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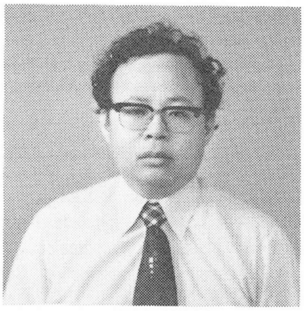
PRESENT STATE AND PROBLEMS OF RATIONALIZED CONSTRUCTION OF CONCRETE DAMS



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SYNOPSIS

The River Bureau of the Japanese Ministry of Construction is actively engaged in efforts to realize rationalized construction of concrete dams. The paper describes dam construction by the RCD Method, development of which was pioneered in the world by the Ministry, the concrete pump method being studied with small-scale dams as objects, and dam construction methods using belt conveyors, sorts out the problems encountered, and also cites the trends in studies on concrete dams in other countries of the world.

Keywords: rationalized construction of concrete dam, RCD Method, concrete pump method, dam construction by belt conveyor

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1. INTRODUCTION

The necessity for dam construction is becoming increasingly great for the purposes of preventing natural disasters through flood control, obtaining water resources for city water supply, and securing energy. With such a background, the trend of dam work under the jurisdiction of the Japanese Ministry of Construction, as shown in Table 1, has been such that whereas before 1950 the number of dams completed annually was only slightly more than one, in recent times the completions have amounted to more than a dozen every year. As of 1982, there were 89 projects consisting of dams being built under the direct control of the Ministry or public corporations, 141 which were subsidized multi-purpose dams, and 61 comprising subsidized flood control, or a total of 291 projects, an extremely large number.

Tables 2 and 3 show the transitions in the types of multi-purpose dams and average heights of dams. According to these tables, although there has been a recent trend for fill dams to increase in number for reasons of geological conditions of damsites, concrete dams make up 90% of the dams completed, with approximately 70% of the dams under construction during 1982 being concrete dams. Furthermore, on examining dam heights, it may be seen that both direct-control and subsidized dams are becoming larger. In view of such a situation, it was considered extremely important for studies to be made on constructing concrete dams more rationally, and the Ministry of Construction is grappling with this problem in a very positive manner. The present state of rationalized construction of concrete dams executed by the Ministry and the problems involved are described here while trends in various other countries are also cited.

Table 1. Transitions in Multi-purpose Dam Construction Projects (Number Completed)

Year / Project	Up to 1950	1951 to 1955	1956 to 1960	1961 to 1965	1966 to 1970	1971 to 1975	1976 to 1980	Total
Direct Control Dam	1	4	15	7	13	14	11	65
Subsidized Dam	8	16	15	24	17	44	40	164
Total	9	20	30	31	30	58	51	229

Table 2. Transitions in Multi-purpose Dam Types

Year / Project	Up to 1950	1951 to 1955	1956 to 1960	1961 to 1965	1966 to 1970	1971 to 1975	1976 to 1980	Total
Direct Control Dam		C 2 F 1	C 15 F 0	C 6 F 1	C 12 F 1	C 10 F 2	C 4 F 4	C 49 F 9
Subsidized Dam	C 3 F 0	C 16 F 0	C 14 F 0	C 23 F 1	C 16 F 1	C 41 F 3	C 34 F 6	C 147 F 11
Total	C 3 F 0	C 18 F 1	C 29 F 0	C 29 F 2	C 28 F 2	C 51 F 5	C 38 F 10	C 196 F 20

C: concrete dam F: fill dam

Table 3. Transitions in Average Dam Heights

(Unit: m)

Project \ Year	Up to 1950	1951 to 1955	1956 to 1960	1961 to 1965	1966 to 1970	1971 to 1975	1976 to 1980	Total
Direct Control Dam	0	77.6	71.9	84.9	86.9	77.7	101.5	82.2
Subsidized Multi-purpose	43.7	55.2	60.3	58.3	55.0	61.1	57.3	57.6
Subsidized Flood Control	0	35.3	0	34.9	43.5	42.1	48.0	42.8
Average	43.7	57.7	66.5	60.5	68.0	57.2	62.3	61.4

2. DAM CONSTRUCTION BY RCD METHOD

2.1 Background of Research and Development

A fill dam possesses advantages such as ① fewer restrictive conditions in geological aspects than a concrete dam, and ② the opportunity of seeking economy in execution of construction, but on the other hand, it is weak against overtopping both during construction and after completion, so that there are inherently such drawbacks as ③ a spillway cannot be provided inside the dam body, and at the same time, ④ a greater margin of safety against flood must be secured for the dam.

In contrast, a concrete dam possesses features such as ① superior watertightness and durability, ② high reliability in structural analysis, ③ practically no deformation of the dam body after completion, and ④ ease of maintenance and control.

In view of the above, because the construction time of a concrete dam can be shortened and economy enhanced by introducing the economy of fill dam construction in the method of constructing a concrete dam, and further, with the objective of establishing a rational dam construction method which can cope with wide variations in conditions such as of the geology and topography of the dam, the "Committee on Research Concerning Rationalized Construction of Concrete Dams" (Technology Center for National Land Development) was started. Under the guidance of this Committee, there later were many outdoor and laboratory experiments conducted concerning the RCD Method (Roller Compacted Dam-concrete Method), by which research and studies were carried out.

2.2 Outline of RCD Method

The RCD Method comprises a way of constructing a concrete dam as a series of systems using concrete of a new concept where lean, extra dry-mix concrete is transported by means such as trucks, spread out by bulldozer, compacted by vibratory roller, with contraction joints made by vibratory joint cutter.

This construction method, unlike conventional dam technologies, was developed ahead of the rest of the world as a purely domestically-produced technique.

Dams for which the RCD method was adopted are the three of Shimajigawa Dam (main body portion consisting of height of 89 m and dam volume of 317,000 m^3), Ohkawa Dam (foundation mat portion of dam of height of 78 m and volume of 1,000,000 m^3), and Shin-nakano Dam (foundation of energy dissipation works appurtenant to dam of height of 74 m and volume of 267,000 m^3). In such manner, numerous technical problems were overcome through the research efforts and cooperation of many persons involved. That dams of the class of roughly 100-meter height and several hundred thousand cubic meters were completed as the first in the world by the RCD Method has played a great role in bringing about a technological revolution in concrete dams.

The technical problems resolved in this construction method can be broadly divided into the three items summarized below.

1) Establishment of Method of Designing Mix Proportions for Lean Concrete--In order to compact concrete with a vibratory roller, it is necessary to adopt an extra-dry mix differing from conventional plastic concrete so that a roller placed on top will not sink in. Also, since laying of cooling pipes does not fit into the scheme, it is necessary to adopt concrete of lean mix proportions with low cement content to restrict temperature rise due to heat of hydration. A method of mix proportioning to satisfy the requirements of strength and workability under such conditions was established. As a result, concrete satisfying the quality requirements with an unprecedentedly low unit cement content of 120 kg/m^3 (cement 84 kg/m^3, fly ash 36 kg/m^3) was obtained.

2) Establishment of a Series of Work Execution Systems of the RCD Method Through Development of Various and Diverse Devices and Construction Methods--Studies of compaction machinery, and clarification of the consolidation mechanism were made with regard to problems such as prevention of segregation during spreading of concrete at the site, ensuring uniform compaction with the vibratory roller, prevention of occurrence of voids, securing of strengths of construction joints, joining of plastic exterior concrete and internal concrete according to the RCD Method, etc. As a result, the thin-layer spreading method with which there is little segregation developed and it was made possible for compaction to be done on lifts of thickness of 70 cm. For providing transverse joints in the method where concrete was placed covering the entire surface with one layer at a time, a vibratory joint cutting machine was developed, while for mixing of concrete, innovations were made such as remodelling of tilting type mixers, and adoption of forced-mixing type mixers.

3) Establishment of Quality Control System for the RCD Method--In carrying out work, a quality control system consisting of a series of tests on many cores of large diameters was established. Also, a large-sized vibrating consistency test machine was devised for consistency control of concrete. Further, in order to improve the accuracy of water content control during mixing of concrete, improvements were made also on automatic moisture correcting equipment.

2.3 Advantages of RCD Method

The advantages of the RCD Method can be broadly divided into the five items of ① reduction in construction cost, 2 increased efficiency of work, ③ safety of work, ④ contribution to preservation of the environment, and ⑤ possibility of aiming for diversification of design theory.

(1) Possibility of Reducing Construction Cost

Reduction in construction cost involves the two aspects of saving labor and conserving resources. In the way of saving labor, mechanization of spreading and compacting of concrete, non-necessity of work to provide transverse joint forms, non-necessity of cooling works and grouting of joints, improved efficiency of laitance removal and other works, reduction in manual work through mechanization, and reduction in degree of requirement for skill can be cited as advantages.

Regarding conservation of resources, reduction in quantity of cement used by 30%, reduction in total quantity of forms by 40 to 50% due to the non-necessity of transverse joint forms, reduction in cooling materials and joint grouting materials because of less heat evolution due to less quantity of cement used, reduction in construction equipment costs concerning excavation for travelling cranes at both banks, and reduction in miscellaneous temporary works costs such as safety facilities can be cited as advantages.

(2) Possibility of Increasing Efficiency of Work

Increased efficiency of work will lead to shortening of construction time, and is the greatest objective of rationalized construction in addition to reduction in construction cost. Firstly, the fact that the peak rate of operation of equipment can be maintained for a longer duration can be cited as an advantage. For example, with respect to the performance at Ohkawa Dam, whereas the number of days of operation at 80% of installed capacity or higher was 18 days with the conventional method, it was 70 days with this method. Further, since the main pieces of equipment are general-purpose machines, that flexible deployment according to the work schedule can be made through organization of total number of machines and methods of use constitutes a great advantage. Still further, that rapid construction can be done is also a major advantage. For example, according to the performance at Shimajigawa Dam, the daily average quantity of placement was increased 24% compared with the conventional method, with the daily maximum placement increased 90%. At Ohkawa Dam, it was estimated that placement would require 18 months with 2.0-m lifts, the monthly maximum placement being 22,500 m^3 with the conventional block placement method, but the performance with the RCD Method was placement in 9 months with the monthly maximum being 40,500 m^3.

(3) Excellence of Safety Supervision

The working area is very large compared with the conventional block placement method, while there are less height differences, so that not only are ease of work execution and efficiency superior, but safety is also extremely good.

(4) Contribution to Environmental Preservation Measures

In case of the RCD Method, transportation of concrete is by fixed cable crane or dump truck so that large-scale excavation is not incurred, and the effects on the environment are less than those of the conventional method.

(5) Possibility of Diversification of Design Theory

At a site where the strength of foundation rock is inadequate for construction of a conventional gravity dam, while spillway facilities would be of too large a scale for a fill dam to be constructed, there can be a case when it would be advantageous for a concrete mat to be provided at the foundation to disperse stresses and a conventional dam built on top of the mat. For such a site, the RCD Method with its low cost is optimum for constructing the mat. It will be possible to diversify design theory in this way.

2.4 Drawbacks of RCD Method

Two or three problematic points may be cited as drawbacks of the RCD Method such as 1 since consolidation of exterior concrete is presently done using internal vibrators, preparations different from those for consolidation by roller in the RCD Method are required, 2 measures to cope with flooding during construction are more difficult than for the conventional block method (in the block method, the sides near the two banks are built up higher than the middle to allow flood water to pass through, whereas the feature of the RCD Method is for the entire length to be placed in one layer so that in case of overtopping of the dam due to flood curing construction the entire length of the dam would be overtopped).

2.5 Dam Suited to RCD Method

In view of the advantages and disadvantages of the RCD Method described above, there will be configurations of dams which are greatly suited to the Rċd Method and others which are not. In effect, it will be more suitable for the topography of the damsite to be a U-shape with a greater area available for executing work rather than a steeply-sloped V-shape. Also, in a case of numerous objects to be buried in the dam body such as outlet facilities, inspection galleries, etc., a work area over which concrete transporting equipment of the RCD Method cannot travel about freely can be said to be not very much suited for the RCD Method.

Regarding the scale of the dam also, a range suited for the RCD Method is conceivable. With a dam of small scale, it may be said that the RCD Method is not very suitable since a working area for the RCD Method would not be available. On the other hand, when the height of the dam is a hundred and several tens of meters, the concrete strength according to the present RCD Method (cement content 110 kg/cm^2) will be insufficient compared with the strength required from the design conditions of the dam, and it will be necessary for the strength of the concrete to be increased or the necessary stress to be lowered by increasing the cross section of the concrete. This is a problem of the RCD Method which must be considered for the future.

2.6 Future of RCD Method

In recent years, sites with favorable conditions with respect to topography and geology have become fewer in number, and therefore, it is aimed to diversify design theory through adoption of the RCD Method. It is thought that the RCD Method will be taken up hereafter for many dams because of this. In view of the features of the method, it is considered it will be possible to adapt it for various works other than dams such as airfield runways and foundations of oil storage bases which cover wide areas.

3. RATIONALIZED CONSTRUCTION OF SMALL CONCRETE DAMS

3.1 Background of Research and Development

To look at the sizes of gravity-type concrete dams in projects under the jurisdiction of the Ministry of Construction, dams of concrete volume 100,000 m^3 and under make up 21% of the whole, and those of 200,000 m^3 and under 50%, as shown in Fig. 1. The relations between dam volumes and heights are plotted in Fig. 2.

According to these figures, small dams under 100,000 m^3 are very large in number, while dam heights are about 50 m, so that the concrete strengths required are not

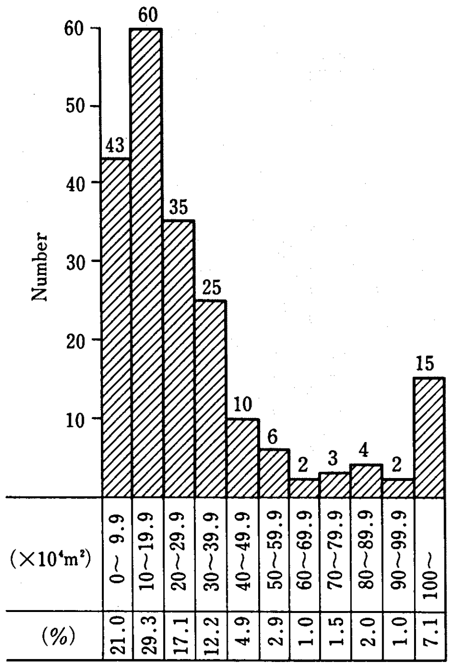

Fig. 1--Dam volume distribution.

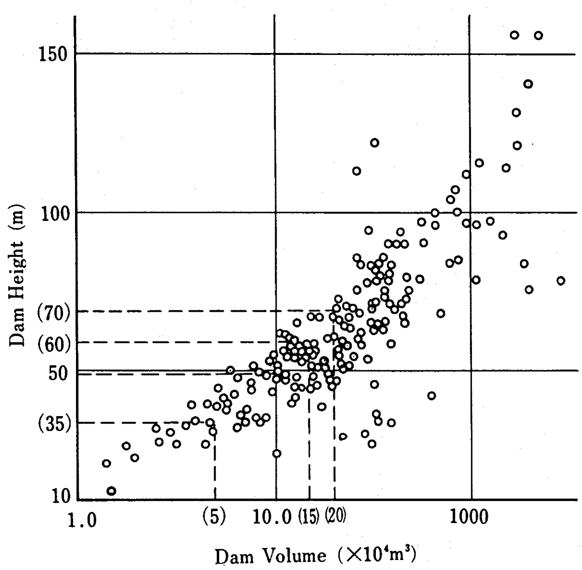

Fig. 2--Dam volume vs. dam height.

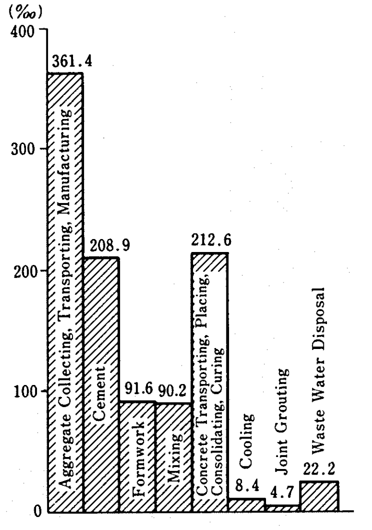

Fig. 3--Proportionate composition of unit price of concrete.

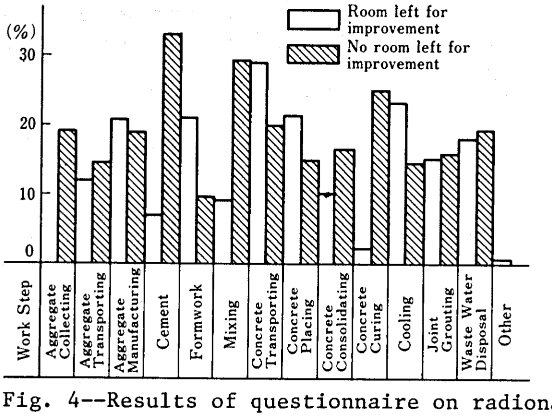

Fig. 4--Results of questionnaire on radionalization of dam construction.

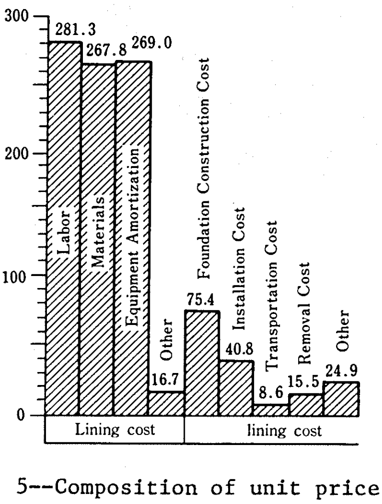

Fig. 5--Composition of unit price of concrete.

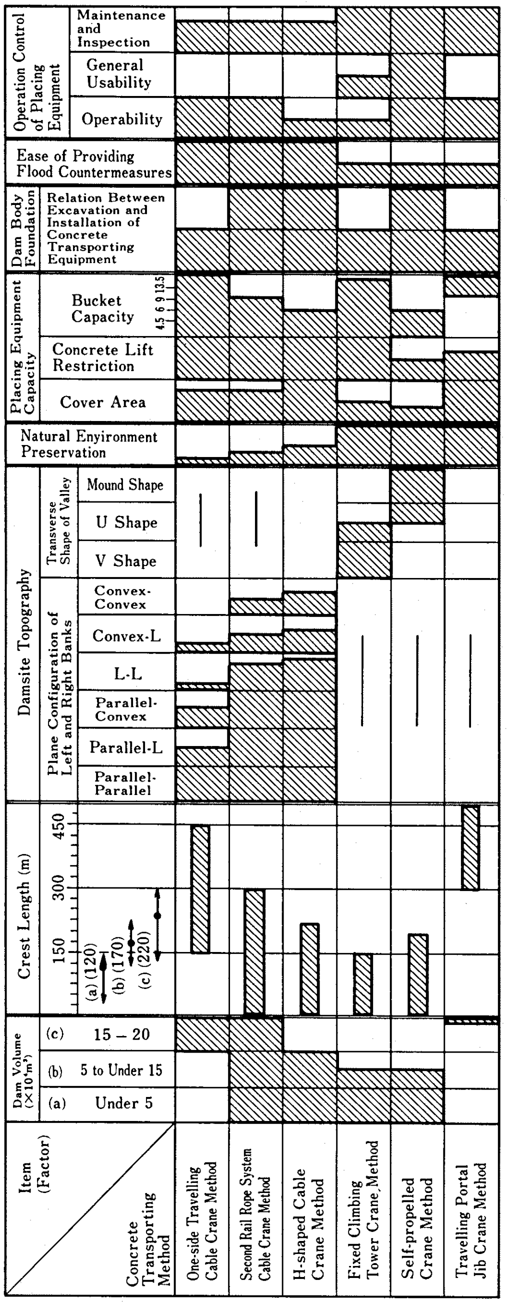

Fig. 6--Schedule for judging scope of application of various construction methods to small, gravity-type concrete dams.

very high. Regarding the construction facilities for such dams, it was thought it might be necessary to consider something appropriate in accordance with size, and since 1978, studies have been made organizing a committee within the Technology Center for National Land Development.

3.2 Focal Points of Rationalized Specimens

On analysis of the unit price composition, it is as shown in Fig. 3.

With regard to room for rationalization, it is as shown in Fig. 4.

As a result of the above studies, the conclusion drawn was that it would be effective for examinations to be made with transporting, placing, and consolidating of concrete as the first stage.

This is considered from the aspects of running costs and fixed costs in the unit price of concrete. As shown in Fig. 5, since fixed costs amount to 20% whereas running costs are 80%, the focal points of rationalization of dam construction by small-size general-purpose machines are to achieve savings in the 20% corresponding to fixed costs, and the 27% out of the running cost.

In effect, if small-size general-purpose machines which are less restricted by topography were to be used, it may be considered that the overall fixed costs including items such as foundation construction costs and installation costs will be greatly reduced compared with equipment exclusively for dams. As for amortization, if equipment exclusively for dams were to be used, there would be fewer opportunities for reuse on other jobs, so that a considerable portion must be amortized at the particular dam project. On the other hand, if small-size general-purpose machines are used, they can be freely diverted to jobs other than dams, so that for the dam project, amortization is for a period limited to the number of days on that job. Accordingly, if small-size general-purpose machines are used, although the work efficiencies of individual job sites will be slightly lowered, it is thought rationalization as a whole can be aimed for.

3.3 Conventional Costruction Methods for Small-size Concrete Dams

As a method of proceeding with studies for rationalization of construction methods, it is necessary at the first stage to establish the procedure for selecting the conditions under which it would be suitable to adopt conventional methods. The first step of this procedure is to eliminate those among conventional construction methods which are not appropriate for the conditions given, and to sort out several construction methods which can be made objects of comparison studies for the damsite in question. The second step is to carry out case studies on the construction methods remaining after the sorting out, and to finally select the optimum construction method from economic and other viewpoints.

The second stage is to extract points requiring future improvement and betterment with regard to conventional methods, and through the betterment and improvement, lead to a more efficient construction method. The third stage is to carry out studies on new construction methods based on the results of studies and analyses of efficiencies, etc., of conventional methods, without being restricted to the scopes of the conventional methods.

A schedule for judging the scope of application of conventional methods as the first step of the first stage is shown in Fig. 6. This schedule only gives fundamental and standard ways of looking at the problem, and does not comprise uniform and fixed criteria for selecting a construction method.

With regard to the second and third stages, since the pumped placement method and belt conveyor method are thought to be promising for rationalized construction of small concrete dams, the processes of studies on these methods are described below.

3.4 Dam Construction Through Placement of Concrete by Pump

(1) Features of Concrete Pump Method

The features of the concrete pump method are ① the principal placing equipment consists of only a pump and pipeline, which is applicable to any topographical condition, and practically no fixed costs such as installation, removal and foundation construction are needed,② consequently alteration of the environment through excavation for foundations of construction facilities can be avoided, ③ the purchase price of equipment is cheap and amortization costs are low, ④ there is little necessity for a skilled operator resulting in adaptability to labor saving, etc.

Because of such advantages, concrete pumps are suitable for an extremely broad field of use, and are widely employed not only in building construction, but also civil works. In dam construction, besides placing of the main bodies of small dams, pumps can be used for placement of aprons of gravity dams which cannot be covered by main cable cranes, energy dissipation works of auxiliary dams, spillways of fill dams, etc., and it is expected that the scope of application will continue to be expanded.

(2) Trial Dam Construction by Pumping

Conventionally, high slumps, rich mixes and small-diameter aggregates had been desirable for concrete pumps. Since low slump, low cement concrete and large-diameter coarse aggregate particles are desirable for dam concrete, it had been considered that pumping of concrete was not adaptable. Within the limits of specifications for concrete pumps presently available, it is considered that pumping of concrete having aggregate larger than maximum size of about 40 mm and slump less than 8 to 10 cm is difficult.

It has been reported that trials for application of the pumping method to dam concrete have been conducted heretofore on check dams in Japan
However, there are problems such as described in (3) which still need to be - resolved, and it may be said that the pumping method has not yet been established as a mature technology for placing dam concrete.

Recently, as the first step toward establishing a dam construction technology using pumpcreting, trials were carried out at Nagayo Dam in Nagasaki Prefecture, and were completed on achieving their objectives.

[Particulars of Nagayo Dam]
Location: Honkawachi, Nagayo-cho, Nishisonogi-gun, Nagasaki Prefecture
River: Nagayo River
Dam Type: Concrete gravity dam, dam height 36 m, dam crest length 171 m, dam volume 57,200 m^3

[Outline of Pumpcrete Method for Nagayo Dam]
① Upstream cofferdam: Dam height 10 m, dam crest length 45.1 m,

dam volume 1,340 m . Prior to construction of the dam proper, various tests were performed by the pumpcrete method in November-December 1981.

② Main Body Construction: The higher-elevation portion of the main body concrete and part of the river-bed portion, a total of 25,000 m^3, was placed by the pumpcrete method. Regarding the remaining lower-elevation portion of $32,000^3$m , it was decided that hauling from the batching plant to the placement surface would be done by dump truck.

③ Size and Capacity of Concrete Pump: Horizontal-type, single-drum, dual hydraulic piston type, discharge 5 - 85 m^3/hr, valve cylinder diameter 220 mm, 8-inch pipe.

④ Concrete Properties: Maximum size of coarse aggregate 60 mm, unit cement content not more than 240 kg/m^3, slump 5 - 8 cm for basic concrete and 10 - 12 cm for concrete using superplasticizer.

(3) Future Problems of Pumpcrete Method

1) Improvement of Concrete Pump--It is looked forward to that improvement and development of a type of concrete pump suited for pumping dam concrete of low slump containing large maximum size coarse aggregate will be realized.

To classify the pumping loads of concrete pumps and pipelines, they are ① load on concrete pump (cylinder portion, wye-pipe portion, tapered pipe portion), and ② load on pipeline (horizontal straight pipe portion, vertical pipe portion, bent pipe portion, distributor portion). According to the results at Nagayo Dam, there is not very much difference in pressure losses whether slump is high or low. From the fact that all clogging phenomena occur in the part of the concrete pump from cylinder to wye-pipe, improvement of this part, and further, development of a new mechanism will be important problems for the pumpcrete method.

2) Improvement of Pumpability of Concrete--The three items for study below exist from the standpoint of materials with regard to the direction that improvement in pumpability of concrete should take.

① Improvement in Superplasticizer: The use of an admixture of superior dispersing performance (superplasticizer) for making concrete of dry consistency with a low unit water content as the basis is extremely useful. It is necessary for the performance to be improved and the method of using and other factors to be examined.

② Utilization of Admixtures: The use of fly ash as an admixture produces the effect of reducing unit water content and the actual amount of cement in the unit binder content. Besides fly ash, the effective utilization of industrial wastes in finely divided form such as slag and rock powders are thought to be beneficial to improvement of pumpability, and this is a matter for further study.

③ Aggregate Gradation Suitable for Pumpability: The pumpability of concrete will be improved if the quantity of minute powders contained in the concrete were to be increased. In the case of dam concrete, there is a limit to increasing unit cement content for reasons of heat evolution so that the influence of minute particles (0.3 mm and under) in fine aggregate is thought to be extremely great. Accordingly, selection of the gradation of fine aggregate and control of handling is considered to be very important. With regard to coarse aggregate also, it is thought that a suitable combination of large and small particles will greatly affect pumpability, and examinations of gradations of fine and coarse aggregates suitable for pumpability are necessary.

3) Establishment of Rational Mix Proportioning Method for Pumped Dam Concrete --Regarding the optimum concrete pumpable, even when improvemet of pumpability is done from the aspect of materials such as described in the preceding clause, the mix will inevitably be different from conventional dam concrete of low slump and large maximum-size coarse aggregate. However, a dam is a permanent structure. There must be no lowering of concrete quality, and hereafter, it will be necessary to aim for a rational method of designing pumped dam concrete mixes thoroughly taking into account considerations of durability of concrete.

4) Establishment of Method of Testing Pumpability of Concrete--Pumpability will be determined by clogging phenomena inside the pipeline. It is thought the basic cause of clogging is a dewatering phenomenon. The pressurized bleeding test method was devised in attempting to reproduce clogged states, but since it is difficult to determine pumpability by only the result of this test, it is needed for data to be collected further, and to establish a method of judging pumpability in advance.

5) Improvement of Workability in Connection with Consolidation, Etc., of Pumpcrete--Concrete is evenly spread out by distributor, following which it is consolidated by internal vibrator, but since slump is higher than for conventional dam concrete and the working conditions for consolidation are not good, consideration must be given to matters such as devising means of providing footholds for workers.

6) Lightening of Pipeline Material--Piping materials will add up to considerable weight when steel pipes are used for extreme difficulty in moving pipelines about, and it is necessary to contemplate utilization of a material lighter than steel but of good abrasion resistance.

3.5 Dam Construction by Belt Conveyor Method

(1) Features of Belt Conveyors

The features of a belt conveyor are ① since it is an apparatus for continuous conveyance the transportation capacity per unit of time is large compared with the manufacturing and installation costs, ② alteration of the environment accompanying excavation for foundations in installation works can be avoided, ③ the purchase price of the equipment is cheap and the depreciation cost is low, ④ there is little need for skilled operators, thus making possible labor saving, and these are substantial advantages.

Belt conveyors have a history spanning a century, and backed by the development of steel cord conveyor belt manufacturing techniques and of various types of machinery and controlling techniques, they are used as transporting facilities for bulk materials such as earth, rock, iron ore, etc. Small ones are portable belt conveyors of unit lengths of several meters, while large ones are long-distance belt conveyor assemblies as much as 100 km in length, and the uses are varied and cover a broad spectrum. However, on the other hand, in case belt conveyors are to be utilized in a dam concrete transporting system, there are drawbacks such as ① since there is a limit to the angle of rise in conveying much restriction will be placed from the standpoint of topography, ② shifting about of the conveyor system is necessitated as the point of placement changes, ③ there is little flexibility in planning concrete placement since it is a continuous transporting system, ④ segregation is likely to occur when concrete falls from the belt conveyor onto the placing surface, and ⑤ mortar will stick to the belt, and it is necessary for these problems to be resolved in order to utilize belt conveyors.

(2) Dam Construction Trials Using Belt Conveyor Method

The following cases have been reported as recent examples of dam concrete having been placed by belt conveyor.

1) Guri Dam, Venezuela--The spillway of Guri Dam (composite dam of gravity-type concrete and earth-rock fill, dam height 106 m, dam crest length 690 m, completed in 1968) was placed by belt conveyor. A bucket of 6 m^3 was loaded on a diesel locomotive running on a trestle in the direction of the dam axis. The bucket was emptied into a hopper of capacity of 10 m under the trestle and the concrete was fed onto a conveyor system with amount of feed controlled by a feed gate. The conveyor system consisted of a feeder conveyor of width of 900 mm, low speed of 30 m/min and length of 18 m, and a main conveyor of width of 600 mm, speed of 135 m/min and length of 142 m, the conveyor suspended from a tower crane being swivelled and raised and lowered to place concrete.

2) Villerest Dam, France--The dam body concrete (slump 2.5 - 5 cm, maximum size of coarse aggregate 100 mm) of this dam (arch-gravity; 350,000 m^3) was placed by belt conveyor. Concrete from the batching plant was received by a hopper of 4 m^3, feed was controlled by a feed gate, and the concrete was hauled by a feeder conveyor (width 750 mm, low speed 45 m/min, length 15 m) and a main conveyor (width 600 m, length 270 m), and placed swivelling a stationary swinger. The placing capacity of the system was 150 m^3/hr.

As can be comprehended from the above cases, a belt conveyor placing system can be broadly divided according to the three functions below.

① Feeder Conveyor: A facility for supplying concrete from the batching plant at a fixed rate, and continuously, to the main conveyor.

② Main Conveyor: A facility for hauling concrete supplied from the feeder conveyor to a spreader system provided near the point of placement.

③ Spreader System: A system for uniformly spreading concrete supplied by the main conveyor over a wide area on the horizontal plane of the point of placement. This spreader system can be varied to use a tower crane, a stationary swinger, or a spreader-type conveyor. This system poses the greatest problem in the belt conveyor placement method.

(3) Problems of the Belt Conveyor Method to be Resolved Hereafter

Of the five drawbacks of belt conveyor systems previously described, it has been reported by the U.S. Army Corps of Engineers that with regard to the countermeasure for segregation mentioned under ④, if concrete is loaded to capacity on the belt, segregation will not occur as a rule, while concerning the measure for removal of the mortar mentioned under ⑤, a belt scraper at the return belt will be quite effective, and solutions to these problems may be said to have been obtained to an extent.

The matters requiring further study with respect to the belt conveyor method are the items ① to ③. From a different point of view, in order to take advantage of the greatest feature of the belt conveyor method of a system suited for continuous, large-volume transportation of concrete, it will be necessary to consider placement by layers covering the entire surface at one time, and not be preoccupied with the conventional block method. The site of concrete placement will change three-dimensionally over a wide area every day, and it is conceivable for the shifting about of the conveyor system to cope with this situation to be done on a large scale in case of a big dam; in case of a dam of small scale it will be important for the facilities to be on a simplified basis. Concerning the two points above, the matter of most importance is to consider systems suited to the conditions of the individual jobs.

4. TRENDS IN RATIONALIZED CONSTRUCTION OF CONCRETE DAMS IN VARIOUS OTHER COUNTRIES

4.1 Outline of CIRIA Report

In June 1981, a conference of CIRIA (Construction Industry Research and Information Association) concerning rolled concrete for dams was held in London. Messrs. Tsutomu Yanagida (The Cement Association of Japan) and Kentaro Takahi (then of the Water Resources Development Corporation, presently Project Manager, Hattabara Dam Construction Office, Ministry of Construction) attended this meeting, and reported on the RCD Method developed in Japan. In other parts of the world, new materials and methods were being devised with full-scale experiments being conducted at the laboratory level, whereas in Japan the RCD Method had already been established with actual dams such as Shimajigawa completed, and thus this drew wide attention.

A preprint for the conference showed the state of development of rolled concrete dams in the world, and this is revised here and given as Fig. 7.

This figure shows that rolled concrete dams may be divided according to four design methods, which are ① high fly ash content concrete dam without joints, ② lean concrete dam with joints, ③ lean concrete at the interior without joints but with a watertight wall at the upstream face, and ④ dam of "as excavated" material stablized with cement (called rollcrete dam).

4.2 Comparisons of Types

The analytical comparisons of the four methods made by CIRIA are given in Table 4.

These comparisons discuss different design systems on the same level, and in addition, methods for which the degrees of establishment of technologies differ with regard to design and work execution theories are handled as being the same, and therefore, may be said to be unreasonable in certain respects.

A dam is a structure of a highly public nature and its safety must be guaranteed. The safety of a dam must be determined based on an overall evaluation of the load condition anticipated and its extent, physical property values concerning the object structure, the method of analysis used, and the factor of safety obtained. The construction methods cited above already have gone beyond the mere execution of work, and contain matters involving fundamentals of design methods so that it is imperative that a comprehensive evaluation be made by starting out from gaining an understanding of basic physical property values, taking account of studies on analysis techniques, and ceaselessly accumulating data.

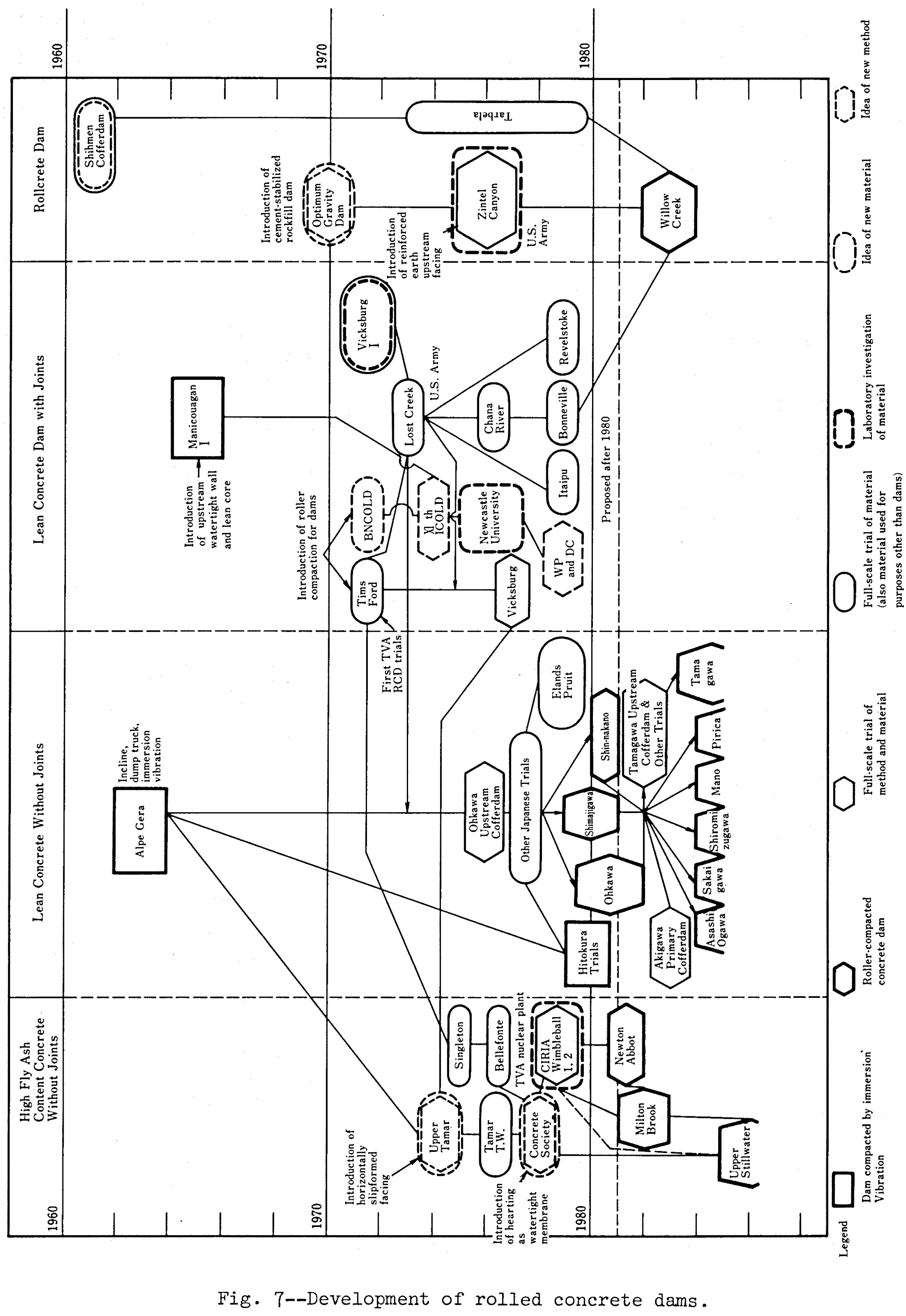

Fig. 7--Development of rolled concrete dams.

Table 4. Comparison of Different Methods of Construction for a Rolled Concrete Dam (from Ref. 5)

Method of Construction	Material Costs(1)	Volume of Dam(1)	Impermeability of Hearting	Horiz. Joint Preparation	Contraction Joints in Hearting	Contraction Joints in Facing	Cranage	No. of Types of Concrete Required	Concrete Separated or Concurrent(2)	Compatibility of Methods of Placement	Additional Requirements
Lean Concrete Dam with Joints	Low	Same	Reasonable(3)	Expensive	Expensive	Expensive	Required for formwork	3	Concurrent	Yes	Plant required for cutting Joints
Lean Concrete Dam Without Joints	Low	Same	Permeable joints	None	None	Very expensive	Required for precast blocks	3	Separated	No	No fines drainage layer required behind upstream wall
High Fly-ash Content Dam Without Joints	Similar or low(4)	Slightly smaller	Good	None(5)	None	Simple	Not required	2	Separated	Yes	Specialised plant required for facing concrete
Optimum Gravity Dam Containing Cement Stabilized Material	Very low	Larger	Poor(6)	None	None	None	Not required	2	Concurrent	Yes	-

Notes: (1) Compared with conventional concrete as used in gravity dams
(2) Timing of placing of hearting and facing
(3) Bedding mix usually used
(4) Depending upon cost of flyash
(5) Except after gaps of more than 3 days
(6) Separate expensive watertight membrane required if dam to hold water

Table 5. Rationalized Construction of Concrete Dams in Japan by RCD and Other Methods (After Construction of Shimajigawa and Ohkawa Dams)

Method	Dam	Juris-diction	Dam Height (m)	Dam Crest Length (m)	Dam Volume (m^3)	Period of Placement or Period of Main Body Construction	Remarks
RCD	Tamagawa upstream cofferdam, other	Tohoku Regional Constr. Bureau	20	273 (Concrete 82 Fill 191)	(Concrete 21,300 Fill 98,900)	Oct. 1981 - Apr. 1982 Placement by RCD	Besides upstream cofferdam (6,000 m^3) by RCD, construction facilities plant foundation concrete (2,500 m^3) also placed
	Tamagawa	Ditto	100	430	1,100,000	RCD placement from Oct. 1983	Incline, G_{max} 150 mm
	Akigawa upstream cofferdam	Water Resources Development Corp.	12	40.4	3,000	1983. Apr	C+F 80 kg/m^3 No formwork Continuous placement without joints
	Pirica	Hokkaido Development Bur.	40	1,480 (Concrete 910 Fill 570)	560,000 (Concrete 360,000 Fill 200,000)	RCD placement from Jun. 1984	
	Mano	Fukushima Pref.	69	239	212,000	Order for main dam scheduled for 1983	Transportation by incline
	Asahi Ogawa	Toyama Pref.	89	252	350,000	Ditto	Transportation by dump truck
	Shiromizu-gawa	Yamagata Pref.	54.5	367	311,000	Ditto 1984	Ditto
	Sakaigawa	Toyama Pref.	115	297.5	626,000	Ditto	Transportation by incline

PCD	Nagayo	Nagasaki Pref.	36	171	57,200	Feb. 1981 - Sept. 1983	20,200 m^3 placed by pump G_{max} 60 mm Slump 8 cm C + F = 217 kg/m^3
Belt Con-veyor	Ohmachi	Hokuriku Regional Constr. Bureau				Sept. 1982 - Dec. 1982 Placement by belt conveyor	Dam concrete placed by spreader belt conveyor
	Ohkawa	Ditto				Nov. 1982 - Dec. 1982	Dam Concrete placed by main conveyor and belt conveyor
	Aseishi-gawa	Tohoku Regional Constr. Bureau				Placement by belt con-veyor from Jun. 1984	Energy dissipation works approx. 10,000 m^3 scheduled for placement by belt con-veyor
Other	Hitokura (Auxiliary energy dissipa-tion works, etc.)	Water Resources Develop-ment Corp.				1979 - 1980	Entire surface layer method Lean concrete, low slump Internal vibrator

5. CLOSING REMARKS

Research on the RCD Method has been continued even after completion of Shimajigawa Dam. While resolving problems concerning the RCD Method encountered in the past, and in order for the method to be further developed into a mature and established technology, work was started on Tamagawa Dam (dam height 100 m, dam crest length 405 m, dam volume 1,105,000 m^3) of the Tohoku Regional Construction Bureau in September 1983. In addition, the concrete portion of Pirica Dam (composite dam, concrete portion dam height 40.5 m, crest length 910 m, volume 374,000 m^3) of the Hokkaido Development Bureau is scheduled to be started in June 1984.

With regard to the pumpcrete method, the results of main dam placement at Nagayo Dam will be examined to provide more improvements and achieve still further development. As for the belt conveyor placement method, after having carried out field trials at several dams under the guidance of the Committee on Rationalized Construction of Small Dams, the present stage is one of detailed studies under way concerning two dams, and it is intended for work on the main bodies of these dams to be started soon. It is believed that these construction methods will become firmly established to form a framework of various construction systems in accordance with the characteristics of individual dams. An outline of rationalized construction of concrete dams after Shimajigawa and Ohkawa is given in Table 5.

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