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PRESENT AND FUTURE OF USE OF PRECAST MEMBERS IN DAM CONSTRUCTION *

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1. BACKGROUND AND OBJECTIVE OF STUDY

Dam construction methods that make flat construction joints such as roller-compacted concrete dam methods and extended layer concrete methods were developed in the mid-1970s to increase the efficiency of concrete dam construction without using dam construction methods involving vertical concreting in blocks at each construction joint. In dam construction methods that make flat construction joints involving less concrete blocks than dam construction methods involving vertical concreting in blocks at each construction joint, however, the

* *Utilisation d'éléments préfabriqués dans la construction de barrages (actuellement et dans le futur)*

construction of structures in the dam body such as galleries and gate chambers affected concrete placement, and the objective of increasing construction efficiency (reducing the construction period) was unlikely to be achieved. To solve the problem, precasting galleries was considered. Fully precasting galleries by integrating precast members into the concrete of dam body has greatly advanced since the 1990s. Precasting elevator shafts and gate chambers has also been attempted at numerous construction sites.

In fill dams, galleries need to be of large structure because all the overburden in the core zone acted on them. Then, galleries would be so heavy that precasting them as structural members was difficult.

Efforts were then made to precast buried formwork supporting the concrete placement surface at the arch of the gallery. Precast formwork has been applied since around 2001 and greatly contributed to the simplification of construction and the reduction of construction period.

Applying precast members offers benefits such as solving the problem of shortage of special skilled workers and reducing the environmental burdens owing to the elimination of the need of woods for special formwork in addition to shortening the construction period.

This paper discussed the present and future of use of precast members as more precast members are being adopted in dam construction.

2. BENEFITS OF ADOPTING PRECAST MEMBERS

In dam construction, precasting is adopted more frequently in galleries of concrete dams than in any other members and offers the following benefits.

(1) Increased safety

Precasting galleries eliminates reinforcing bar assembly and the assembly, dismantling and removal of formwork and supports in narrow space, and offers greater safety than conventional methods. Additionally, galleries can be kept open and materials and equipment can be freely transported to the galleries.

Heavy objects, however, need to be handled using cranes, so safety control within the turning radius of crane is important.

(2) Enhanced quality

Using members manufactured at plants with strict control improves the quality of members over that offered by conventional methods that involve the casting of members in place, with respect to construction joint surface and finishes.

(3) Easier construction

Precast members can be installed quickly by a few workers. Less complicated work is required on the site. Wide work yards and passages can be made available because neither scaffolding nor supports are required.

Neither formwork nor supports need to be assembled, so no skilled worker can construct galleries (no skilled workers are required).

(4) Reduced construction period

Neither in-situ assembly and dismantling of formwork and supports nor bar assembly is required. Precast members can be simply installed and joined in place. Then, construction period can be reduced.

Examples

Otaki Dam (dam volume: 1 000 000 m^3, length of precast gallery was 1486 m while the total length of gallery was 1647 m)
-Period exclusively for constructing the gallery was reduced to approximately one-fifth.

Fuefuki Dam (dam volume: 228 000 m^3)
-Simplifying work by the precasting method is expected to reduce the period of concrete placement by 30 days from a total number of 759 days.

(5) Economy

Precast members are generally expensive. This is ascribable to the need of specially designed formwork for precasting and the high cost of transportation of precast members from plants. The impact varies greatly according to the site condition.

In the case where precast members are applied to structures that involve a large number of steps for construction, the formwork for producing precast members can be used many times, and cost can be reduced. The key to the reduction of member production cost is to unify and simplify the cross section, size and slope of structures such as galleries to the maximum extent possible to increase the frequency of use of formwork.

The cost of transport of members is greatly affected by the location of the manufacturing plant. The selection of plants is therefore a major cost reduction factor.

Shortening the construction period by adopting precast members is expected to reduce temporary facilities cost. Cost effectiveness should therefore be determined not through simple comparison with conventional methods but based on a comprehensive judgment of the cost reduction owing to the shortening of construction period, the cost required for producing and installing precast members and the cost expected in the case where a conventional method is adopted.

Examples

Otaki Dam (dam volume: 1 000 000 m^3, length of precast gallery was 1486 m while the total length of gallery was 1647 m)
-In order to use precast members nearly throughout the galleries in the dam body, major members have been classified into 15 types and combined with one another for application in horizontal sections, staircases and T- and L-shaped intersections.

Fuefuki Dam (dam volume: 228 000 m^3)
-The number of special sections (staircases and intersections) has been minimized in the design phase. A uniform slope of 1:1.2 has been adopted for simplification.

3. POSITIONS WHERE PRECAST MEMBERS ARE ADOPTED

3.1. CONCRETE DAMS

With the advancement of techniques for increasing the efficiency of concrete dam construction, the need increased for efficiently constructing structures in the dam body and various members have been precast. Precasting galleries that require the largest number of steps for construction among the structures in the dam body has greatly improved work efficiency, ease of construction and working conditions including safety. In recent years, precasting has been adopted more frequently for overhangs, balustrades or such structures in the dam body as gate chambers and valve chambers.

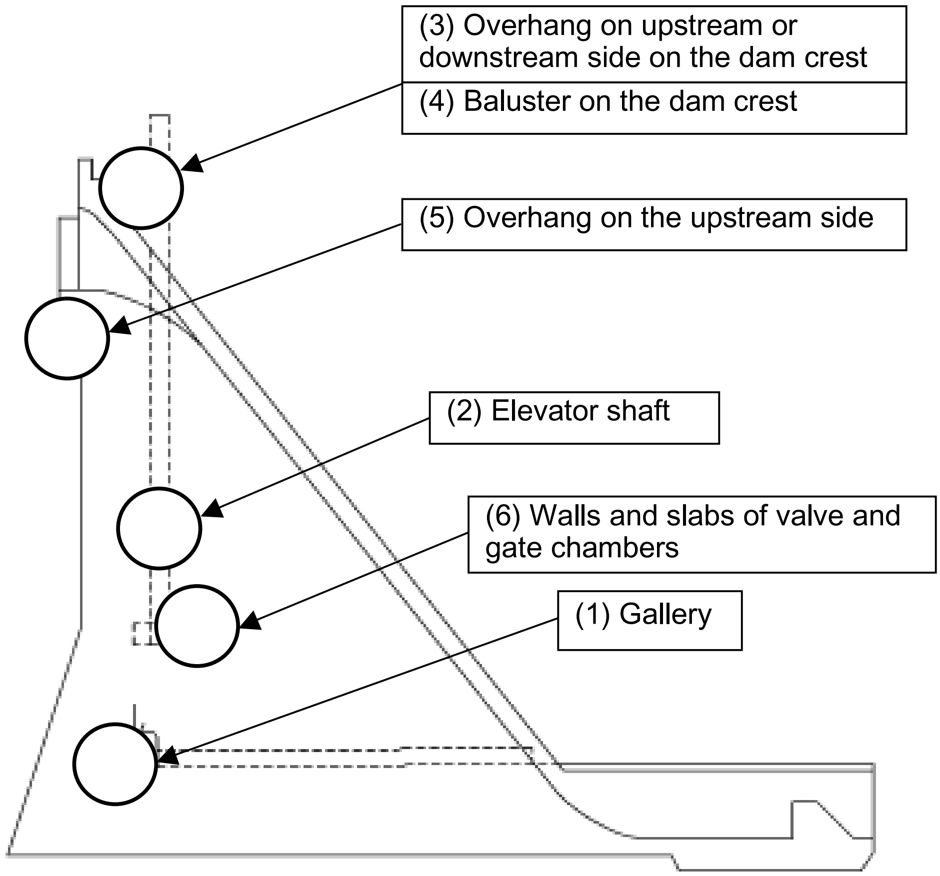

Fig. 1

General view of positions where precast members are adopted in a concrete dam

Vue générale de l'emplacement des éléments préfabriqués dans un barrage en béton

1. Galerie - 2. Puits d'ascenseur - 3. Porte à faux coté amont ou aval du couronnement - 4. Garde-corps au couronnement - 5. Porte à faux sur le parement amont

(1) Galleries

Various types of precast galleries have long been developed. At present, circular, semi-circular and gate-shaped precast galleries are adopted. The upper half is either circular or trapezoidal.

A large number of precast galleries have been adopted and precasting galleries has been serving general purposes although arguments have been made concerning the integration of precast members with the concrete of dam body and the inability to evaluate cracks in the dam body.

Fig. 2
Installing a precast segment of gallery
Mise en place d'un élément de galerie préfabriqué

Fig. 3
Positioning precast galleries
Positionnement de galeries préfabriquées

(2) Elevator shafts

Elevator shafts have been precast as well as galleries. Most elevator shafts have a cross section based on the structural calculations for the openings in the dam body. Surrounding structural reinforcement has been burried.

For installing a precast elevator shaft, precast blocks delivered to a designated position in the dam body are lifted using a crane and joined together. Ease of construction and safety increase substantially and the concrete placement process is not affected.

From a viewpoint of quality, it has been verified that precast elevator shafts are integrated into the dam concrete by tipping concrete surface of precast and connecting member joint.

Cost effectiveness is determined by the number and structure of precast members produced and the conditions of plants (location of the plant and the applicability of existing formwork). There is little difference in cost effectiveness from the case where conventional steel dam formwork is used.

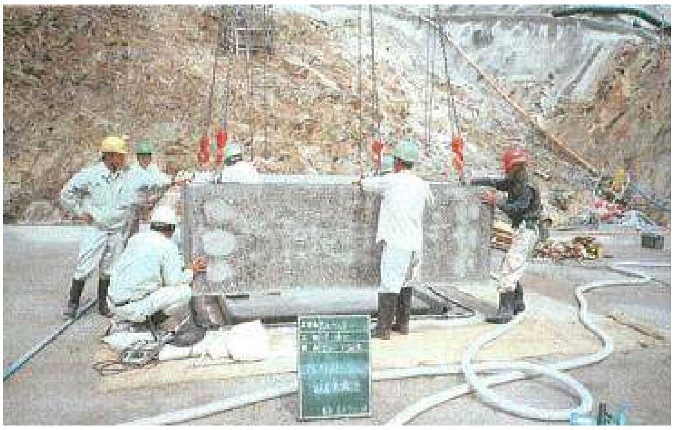

Fig. 4
Installing a precast elevator shaft
Mise en place d'un puits d'ascenseur préfabriqué

Fig. 5
Installed precast elevator shaft
Puits d'ascenseur préfabriqué monté

(3) Overhangs on upstream or downstream side on the dam crest

Overhangs on upstream or downstream side on the dam crest have recently been precast instead of using brackets as conventionally practiced, to increase construction efficiency.

The greatest benefit of precasting overhangs on the dam crest is the considerable enhancement of safety owing to the elimination of the need of work outside the dam body because neither scaffolding nor supports are required. The construction period can also be reduced greatly.

For precasting, overhangs are structured using buried formwork that is constructed by combining precast members with a thickness of approximately 10 cm, or large blocks are constructed as structural members. Thinner precast plates with a thickness of 30 to 40 mm have recently been adopted with the introduction of polymer-impregnated concrete (PIC) and high fluidity concrete reinforced with steel fiber (SFRC).

Precast plates are fixed to buried steel in the dam body. The method is less costly than conventional methods that involve the installation of bracket supports outside the dam body because no supports are required.

Using precast blocks as structural members involves high material cost but the installation costs is low.

Fig. 6
Installing precast formwork on an overhang on upstream or downstream side of the dam crest
Mise en place d'éléments de coffrage préfabriqués pour un porte à faux sur le parement amont du barrage

(4) Balusters on the dam crest

Balusters on the dam crest, as well as (3) overhangs on upstream or down stream side on the dam crest, are precast because of cost reductions owing to the elimination or downsizing of scaffolding outside the dam body, enhancement of safety and facilitation of construction, and guarantee of good quality.

Formwork of any shape can be selected to meet aesthetic requirements together with the baluster. Thus a high value can be added. Concrete strength can be increased in design, so the thickness of members can be reduced. As a result, the width of dam crest can be reduced.

From a viewpoint of economy and construction safety, precasting balusters on the dam crest has recently been widely adopted.

Fig. 7

Installing a precast baluster on the dam crest

Mise en place d'un garde corps préfabriqué sur le couronnement du barrage

Fig. 8

Installed precast baluster on the dam crest

Garde corps préfabriqué monté sur le couronnement du barrage

(5) Overhangs on the upstream side

On the dam crest, large overhangs may be constructed to accommodate normal spillways, crest bridges, intake towers or other structures. To that end, construction was conventionally staged by embedding large brackets or steel into the dam body.

For large overhanging structures, no supports have been provided from below because lighter weight precast plates have recently been adopted and more effective supports have been applied.

For supports, steel pedestals fit for the shape of overhangs are embedded into the dam body and precast plates are fixed to the pedestals using reinforcing steel.

Then, no scaffolding is required outside the dam body, and overhangs can be firmly installed. Construction also becomes easy. Safety, ease of construction and quality are therefore expected to be improved. The method is also cost effective.

Fig. 9
Installing precast formwork on an overhang on the upstream side
Mise en place du coffrage préfabriqué d'un porte à faux coté amont

(6) Walls and slabs of valve and gate chambers

In the openings in the dam body for accommodating various facilities, machines are installed first. Removing the formwork or installing the scaffolding is therefore complicated. The process of concrete placement in the dam body is also greatly affected. In order to solve these problems, buried formwork composed of precast plates have been adopted. Precast plates are regarded as formwork, so reinforcement needs to be arranged inside the precast formwork as designated.

Precast panels to which steel bars are attached in advance are moved to the site using a crane and fixed on a stationary pedestal. Assembly of supports is unnecessary. Safety and ease of construction are improved and the construction period is shortened.

Fig. 10
Installing precast formwork for walls of a gate chamber
Montage du coffrage préfabriqué d'une chambre à vannes

Fig. 11
Installing precast formwork for a slab of a gate chamber
Mise en place du coffrage préfabriqué d'une dalle de chambre à vannes

(7) Footing formwork

Footing formwork can be handled like ordinary formwork by pulling precast plates by separators. The scaffolding on the front face of the formwork can be eliminated, so safety and ease of construction are improved.

Fig. 12
Installing footing formwork (inside)
Coffrage d'une semelle (vue intérieure)

Fig. 13
Installing footing formwork (outside)
Coffrage d'une semelle (vue extérieure)

(8) Formwork on upstream or downstream face of a dam

Precast formwork has recently been developed also for formwork on upstream or downstream face of a dam.

Durability of the upstream or downstream face of the dam body is expected to increase and various aesthetic measures can be taken.

In trapezoidal CSG (cement, sand and gravel) dams, precast formwork has been adopted on upstream or downstream face of a dam as a standard practice to shorten the construction period.

Fig. 14
Installing precast formwork on upstream or downstream face of a dam
Coffrages sur la face amont ou aval du barrage

Fig. 15
Precast formwork segment for installation on upstream or downstream face of a dam
Elément préfabriqué pour mise en place sur le barrage (coté amont ou aval)

(9) Other

One of the examples of solving construction problems is precast footing staircases although they are of small cross section.

Cast in situ method results in satisfactory footing staircases but involves complicated work. Constructing footing staircases using steel formwork facilitates assembly but leads to honeycombing on treads.

Fig. 16
Precast formwork for footing staircase
Coffrage préfabriqué pour escalier

3.2. FILL DAMS

In Japan, precast members (forms) have been adopted only for galleries in fill dams. Galleries in fill dams, unlike those in concrete dams, (i) have larger cross section because all the overburden acts on galleries and (ii) are excavated in the rock mass to prevent hard objects from entering the dam body. Constructing galleries therefore requires much cost and efforts.

On river beds in particular, the construction of galleries forms a critical path between the completion of foundation excavation and the start of filling. In the case where the river bed has a moderate longitudinal slope, a large number of steps are required before the start of filling, so numerous formwork supports are needed at once. Using precast formwork only requires the installation of precast segments on the base concrete once the required quantity of segments have been produced in advance. Thus, construction period can be reduced and cost effectiveness increased.

Formwork needs to be assembled and dismantled on steep slopes at the abutments on both banks. Using precast formwork can improve safety and ease of construction.

Inspection galleries need to be installed prior to filling work at each elevation. Reducing the time required for constructing inspection galleries is important to the shortening of total construction period.

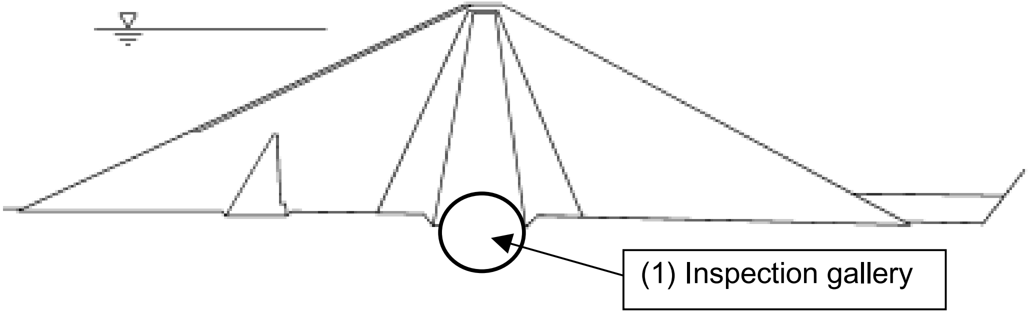

Fig. 17

General view of positions where precast members are adopted in a fill dam

Vue générale des emplacements possibles d'ouvrages préfabriqués dans le cas d'un barrage en remblai

Precasting galleries including reinforcing bars causes the member thickness to increase and poses several problems.

In numerous cases, U-shaped precast concrete members are used instead of formwork, and reinforcing bars are assembled separately.

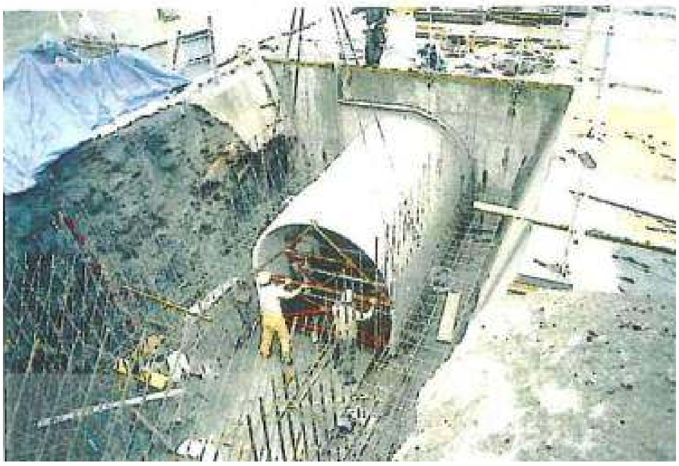

Fig. 18

Installing a precast inspection gallery in a fill dam

Mise en place d'une galerie de visite préfabriquée dans un barrage en remblai

4. FUTURE TASKS

4.1. USE OF LIGHTER WEIGHT AND SIMPLER MEMBERS

Using precast members offers various benefits but at the same time involves large-scale transport and installation of the members. For example, large cargo handling machines are required because segments are relatively heavy. For solving the problem, reducing the weight of members to facilitate handling is effective. Reducing the weight offers great benefits in galleries in particular as structural members with built-in reinforcement are employed in galleries.

In the Unazuki Dam, a gravity concrete dam with a dam height of 97 m, crest length of 190 m and volume of 510 000 m^3, stress was measured in the surrounding areas after the construction of a gallery. As a result, it was revealed that from a stress-strain viewpoint, the stress in the arch of the gallery was in compression in approximately one year after concrete placement, that thermal stress was predominant around the gallery and that the loads of lifts of concrete had little impact on the gallery. Using precast members therefore is expected to reduce the weight of members through the reduction of reinforcement at the arch of gallery or reduction of member cross section.

When using precast members as formwork in galleries and other locations, reducing the weight is desirable. With the development of polymer-impregnated concrete (PIC) and steel fiber reinforced concrete (SFRC) plates, it became possible to reduce the thickness of precast formwork members to 30 to 40 mm. In fill dams, galleries at abutments are frequently constructed on steep slopes. Under such conditions, the lighter the member, the more efficient and safer the work.

Further reduction of weight of precast members leads to the reduction of reinforcing materials and the simplification of support pedestals or connection metals that are required for attaching and fixing members to designated positions. Thus, more efficient construction becomes possible. Increasing the length of segments is expected to further reduce the period of transport and installation even where the weight remains the same.

4.2. UNIFICATION AND STANDARDIZATION OF CROSS SECTION

For adopting precast members in galleries or other structures, a review is made and cross section is determined in the design phase. At present, owners determine the cross section in accordance with their standards or criteria. This results in cost increases because formwork is not reused numerous times or operated at a low rate. Unifying the cross section for standardization for respective locations including galleries in the design phase is likely to considerably increase the ease of construction and cost effectiveness.

For galleries in gravity dams, the Japan Dam Engineering Center has been taking the initiative in standardizing precast members. It is hoped that wide varieties of stakeholders including owners and contractors will actively exchange views and make cooperative efforts for standardizing precast members.

4.3. COST REDUCTION

At present, using precast members indirectly reduces cost through the reduction of construction period instead of directly reducing construction cost. Cost reduction measures should be sought in the future paying greater attention to the direct costs of construction and transport, for which numerous improvements have yet to be made.

The keys to cost reduction are weight reduction and standardization of members.

Reducing the weight of precast members is expected to offer numerous benefits such as the reduction of member production cost and the reduction of construction cost through the downsizing of cargo handling machines and the simplification of installation pedestals. Costs of transporting members will also be reduced.

The cost of producing formwork accounts for a large percentage of member production cost. The effect of cost reduction is therefore expected to be large for formwork. If the cross section is standardized and leased products are used widely, formwork will be re-used more frequently and operated at a higher rate. Then, the cost involved in the use of formwork will be reduced. Transport cost can be reduced considerably by having nearby secondary production plants produce precast members. There is a possibility that more precast members will be employed in the construction of small dams although their use has not conventionally been promoted because of high costs of formwork production and transport.

5. CLOSING REMARK

An increasing number of precast members have gradually been adopted in dam construction in Japan. Increasing their application further requires not only improving precast members themselves but also taking measures in the planning phase such as the standardization of members in the design phase.

From a viewpoint of protection of global environment, use of precast members will lead to the reduction of wooden formwork. Active efforts should be made in the future to use more precast members in dam construction.

RÉSUMÉ

Les techniques de construction par tranches horizontales de barrages en béton sans joints longitudinaux, telles que le B.C.R. et la construction par couches étendues (méthode ELCM) ont commencé à être appliquées au Japon vers les années 70. Dans la construction par ces procédés, l’exécution des galeries de visite ou des autres ouvrages annexes internes du barrage peut constituer une entrave à l’avancement des travaux plus souvent que dans la construction par plots. Pour y remédier, des éléments préfabriqués ont été utilisés dans la réalisation de galeries de visite et se sont avérés, dans une certaine mesure, efficaces en termes de réduction des délais d’exécution. Les recherches et les expériences qui s’ensuivaient ont conduit au développement de l’application des éléments préfabriqués à des ouvrages internes du barrage. Leur domaine d’emploi va maintenant de l’exécution de galeries jusqu’à la réalisation de cages d’ascenseur, de chambres des vannes et d’ouvrages annexes sur le couronnement dans le cas des barrages en béton.

L’emploi d’éléments préfabriqués offre de nombreux avantages : (i) réduction des travaux sur chantier et par conséquent des délais d’exécution, (ii) contrôle de qualité plus facile des éléments fabriqués en usine, (iii) facilité d’exécution des travaux et sécurité améliorée en l’absence des travaux compliqués dans des espaces exigus, (iv) réduction des incidences sur l’environnement du fait que les bois pour des coffrages spéciaux ne sont plus nécessaires.

Au point de vue économique, le réemploi plus fréquent des moules est plus avantageux, quelles que soient les conditions du site. Il faut donc rechercher autant que possible l’uniformisation des coupes transversales et des formes pour comprimer le coût de préfabrication. La réduction des coûts indirects résultant de la diminution de la durée d’exécution est plus importante que la réduction des coûts directs.

Sur le plan technique, il est important que les fissures éventuellement développées dans le barrage en béton soient visuellement observables à partir des galeries de visite. La liaison entre les éléments préfabriqués et le béton du corps doit donc être parfaite, de sorte à assurer la continuité, entre ces deux bétons, du comportement face aux fissurations. À cet effet, s'effectuent le lavage à haute pression pour rendre les surfaces de contact rugueuses ou le remplissage des vides sous les dalles de fond avec du béton plastique.

Dans les barrages en remblai, comme dans le cas des barrages en béton, l'exécution des galeries de visite est une entrave à l'avancement des travaux. Dans ce type de barrage, la charge appliquée sur les galeries de visite étant importante, celles-ci ont inévitablement une large coupe transversale. L'emploi d'éléments préfabriqués était donc considéré comme difficile. Les années récentes ont vu cependant l'utilisation du coffrage perdu préfabriqué en béton à la place du coffrage glissant en cintre en vue de réduire les délais d'exécution. En effet, la réalisation plus rapide des galeries de visite, en particulier sur le lit du cours d'eau, permet le commencement plus tôt de l'édification du remblai du noyau. Comme dans le cas des barrages en béton, la liaison parfaite entre les éléments préfabriqués et le béton de structure étant importante, les surfaces de contact sont rendues rugueuses ou d'autres mesures sont adoptées.

Avec les exemples toujours plus nombreux de leur emploi dans la réalisation des galeries de visite, les éléments préfabriqués connaissent un développement de leur application à d'autres ouvrages continus ayant une coupe transversale constante, tels que cage d'ascenseur, tête des parements amont et aval et parties en porte-à-faux des ouvrages de prise et de vidange. Les éléments préfabriqués, lorsqu'ils sont utilisés dans la réalisation des parties en porte-à-faux, permettent de réduire des travaux compliqués et dangereux, tels que la mise en place des consoles noyées et le dressage des échafaudages, et contribuent ainsi à une meilleure sécurité. Ils apportent par ailleurs une finition homogène et des résultats esthétiques satisfaisants.

Le développement de moules ayant une plus grande applicabilité par une standardisation poussée des coupes transversales permettra de réduire davantage le coût de construction et d'améliorer l'économie de l'ensemble. Des coffrages perdus préfabriqués en béton sont employés à titre d'essai dans la réalisation de parements amont et aval et de semelles. Facilitant les travaux et demandant donc peu d'ouvriers qualifiés, la construction en éléments préfabriqués pourra trouver des applications de plus en plus étendues.

SUMMARY

The adoption of concrete dam construction methods that make flat construction joints such as roller-compacted concrete dam (RCD) methods and

extended layer concrete (ELCM) methods started around the 1970s in Japan. In dam construction methods involving vertical concreting in blocks at each construction joint, unlike in dam construction methods that make flat construction joints, the construction of structures in the dam body such as inspection galleries is likely to be detrimental to the progress of dam construction. To solve the problem, using precast members in inspection galleries proved to be effective to some extent for reducing the construction period. Subsequently, researches were made and results were produced. Then, more precast members have been applied in structures in the dam body. In concrete dams, precast members have been adopted not only for galleries but also for elevator shafts, gate chambers and structures on the dam crest.

Benefits of using precast members are (i) less on-site work and shorter construction period, (ii) easy quality management owing to the production of members in plants, (iii) greater ease of construction and safety with no complicated work in narrow space, and (iv) reduced environmental burdens owing to the elimination of the need of woods for special formwork.

The more frequently the formwork is re-used, the higher the cost effectiveness regardless of site conditions. Production cost should be controlled by unifying the cross section and shape as much as possible. The reduction of indirect cost through the shortening of construction period is larger than the reduction of direct cost.

From a technical viewpoint, it is important that cracks in the concrete dam body can be visually observed from inspection galleries. It is therefore necessary that the dam concrete is fully integrated into precast members and that elongation at break is ensured between the concrete and precast members. To that end, the bond surface is roughened using high-pressure water, or the space under the bottom slab is filled with plasticized concrete.

In fill dams as in concrete dams, constructing inspection galleries poses problems in the progress of dam construction. In fill dams, large loads act on galleries and galleries are of large cross section. Using precast members was therefore considered difficult. In recent years, however, precast members have been used as arched formwork instead of slide centering contributing to the shortening of construction period. As the period of construction of inspection galleries on river bed in particular is greatly shortened, the filling work using core materials can be started earlier. The integrity of precast members with dam concrete is important as in concrete dams, so bond surface is roughened or other measures are taken.

As more precast members were used in inspection galleries, precast members have been actively adopted in continuous structures of uniform cross section such as elevator shafts, dam crest on upstream and downstream faces of a dam, and overhangs in water intakes and outlet works. In overhangs, complicated dangerous work has been reduced such as the embedment of brackets and the erection of scaffolding, and safety has been increased. Homogeneous finishes are provided, and aesthetic requirements are met.

Increasing the general applicability of formwork through further standardization of cross section is expected to reduce direct construction cost and provide higher cost effectiveness. Precast members have been constructed on a trial basis as permanent formwork on the upstream and downstream faces of a dam or on the footing. Structures using precast members will find wider application in the future because such structures can be constructed easily by few skilled workers.