting of this example is Bali and the general conditions already described in Examples 5.1 and 5.3 apply. In this case, a 13 km long main canal conveys water along a steep, forested, mountain slope to a 382 ha scheme. The design discharge is 760 l/s flowing at an average velocity of about 0.8 m/s. More than one kilometer of the canal is through 21 segments of tunnel. Part of the canal is cut into rocky cliffs while other parts cross unstable hill slopes and part of the canal is lined. This lined part includes various pipes and elevated flumes, and sections of canal covered with concrete slabs. Landslides and falling rocks often clog or break the canal.

Conveyance Structures to Protect the Canal

When the wall of the canal collapsed as shown in Figure 6.9.1, the irrigators quickly installed two parallel pipes made from ordinary 200-liter drums. They removed the top and bottom of the drums and joined them by using fabric coated with bituminous material. The pipes worked with minimal leakage. The drums were later replaced with buried polyvinyl chloride (PVC) pipes by the Irrigation Department. PVC pipes were preferred to iron galvanized pipes because of the cost and ease of transport.

Figure 6.9.4. Collapsed masonry wall that was undermined by a natural drain, Bali, Indonesia.

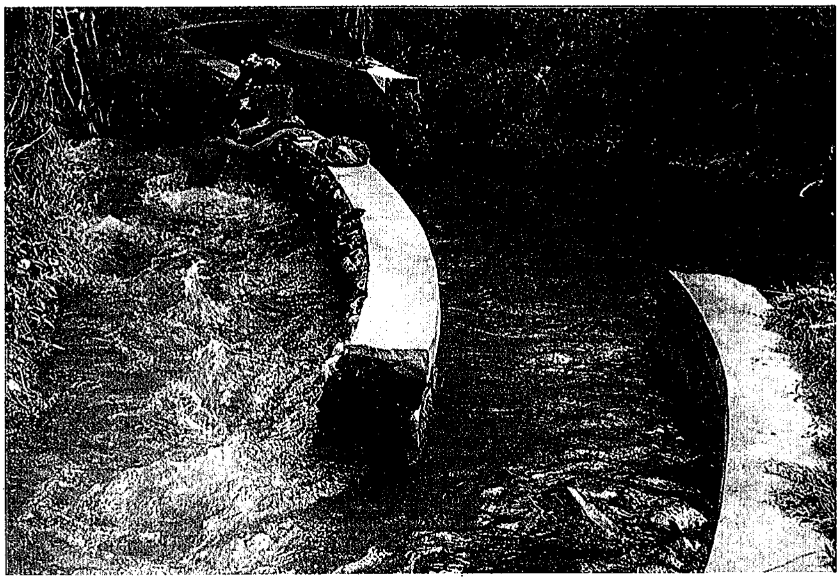


Photo by Y. Bellekens.

However, because their protective cover was not maintained, they were soon damaged by falling rocks.

One way of reducing canal blockage by debris falling from above the canal was to cover the canal. Masonry sections of the canal were rebuilt and extensive portions covered with concrete slabs. Intermittent openings were left to allow canal cleaning (Figure 6.9.2).

The solutions of barrel pipes and covered canal both required the building of retaining masonry walls to support them and to prevent erosion of their foundation material (Figure 6.9.3).

Natural drains on the hillside can cause serious problems. The drains are usually steep with high velocity flow which can erode the canal structure. Excess flow entering the canal can cause it to overtop the sidewalls resulting in serious hillslope erosion and possibly undermining the canal, resulting in its collapse. Figure 6.9.4 shows a collapsed masonry wall that was undermined by a natural drain.

Both underpassages and superpassages were designed to reduce the danger of this type of failure. Figure 6.9.5 shows a simple superpassage for a small drain. Figure 6.9.6 gives the detailed layout of a typical superpassage as designed by the Irrigation Department. Underpassages were significantly more expensive to build than the superpassages because they are more complex and involve more construction material and technical expertise.

The pipes and drainage passages were simple structures which irrigators could build either by themselves or by hiring contractors. Each individual structure did not take very long to build even though construction was rather difficult because of access problems. They were spread along the main canal and could not be served simultaneously by the limited construction equipment available.

Stone, gravel and sand were available locally but had to be hand carried on steep slopes. A wooden flume was used to convey material down the slope to a small platform where the concrete mixer was placed. The mixer had to be lowered using a cable. Bags of cement were also lowered by using the flume and water was pulled up

Figure 6.9.5. Superpassage used to route drainage water over the canal, Bali, Indonesia.

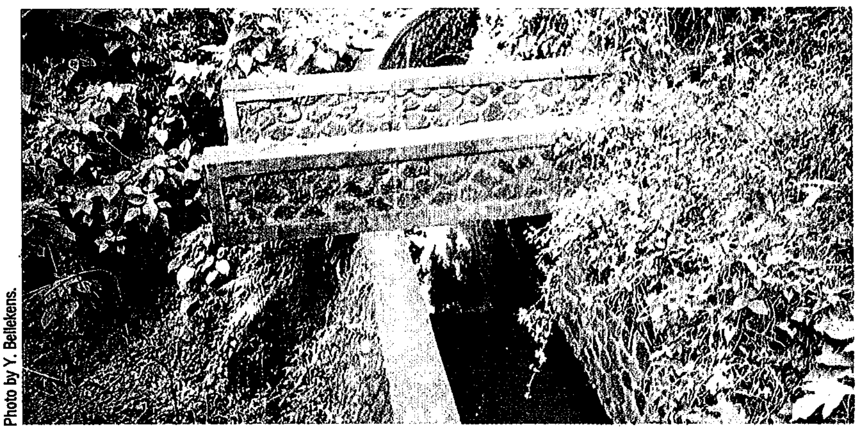
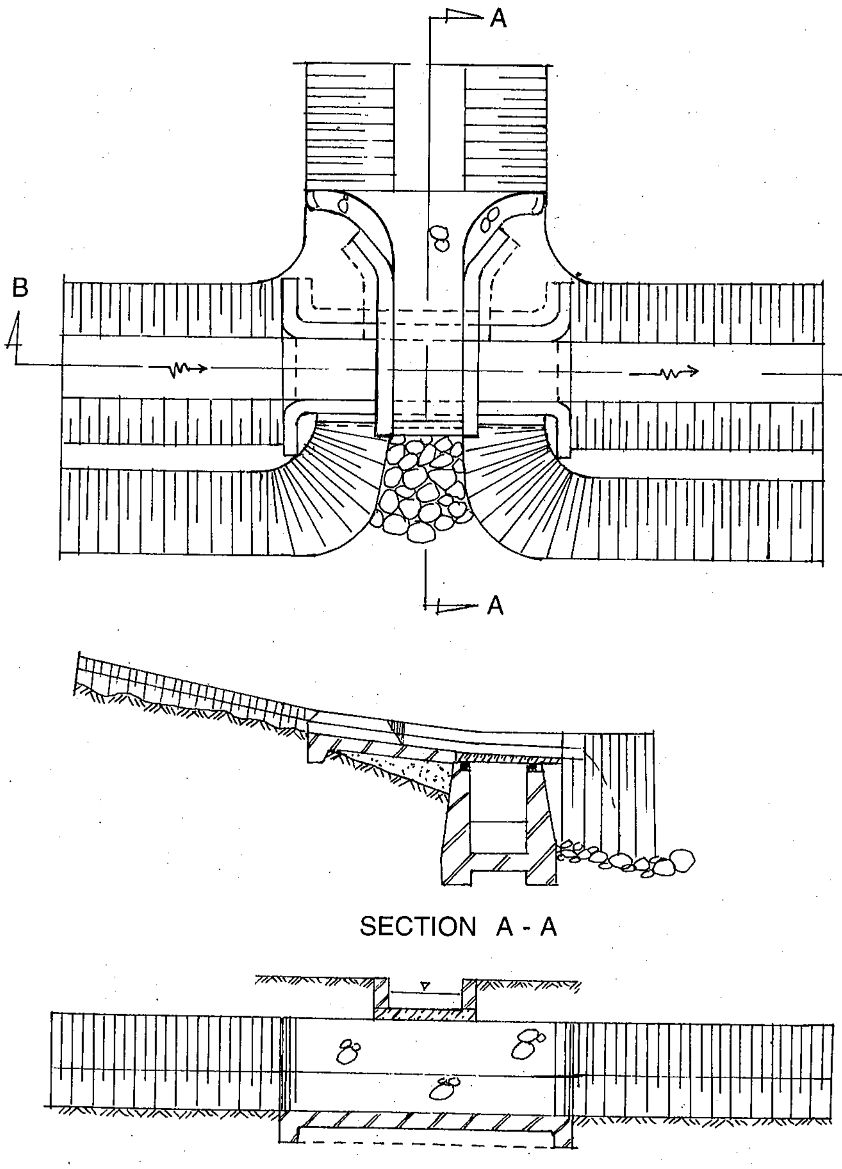


Photo by Y. Bellekens.

from the river in buckets. A 20 cm diameter pipe was used to bring mortar down the mountain cliff to each individual construction site.

Because the structures did not in all cases prove durable and resistant enough to the impact of falling rocks or stream erosion, many were damaged or had to be modified, adjusted, and reconstructed, a process requiring the same difficult construction arrangements. This proved time-consuming and expensive. Local farmers were seldom used as advisors or laborers during construction by the Irrigation Department because work extended over rather long periods of time and conflicted with other farming activities and with the pace of work farmers are used to.

Figure 6.9.6. Design of superpassage used by the Irrigation Department, Bali, Indonesia.



Improvements suggested by the irrigators included additional protection of the structures against the impact of falling rocks by placing riprap appropriately and the protection of the downstream part of structures against erosion by drainage flows. The irrigators also requested openings at regular intervals when concrete slabs were used to cover the canal. This was to facilitate removal of silt and gravel. They also requested that the sidewall be made higher to accommodate the added flow of runoff.

After trial and error, it seems that the canal is now equipped with the necessary protection devices and that it functions relatively well. It was observed, however, that the irrigators would not have replaced the pipes made from drums that they had built. They felt they worked well and did not wish to pay to replace something that they considered functional.

Example 6.10

Covered Concrete Pipe through Landslide Area in Sindhupalchok, Nepal

Robert Yoder[39]

Goal: *To replace a 24 m length of small farmer-owned canal, which had high seepage and failure risk because of instability of the fractured rock slope which it must cross. The preferred solution for renewal was to carry the water across this section in a reinforced-concrete pipe; this choice was the cheapest in capital terms, but in practice it brought many difficulties, including quality control in construction, and siltation control during operation. Such pipes need frequent access openings for cleaning; and they can be a constraint to expansion of water uses at the command.*

The Setting

In the same system described in Example 6.6, "Suspended Pipe Aqueduct for Crossing Ravine in Nepal," the technical assistance project proposed that concrete pipes be installed in sections of the canal where the canal foundation was secure but the slope above the canal was unstable. Small slides of rock and earth frequently blocked the canal causing it to breach and erode the hillside. This example examines the design of the covered pipe canal and unanticipated problems associated with its construction and operation.

Covered Concrete Pipe

A team of technicians, together with a group of irrigators familiar with the maintenance problems, inspected the canal. The irrigators identified all the locations where the canal was unstable. In many cases, the foundation of the canal required extensive support by dry-stone masonry walls from below. In other cases, the foundation was secure but earth and stone from the slope above were continually sliding into the canal when it rained. Damage from previous breaches of the canal was clearly evident. The farmers requested assistance in protecting the problematic sections.

The most frequent approach that farmers use when maintenance is their responsibility is to simply let nature take care of the problem by allowing the slope to slip until it is stable. This requires repair and cleaning of the canal after each incident. Fortunately, this causes less damage than one might expect. Most farmer-built systems have temporary brush/stone diversions that are easily damaged by the rain-swollen stream. It is the same rain that often causes damaging slips along the canal alignment. Since it takes longer for the hillslope to saturate and cause a slip than for runoff to cause the stream to flood and damage the diversion, disrupting the supply, there is often no water in the canal to cause a serious breach when a landslide occurs.

Since the improvements requested by the farmers included strengthening of the diversion with a rock-filled, wire cage (gabion) structure, it was more likely that the canal would be flowing when slips occurred and a number of sections of the canal were proposed for protection. The one described here is a 24 m section of canal only 25 m from the diversion. This section had a fractured rock foundation that is stable but was losing water through seepage. Unstable conditions above the canal threatened earth and rock falls into the canal that would block it.

One alternative was to cover the open channel with reinforced precast concrete slabs. To provide structural support for the cover, it was determined that the canal itself would need to be reworked to provide uniform dry-stone masonry walls on each

39 Associate Specialist, International Irrigation Management Institute, Colombo, Sri Lanka.

side of the canal. The second alternative was to precast a reinforced concrete pipe (hume pipe) and place it into the existing canal and cover it with stone for protection.

The estimate for a precast pipe indicated that it would be considerably cheaper than a covered canal. Plastic pipe instead of concrete pipe was also considered but was found to be much more expensive. One criterion that the project had established was that concrete pipe or other rigid lining could not be used in areas where there was evidence that the canal was moving due to mass slumping or landslides. Experience in other hill irrigation projects was that while slumping may be caused or exacerbated by seepage from an unlined canal, frequently rigid lining alone did not stop the movement. When rigid lining such as concrete pipe shifts, it breaks and is not easily repaired by farmers. However, in this example, the foundation was secure.

A surveyor's level was used to establish the existing canal gradient. The design discharge was computed as explained in Example 6.6. The slope and assumed friction coefficient were used in the pipe-flow equation to establish the discharge and velocity at full flow. Manning's equation was used to check the velocity at partial-flow conditions to ensure that silt would not be deposited in the pipe.

To make the precast concrete pipe, a form was required. Since it is expensive to fabricate a form, the project chose to use one standard size pipe in all of the canals being improved. Therefore, the calculation for the pipe design was primarily to determine if a standard precast concrete pipe of 300 mm diameter would be suitable given the available head and discharge of the canal section under consideration.

While precast concrete pipe has been used successfully in many locations in Nepal, it is best suited to situations where it can be mass-produced near a riverbed where good quality sand and gravel are readily available and where water is abundant to keep freshly cast pieces wet for proper curing. However, in this situation, transport of the pipes after casting was not possible. It was necessary to cast the pipe near the point of use and carry all materials to the site.

Many problems arose while casting the pipe. The form was not designed properly and had to be rebuilt. It was difficult to get clean, uniformly graded sand and stone chips, and there was an inadequate water supply for curing the pipe. More serious was the level of skill necessary for consistent, good quality production of pipe sections. It was assumed that farmers could be trained to do the casting. Indeed that was possible but by the time a group learned the technique, it would be time to move the form to another location and another group needed to be trained. The result was a high degree of broken and unusable pipe sections which increased the cost above the estimated amount.

Though, at the time of selecting the type of structure to be built, the farmers had agreed that a 300 mm diameter pipe would be acceptable, they were adamantly opposed to the pipe when they actually saw the first section. The dimension did not carry meaning until the first pipe was available for examination. They felt that the size was too small for the discharge they expected in the canal. The farmers planned to increase the discharge in the canal to the maximum available to allow additional expansion of the command area, and to operate a water-powered mill if possible. Though the design calculations were correct for the proposed command area, a pipe with a fixed discharge did not allow flexibility to increase the discharge for periods when water was available. The farmers saw this as a serious defect in the design and wished they had insisted on a masonry canal with a concrete slab cover or even an open channel with improved sidewalls. Ultimately they accepted the pipe for installation because the money had already been spent and they had no resources to implement a modified design.

While the calculation of maximum discharge made during the design of the pipe was correct, there was no allowance for improper installation. During design, it was assumed that the proper slope would be achieved during installation but neither the farmers nor the technicians supervising the installation were equipped to check the gradient properly.

In the first monsoon season of operation, the farmers' worst fears were realized. The rain swollen stream did not break the improved diversion and carried enough silt to block the pipe. There was a small landslide partially blocking the outlet end of the pipe that may have caused silt to be deposited in the pipe. The only way the farmers found for removing the silt was to break open a section every

5 m so that a bamboo pole could be pushed through to open a passage. They were then replaced and remain in operation. In this case, the fact that the farmers themselves had installed the concrete pipe in the first place gave them the skill necessary to accomplish its maintenance.

The farmers concluded that only a pipe with a large enough diameter to allow a person to enter for cleaning should be used. They also suggested that there should be an access opening every 5 m to allow inspection and cleaning.

Example 6.11

Hollow Concrete Block Bench Flume and Covered Pipe Structures

Dionisio B. Asencio[40]

Goal: *To convey a new canal, supplying water to 300 ha, through two difficult stretches, a 90 m length around a steep hillside, and a 130 m length in a deep cut with risk of debris falls. The solutions adopted were a flume with concrete-block sidewalls on a bench cut into the hillside; and a reinforced-concrete pipe with cleaning manholes at 20 m, for the debris-threatened cut. Total cost for the two special structures was equivalent to US$98 per meter.*

In 1986, the Cabacungan Communal Irrigators' Association was organized in Negros Occidental. The organization was formed in preparation for assistance by the National Irrigation Administration (NIA) in constructing a new irrigation canal. Within the proposed command area there are two existing private stone/brush dams owned and managed by groups of farmers. They irrigate about 50 ha of lowlands from different water sources.

A memorandum of agreement was signed by the Irrigators' Association (IA) and NIA on April 8 1987. This spelled out the rights and obligations of both the NIA and IA. Construction of the Cabacungan Irrigation Project was started in 1987 with the assistance of members of the IA. Project completion was scheduled for 1992. NIA assured the farmers that the entire command area of 300 ha will be fully irrigated.

The Setting

The project area is situated at the foot of the active Canlaon Volcano. The command area is about 140 m above sea level. Annual rainfall is about 2,750 mm. There are two distinct seasons, a relatively dry period from January to April and a wet season during the rest of the year. Heavy precipitation generally occurs from July to November. The temperature is uniform over the project area. The temperature ranges from 31 °C to 17 °C.

Water for irrigation is the most important natural resource in the project area. The main water source for the irrigation system is the Inti-pigiwan River; Cabacungan Creek is a supplementary source. The average wet season discharge available from the two sources is about 1.4 m^3/s and in the dry season it is 0.4 m^3/s.

The watershed has an area of about 12.5 km^2 and is mostly forested. Plots have been cleared for *Kaingins* (slash-and-burn) farming. Some of the substantial bed load passing the diversion of the irrigation system is attributed to the *Kaingins*. The river has a steep slope. Rock outcrops and high banks confine the river to its course.

40 Chief, Design and Specifications, National Irrigation Administration (NIA), Region 6, Iloilo City, the Philippines.

Factories and mining activity upstream of the diversion will not be allowed since mill and mine tailings would pollute the irrigation water. The expected major problem threatening the irrigation system is the eruption of the Canlaon Volcano. The system is in the danger zone and would be damaged by lava or mud flows.

Most of the farmers live near the command area. The largest landholding is a "hacienda" (a large estate) with an area of 120 ha while the smallest landholding is 0.4 ha. The average size of landholding is 4.8 ha. About one-fourth of the land is owner-cultivated with the remainder having some type of tenurial arrangement. Some farmers consume all that they produce while others have surplus to sell to private traders who come during the harvest season. The command area is accessible to transportation.

The IA has formed a committee for operation and maintenance of the irrigation system. NIA provides the technical assistance for major repairs but the IA is responsible for all the routine maintenance. In addition, NIA assists members of the IA in resolving conflicts pertaining to operation and maintenance. The IA's contribution toward the construction of the project is in the form of labor and materials which are considered as equity generated by it.

Hollow Concrete Block Bench Flume

The Irrigation Design Engineer together with the farmers inspected the proposed main canal route and alternative routes to determine the alignment and type of structure required in each. The alignment selected required a 3.8 km long gravity canal to deliver water from the diversion works to the irrigable area. Portions of the canal pass along a steep hillside and in other sections a deep cut was required. A 90 m long bench flume made of hollow concrete blocks was built along the steep hillslope. The hollow concrete blocks were found to be cheaper, even with the necessary stiffeners, than reinforced concrete.

This flume was constructed by cutting the bench, casting a base slab, erecting the sidewalls with hollow concrete blocks, and placing reinforced concrete stiffeners at 3 m intervals. The design discharge was determined from the command area size and crop water requirements with appropriate compensation for losses. Open channel conditions were evaluated in determining the flume size. A square, 0.8 m x 0.8 m, flume was found to be appropriate. A narrower section may be economical along a steep hillside where rock excavation is required and right-of-way is restricted.

The provision of a spillway just upstream of the bench flume was necessary to prevent overtopping of the sidewalls. In the event that the inlet gate was not closed during a flood, overtopping would cause scouring of the loose portion of the structure foundation. The spillway was made of reinforced concrete and sized to accommodate the full design flow in case the canal became blocked.

Photo by Negros Occidental Provincial Irrigation Office Staff.

Figure 6.11.1. Sluice gate and inlet gate upstream of the bench flume in the Cabacungan Communal Irrigation System, the Philippines. The bench flume runs for 90 m to the right of the group of people.

Covered Pipe

In the 130 m long section where deep cutting was required, a covered pipe was installed to minimize the problem of material falling into the canal. The pipe was made of reinforced concrete and sections were joined by reinforced concrete collars. A reinforced concrete outlet transition was also used. Manholes were installed at 20 m intervals to facilitate the cleaning of silt that might be deposited in the pipe.

The cost of the combined concrete hollow block bench flume with spillway and the covered pipe with manholes was about P 538,000 (US$21,500 in 1990). Figure 6.11.1 shows the sluice gate in operation. This is located just upstream of the bench flume.

Example 6.12

Inlet Box for Pipeline in the Chirang District, Bhutan

Ian K. Smout,[41] Robert J. van Bentum[42] and Langa Dorji[43]

Goal: *To form a smooth transition at the place where water conveyed in an open canal is transferred into a pipeline section, and to protect that pipeline against blockage risks by incorporating a trash-retaining screen in the transition structure.*

The Setting

An inlet box is used on gravity canals as the transition from a lined or unlined channel to a pipeline. This case describes the inlet box designed for the Chirang Hill Irrigation Project in Bhutan, to be used with both concrete and high density polyethylene (HDPE) pipelines. This is the same project described in Example 5.8. Details about the setting and irrigation systems are given in that example.

The structure was one of a number of works designed for the improvement of existing farmer-built canals. The farmers requested that their canal should be improved, and participated in the selection of work to be done and the construction, providing the unskilled labor without pay. They remained responsible for operation and maintenance.

The construction period contributed to the development of the capabilities of the water users' association (WUA), by requiring the farmers to work together (without pay) to an agreed timetable on construction work. Some farmers had the skills and motivation to be taken on as paid assistant masons on the project, which developed their skills further and it should enable them to make a valuable contribution to future maintenance.

The Chirang Hill Irrigation Project aimed at improving about 80 of these farmer-built canals during the period 1986-91, with financial assistance from the Asian Development Bank. The design procedures and structures are described in the project irrigation manual (RGOB 1990).

The Inlet Box

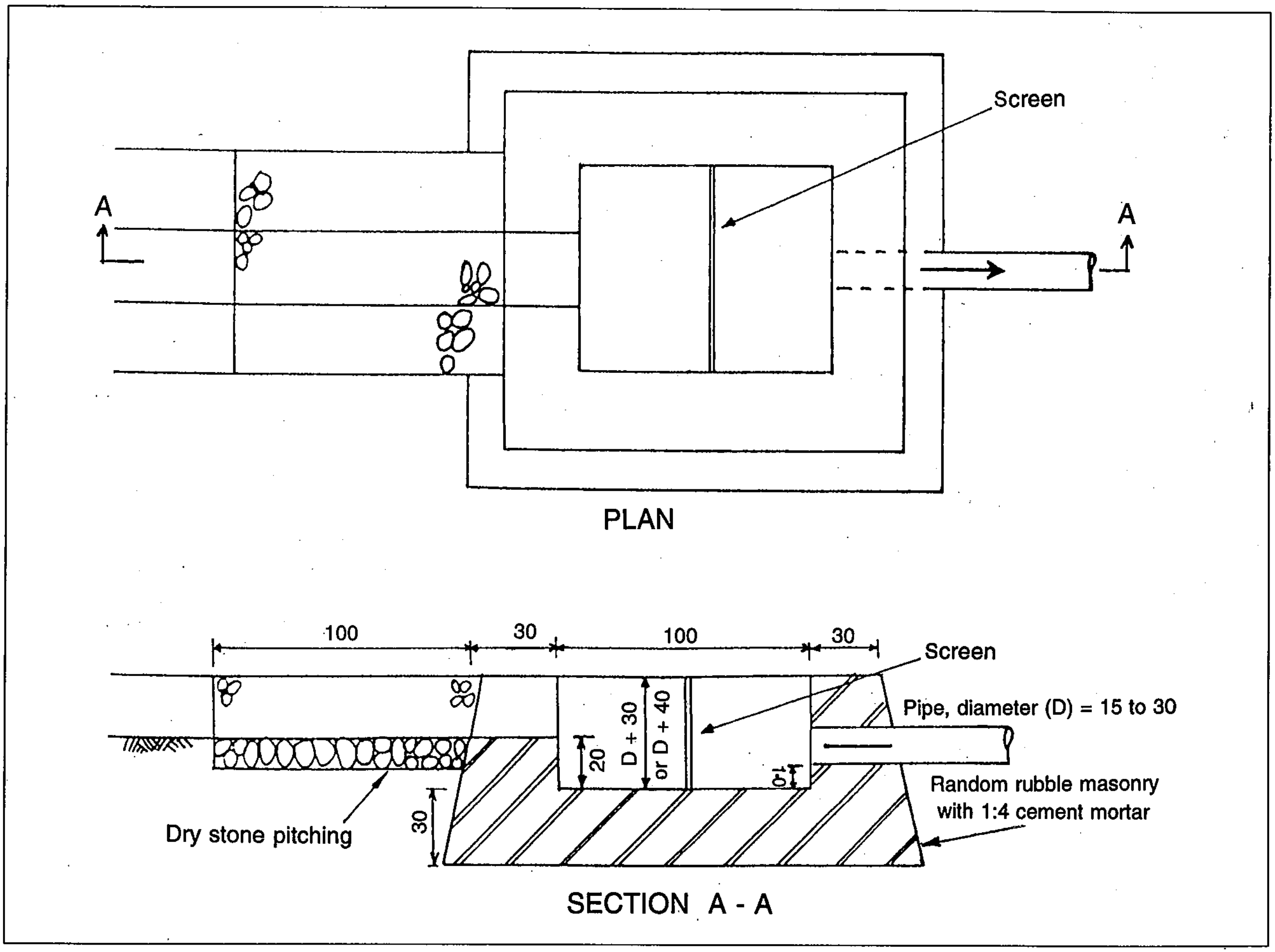
Figure 6.12.1 illustrates the inlet box and Figure 6.12.2 shows the completed structure. They were built of 1:4 cement masonry, and therefore had to be built on stable foundations.

41 Lecturer, Water Engineering and Development Centre (WEDC), Loughborough University of Technology, UK.

42 Research Associate, WEDC, Loughborough University of Technology, UK.

43 Section Officer, Department of Agriculture, Royal Government of Bhutan.

Figure 6.12.1. Structure of pipe inlet box, Chirang Hill Irrigation Project, Bhutan.



The inlet box acts as a sand trap and contains a vertical screen made of welded mesh built into the walls of the box. The mesh used has 55 x 55 mm openings and prevents debris being carried into the pipeline.

Site investigation included walking the length of the existing canal with some of the farmers, identifying the problem areas, agreeing on the works to be carried out, and collecting information. The information included the length of the canal and the command area, which were used to decide the design discharge of the canal corresponding to one of the four standard canal sizes: 26 l/s, 56 l/s, 104 l/s and 164 l/s. The design options included concrete pipe of internal diameters 150 mm, 225 mm and 300 mm, and HDPE pipe of outside diameters 160 mm and 225 mm. Where a pipeline was selected, a convenient stable site for the inlet box was chosen.

The depth of the box was set to ensure that the maximum-size pipe would be submerged, allowing a depth of 0.10 m for silting. A freeboard of 0.10 m was provided as on the lined canal. This could be increased to 0.20 m to give greater security of the structures. The position of the screen has been fixed at 0.3 to 0.5 m from the pipe inlet to allow access behind the screen for cleaning.

The standard widths of the box are given in Table 6.12.1. Where the available space is limited, the inside width of the box may be reduced but must not be less than the outside diameter of the pipe installed plus 0.3 m. For example, if two concrete pipes are to be installed then the inside width of the box must be a minimum of 2 x (0.3 m pipe opening + 0.06 m wall thickness) + 0.3 m side clearance = 1.02 m or about 1.0 m.

Figure 6.12.2. Pipe inlet box, Chirang Hill Irrigation Project, Bhutan.

Photo by Ian Smout.

The stability of the walls was the main concern in the structural design. The design was prepared for the condition in which the canal is empty and surcharge is provided by an earth slope above the canal at a maximum slope of 1:1. Stability against overturning was provided by the 5:1 backslope on the wall. In practice, structural failure appeared more likely to arise from land movements than from design loads such as these. Failures will occur in such circumstances, requiring major repairs, and it is probably not cost-effective to try to prevent this. The structure is built of cement masonry and therefore must be built on stable foundations.

Table 6.12.1. Standard widths of pipe inlet/outlet box.

Channel width (m)	Inside width of box (m)
0.3	0.8
0.4	1.0
0.5	1.2
0.6	1.4

In general, boxes need not be covered except where there is danger of soil or rock collapse into the box or where vegetation rubbish falls into the box, and in these cases reinforced concrete slab covers should be used.

The inlet box requires daily attention during the monsoon to clear sand and remove leaves and debris from the screen. Problems were experienced with an earlier design where the position of the screen did not allow access behind it for cleaning. After increasing the space the design has been successful. Some failures have occurred due to land movement, which can only be avoided by careful siting of the structures.

Example 6.13

Traditional Technologies for Irrigation Tunnels

Yves Bellekens[44]

Goal: To construct tunnels, using farmers' traditional tools and technology, to shorten canals passing through mountain slopes, to reduce water loss to seepage, to provide access to additional cultivable land, and to reduce subsequent maintenance and operation efforts.

The Setting

In mountainous terrain, much of the culturable land cannot be irrigated because it is technically difficult and prohibitively expensive to connect it with a reliable and sufficiently large source of water. Long canals meandering along the side of a mountain, crossing numerous natural drains and unstable areas are expensive and time-consuming to build, difficult and expensive to maintain, and fraught with risks of failure. Furthermore, water losses from the canal by seepage and leakage increase with the length of canal.

Another drawback is the loss of hydraulic head in a long canal. As the canal drops, the area above it cannot be irrigated by gravity flow. This can only be overcome by building the river diversion structure higher up the river. However, generally, the higher one taps a river or stream the lesser the available water. This may again reduce the area that can be irrigated.

A solution irrigators have used is to dig a tunnel through the hill to significantly shorten the canal. In mountainous areas where tunneling technology has not been used by farmers, sizeable water resources are often not tapped and large culturable areas have remained unirrigated because a canal would be too long and irrigation difficult. Comparing the situation in Bali, Indonesia, to other Asian countries, it seems that there is sizeable potential for improving existing irrigation systems and extending them to new areas by constructing tunnels.

Tunnels are also used as a means to protect the conveyance system from surface drains and falling rocks. Instead of excavating a canal and then covering it with concrete slab, a tunnel may be constructed to avoid problems on the surface. Once constructed, a tunnel needs little maintenance. As a result operation effort is much reduced in terms of financial outlays, time spent, inconvenience and risk to life when operating from dangerous hillsides. Moreover, tunnels, unlike canals, neither get easily clogged nor overflow.

Though the cost (per unit length) of digging a tunnel may be as much as ten times the cost of open canal, the benefits may still make it worthwhile. Possibly most important of the benefits of the tunnel are the reduction in length of canal and the opportunity to reach otherwise inaccessible command areas. However, less water loss from leaks, reduced operation and maintenance costs, and increased reliability are also important factors.

Tunnels have been used extensively in Bali, Indonesia, to shorten canals and open new command areas. Population pressure has encouraged intensive irrigated agriculture for hundreds of years and tunnels are a technology that has allowed intensive use of the abundant water on a limited land resource.

Tunnel Construction

Tunnels have been constructed for irrigation from time immemorial by local communities in Bali and Nepal. Selection of a suitable tunnel site is most important. It must take into account local hydrology, availability of water, water rights, soil and

44 Senior Evaluation Specialist, Asian Development Bank, Manila, the Philippines. The views expressed in this paper are those of the writer and not necessarily of the Asian Development Bank.

geophysical conditions, distance, elevation, and size of the future command area. Risks are significant since digging a tunnel is a major undertaking for local communities. It requires specialized skills and substantial effort and cash. Often, it takes many years to complete a tunnel using traditional technology. In Bali, the water priest and village elders participate intensively in selecting the tunnel site and their role is based on their extensive knowledge of the area. Special prayers and a ceremony are held and a water temple is built near the tunnel inlet.

The technology used has evolved locally and is simple but robust. The Balinese have fabricated tools such as chisels, rulers, saws, etc., for making instruments needed to establish a straight alignment. To measure differences in elevation and verify the slope between two points they have devised simple instruments. Two instruments are shown in Figure 6.13.1. Figure 6.13.2 shows the method used for establishing the elevation of the outlet relative to the inlet. After roughly determining the tunnel inlet and outlet locations, bamboo stilts are aligned on the hill along a straight line corresponding to the direction in which the tunnel is to be built. The difference in elevation between inlet and outlet is determined step by step along the stilts using the instrument devised for the purpose (Figure 6.13.1).

Tunnel excavation generally starts from both ends and the diggers meet inside the hill. The slope of the tunnel bed will be constantly checked using the simple instrument shown in Figure 6.13.1. Alignment of the tunnel is controlled by using strings to suspend plummets in the tunnel for establishing a straight line. In Bali, light is provided in the tunnel by a coconut oil lamp. In Nepal, a torch is made from bamboo specially treated to reduce the smoke. Tunnels in Bali are generally 0.8 m wide, up to 1.8 m high, and are generally triangular in shape. Considerably smaller cross sections are also dug in either a sitting or lying position.

The length of indigenous tunnels in Bali can vary from a few meters to several hundred meters. It is not rare to find tunnels exceeding 300 m in

Figure 6.13.1. Instruments used to measure and transfer elevation for tunnel alignment, Bali, Indonesia.

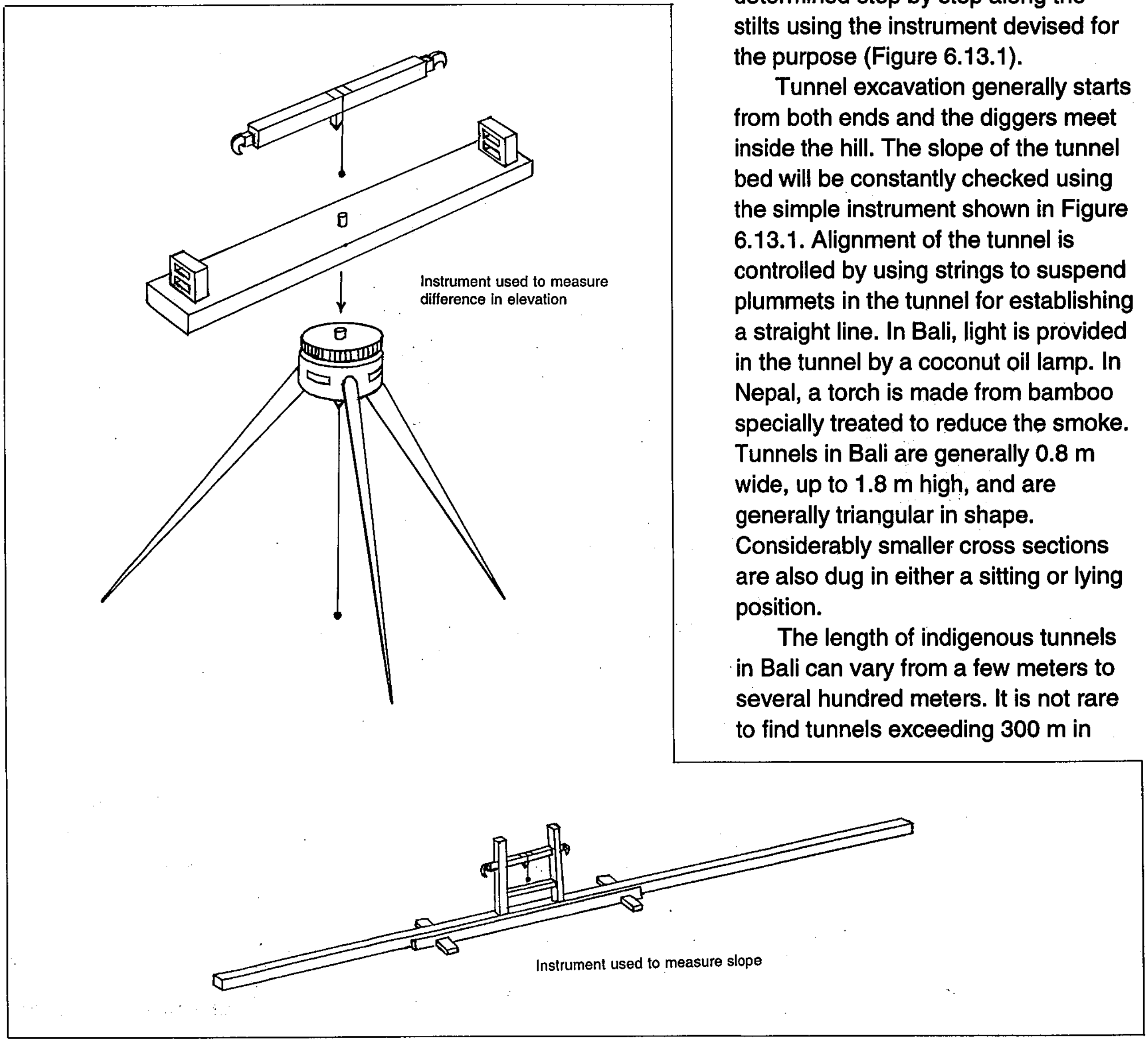
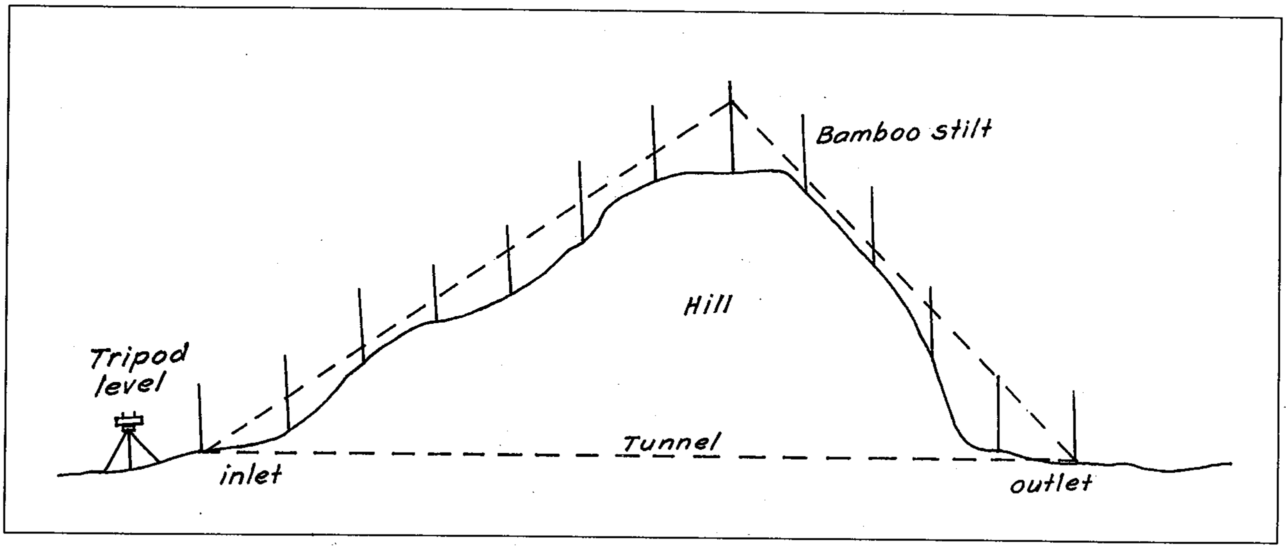


Figure 6.13.2. Method used to determine alignment of tunnel through a hill, Bali, Indonesia.



length. These are dug using simple traditional chisels, hammer, iron rod and shovel. Locally made gunpowder is used to crack the rocks. Excavation can proceed at the rate of as much as one meter a day working simultaneously from both ends of a tunnel. When digging is done in compact soil with stones or through rock material, the progress is much slower and may be as little as 4 cm per day from both ends of the tunnel. In these conditions, several years may be necessary to dig a tunnel using local methods.

Depending on the length of the tunnel, it becomes necessary to dig shorter lateral tunnels or ducts to the outside. Ducts generally do not exceed 6 m in length and provide control points for the main tunnel during construction and operation. They are also important for ventilation and removal of spoil. Ducts may be spaced every 30 m when the main tunnel is not far from the hill or mountain side. They may also be spaced more widely depending on soil type, moisture content and working conditions such as smell. Available manpower and topography also help determine the number of ducts.

Tunnel excavation is labor-intensive making it well suited for use in a place like Bali or other countries where the population is increasing. It provides employment opportunities while expanding the food production capacity.

Indigenous tunnel technologies, design methods, and survey and measurement devices could be improved. Research, in association with local communities and tunnel workers, is needed to develop appropriate improvements which they can readily adopt. Adequate incentives and training programs must be provided for tunnel diggers and engineers.

An example of a possible improvement would be to introduce a portable drilling machine to be used in hard-rock strata. This would enable tunnel excavation considerably faster than that using only traditional tools like the chisel, hammer and iron bar. In recent years, a new technology is used to transfer the tunnel elevation around a ridge or hill. A rifle is mounted on a tripod so that it can be leveled and aimed accurately. By calibrating the drop of the bullet over a measured distance, it is possible to fire the rifle at a target set at measured intervals to transfer the elevation over that distance.

These local innovations for tunnel alignment and construction have worked successfully and should encourage engineers to more frequently consider tunneling as a conveyance option.

Example 6.14

Soil Cement for Canal Lining in Syanja District, Nepal

Dan Spare[45]

Goal: To conserve water in a new canal system conveying water to 275 ha of irrigable land, using soil-cement lining as a low-cost option which can be used by farmers. Results are initially satisfactory, but farmers think the external project is giving them something second-rate and have sought a guarantee that if it fails the external project will replace it with some superior technique. To prevent such negative reactions it would be better to promote such low-cost techniques in places where the costs are being met by the farmers' organization.

The Setting

This canal lining technique is being used in an irrigation system located in the Himalayan foothills of Nepal at an elevation of about 600 m. The average annual rainfall is over 1,700 mm. Most of this comes in the warm monsoon months from mid-June to the end of September. Light showers occasionally fall between December and March. Nighttime temperatures in December and January can be as low as 5 °C.

Depending upon available water, farmers follow different cropping patterns. They prefer to grow as much rice as they can. So, where water is plentiful, they will raise two rice crops and a wheat crop. When irrigation is not adequate, the monsoon rice crop is followed by wheat and maize in succession. With relatively scarce water, the rice crop is abandoned in order to permit a long-season maize variety to be relay-cropped with millet. This may be followed by a wheat crop if there is sufficient soil moisture. Irrigation or the lack of it is a major factor in the decision making for growing various crops. Highly variable and scarce rainfall during the non-monsoon months makes wheat and maize yields quite low and unpredictable.

The Irrigation System

The source of water for this system is the Andhi Khola, a river that has a highly variable discharge. During ten months of the year, sufficient flow is available. During some years, a water shortage exists in April and May. The intake facility consists of a 6 m high dam, a desilting basin, a 1,200 m long tunnel with 4 m^3/s capacity, and a gate operated by winch. The headworks facility is owned and operated by a power company which uses up to 2.7 m^3/s of water for a 5 MW power station.

The Andhi Khola Water Users' Association (AKWUA) has an agreement with the power company to take upto 0.8 m^3/s for the estimated 275 hectares to be irrigated. The association will share in the costs of operating and maintaining the intake facilities. In case of water shortages in the Andhi Khola, the power company has higher priority water rights.

The main canal will extend 1 km westward and 5 km eastward when complete. Offtakes are located on the ridges, permitting secondary canals to convey water down the ridges. The two command areas with secondary canals nearest the intake have been receiving irrigation flows since November 1990 and the third began receiving water from December 1991. The largest sections of command area are located in the farthest east end of the system. To reach the end, eight deep gullies must be crossed. The command area consists of a series of alluvial terraces with general slopes of 1° to 4°. The upper levels of these consist of much steeper slopes ranging up to above 30°.

Landownership by farmers in the area varies considerably, but most holdings are small. In 1982, 82 percent of the households owned less than

45 Irrigation Engineer, United Mission to Nepal, Kathmandu, Nepal.

0.5 ha. Size of plots is usually quite small and parcels are usually not contiguous. Most farmers have some forest land, some steep grass land and some non-irrigated crop land. Some farmers have land partially irrigated from seasonal stream sources.

Grain production in this mountainous area is insufficient to provide the food requirements of the population. A paved highway in the immediate area allows the transportation of additional food grains from other areas of Nepal.

This irrigation system is set up so that those persons who want to participate in the benefits of irrigation may purchase "water shares" by their labor during construction or by monetary transaction. The total amount of water shares is delivered into the main intake at the rate of 0.032 liters per second per share using a broad-crested weir for measurement. From that point onwards, water is distributed proportionally according to the requested point of requirement for each share.

Water shares are a transferrable property right, not connected to landownership. Shares which are not required on one's own land can be leased or sold to another individual.

Water distribution is continuous in the main canal. It is normally continuous in the secondary canals. However, when the water supply is limited, the farmers will switch to rotation on the secondary canal.

Operation and maintenance (O&M) in each secondary canal are overseen by a three-member secondary canal committee, with one selected as leader. The detailed responsibilities of the committee and the leader have yet to be worked out in detail, though the constitution and bylaws currently in effect do outline the principles.

Operation and organizing of maintenance of the main canal and its structures will be the responsibility of AKWUA's hired personnel. Labor will come from the membership. Work contributions for repairs and maintenance will be proportional to the quantity of shares owned. Many other details regarding maintenance responsibilities are yet to be worked out.

Authority for policies, fees, and settling of disputes lies with a board whose members are elected for a one-year period. An "auditing" committee is also elected annually and is empowered to disband the board if irregularities are discovered.

Water fees are levied twice yearly (timed to correspond with harvest schedules) to repay loans for some capital costs and administrative costs during the construction period. Some of the fees are used to pay the power company for AKWUA's proportion of expenses associated with O&M related to delivery of water to the irrigation intake structure.

To date, the irrigators have invested an equivalent of 15,700 days of labor in the construction. The value of external grants and loans invested to date is over US$100,000.

Soil Cement for Canal Lining

Water seepage from new canals is usually undesirable. In Nepal, to seal canals when the water supply is short, farmers sometimes plaster sections of the canal with a mud mixture. On the opposite extreme, the normal method of reducing seepage would be to line the canal with stone masonry and cement mortar, a very expensive alternative. This example describes a method of canal lining that employs red soil and cement mixed as a mortar. When sieved and mixed properly and applied firmly to the canal floor and walls this mixture hardens quite well and forms a relatively impermeable surface. Figure 6.14.1 shows a typical section of soil-cement lined canal.

The soil used in the soil-cement applications to date is a red sandy silt. The red color is an indication of the presence of iron which "generally reacts exceptionally well with cement" (Portland Cement Association 1979). All the material passing a 15 mm sieving screen was included. Larger lumps and clods of red soil were broken up with a tamper. The soils to which the soil cement was applied are highly friable phyllitic gravel in which the permeability is very high.

In some canal sections, the original ground slope is relatively high and potential piping situations endanger the canal. In other sections where the ground slope is less, the soil is highly permeable, thus requiring a method simply to reduce water losses.

Since the main canal alignment crosses different types of terrain and soils, the engineering

Figure 6.14.1 Soil-cement lined section of canal, Andhi Khola Project, Nepal.

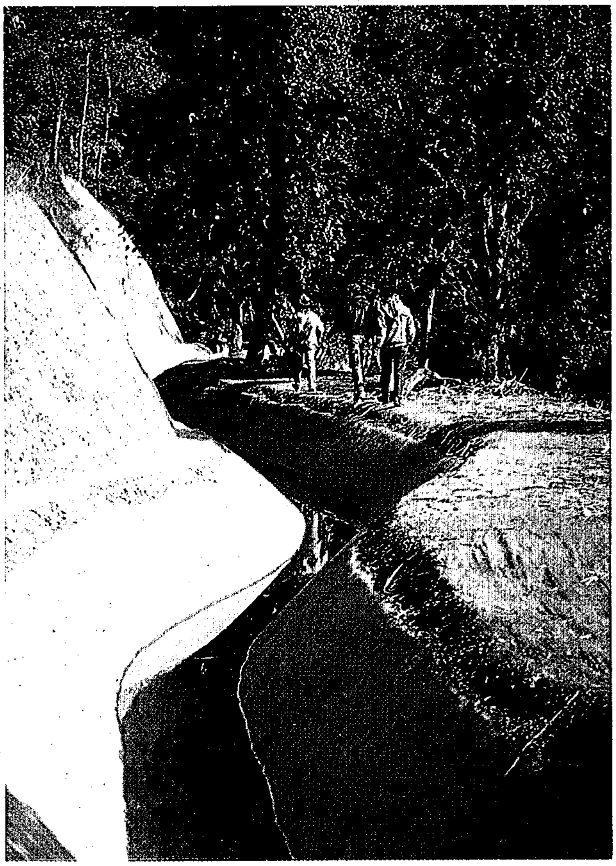


Photo by Dan Spare.

design calls for different canal cross section and lining methods. Some sections were proposed to be left unlined while others were fully lined and covered, depending on soil stability above and below the canal and the land gradient perpendicular to the canal.

The engineering design suggested unlined canal for sections where seepage would not be expected to create slope instability. Some of these sections were in fractured phyllite. Other sections had soils consisting of a tight, reddish silty soil matrix. The design engineer suggested a "B-type" canal for areas where the cross slope was somewhat steep and the soil firm, but where the possibility existed for destructive "piping" to occur. This lining specified a trapezoidal shaped canal with a 1:1 side slope and a water velocity of not more than 0.7 m/s. Plastic sheet was to be laid on the soil to provide the impermeable layer. A thin layer of dry stone masonry would provide the exposed, durable canal surface. Figure 6.14.2 illustrates this concept.

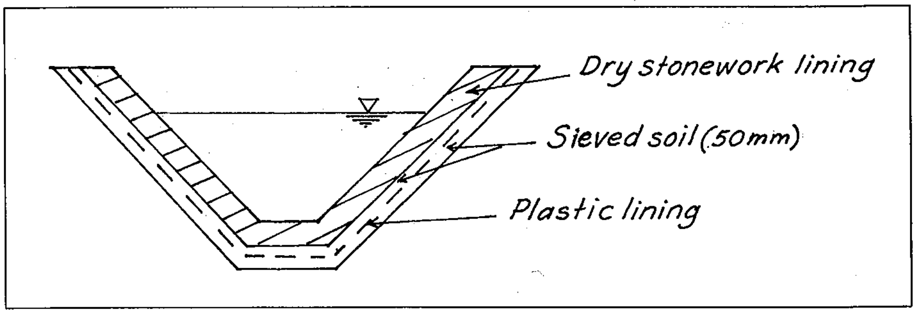
Other more vulnerable reaches of the main canal were to have various types of lining and they have turned out to be quite expensive as stone and sand for concrete and stone masonry must be carried long distances by human labor.

As construction of the main canal has proceeded, soils in some of the sections of main canal designated to be unlined have proved to be much more fractured and porous than anticipated. The farmers towards the tail end of the system have requested a lined canal so that a share at the head end would represent the same amount of water towards the tail end.

Lining of these sections with stone masonry was expensive. Other alternatives were sought which would greatly reduce seepage losses, yet would be durable in flowing water. Wading of animals in the canal was not anticipated as a problem, as the farmers believed they could eliminate or control that situation. Freezing does not occur in this area. Swelling clays are also not present in these canal reaches.

Soil cement was presented to the farmers as an option. But the farmers had no experience with this technique. The Portland Cement Association in the USA has published a book which has been helpful. However, the experiences described in the "Soil Cement Construction Handbook" (1979) are mostly those using machine applications. Minimum thicknesses described are 100 mm, and the applications are roads or large reservoirs or very large canals.

Figure 6.14.2. Section of "B-type" canal showing proposed plastic sheet lining.



Since the project has external funding, there have been some possibilities for experimentation and risk-taking. With this in mind, the project decided to try lining some trial sections with a 40 mm layer of soil cement. Sieved red soil (which is locally available), and sand and cement were mixed at the ratio of 10:1:1, respectively. After mixing the above dry ingredients with shovels, water was applied and mixed in thoroughly. The surface to receive the mortar was wetted, then the mixture applied firmly and packed tightly to eliminate air pockets. The surface was troweled shiny smooth and then kept humid for a minimum of one week (Figure 6.14.3).

Figure 6.14.3. Soil-cement application for lining canal in Nepal.

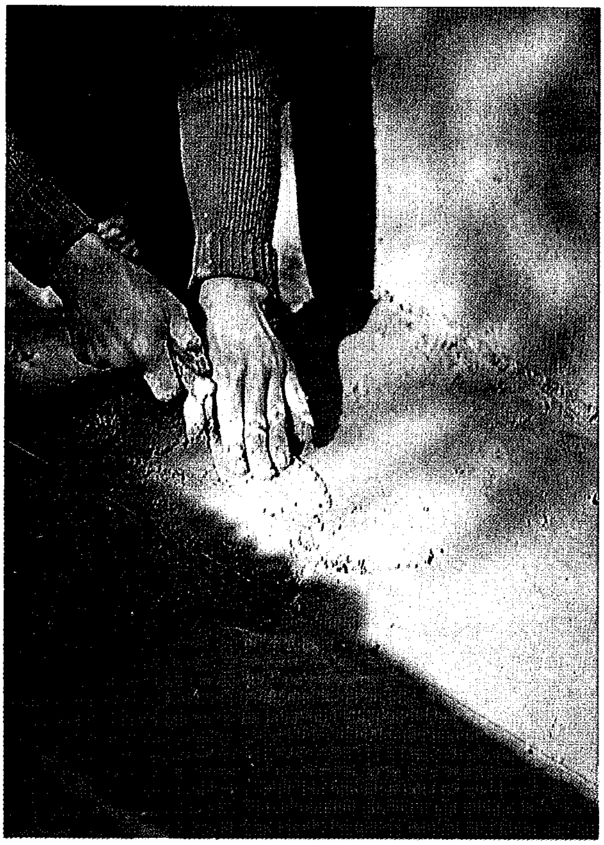


Photo by Dan Spare.

The results of the applications done to date have been generally better than expected. Sections completed in 1990 developed some small regular cracks within a week. No further deterioration is apparent since then. Application of 140 m^2 of canal done in October 1991 has developed virtually no visual cracks. One primary difference between these two applications was in the sieving. The 1990 red soil was sieved with a 4 mm screen. The 1991 sieving used a 15 mm screen which allowed some gravel particles.

The good experiences gave the project staff sufficient confidence to apply soil cement in the section where the "B-type" canal had been planned. Additionally, one 25 m section of canal having a gradient of 1:20 and a planned velocity of 1.3 m/s was lined with soil cement instead of the cement plaster initially specified. The soil cement appears to have set well in both instances. A further test will come months later when the canal is operated to capacity.

The water content in the soil-cement mortar is critical. A certain amount is required for hydrating the cement. Whatever is included above that amount will lead to cracking as it migrates from the applied mixture.

The project masons, however, have had good results in over 200 m^2 of recent soil-cement lining as they are using a technique of water/soil mixing which is the same as that used in local, traditional house construction. Water is worked into the soil-cement mud mixture by treading with the feet. The final mixture is packed in "balls" about 20 cm diameter and taken to the site of application.

The applications in 1990 used a tamper to pack the mortar. The more recent applications have not used the tamper, though the masons have given special attention to packing the mortar very well by hand.

One factor in favor of this lining technique is that it is cheap, and the procedures are easy to learn. Further, except for cement, the materials are locally available. Red soil is available in pockets throughout the command area. Even if the lining deteriorates every 10 years or so, the procedure of removal and re-lining is very cheap. This work, in the future, can be done by the association with minimal guidance from technicians.

Construction costs for this project are shared equally between AKWUA and the project up to a limit. Beyond that limit the expenses are treated as a grant. As the limit has nearly been reached, efforts to reduce costs of construction are not a high priority for the AKWUA farmers. This soil-cement lining is currently being discussed by the farmers as a second-rate technology. For now, the farmers are reluctantly accepting the sections that are lined with soil cement. The project is committed to replacing any soil-cement failures with better options during the five years of construction.

Further testing and applications need to be carried out to prove this technology in broader contexts and to refine the application methodology. Simple tests must be developed as standard procedures to develop guidelines for optimal mixture quantities of cement and water and any other constituents to be added. It would be good to try this technique with very careful supervision in other farmer systems where all costs are borne by the farmers and there is a sincere motivation to economize on expenses.

Example 6.15

Plastic Lining of Bijayapur Main Canal, Nepal

Achyut Man Singh[46] and Bharat Bastola[47]

Goal: *To reduce seepage of water from a larger canal, with a capacity of 2.5 m^3/s, in an area of unstable rock where rigid linings are broken by settlement. The solution was the use of twin sheets of plastic separated by a 10 cm layer of clay, with careful attention to providing graded underlayers and protective cover layers.*

The Setting

The Bijayapur Irrigation System is located in the Pokhara Valley in western Nepal. The landform upon which the canal is built and which the irrigation system serves is glacial outwash. The soil is very porous.

The canal was constructed in 1960 and has a design capacity of about 2.5 m3/s. Just downstream of the intake, the riverbed has scoured to a depth of many meters. The gravity canal has been cut into a steep unstable slope as it leaves the river gorge. This area is geologically weak and the canal is susceptible both to blockage from above by landslides and to undercutting by the stream below.

Plastic Lining of a Canal Section

After the Rate-Mate and Dhartiphant sections of the canal experienced high seepage losses, in 1976, the Department of Irrigation lined it with rough rubble masonry. Subsequently, the entire soil mass moved and the masonry lining collapsed. Infiltration of rainwater above the canal and seepage from the canal were considered contributors to the instability of the area. Catch drains were constructed above the canal and the canal section was redesigned with plastic sheet lining in the lower portion. Settlement was again observed and afforestation was done in the area to strengthen the soil mass. In 1984 and again in 1986, sections of the canal were reworked.

To intercept drainage from the slope above the canal and relieve pressure on the sidewall, a trench was dug along the bottom inner edge (on the side toward the hillslope) of the canal. The trench was filled with boulders and, at intervals, a perforated 10 cm diameter high density polyethylene (HDPE) pipe was run to the outer edge of the canal to drain the trench. Figure 6.15.1 shows the location of the drain and placement of lining materials.

In segments where the old lining was undisturbed, the canal was cleaned down to the plastic. Where the canal had settled, fill was added to level the bed. The bottom of the canal was lined with a base of gravel which was covered with sand

46 Senior Divisional Engineer, Department of Irrigation, Pokhara, Nepal.

47 Project in Charge, Department of Irrigation, Pokhara, Nepal.

Figure 6.15.1. Details of plastic-lined canal in the Bijayapur Irrigation System, Nepal.

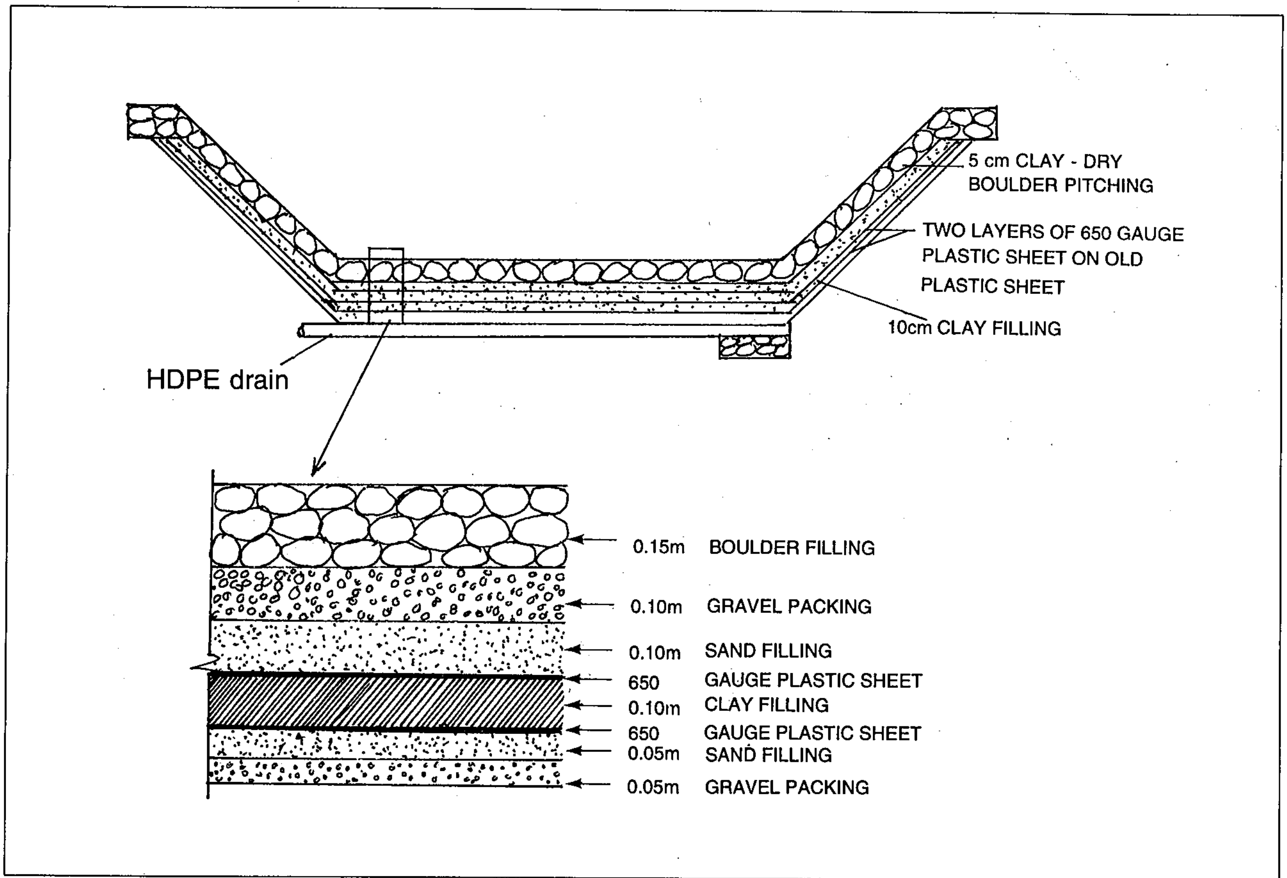


Figure 6.15.2. A view of a segment of canal lining where plastic sheet was used, Bijayapur Irrigation System, Pokhara, Nepal.

to fill the voids. A 650 gauge plastic sheet was placed on top of this sand layer or directly on top of the old plastic sheet in areas where it had not settled. A 10 cm layer of clay was placed on top of the first layer of plastic and a second sheet of 650 gauge plastic placed on top of the clay. This was covered with 10 cm of sand followed by 10 cm of gravel. A layer of boulders was placed as the final cover. The plastic sheets were continuous to the top of the sidewall. The plastic in the sidewall was protected by 5 cm of clay-dry boulder pitching.

Figure 6.15.2 shows a segment of the repaired canal lining. In the past five years, there has been about 20 cm additional settlement in this section of the canal. However, the plastic sheet lining has been flexible enough to prevent leakage and it now appears that the slope has stabilized.

Example 6.16

Siphon Pipe in Northern Pakistan

Hussain Wali Khan[48]

Goal: *To carry water across a valley and raise it to more than 100 m above the valley floor, using a siphon pipe, so that villagers and land on one side of the valley can derive benefit from an irrigation source that is on the opposite side and higher up. Collaboration of three Village Organizations ensured the success of this.*

The Setting

The structure described in this example is a siphon used to convey irrigation water across a valley. The irrigation system is located in Chalt village about 50 km north of the town of Gilgit. This is in the Karakoram mountains at an elevation of about 5,000 feet. The area is in a rain shadow, and as such receives minimal precipitation. All agricultural activities here are dependent on irrigation.

The villagers were assisted in the construction of the structure by the Aga Khan Rural Support Programme (AKRSP), the same program mentioned in Example 6.2. The AKRSP approach is to assist communities in setting up sustainable village-level institutions which are called Village Organizations (VOs). This is done through a series of dialogues between project staff and the villagers. The terms of partnership call for reciprocal obligations. The villagers must organize themselves into a VO, start a regular program of collective savings, and upgrade human skills. AKRSP offers a one-time grant to the VO for an infrastructure project identified collectively by the VO. The project must provide equitable benefits, and the VO is responsible for construction, operation and maintenance.

Because the elevation is lower in Chalt than in the case of Example 6.2, the growing season is long enough for two major crops. Wheat followed by maize is the most common cropping pattern. Vegetables and fodder are also important crops. The Chalt villagers have traditional rights to local forests but on-farm forestry is also important. The average household farm size is about 0.4 ha. Generally, farmers have little surplus agriculture produce. However, some fresh and dried fruit is marketed. Because of growing population pressures, Chalt villagers preferred irrigation development over all other possible projects.

Chalt village lies about 3 km west of the all-weather Karakoram Highway, and has better accessibility to inputs and marketing than most villages in the region. Access to the irrigated area which is about 1 km north of Chalt is by pony track from Chalt village.

The Irrigation System

Members of Chalt's three VOs agreed that building an irrigation system to carry water to a large parcel of undeveloped land was their highest priority. This parcel of nearly 200 ha could not be reached by a

48 Deputy General Manager, Aga Khan Rural Support Programme, Gilgit, Pakistan.

gravity canal from the available source of water because of the long deep valley. They had not been able to irrigate this area with their own resources. Figure 6.16.1 shows the layout and profile of the irrigation system.

The Siphon Structure

Villagers joined AKRSP technicians in conducting an on-site investigation to determine the feasibility of the siphon project. The engineers verified that the only possible way of taking water to new land was by installing a siphon system. The engineers also estimated requirements of material, time and labor for the project, including the widening of the existing channel up to the intake inlet.

The length of the irrigation channel from the source to the tank connecting the siphon is about 800 m. The pipe itself is nearly 1,200 m long. The pipe inlet also acts as a desilting tank. During operation, if the pipe becomes blocked, the villagers disconnect several of the flanged pipes and flush out debris. There have been no major maintenance problems. Most of the pipeline is resting on the ground. In a few places, where the ground slope changes abruptly, small pillars had to be constructed for support.

The size of the pipe was the major design consideration. The design discharge, length of pipe, inlet and outlet losses, pipe friction loss, and available hydraulic head were the key variables. The design discharge was based on the expected crop water requirements of the newly developed land. Inlet and outlet losses were deducted from the available elevation difference between the inlet and outlet of the pipeline to determine the hydraulic head available. Then, the pipe size was determined by using pipe flow equations and assumed friction losses. This procedure confirmed that an eight-inch diameter galvanized iron pipe was adequate for this application.

Figure 6.16.1. Plan and profile sketch of the irrigation system in Chalt, northern Pakistan.

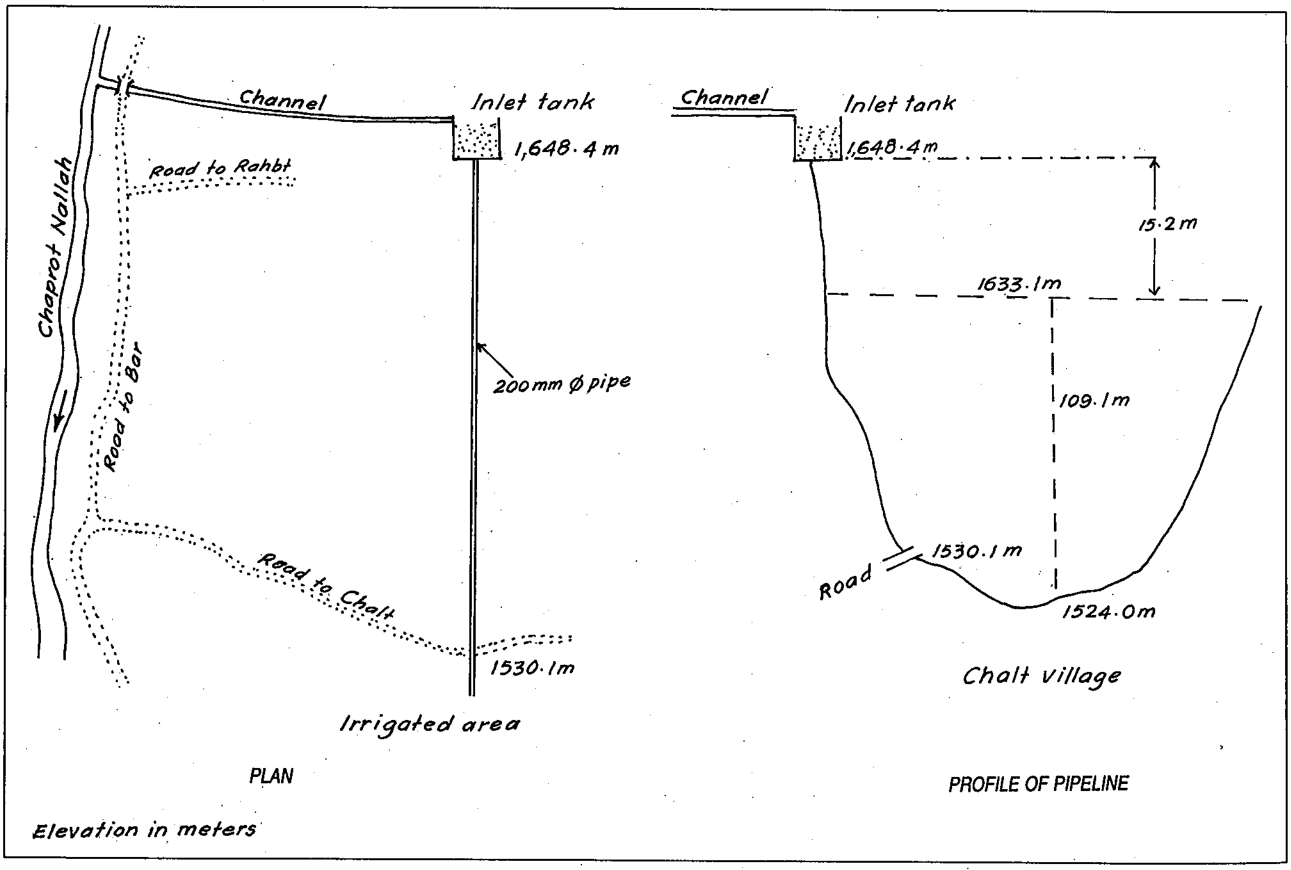
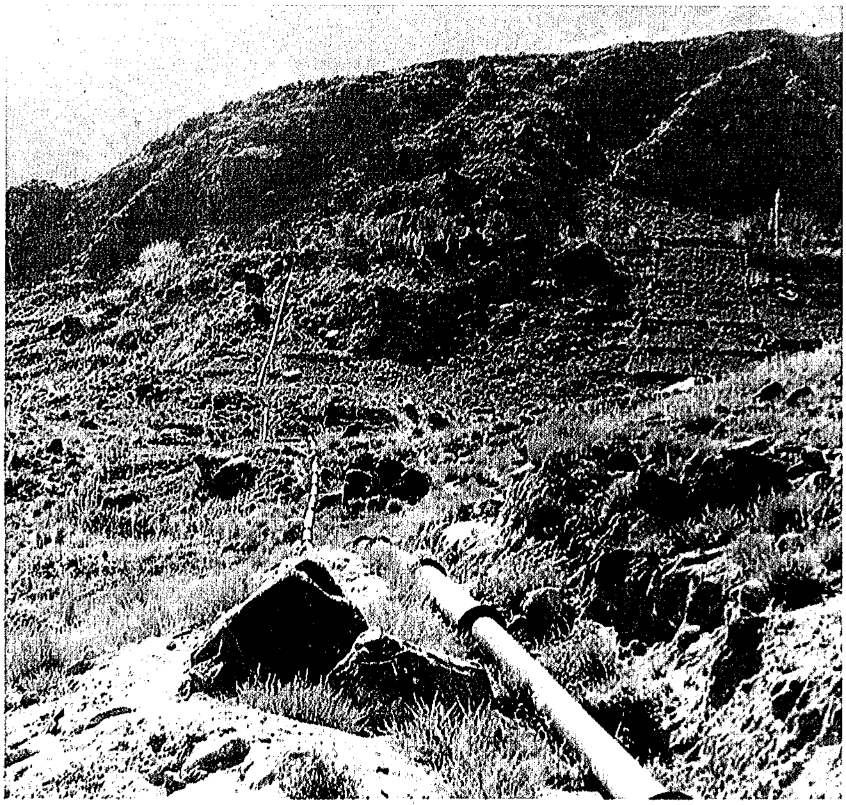


Figure 6.16.2. View, from near the inlet tank, of the siphon pipe crossing the valley, Chalt, northern Pakistan.



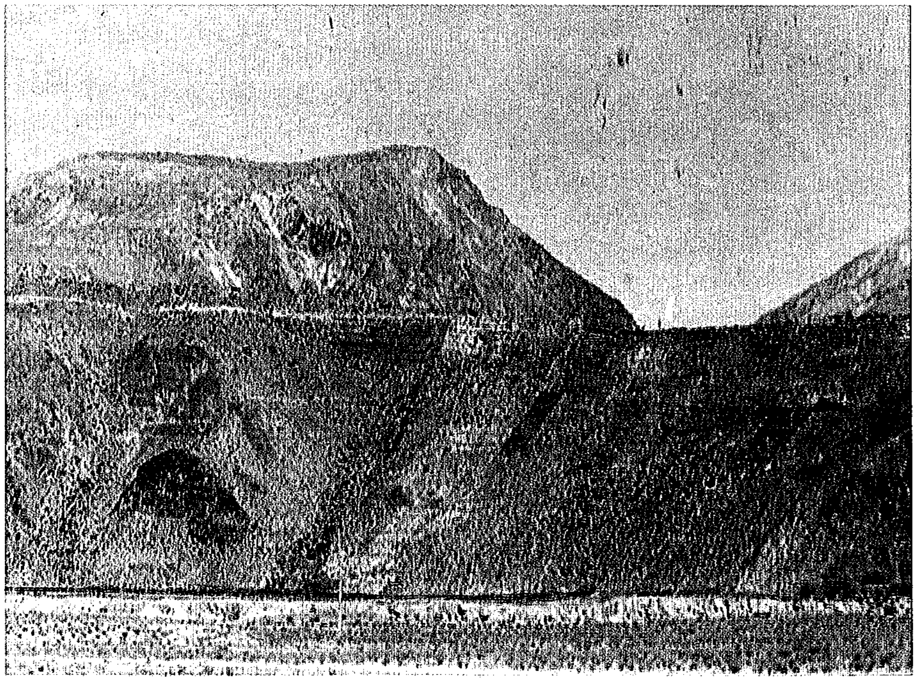
Photo, courtesy AKRSP.

area, primarily the slopes, can be irrigated.

The water source for the syphon irrigation system is a water channel which has discharges of 15 l/s and 50 l/s in the winter and summer months, respectively. This channel was widened by the villagers so that extra water could be used via the siphon for the new area. The primary source of water is snow/glacial melt. The command area lies mainly on the steep slopes of a hill where terraces are being developed. With the construction of the siphon, the total land under irrigation has

A dispute erupted among the Chalt VOs regarding the water source for the siphon system. AKRSP engineers had designed the structure on the assumption that water would be available from an existing channel that was at a higher elevation. This would have allowed all the new land, including a plateau on the hill, to be irrigated. However, the villagers agreed to the use of a lower channel as the source of water for the siphon system. As a result, only part of the new

Figure 6.16.3. View of the hillslope newly terraced for afforestation and irrigation by the siphon pipe irrigation system, Chalt, northern Pakistan.



Photo, courtesy AKRSP.

almost doubled. The new land has been divided equally among the households of the three VOs.

At the inlet of the siphon, a cemented tank has been constructed in the existing canal. From the tank, an eight-inch diameter pipe carries water down into the valley and then up to the new land (Figure 6.16.2). At the command area, two small water channels have been constructed for distributing the water. Within the system, water has been allocated to individual households on a *warabundi* basis (irrigation is on a fixed rotational basis). Each household gets water for two hours every 9 days.

The siphon was constructed in 1987 and has been operated by the VOs since that time. The three VOs have fully internalized the new irrigation structure. They are responsible for management, maintenance and repairs. The presidents and managers of the three VOs formed a committee to manage the irrigation system. The committee also solves disputes related to the use of the new facility. The committee employs two *chowkidars* (watchmen) to look after the system from the primary source to the newly irrigated land. Each watchman receives 250 kg of wheat and 250 kg of maize from each VO as payment for their work.

AKRSP provided a grant of Rs 519,974 (US$305,77) for installation of the siphon pipe and widening of the existing channel. The scheme is now fully operational. Figure 6.16.3 shows the terracing prepared for afforestation of the hillslopes.

Example 6.17

Masonry Aqueduct Crossing a Valley in Hubei Province, China

Liu Zhaoyi,[49] Chen Deliang,[50] and Zhang Changmin[51]

Goal: *To carry a large canal with a capacity of 2.5 m^3/s, across a valley, using a direct crossing instead of following the valley sides, in order to save 1.8 km of canal length and a corresponding amount of head. The solution was a 15-arch masonry aqueduct, 360 m long, built with local skills.*

The Setting

In hilly areas of China, the aqueduct is the most commonly used irrigation structure for delivering water across a valley, road, stream or river. An aqueduct normally consists of a flume portion, supporting members, foundations, and inlet and outlet transitions. In this example, the Wufan Aqueduct is described. It is a masonry arch aqueduct that spans a valley .

The Wufan Aqueduct is in the East Main Canal of the Meichuan Irrigation System. This is the same system in which the Longmenchong Siphon Spillway is installed. For a full description of the irrigation system, topography, climate, and agricultural practices see Example 6.8.

The Wufan Aqueduct

The East Main Canal crosses an alluvial valley about 9 km from the headwork. Crossing the valley directly instead of looping the canal up the valley reduces the length of canal by 1.8 km. Given the poor geological conditions of the banks of the canal and the need for a small-span aqueduct with a

49 Professor and President, Wuhan University of Hydraulic and Electric Engineering, Wuhan, China.

50 Professor, Wuhan University of Hydraulic and Electric Engineering, Wuhan, China.

51 Associate Professor, Wuhan University of Hydraulic and Electric Engineering, Wuhan, China.

release gate to cross the stream in any case, the most feasible options were to cross the valley with either an aqueduct or an inverted siphon.

Figure 6.17.1. View of the Wufan Aqueduct and Meichuan Valley, Hubei Province, China.

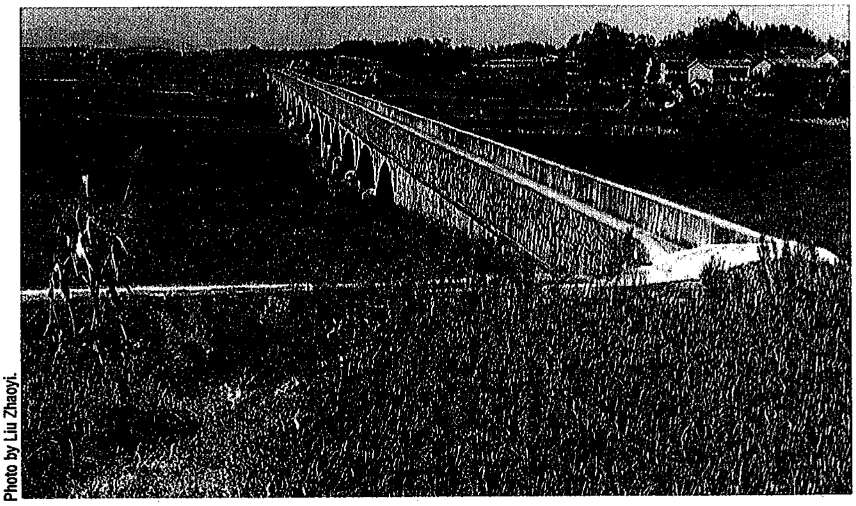


Photo by Liu Zhaoyi.

An inverted siphon had several disadvantages. It would give higher head losses decreasing the potential area for irrigation by gravity. Also, since the silt carried by the canal settles in the inverted siphon, it would make management difficult. An aqueduct had the advantages of less head loss, flexibility of design to prevent silting in the structure, and smaller area of cultivated land it occupies. For these reasons an aqueduct was selected as the most reasonable structure. In addition, there was abundant stone near the site to use as building material for an aqueduct and the local farmers had experience with stone masonry construction. This material would not have been suitable for the inverted siphon.

The aqueduct is 360 m long and 9.8 m high at the highest point. Figures 6.17.1 and 6.17.2 show the Meichuan Valley and the Wufan Aqueduct. Five masonry plate arches with single spans of 12 m each were designed for the lower height, and 10 masonry double- curvature arches with single span of 20 m each for the larger height (Figure 6.17.3). The masonry flume body was lined with mastic cement and has a rectangular cross section 1.75 m height and 2 m width. The arch abutments, made of masonry, stand on granite foundations.

The hydraulic design of the aqueduct involved determination of the slope, cross section, head loss and elevation of junction points with the outlet canal. The best slope was determined to be 1/2,000. The head loss was calculated to be 0.17 m at the design discharge of 2.5 m^3/s. The structural design consisted of strength and stress analysis of the flume body, arch ring and pedestal abutment. The construction of the Wufan Aqueduct was started in 1977 and it was put into operation in 1979. The total cost of the aqueduct was about US$30,000.

In its eleven years of operation the aqueduct has performed perfectly. No maintenance has been required and no cracks have developed. The main reasons for success are the

Figure 6.17.2. View from below the Wufan Aqueduct, Hubei Province, China.

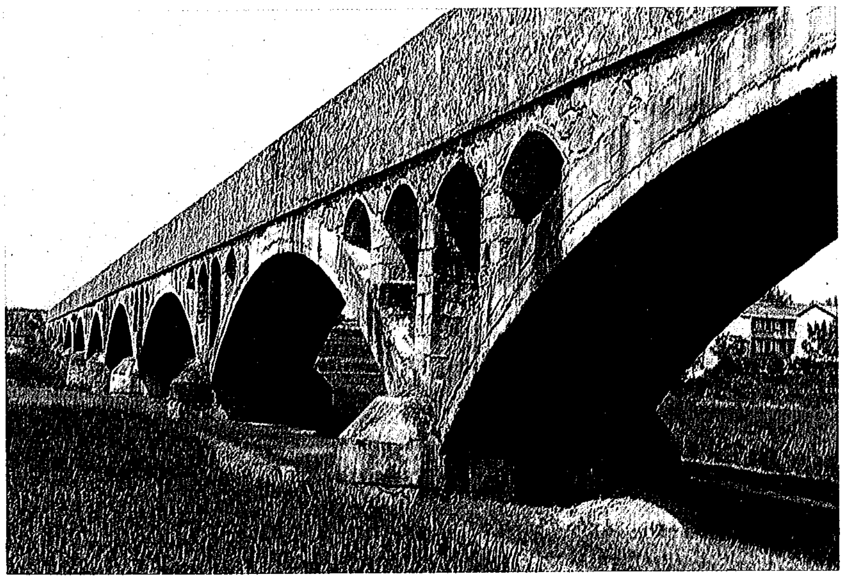


Photo by Liu Zhaoyi.

following: 1) the geologic condition of the foundation is excellent, 2) local residents were skilled in the construction of masonry structures and buildings with local materials, and 3) the expansion joints placed along the flume body have a well-designed rubber seal.

Although there has been no need for maintenance, the Canal Management Section is prepared for any daily operation and maintenance needs. The expenses for maintenance comes from the water use charge which is US$9.00/ha.

Figure 6.17.3. Details of the Wufan Aqueduct, Hubei Province, China.