Lining Joints and Translation of Techniques:  
Two-stage Compulsory Filling Method

Kazunori Kato*

Abstract  After the 1970s' peak, the worldwide rate of irrigation development rapidly declined, and most financial assistance has been concentrated on operation and maintenance rather than new development of irrigated lands.

In spite of this effort, most irrigation departments in developing countries face heavy burdens of operation and maintenance costs. An analysis of this phenomenon ascertained that more emphasis had been placed on operational work than on maintenance work. It identified the maintenance and repair of canal systems as main drains on budgets. The most expensive work is repairing lined canals. Collapse of canal linings begins with seepage through the joints.

After displaying flaws in conventional jointing methods, the study disclosed a new method of making a construction joint, called the "two-stage compulsory filling method." This technique is characterized by two-stage placement of mortar with different cement contents and zero slump. Heavy blows of a wooden plate can drive masses of mortar into the joint, and result in meeting a full set of requirements for the construction joint. This method can be applied to the expansion joint due to its flexibility.

It has been proven that, if existing techniques are translated into a method truly required in situ, we can improve canal performance.

I. Introduction

After a flourishing period in the 1970s the worldwide rate of irrigation development rapidly declined, and most international funding agencies seem to have shifted their attention to funding institutional improvement, represented by Operation and Maintenance (hereinafter abbreviated to O&M), rather than construction of new irrigation systems.

It is widely known that most large-scale irrigation projects were formulated and implemented by consultants and the Irrigation Department of the country, using international funds. It is undeniable that this procedure had a tendency to overlook various requests of cultivators. Increase of funding for O&M, therefore, will be useful in filling in the blanks.

Is it certain that emphasis on O&M improvement will help in overcoming difficulties which have been inherited from past projects?

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II. Background of the Study

The greater part of the world's irrigated land was developed in this century. Irrigated land amounted to 40 million hectares (ha) in 1900\(^1\), and had increased to more than 220 million ha by the middle of the 1980s. Worldwide net irrigated area grew at a compound rate of 2 percent\(^2\), and there have not been wide discrepancies in the overall growth rates among the continents\(^3\). The growth rate of net irrigated area peaked in the early 1970s and has slowed to 0.9 percent since 1980.

Researchers have analyzed this recent decline and pointed out the following:
(a) Some newly constructed large irrigation schemes were either not functioning at all or not functioning properly\(^4\).
(b) Many irrigation departments have been experiencing severe budgetary difficulties\(^5\).
(c) The cost of state-financed irrigation has often been found to be very high in terms of both capital and subsequent operational requirements\(^6\).
(d) New project sites and water sources have been either unavailable or too difficult and costly\(^7\).
(e) Irrigation projects have failed to reach the anticipated yield set forth in feasibility studies and project documents\(^8\).

In addition to these negative factors, funding agencies and the irrigation department had been coming to recognize that irrigation systems should be operated by cultivators and that many of the best-operated irrigation systems were managed by cultivators\(^9\). Consequently, many irrigation agencies have shifted their interest from developing new large-scale irrigation projects to improving the operational efficiency of existing systems or to involvement of the cultivators in the design and construction stages of small-scale projects.

In the context of this movement, International Irrigation Management Institute (IIMI) was established in 1984 in Sri Lanka, which has been putting great emphasis on operational problems of irrigation systems. In parallel with a number of research activities, many irrigation agencies began to open training courses on maintenance with financial assistance\(^10\). Regarding the involvement of the cultivators, several researchers reported case studies conducted in Africa\(^11,12\).

In spite of tremendous efforts by researchers, funding agencies, governments, and the irrigation departments face the difficulty that O&M costs are burdensome, and often considerably larger than anticipated. This leads irrigation agencies to be dubious about the structural durability of irrigation infrastructures.

The study, therefore, starts by showing how heavy the O&M costs are for both the irrigation department and the cultivators, and analyzes what kinds of work in O&M have made them spend much money. This study will also attempt to propose some countermeasures to improve irrigation performance in existing
Irrigation projects subsidized by the government have devoured governmental budgets. According to the detailed studies conducted by Les Small et al. in 1986\(^{13}\), O&M costs of irrigation projects were equivalent to 128 percent, 107 percent, 181 percent, 83 percent, and 500 percent of the revenue of cultivators in Indonesia, the Republic of Korea, Nepal, the Philippines, and Thailand, respectively. This study gave an example from Pakistan, where about 1 billion Rupees had been collected in payment for public irrigation services, while O&M costs were estimated at 2 billion Rupees and annualized charges for past irrigation investments were about 5.9 billion Rupees. These results indicate that most countries cannot cover their O&M costs, much less their capital costs. The total annual investment in irrigation needed today for infrastructure maintenance is estimated at 10 to 12 billion U.S. dollars\(^{14}\). This estimate does not include major costs for important rehabilitation projects. It is easy to presume that the irrigation departments have budget shortfalls.

Hence, the present study shifts its attention to discussing whether the O&M works of an irrigation project are wasteful of funds and what kinds of works are the main drains on budgets.

Since there are not yet reliable data regarding the costs required for O&M of hydraulic systems from the upstream end (i.e., dams) to the downstream end (i.e., drainage canals) in developing countries, the study looks at files published in the Annals of the Society of Civil Engineers\(^{15}\).

Table 1 shows O&M costs of an irrigation project in the U.S. surveyed in 1967 and 1968. This project includes a full set of hydraulic structures from the upstream end to the downstream end. The costs include indirect costs such as costs for camps and buildings and general expenses.

Very large structures such as dams, reservoirs, and appurtenances need relatively small O&M outlays. In 1967 and 1968 these items (the sum of items 1+2 in Table 1) are 6 percent and 3 percent, respectively. The largest cost is that

<table>
<thead>
<tr>
<th>Description</th>
<th>1967 in dollars</th>
<th>percent</th>
<th>1968 in dollars</th>
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<td>1. Diversion dam</td>
<td>3,742</td>
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<td>2. Storage dam and reservoir</td>
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<td>3. Canal system</td>
<td>20,485</td>
<td>14</td>
<td>17,807</td>
<td>10</td>
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<tr>
<td>4. Lateral system</td>
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<td>5. Drainage system</td>
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<td>6. Delivery of water</td>
<td>20,281</td>
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<td>7. Camps and buildings</td>
<td>6,637</td>
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<td>8. General expenses</td>
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<td>149,859</td>
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Table 2: Detailed O&M costs of canal and drainage systems
(Item 3, 4 and 5 of Table 1)

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<thead>
<tr>
<th>Description</th>
<th>1967 in dollars</th>
<th>percent</th>
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</tr>
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<tr>
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<td>c. Cleaning</td>
<td>3,002</td>
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<td>d. Structure maintenance &amp; repair</td>
<td>7,878</td>
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<td>12</td>
<td>2,170</td>
<td>12</td>
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<td>f. Maintenance roads, fences and yards</td>
<td>441</td>
<td>2</td>
<td>352</td>
<td>2</td>
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<td>g. Miscellaneous minor expense</td>
<td>205</td>
<td>1</td>
<td>202</td>
<td>1</td>
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<tr>
<td>h. Rehabilitation and new construction</td>
<td>95</td>
<td>1</td>
<td>—</td>
<td>—</td>
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<tr>
<td><strong>Total</strong></td>
<td>20,485</td>
<td>100</td>
<td>17,807</td>
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<td><strong>-Lateral systems-</strong></td>
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<td></td>
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<td>a. Operation</td>
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<td>c. Cleaning</td>
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<td>f. Burrowing animal control</td>
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<td>16</td>
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<td>68</td>
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<td>j. Rehabilitation and new construction</td>
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<td>32,654</td>
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<tr>
<td><strong>Total</strong></td>
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<td>73,839</td>
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<tr>
<td><strong>-Drainage systems-</strong></td>
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<td></td>
</tr>
<tr>
<td>a. Operation</td>
<td>21</td>
<td>—</td>
<td>7</td>
<td>—</td>
</tr>
<tr>
<td>b. Bank &amp; channel protection</td>
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<td>c. Cleaning</td>
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<td>i. Rehabilitation and new construction</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td>11,294</td>
<td>100</td>
<td>6,791</td>
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LINING JOINTS AND TRANSLATION OF TECHNIQUES

required by irrigation and drainage canals (items 3 + 4 + 5 + 6), which accounts for 66 percent in 1967 and 68 percent in 1968. The costs for camps and buildings as well as general expenses seem to be nearly constant—28 percent in 1967 and 29 percent in 1968. Table 2 shows detailed O&M costs of canal and drainage systems (items 3, 4 and 5).

Regarding the O&M costs for canal systems, the most important expenditure is that for structure maintenance and repair (item d)—38 percent in 1967 and 53 percent in 1968. Contrasted with this, the operation cost of the canal system is small (item a)—2 percent in 1967 and 1 percent in 1968. For lateral systems also, structure maintenance and repair (item d) remains the dominant item, consuming 38 percent of allocated funds in 1967 and 27 percent in 1968, although considerable increase in the total O&M cost of the lateral systems in 1968 is due to their rehabilitation and new construction. In the drainage systems, the most expensive work is cleaning (item c), which accounts for 59 percent of the allocated budget in 1967 and 55 percent in 1968.

The low O&M costs for dams and their appurtenances shown in Table 1 suggest their high quality of construction. Is this tendency found in the dams and appurtenances constructed in developing countries?

A. da Silveira\(^\text{16}\) conducted a detailed study on the durability of 1,105 dams and their appurtenances constructed over the world between 1900 and 1975. He reported that the largest number of structures were built between 1960 and 1975. The percentage of failures in concrete and masonry dams during this period was 1.9 percent. For embankment dams, the percentage of failures in the same period was 17.6 percent. In comparison, a maximum of 9.3 percent relative to failure was found in concrete and masonry dams completed between 1920 and 1939, and a maximum of 21.2 percent was found in embankment dams completed between 1900 and 1919. Regarding the appurtenance work, the largest percentage of failures (28.6 percent) was found in structures constructed in the periods 1900—1919 and 1920—1939. Da Silveira concluded that these good results were the result of improvements in technology used in dam design and construction of dam. From this discussion, we can recognize as follows:

(a) Irrigation projects benefited less from improvements in technology than dams did.

(b) In order to lower O&M costs in irrigation projects, we have to pay much more attention to canal systems.

(c) In order to minimize O&M costs of canal systems, we have to reduce the structure maintenance and repair costs which account for the largest percentage of expenditure.

IV. Crucial Problems Relating to Canal Systems

The Food and Agriculture Organization of the United Nations (FAO) conducted a comprehensive study in 1986 with the purpose of clarifying relationships between design and operation of irrigation systems for smallholder agriculture in

\[ J. \text{ of IERP No. 29 (1995)} \]
The study report indicates not only the influence of design upon operation in water supply systems, but also important problems arising from existing canal systems.

According to the report, most of the major systems constructed earlier in the development of irrigation in South Asia had unlined canals. The report, however, insists on considering the option of lining of principal canals (main, secondary, and tertiary canals), with available water resources approaching full development and with irrigated agriculture now becoming a key factor in meeting the needs of growing populations. Following this description, we find such contradictory and bothersome sentences as follows:

"A primary issue in evaluation of canal lining is its durability. While linings in many major systems have performed satisfactorily for decades, others have deteriorated to a serious degree within three or four years of being placed in service. Repair of a deteriorated lining is difficult, and usually amounts to little more than patching of worst areas, becoming a substantial annual maintenance item."

The report allocates an important part of its text to problems with linings which have occurred in irrigation projects in South Asia, while unlined canals are only lightly touched on. The FAO survey mission found four types of lining—formed-in-place concrete lining, brick lining, stone-slab lining and pre-cast concrete slab lining—all of which have started to collapse due to deterioration of joints. The report, however, failed to propose a fundamental solution to this problem.

This report is likely to recommend linings because of their technical advantages, although lining techniques are uncertain and repair of a deteriorated lining is difficult and costly. It also points out that canal structures have short lives. The fragility of irrigation infrastructures in Africa is reported by J. Kimani and J. Ubels.

To cope with the deterioration of irrigation systems, seminars and training courses have been opened to strengthen maintenance skills. Their outcome has been published in the form of various handbooks or manuals, of which the study takes up the handbook prepared for the training course of Thailand.

In Thailand, the concrete structures are in excellent structural condition. The quality of the construction work has been very good. The primary difficulty is found near the joint opening of the end of the outlet transition structure and the lining. There is also a problem with the cavity around the structure. For earthen canals, the most obvious maintenance problems are sedimentation and aquatic and vegetative growth. Removal of these materials from the canals and sodding of the canal bank is the main target of maintenance work. The biggest problem relating to drainage canals is clogging from extensive vegetative growth, followed by accumulation of sediment. Drains can be reused if accumulated materials are removed. The formation of cavities behind the inclined concrete lining panels is the main cause of deterioration of concrete lined canals. This is the most important of all maintenance activities, because of the great loss.
LINING JOINTS AND TRANSLATION OF TECHNIQUES

in capital and investment costs each year and the tremendous cost of rehabilitation in the relatively short time period of 5—15 years. This handbook puts the greatest priority on examining formation of cavities behind the concrete lining panels, but fails to present any solution to this problem.

Herald D. Frederiksen\textsuperscript{26} checked irrigation and drainage projects with the World Bank's funding, and showed that their construction has been substandard. He emphasized that one important feature among various physical features was the use of and type of lining, which impacted seriously on O&M works. Taking into consideration the unpleasant reputation of canal lining in developing countries, he sent a questionnaire to various projects in the U.S. in 1986 with the primary purpose of securing a general view of lining performance over a period of time and under various climatic conditions. We can extract the following good suggestions from his study:

(a) Concrete canal lining is the preference stated by all the projects reporting from locations experiencing only limited and heavy freezing.
(b) Concrete lining displayed advantages over other types of linings such as heavy compacted earth or buried membrane linings.
(c) Maintenance costs of unlined and various types of lined canals vary, obviously depending on the specific canals, agency practices, and accounting principles applied.

He raises the question of why developing countries could not have gained from the advantages of canal lining.

We can obtain the following instructions from this section:
(a) Canal lining raises the most serious and costly questions.
(b) Lining of joints is a crucial problem.
(c) Canal lining has been much less appreciated in developing countries due to rough construction techniques.

Application of lining is predominantly determined by the costs. Large-scale irrigation projects in developing countries are usually financed by international funding agencies. They check each project from the point of view of economic acceptability and suitability of the project’s concept and components. This leads the engineers formulating the project to:

1. maximize the irrigation area;
2. select a crop whose price is competitive in the international market e.g. less than 300 U.S. dollars/tonne in paddy, F.O.B. Bangkok; and
3. cut the construction cost.

At the same time, the engineers have to examine from the viewpoint of technical acceptability whether the technique adopted in the project can be realized by the builders and whether maintenance and small repairs can be handled by the Irrigation Department together with cultivators after the engineers and builders have left the project site.

For cutting the construction cost, the engineers try to maximize the use of materials and products available in the local market and minimizing the imported materials. Many developing countries do not produce reinforcement bars, gates,
water-resistant plywood or moulds for prefabricating concrete products, whereas they have cement production plants and they are experienced in fabricating bricks, stoneslabs, concrete panels and concrete blocks. Thus, newly proposed irrigation projects which have been accepted by international funding agencies for the Asian region have total construction cost (including installation of headworks, pumping station, irrigation and drainage network and rough on-farm development) of less than U.S. $10,000 per hectare on a loan basis; the most expensive projects are found in Africa, where construction costs range from U.S. $15,000 to $25,000 per hectare.

Even if economic feasibility allows the project to apply canal lining, lining methods and materials should be determined by alternative-cost studies. In this study, the cost of unskilled labor engaged in lining work does not represent a critical factor in developing countries, because the wage for unskilled labor is about one U.S. dollar/day. The critical factor is choice of materials. When prefabrication of lining pieces is feasible at the project site, the plant cost represents an important portion.

Whatever methods and materials are adopted, lining pieces should be jointed in situ to form a canal.

V. Conventional Jointing and Subsequent Phenomena

Canals commonly found in developing countries have transversal cross-sections with a trapezoidal shape. Lining pieces needed for a canal with a trapezoidal cross-section can frequently be made without reinforcement bars and a minimum use of forming materials. Both canal types and lining materials are familiar to the local builder and laborers. The quality level of side slope formation to support lining pieces, from behind, however, should be much higher in a trapezoidal-section canal than in a self-standing canal with a rectangular cross-section.

Lining pieces must be placed on the bottom and side slopes of the canal and jointed with an adhesive substance. Cement mortar is widely used as adhesive material to connect bricks, concrete blocks, concrete panels, stoneslabs, and precast concrete slabs. The irrigation canal should be provided with appropriate compensating devices for shrinkage of lining pieces at certain intervals along the longitudinal section. Thus, lining canals have two types of joints. The first type is a “construction joint” which is installed to bond the lining pieces. These pieces should be integrated to a single panel. The second type is an “expansion joint” which is usually installed at junctions between alternate panels to compensate for shrinkage and subsidence subsequent to placing the lining materials.

Regarding the expansion joint, if the panel is thick enough (e.g. 10 cm) to insert a polyvinyl chloride (PVC) plastic or rubber water stop as shown in Figure 1, seepage through the joint will be stopped. However, in a case where the water stop cannot be installed, it will not be easy to hamper cavity formation behind the joint. We can see a typical example in Thailand(27).
"Generally, the concrete lining panels are three meters in length. Alternate panels are formed with wood strips and then poured in-place. Later, the wood strips are removed and the open space three meters in length is completely filled with concrete. A triangular-shape piece of wood is used shortly after pouring to etch a joint about 1—2 cm deep. However, upon drying, there is frequently an open joint between the concrete panels that is 2—5 mm wide."

This leads to seepage of water from behind the joint, which results in some sediment being carried into the canal. Then a small cavity near the joint is formed into a water path, which progresses upwards to the top of the panel. Finally, surface runoff starts to run into the open cavity.

Regarding the construction joint, the simplest traditional practice is to form a joint with 5 to 10 mm of mortar "pointing" with a trowel. Any slight subsidence resulting from introducing irrigation water into the canal, or simple temperature changes, cause fine hairline cracks to appear in the pointing at a proportion of joints with time. Seepage begins, and weeds grow within and behind the joint. This results in displacement or eventual separation of lining pieces from the side slope. Finally, the stream starts to erode the canal surface.

VI. Requirements for Making Joints

Joints in lining should not be poured or mortar-pointed, but should be made firmly in accordance with their required strength. Since the expansion joint can be made by applying the construction joint method, the study starts by discussing the way to fabricate construction joints.

The Concrete Manual defines construction joints as the contact between newly placed concrete and existing concrete surfaces that have become so rigid that new concrete cannot be incorporated integrally by vibration with that previously placed. The Manual indicates that the quality of a joint depends on the quality of the concrete and on the cleaning of the joint surface, and that a rough surface, in itself, does not assure a good construction joint. Where bond and watertightness at construction joints are desired, experience and investigation show that the surfaces of existing concrete should be wet-sandblasted and washed thoroughly and completely dried immediately prior to placement of fresh concrete.
concrete. The Manual gives us valuable guidance in making the joints. Essential requirements are as follows:
(a) Removal of laitance from the surfaces of existing concrete.
(b) Polishing of the surfaces with a wire brush or wet sand.
(c) Washing of the surfaces with water and removal of surplus water from them.
(d) Coating the surfaces with cement paste or mortar.
(e) Placement of fresh concrete.

Since the construction joint implies bonding of lining pieces which are manually placed on the side slope of the canal, it will be important to observe the habits of laborers who handle them on site. To simplify the discussion, it is assumed that laborers make construction joints after emplacing pre-cast concrete blocks with dimensions of \(50 \text{ cm} \times 50 \text{ cm} \times 7 \text{ cm}\). They have to unload blocks from trucks and pile them on top of the canal embankment. Then they move every block to the right location. Considering that a block weighs about 45 kg, they prefer to slide each block alongside the slope with their hands and gently put it in the place indicated by a supervisor. This technique results in making soil lumps adhere to the bonding surfaces of the block. It implies that in addition to the requirements mentioned above, we have to find an effective way to remove soil lumps from the bonding surface. Furthermore, it will be good to place inverse T character supporters under the joints to strengthen their structural form, taking into consideration the thickness of the concrete blocks. The process of making the construction joint can be mastered by laborers on site without any difficulties.

VII. Translation of Existing Techniques into a New Method

The materials and tools used for construction joint work include a wire brush, sand, water, cement, and air jet. Of them, the wire brush should be excluded because the bonding spaces are too narrow to insert it (see Figure 2). The remaining materials are ordinarily available at the construction site. Can we meet all the requirements with a combination of sand, water, cement and air? A simple combination of these materials is cement mortar. Supposing that we utilize the mortar, we examine each requirement referring to the items summarized in the previous section, and try to specify the characteristics of the materials as follows:
(a) Laitance can be removed from the surface of existing concrete by scrubbing with sand particles. This action also contributes to eliminating soil lumps which have adhered to the bonding surfaces during placement. Strong scrubbing can be done by inserting a wooden plate with a thickness a little smaller than the space required for the joints.
(b) The surfaces can be polished by repetitious scrubbing with sand containing water. This action can be induced by reducing the water content of mortar: if mortar is lacking in water the laborer doing filling work is forced to push and strike the filling material again and again.

*Irrigation Engineering and Rural Planning No. 29, 1995*
Figure 2 Typical placement of concrete block

(c) A minimum amount of washing water should be supplied from the mortar. This requirement can be met by striking the mortar with all one's might and main, because sand particles discharge water instantaneously when they are strongly vibrated or pressed.

(d) and (e)
Coating with cement paste and placement of fresh mortar are done after scrubbing the bonding surface with a wooden plate. Excessive mortar which is strongly pressed during the above process intrudes into the backside of alternate blocks from the joint. This results in forming an inverse T character supporter.

Supposing that the embankment is compacted at an optimal water content and the cross-section of the canal is shaped as the drawings specify, the procedure for making the construction joint in the block lining is as follows:

(1) Prepare a bucket, an empty can, a wooden plate, cement, sand, water, a trowel or a piece of steel plate and a scrubbing brush.
Remarks: (a) The wooden plate may be collected from the packing boxes used for spare parts or other machines. One end should be flat, and its dimensions should be such that a laborer can grasp the plate firmly with his hand.
(b) It is better to wash the sand if it contains soil lumps. Placing the sand on a fine meshed wired sieve and watering over it will remove clay.
(c) A trowel can be used for finishing work.

(2) Measure the sand and cement with a can according to the volumetric method.
Remark: It will be sufficient to apply the mortar with a mixing ratio of 1 (cement) : 3 (sand) to the first layer.
(3) Prepare zero slump mortar by adding water.
   Remark: Zero slump mortar can be defined as the water content when a laborer strongly grasps a mass of mortar in his hand and perceives water traces on his palm after he opens the hand.

(4) Place masses of mortar on the joints.

(5) Grasp the wooden plate and strongly strike over the masses.

(6) Continue striking the mortar along four sides of block while the bonding spaces are supplied with other new masses of mortar.

(7) When cavities under the joints are filled with mortar, the filling line rises gradually. Stop supplying mortar when the filling line reaches half or two thirds the depth of the bonding space (see Figure 2).

(8) Even out the surface of the mortar with the wooden plate.

(9) Wait for a few days.

(10) Clean the existing mortar surfaces with a water-wetted brush.

(11) Measure the sand and cement with a can according to the volumetric method and mix them with water.
   Remark: (a) Mixing ratio of 1 (cement):2 (sand) is recommended because the second layer of mortar has to be watertight.
   (b) Water content of the second layer should be a little larger than that of the first layer.

(12) Fill the bonding space with mortar and tap the surface of the fresh mortar with a wooden plate. Finish it with a trowel or a piece of steel plate.
   Remark: It is recommended that the joints be covered with water-wetted jute sacks in order to prevent the appearance of cracks after completion of this work.

The quality can be checked as follows:

(1) Prepare a pickaxe.

(2) Remove its wooden handle.

(3) Grasp the pickaxe in the hand.

(4) Strike the joint to the utmost.

(5) If the extremity of the pickaxe penetrates into the joint, that part should be disqualified and reconstructed. If the pickaxe rebounds from the joint, that part is regarded as perfect.
   Remark: The whole route of joints should be checked.

When we shift our attention to the expansion joint, we have to keep in mind that making expansion joints implies artificial or intentional fabrication of weak points, and thus to reduce the bonding strength compared with the construction joint. The procedure for making the expansion joint can be summarized as follows:

(1) is the same as item (1) of the construction joint.

(2) Measure the sand and cement with a can according to the volumetric method.
   Remark: The mixing ratio should be changed to 1 (cement): not less than 4 (sand), because the purpose is to remove all soil lumps and
laitance from the joint surface and to hamper penetration of weed 
roots from the backside of joints.

(3) to (9) are the same as items (3) to (9) of the construction joint.

(10) Cover the joint with adhesive packing tape and wait for a few days.

(11) Make sure that the construction joints have no cracks and the expansion 
joint has cracks alongside the joint.

(12) Clean the existing mortar surface with a dried brush.

Remark: Never apply water, because moisture on the surface prevents 
good adhesion of mastic sealant.

(13) Fill the joint with mastic sealant.

(14) After waiting a few days, draw a part of the sealant. If there is no 
separation, the expansion joint is in good condition. The method described 
above is called the “Two-stage compulsory filling method”.

VIII. Results and Discussion

The two-stage compulsory filling method was applied to “K” and “M” projects 
in a tropical country of Africa. These projects required placement of more than 
one million pre-cast concrete blocks, with dimensions varying from 30 cm×30 
cm×3 cm to 50 cm×50 cm×7.5 cm, for the lining of main, secondary, and 
tertiary irrigation canals, exclusive of field canals. Lining materials and 
methods were determined based on alternative studies of economic and technical 
acceptability. The projects were constructed in the 1980s. They are functioning 
well. According to our informants\(^2\), cultivators of “K” project have started 
block lining of the field canal with their own money, which suggests that they 
have recognized the advantages of canal lining.

However, there remain several technical problems:

(a) How can we prevent surface water from penetrating into the backside of 
lining panels?

We cannot completely stop the penetration of water behind the lining 
panels. Thus, we have to consider such supplementary measures as the 
following:

(i) Side weep holes are installed so as not to allow soil behind the lining 
panels to be washed into the canal and to relieve hydraulic pressure behind 
lining panels as well.

(ii) Concrete is placed on top of the panels to retard the penetration of water 
behind them.

For (i), a good manual\(^3\) is available, and this technique is well known to 
the local builders and villagers. Explanation of this technique is omitted.

Technique (ii) is illustrated in Figure 3, which shows a sample placement 
of top concrete. When precast concrete blocks are placed on the side slope, 
soil lumps inevitably adhere to the bonding face indicated by Section A in 
Figure 3. These soil lumps can be removed by tapping the bonding face 
with a water-wetted brush prior to placement of fresh mortar. After coating

\(^2\) J. of IERP No. 29 (1995)
the surface with mortar, fresh concrete containing smaller particles of coarse aggregate should be set in place, and a wooden plate should be tapped over the surface—in particular, over the bonding face. Sod facing should be applied to the upper unlined side slope.

(b) How can we deal with subsidence of the canal bottom?

Looking at Figure 4, we can easily understand that bonding strength at Sections B1 and B2 is smaller than that at Sections A1 and A2, even if we install corner blocks which allow enlarging of the bonding surface. This segregation is found in particular after the first introduction of irrigation water into canals. A problem with maintenance arises. This maintenance work can utilize the two-stage compulsory filling method.

(c) How can we overcome the discrepancy between design and construction?

Figure 5 shows a cross-section to be applied to lining of field canals. Since the depth is small, side slopes seem to be constructed with a single pre-cast concrete block, and the bottom is likely to be formed by placement of fresh concrete.

However, this design is not technically feasible at the construction site, because fresh concrete is placed as if the bottom concrete were suspended from the pre-cast concrete blocks put on the side slope. Soil lumps would hamper bonding between the block and fresh concrete. There is no effective
way to remove soil lumps from Sections B1 and B2. If the designer wishes to make this drawing technically feasible on-site, he must change the "cast-in-site" concrete bottom into a pre-cast concrete block bottom on one hand. This modification allows application of two-stage compulsory filling between the side block and the bottom block. On the other hand, he may modify the drawing as shown in Figure 6. This drawing indicates that we can lean the pre-cast concrete blocks on the side slope with one end fixed on the firmly anchored basement. The way to make this arrangement is as follows:

1. Place local-made rectangular concrete blocks along the canal bottom.
2. Cast fresh concrete on the canal bottom.
3. Scrub and thrust Sections C1 and C2 of Figure 6 with a wooden plate. This effects strong adhesion of bottom concrete to the rectangular concrete and elimination of voids formed during placement of fresh concrete.
4. On finishing the process described in item (3), lay a wooden bar or plate across the local-made rectangular concrete blocks and move it back and forth to remove excessive concrete and level the surface.
5. Place pre-cast concrete blocks on the side slope.
6. Apply two-stage compulsory filling to Sections B1 and B2.
7. Place fresh concrete on top and tap it with a wooden plate.
This method requires some maintenance work nonetheless, because the bonding strength of Sections B1 and B2 is smaller than that of Sections C1 and C2.

IX. Conclusion

Compared with very large structures, construction of small structures and canal lining requires the intervention of a large number of laborers. So long as the designer and the supervisor look only at "office work", they will fail to observe what is needed on site. If the site can benefit from improvements in technology, it will be possible to economize on maintenance costs.

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