A Prefabricated Modular Weir[§]

Wipat Kiwanon[§§]

RATIONALE FOR USING A PREFABRICATED MODULAR WEIR

A WEIR IS a type of irrigation structure built across a watercourse to raise the level of water flow and thus enable the diversion of water through canals to irrigate arable land. Weirs are useful during periods of low rainfall such as at the beginning of the agricultural cycle when it would otherwise be necessary to mechanically lift or pump water to reach fields, requiring expenditure of labor and providing water for only a limited area. Weirs also enable storage of water for dry-season use in streams that do not flow all year round. A weir is thus one form of labor-saving device.

Another important function of a weir is to serve as a spillway to prevent flooding that would damage crops during periods of heavy rainfall and high stream flows. Thus, a weir can serve two opposing functions: to raise the water level sufficiently for diversion of water for irrigation as well

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[§] This is a 1989 translation by Roberta Sharples of a 1969 report. Prices quoted and project information have not been updated. In 1969, 20 baht = US$1.

[§§]Mr. Wipat Kiwanon was Head of the Design and Construction Section, Department of Land Cooperatives of Thailand when he wrote this report, and was later General Inspector of the Ministry of Agriculture and Cooperatives from 1981-88. He is now retired.

[Editor's note: This report was prepared by Mr. Wipat Kiwanon for the Department of Land Cooperatives in Thailand in 1969. It is very interesting to note that 20 years ago Mr. Wipat was advocating a design model based on principles of 1) simplicity; 2) low cost; 3) use of local participation and resources; and 4) durability, versatility, and flexibility. Despite his report on the construction of 12 modular weirs using funds of the Department of Land Cooperatives the design model received little attention. Nevertheless, many of these principles are of the same design and farmer participation principles are becoming recognized more and more as important and valid for farmer-managed irrigation systems today. The fact that Mr. Wipat began calling attention to these aspects 20 years ago suggests that acceptance of many fundamental ideas requires a long gestation period.]

as to enable the highest possible volume of water storage while allowing rapid and safe passage of excessive water flows. The construction of a weir thus requires thorough investigation of each site and a large degree of technical knowledge.

Weirs constructed under the Department of Land Cooperatives must consider three important conditions: 1) technical concerns, 2) financial concerns, and 3) the cooperation or participation of cooperative members.

Technical Concerns

Construction of a weir that will be useful requires thorough collection of quantitative statistical information for proper design. This process includes:

1. A detailed topographical survey specifying the relative elevations within the command area, profiles of the stream or watercourse at the site, and details of the areas expected to be flooded and the area downstream of the site.
2. A hydrologic survey to determine the volume and velocity of stream flows, the volume of water required for agricultural uses, as well as the volume required to pass over the spillway.
3. A geologic survey to determine soil strengths within the profile, soil permeability, and to identify sources for the materials to be used in construction.

In addition, to assure precision in construction, an experienced technician must be available at the site to resolve problems and effectively supervise construction.

Unfortunately, the Department of Land Cooperatives would have difficulty meeting the above conditions in implementing a weir construction program. There are not enough technicians, nor time nor budget to allow broad and precise collection of all the information required for use in design. The work at each site is too urgent to warrant as much time in technical preparation as would be desired, and instead must be carried out using local knowledge as much as possible. *These conditions mean that work of technical complexity must be reduced as much as possible and the majority of the information used in design must be collected from the local community.*

Financial Concerns

In general, important structures are designed and budget estimates are made prior to the request for funding for construction. However, when conditions are such that a complete and precise design is left open, budget estimates are uncertain. Considering the high cost of an individual weir, the government cannot guarantee to fund the entire cost. When the government can support only a part of the cost of any weir, the weirs that are designed should be amenable to intermittent construction to be carried out according to the financial resources available at any one time.

To reduce costs, wherever possible, local materials and local labor must be used. The design should also allow flexibility, so that gradual improvements or adjustments can be made. Of

critical importance is the capacity for continuing construction under financial conditions similar to an installment plan. *This means that construction is carried out in phases, and continued according to the availability of funds.*

Participation of Cooperative Members

Land development as carried out under the Department of Land Cooperatives focuses on the use of local cooperatives and their efforts to increase farmers' incomes. Members of a cooperative help themselves by helping one another. The construction of any type of public use facilities must thus be carried out under conditions that contribute to, or reinforce, this cooperative spirit. Opportunities and implementation are thus critically important to the success of this process. This includes the procurement of materials, contribution of labor, and collection of funds from each member. When people participate together in this manner there is a sense of ownership and a propensity for helping one another to maintain the structure.

Viewed superficially, it would seem that a structure developed in this manner would be less expensive. However, it actually turns out to be much more expensive because the work that should be completed within a month may take over six months. On the other hand, the extra time and money expended may be considered a fair tradeoff for the local community spirit and sense of unity generated among members during the process. This is the rationale underlying the argument that proper investment now will naturally lead to a gradual decrease in government financial support of community projects in the future. *This highlights the need to work in accord with and to the satisfaction of the local community, enlisting the ideas and cooperative energies of all members.*

Construction of weirs under the Department of Land Cooperatives has evolved within the constraints described above, with a modular design and implementation process amenable to these difficult conditions. Weirs can be built wherever needed almost immediately. The structure can be altered, augmented, or disassembled easily if necessary, to the extent that if the site is found to be unsuitable, the entire structure can be moved to a new location. Construction can be carried out intermittently according to the availability of financial resources over a relatively unlimited period of time. Opportunities are open for members to participate as much as possible according to their skills and energies and according to their convenience. (Usually, members are less busy after rice is transplanted and high stream flows prevent construction of traditionally designed weirs, or during the dry season prior to planting of seedbeds when the government is not easily able to allocate and disburse funds.)

The most important characteristic of the weir design is its appropriate use of technical knowledge and techniques in design. The design is an improvement over farmers' traditional methods, can be gradually developed into a useful complete structure, uses durable and easily available local materials, can be used even before construction is complete, is easily repaired, and is not particularly expensive.

DESIGN OF THE WEIR

This ingenious design uses separate modular blocks which can be easily and conveniently constructed as conditions allow and then assembled later. Weir size and proportions can be determined to fit with local conditions and later adjusted as appropriate by separating and reintegrating the blocks according to the newly defined needs.

The elementary unit used in this construction is steel-reinforced concrete plates which are fastened together using U-bolts and nuts to form standard-size, hollow cubic blocks. These modular blocks can then, in turn, be fastened together side by side using the same size U-bolts. The proportions of the weir -- the width across the watercourse, the crest height, and the upstream and downstream slopes of the design -- are thus constructed by joining a variable number of overlapping, interconnecting blocks (see Figure 1).

The weir is constructed by assembling the concrete blocks side by side into walls. The spaces between the walls are filled with sand, gravel, and large stones, if available. The concrete blocks can also be used to build head regulators or small weirs in canals for raising and diverting water to fields.

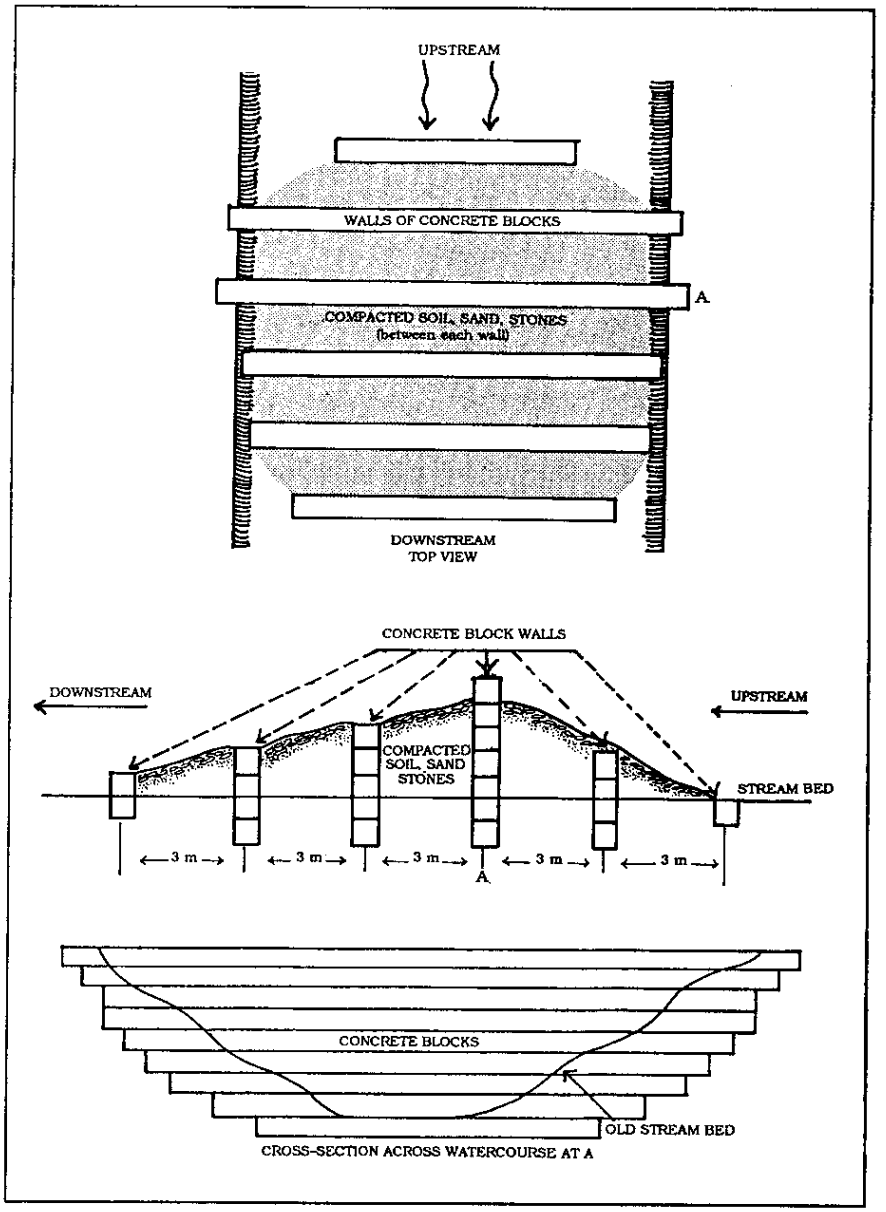
Physical Properties of the Reinforced Concrete Blocks

Dimensions. The concrete blocks are 50 centimeters (cm) wide, 50 cm long, and 50 cm high. Each of the concrete plates which comprises a block is 8 cm thick and is reinforced by 12 vertical and 4 horizontal rods of one-fourth inch steel. There are one-inch holes for inserting five-eighths-inch U-bolts used to fasten the plates together. The total weight of one reinforced concrete block is 145 kilograms (kg).

Materials needed for one plate:

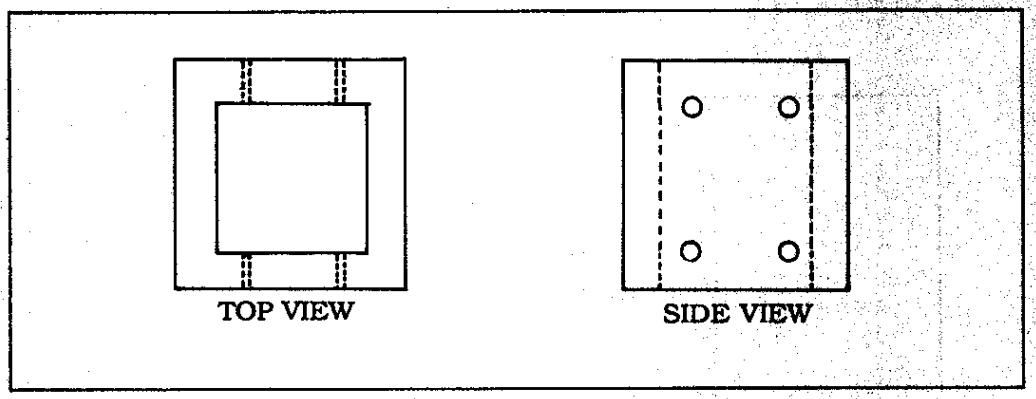
1. One-fourth-inch steel rods: 12 rods, each 50 cm long; 4 rods, each 2 meters (m) long. Total weight: 3.5 kg.
2. #18 size wire: 10 m. Weight: 0.1 kg.
3. Concrete mixed in proportions of 1:2:4 : 0.064 cubic meters (m^3).
   a) 20.5 kg cement
   b) 32 liters of rough sand
   c) 64 liters of #1 and #2 stones or gravel.

Figure 1. Modular weir design. Example from the Northeast Region Land Improvement Cooperative Project, Muang District, Roi Et.



Source: Site Plan number SJ 001947/09.

Sketches of each cross-section:



Safe load:

	Top	Side
Uniform compression	53 tons	32 tons
Uniform tension	4.6 tons	3.1 tons

Five-eighths-inch screw nut, with tension of 2.3 tons and shear of 1.7 tons.

THE IMPLEMENTATION PROCESS

In general, when the prefabricated weir design is recommended for a site the Department of Land Cooperatives allocates a supporting budget. The first step is to quickly compile relevant information. Aerial photographs which show 10-meter contours are used to roughly estimate the expected command area and, wherever possible, data is collected from other government agencies such as the Royal Irrigation Department, the Department of Land Development, and the Department of Meteorology. An especially useful part of the process is the reconnaissance survey where technicians talk with local people in the project area. Sometimes it is possible to develop a site plan or profile of the proposed weir site and to plan the design immediately. The design designates the pattern for assembling the hollow modular concrete blocks. Local officials from the Department of Land Cooperatives and a technician carry out the implementation.

The specific proportions of each design are determined prior to construction with a large margin of safety provided. The size and proportions of the weir can be readily adjusted throughout the construction phase. This process is affected by several factors: 1) the willingness of the government to continue subsidizing the project by providing technical expertise and money, 2) the interest of the local community, and 3) the willingness to lower the design safety margin and risk some (repairable) damage to the weir and the banks of the watercourse.

Design principles. The principles for designing the weir are relatively simple.

1. Select a site where the height of the weir structure is as low as possible while still being capable of raising water to the level required for irrigation.
2. The crest of the weir should be about the same height as the elevation of the command area.
3. The weir should be designed as wide as possible to allow a large volume of water to be passed downstream when necessary. The combined cross-sectional area above the spillway, together with that of the canals constructed for irrigation, should be approximately equal to the cross-sectional area of the original watercourse at its narrowest point in that vicinity.
4. The slope of the upstream section depends upon the crest height and the abruptness of the stream banks. The slope should not be steeper than the banks but it should not be too gradual to avoid sedimentation. A slope of about 2:1 (horizontal:vertical) ratio is workable.
5. The slope of the downstream section depends upon the force of the stream. If the farmers describe the current as very strong the slope should be very gradual. Otherwise, it may be somewhat steeper but not less than 6:1 ratio in any case.

COSTS

An essential part of government assistance is to provide technical support. This consists of a survey, design, and direction of the process of weir construction both technically and organizationally within the cooperative. The cost of most of this assistance is in the form of monthly salaries for government personnel, per diem, transportation, and purchases of tools and equipment. Funds may also be required to purchase such materials as cement and steel rods that the local community cannot procure for themselves.

In the northern region, the amount of support required is minimal since labor, sand, and gravel are resources relatively easily obtainable and the people are generally willing to contribute almost all the necessary resources. At most sites it has become difficult to obtain the hardwood needed to repair the traditional wooden weirs. Persons cutting hardwoods in public forests run the risk of being arrested by forestry officials or police. The switch to a concrete weir from the traditional wooden weir enables the community to make use of sand and gravel which are more readily available.

In the northeastern region where people are less familiar with the construction of weirs and have fewer resources more extensive government support is required. The materials are not only more difficult to obtain but are also much more expensive than in the north.

Principal Expenses

Molds. The molds used to cast the modular concrete plates should be formed as thick and as precisely as possible. There are two types of molds, one appropriate for use where cement-mixing equipment is available and the other for hand mixing. Both types cost approximately 1,700 baht

each. Each mold can be used to cast more than 100 plates without impairment. The mold used with cement-mixing equipment allows faster production of up to four plates per day. The cost for additional molds is less because it is only necessary to construct an exterior shell. Each project should have at least 20 molds.

Concrete mixer. A concrete mixer, of size 7 input/5 output, and a small concrete vibrator are important. Together, these cost about 25,000 baht. Although work can be accomplished without these product quality is lower, production is much slower, and much more labor is necessary. When a concrete mixer and vibrator are available the average cost of labor is about five baht per block. Without this equipment labor cost averages about eight baht per block.

Tools and other equipment. Wire cutters, shovels, hoes, trowels, rope, concrete buckets, baskets, wrenches, a block and tackle, and a wheelbarrow are additional equipment needed for construction. Metal sheets are also needed. The molds are placed on these while the concrete plates dry.

Building materials. Cement, rough sand, stones and gravel, steel rods, and U-bolts are needed. Costs vary from area to area. In general, these expenses are less in the northern region as compared with the northeast. The cost of materials for one concrete block in 1968 ranged from 48 to 66 baht.

Transportation costs. The cost of transporting building materials varies from place to place. Most work is carried out at the cooperative unit or near the weir site, depending on which is more convenient. The average cost of transport per block depends on whether the unit owns a vehicle or must hire a private vehicle.

Labor costs. Calculated on the basis of the 12 projects implemented in 1968, labor costs average from 3 to 12 baht per block. The large range is a function of the differences between methods of employing labor. These methods are listed below in order of the least to the most expensive:

1. The cooperative uses its own funds to contract labor.
2. Government funds are used to contract labor.
3. The cooperative uses its own funds to hire labor on a daily-wage basis.
4. Voluntary labor of members is used on a rotating basis.

The last method is the most expensive because it requires continuous training of new workers, involves many workers arriving late, and leaves uncertainty about the exact number of workers who will participate each day. Another factor influencing the cost of labor is the availability of cement-mixing and vibrating equipment, with labor costs much higher where shovels and hoes must be used.

Labor costs and expenses for assembling the modular blocks, filling in and compacting the soil, sand, and gravel, as well as for placing rocks against the front of the weir are difficult to calculate precisely. In most cases, this is accomplished using voluntary group labor on a daily basis. Sometimes this is supplemented by some hired labor, as necessary. This category of expenses includes the cost of labor and its attendant expenses and materials such as soil and large rocks. These are generally paid for in cash, but a very rough estimate is approximately 30 to 40 baht per block.

Thus, very roughly, an estimate of the cost of one modular block for a prefabricated weir ranges from 85 to 155 baht or an average of 120 baht. The actual expenditure will depend upon the particular cooperative and its members and the degree of cooperation generated in the process.

PROJECTS

Twelve weirs were constructed with help from the Department of Land Cooperatives in 1968. At the time of this report most of these were still under construction. At some sites, the first set of blocks were still being cast. At others, the process of assembling blocks into a weir had just begun, and at still others, this process was more advanced but awaiting the next dry season to continue work. Thus, the available data are incomplete.

At some sites local people provided all labor and some materials. At other sites, all required resources except cement and steel rods were provided locally.

Projects vary greatly in size. Several include construction of head regulators or gates as well as the weir. Erosion of stream banks due to fine sand soils is a problem at some sites in the northeast.

REGIONAL DIFFERENCES

Aside from specific on-site considerations, application of this design on a nationwide basis would require consideration of regional differences which influence the general approach to be taken.

Northern region. The northern region is characterized by topography with very steep slopes, dense forests, and highly permeable soils. Rainfall runoff may cause rivers to overflow their banks but this subsides rapidly and thus there is seldom damage due to flooding. Rather, more than 3,000,000,000 m^3 of runoff are unnecessarily lost (out of the region) each year. Water flows in the streams throughout the year. This is conducive to the development of gravity-based canal systems.

The farmers in the north have built weirs and dug canals to reach their fields for more than 700 years. In the two provinces of Chiang Mai and Lamphun, local people have worked together to build over 2,000 weirs, irrigating an area of approximately 96,000 hectares (ha).

In this region the Department of Land Cooperatives needs to provide both technical and financial support to the people in their efforts to improve and strengthen existing weirs thereby avoiding expensive annual repairs. Eventually, this should mean a replacement of the traditional weirs by more durable, technically acceptable structures.

Another important aspect of this work is the need to cooperate with the Royal Irrigation Department in promotion of water conservation:

1. Efforts should be made to organize and consolidate into a cooperative the many weirs that may jointly irrigate an area.
2. The crest height of existing weirs should be reduced as much as possible while maintaining irrigation capabilities. Regulators should be constructed at the head of all canals. The Royal Irrigation Department has already constructed head regulators in most areas and the Department of Land Cooperatives can be of the greatest assistance by arranging the construction of regulators or gates at points along canals or at the tail end of canals to facilitate the diversion of water into fields.

3. Assistance should be provided to local people in developing water-delivery systems and building various small irrigation structures that will enable both thorough coverage and increased conservation of water.

Implementation in this region has been primarily a matter of helping people in the rehabilitation of existing weirs. This requires planning to assure that the weirs can be used productively each year even while the process of construction may continue over several years. Cooperative members participate in construction by procuring sand and gravel and casting a portion of the blocks required in the dry season. These blocks are then assembled at the site prior to the beginning of the rice-production season. After rice transplantation when the farmers are less busy more blocks are cast to be used to augment the structure during the following dry season.

Northeastern region. The northeastern region consists of an elevated plain with gently undulating topography, sparse forests, and shallow topsoil of low permeability. The monsoon rains cover the entire lengths of the Moon and Chi Rivers and streamflow is strong and swift. Heavy rainfall alternates with dry spells in 2-3 potentially crop-damaging cycles throughout the rainy season. During the dry season water sources for most streams dry up. This is not conducive to the use of weirs. Hence, the people in this area are not familiar with weirs except for the construction of earth embankments at the end of the rainy season. These embankments serve to store water for dry season use but they are generally washed out each year.

Modular weirs may be useful in this region mainly for providing storage of water for dry season use, with at most only two out of every ten weirs actually serving to divert water for irrigation. The creation of reservoirs is a cost-effective and useful alternative, however, and modular weirs are also suitable for this purpose. Thus, the policy for this region should encourage people to cooperatively build as many modular weirs as feasible at intervals along streams so that sufficient water supply is available throughout the year. Even if weirs at some sites are washed out by heavy flooding they are easily repaired without much waste of either materials or labor because the individual concrete blocks will not be significantly damaged even under these circumstances.

Central and southern regions. No projects are as yet planned for the central or southern regions although the convenience of this process may lend itself to application in building other types of irrigation structures such as gates, head regulators, or small diversion structures.

BENEFITS OF THE PREFABRICATED, MODULAR WEIR

The weir serves as a rapid, effective means of accelerating water-resource development and can control water in a variety of situations. It provides a means for conserving or storing water or it can provide supplementary rainy- season irrigation or water for irrigating a second crop. In cases where many weirs are built along one stream they help control flood waters. At some sites it may provide water for a piped water system. At other sites the project facilitates communication.

The durability of the modules means that even where safety margins are low damage is not great. The versatility of the modules enables their application in construction of gates, dams, regulators, and even temporary bridges.

In the northern region, construction of the cement weir helps conserve forests by substituting the use of concrete for wood.

The opportunity to make extensive use of local participation and resources helps reduce the cost to the government.

Although the use of the prefabricated, modular blocks to construct weirs or other irrigation facilities is neither a precise methodology nor the most economical procedure available, it is capable of resolving a variety of problems and is worth considering as an option for water-resource development.