ICOLD 75th Annual Meeting
Saint Petersburg, Russia, June 24-29, 2007

Symposium: «Dam Safety Management. Role of State, Private Companies and Public in Designing, Constructing and Operating of Large Dams»

COST REDUCTION MEASURES FOR DAM PROJECTS IN JAPAN

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Abstract : In Japan, cost reduction in public works projects has become a major issue, and dam projects are drawing attention because they require a large amount of investment. Based on a report prepared by a subcommittee of the Japan Commission on Large Dams concerning cost reduction measures for dam projects, this paper identifies construction cost categories that can influence cost reduction and measures that are likely to contribute to cost reduction and describes concepts for those cost reduction measures. Focusing on three measures that are thought to greatly contribute to cost reduction, namely, effective use of low-quality aggregates, foundation treatment and the pre-cast concrete material, this paper also describes methods of implementing those measures, challenges, and the expected effects of those measures. Examination of these considerations has revealed that in order to enhance the effectiveness of cost reduction efforts, it is necessary to start conducting studies and make preparations prior to the planning, design and construction stages.

Chapter 1 Background and objective of the study

In Japan, it is taken up as a major challenge to reduce the flow of money into public works projects. Among public works projects, dam construction with a big public expenditure attracts attention rather than to this more. The Japan Commission on Large Dams formed a task force to study the cost reduction measures for dam construction works.

Chapter 2 Principal cost reduction measures

The numbers of cost reduction measures that can be taken in the construction phase are limited. A substantial cost reduction effect can be achieved by taking the measures in the series of planning, design and construction phases. In this paper, the cost reduction measures are studied from the following five standpoints.

(1) Concepts on reducing the cost in the planning phase

(2) Review of technical standards and guidelines

(3) Review of design methods

(4) Review of construction methods

(5) Promotion of technical developments

Table 2-1 Matrix of dam cost reduction measures (Construction phases)

Conceptualization and planning (system and mechanism)			(1) In the planning phase	(2) Technical standards	(3) Design methods	(4) Construction methods	(5) Technical developments
1.Dam body work	①Foundation excavation	• Utilization of excavated soil for dam body materials			○		
		• Improvement of specifications of finishing excavation			○		
	②Material exploitation	• Promotion of use of low-quality materials			○	○	
		• Quarries in reservoirs and under the ground			○		
	③Concrete dam body	• Review of classification of concrete (external, internal and structure)	○				
		• Active introduction of new construction methods(RCD, ELCM and others)	○				
		• Design techniques of dams under seismic force		○			
		• Establishment of new design systems, including a safety factor setting		○			
		• Design of a mix proportion that meets the required specified strength of concrete			○		
		• Adoption of pre-cast concrete material, fiber concrete			○		
		• Study of continuous concrete placing by detailed checking of temperature controll, increase in lift height, simplification of preparation and others				○	
		• Reduction of frequency of sampling test piece				○	
		• Simplification of equipment, including simplification of concrete placing equipment, introduction of mobile crushing machine, and others				○	
		• All-weather construction methods				○	
		• Development of construction equipment based on the latest IT technology and construction management tools					○
		• Adoption of cable-less buried instruments					○
		• Promotion of development of belt conveyor, slip form and others					○
		• Promotion of dam crest construction equipment					○
	④Fill dam body	• Optimization of zoning of fill dam body	○			○	
		• Reduction of dam body volume and shortening of work periods by adopting the CFRD and others	○				
		• Design techniques of dams under seismic force		○			
		• Establishment of new design systems, including a safety factor setting		○			
		• Evaluation of material strength that takes into account the dependence of rock materials on confined pressure			○		
		• Evaluation of physical properties of core, filter and riprap			○		
		• Adoption of artificial materials (adoption of geotextile for filter materials, and others)			○		
		• Increase in thickness of layer by the introduction of large-scale compaction equipment				○	
		• Mechanized construction of contact clay				○	
		• Study of specifications of compacting fill dam materials on a material property basis					○
	⑤Forms	• Pre-cast concrete of inspection gallery, elevator shaft, dam top railing and others			○		
		• Pre-cast concrete of upstream and downstream dam surfaces			○		
2. Foundation treatment work		• Detailed checking of improvement target values based on the scale of dam (working water head)			○		
		• Detailed checking of improvement target values of rim grouting			○		
		• Change of the layout of consolidation holes to the portion where geological conditions and stress distribution are taken into account			○		
		• Application of treatment methods other than grouting, including soil blanketing			○		
		• Re-evaluation of double-tube grouting			○		
		• Rationalization of effect judgment method (layout of holes, evaluation unit)				○	
		• Shortening of construction time by changing the restrictions on consolidation grouting based on the sequence of grouting from area to row basis				○	
		• Adoption of percussion drilling method				○	
3. Turbid water treatment work		• Use of materials (e.g. top soil) generated from construction at dam sites as base materials for vegetation				○	
		• Effective use of industrial wastes (surplus soil after excavation)				○	

Chapter 3 Analysis of dam construction cost

Dam construction cost is broken down into the costs of river diversion, foundation excavation, foundation treatment, dam body, inlet and outlet, and turbid water treatment. As a result of analyzing two gravity concrete dams, the river diversion, foundation excavation, foundation treatment, dam body, inlet and outlet, and turbid water treatment constitute 3.0%, 9.0%, 4.2%, 31.9% and 14.2% of the dam construction cost, respectively. As a result of analyzing two rock fill dams, the river diversion, foundation excavation, foundation treatment, dam body, and inlet and outlet constitute 3.4%, 4.9%, 7.9%, 32.2% and 4.8% of the dam construction cost, respectively. Regardless of the type of dam body, the components of dam construction cost are in almost constant proportions. (Fig. 3-1)

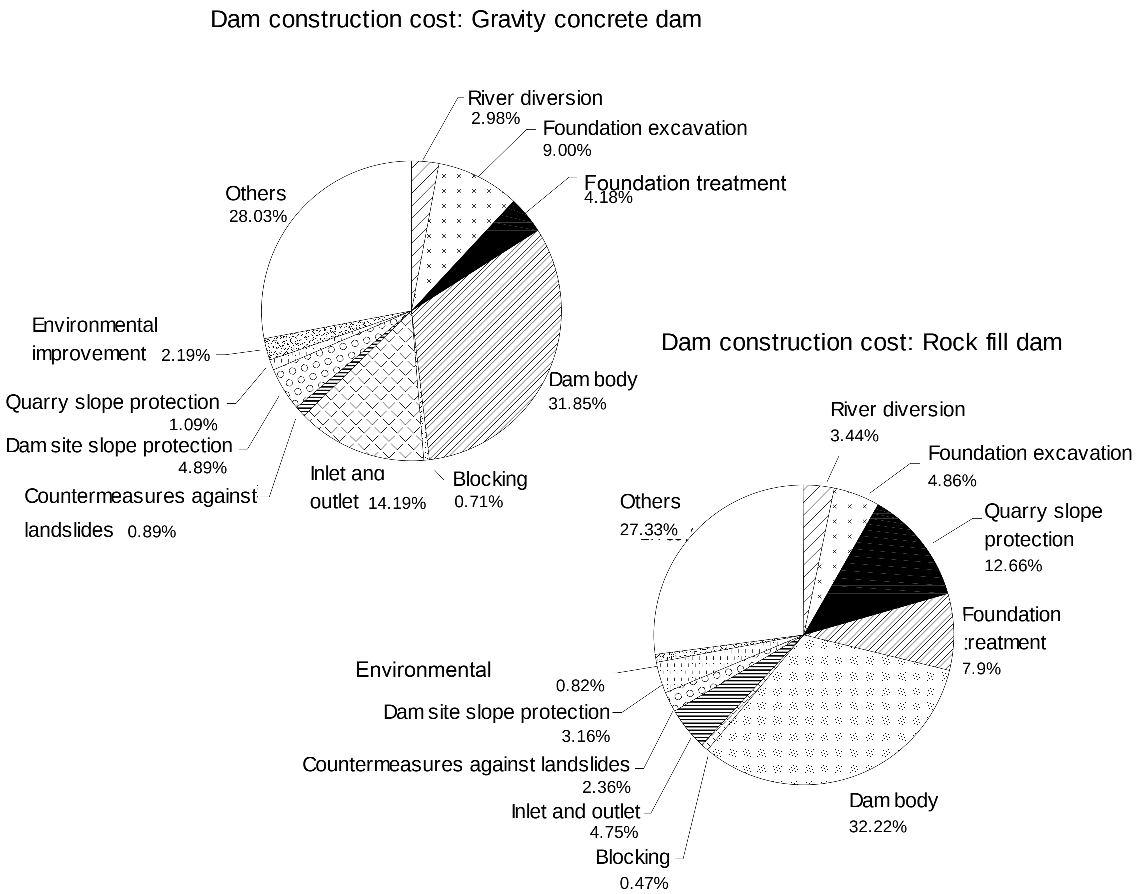

Fig. 3-1 Components of dam construction cost

Of the dam construction cost, the foundation treatment forms a relatively large proportion. This is an important point toward which attention needs to be directed in reducing the dam construction cost. It is inappropriate to simply compare the costs of foundation excavation because each dam has specific topographic and geological conditions at dam site.

3.1 Components of dam body cost and points toward which attention needs to be directed in reducing the cost

Of the components of dam body cost, concrete materials, concrete placing, and formwork account for 51.0%, 38.5% and 9.8%, respectively. (Fig. **3-2**) As regards the concrete materials that make up the largest proportion, a large effect of reducing the dam body cost is expected to be produced by rationalizing the design of dam body and effectively utilizing low-quality aggregates that have been handled to be disposed. In addition, this will have a large spillover effect of decreasing soil disposal area. Of the components of materials, cement, admixture and aggregates account for 21.6%, 1.5% and 76.9%, respectively. The effective use of low-quality aggregates is expected to produce the largest effect on the reduction of the dam body cost. (Fig. **3-3**)

The RCD construction method that was developed in Japan is in widespread use as a general construction method for concrete dam body. To achieve further cost reduction, a new RCD construction method (*1) is being researched. Test construction is also carried out by the trapezoidal CSG construction method (*2) that was developed to effectively use low-quality aggregates.

Various frameworks are used for upstream and downstream dam surfaces, crest curve, bucket curve, inspection gallery and others. The cost can be reduced by introducing pre-cast concrete forms not only for inspection gallery, elevator, handrail, and pier overhang structure but also for upstream and downstream dam surfaces.

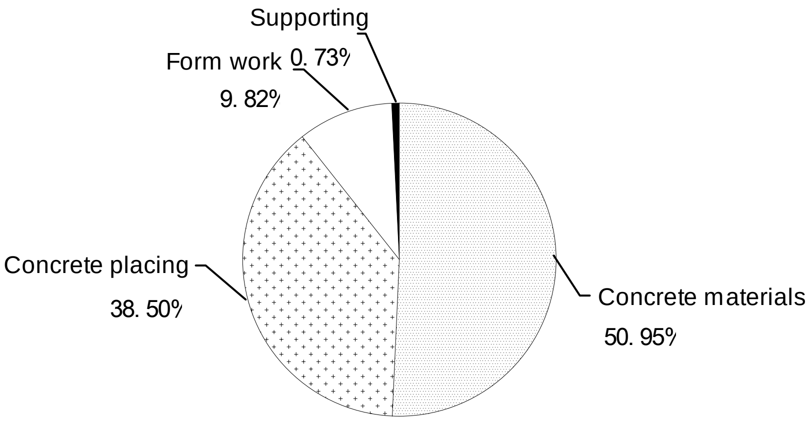

Fig. 3-2 Concrete dam: Components of construction cost

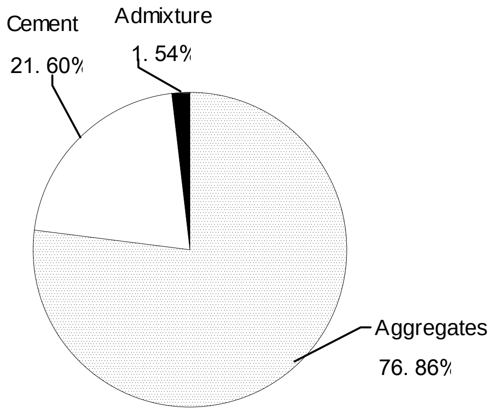

Fig. 3-3 Concrete dam: Components of materials

Chapter 4 Study of cost reduction

Based on the study results in Chapters 2 and 3, construction cost elements that may have effects on the cost reduction are extracted and the ways of thinking about them are sorted out. As a result, the following items are studied.

- Effective use of low-quality aggregates
- Foundation treatment
- Pre-cast concrete material

4.1 Effective use of low-quality aggregates

4.1.1 Present state of aggregate production

The analysis of dam construction cost revealed that aggregate production cost makes up a large proportion of about 20% of the cost. The aggregate production cost includes the costs of not only exploitation, crushing, classifying, stockpiling, and transporting aggregates used for dam body but also constructing service roads to the quarry, treating surface soil at the quarry, and handling waste rocks or rocks judged unfit for dam body aggregates.

The following results were obtained from the past survey of the exploitation of aggregates for concrete dams at a quarry.

(1) Yield rate of excavated rocks that were used for aggregates was 55%.

(2) Surface soil, soft rock and others accounted for 26%, 49% and 25%, respectively, of the waste material.

As can be seen from these results, not only a large cost reduction effect but also a spillover effect of decreasing soil disposal and quarry development areas is expected to be produced if parts of soft rocks that have been disposed of are used for aggregates.

The same is true of fill dams. Because a wide range of materials, from soil to rock, are used for fill dam body and it is possible to ensure the safety of dam body while giving materials flexibility by zoning in accordance with the properties of materials, the effective use of materials for fill dams is considered more easier than for concrete dams.

4.1.2 Efforts and challenges toward effective use of low-quality aggregates for concrete dams

(1) Efforts in the design phase

1) Introduction of new design systems for the CSG and others

Because the materials that have rarely been used for dam body, including the materials generated from the excavation of dam body and low-quality aggregates, come into use, an appreciable cost reduction effect is expected. These materials are adopted for dam body.

2) Use in combination with pre-cast concrete material

The effective use of low-quality aggregates is studied mainly for internal concrete. Because water tightness and durability are required of external concrete, external concrete has a disadvantage of an increase in the plant cost due to the need for two crushing lines, or screening and stockpiling, when exploiting aggregates at a quarry. In replacement of external concrete, if pre-cast concrete members in widespread use in recent years are used for both upstream and downstream dam surfaces, the required quality of external concrete can be ensured.

3) Appropriate review of standards for usable aggregates

Concrete dams are structures that must be used for a long term. Before using the aggregates for the external concrete, the standards for external concrete have many subjects to be studied. However, the low-quality aggregates can be used for internal concrete except for specific high dams. In this case, an appropriate review of physical and chemical standards, including the review of harmful mineral contents and the omission of aggregate washing process, can be made by designing the mix proportions best-suited to usable aggregates based on required strength, adopting the optimum aggregate evaluation technique for the design of dam body on the condition that the concrete containing the aggregates is used, and using the admixture that have recently provided noticeable improvement in performance in combination with special cement for dams.

(2) Efforts in the construction phase

1) Use of materials generated from excavation

At dam construction sites, a massive volume of rock is generated from the excavation of dam body, diversion tunnel and others. In addition, because concrete dams are constructed on a good foundation ground, rocks generated from excavation at the sites contain a large volume of materials that can be used as aggregates for dam body. There have recently been cases where materials generated from excavation of dam body are used as aggregates without developing a quarry, which contributes to cost reduction and environmental conservation.

The challenges for the use of materials generated from the excavation of dam body and others as aggregates are as follows.

- There is a time lag between excavation and use of materials as aggregates, and it is necessary to provide a yard for temporarily stockpiling a massive volume of aggregates. It is necessary to determine in the planning phase whether the materials can be used as aggregates.

- Because the materials generated from the excavation of dam body at a place different from the quarry are used in combination with the rocks mined at the quarry for the same dam body, it is necessary to study in advance the classes of concrete and the methods of mixing the materials and rocks, including mix proportions.

- Excavations of dam bodies are in many cases carried out in precipitous terrains. It is often difficult to carry out the excavations while classifying soil and rock at dam construction sites in the terrains. It is necessary to study excavation methods, screening facilities for excavated material, and others.

- It usually requires considerable experience to distinguish materials on the borderline of whether they can be used as aggregates or not. An acceptance/rejection criteria is prepared and a difference is in many cases distinguished based on the criteria by experienced engineers. For the purpose of quick and precise judgment of materials, preparation of guidelines for simple judgment methods that enable everyone to judge with ease are desirable.

2) Use of riverbed materials

- A trial to utilize gravel and sand of a riverbed and the sediment of a reservoir as materials of concrete and CSG.

  These are desirable from the viewpoint of effective use of natural resources. In addition, because dams with their ratios of sediment to reservoir storage capacity exceeding 100% have begun to appear, soil and rock settled in reservoirs are considered usable as effective materials. However, the following problems with the sediment need to be addressed.

- Quality of sediment varies greatly, which influences the quality of concrete.

- Impurities, including driftwood, need to be removed.

- There is a problem of a riverbed descent.

4.1.3 Efforts and challenges toward effective use of low-quality materials for concrete dams

(1) Efforts in the design phase

1) Introduction of new design systems for CFRD (Concrete Faced Rockfill Dam) and others

Introduction of new design systems for CFRD allows the cross section of dam body to be decreased and the range of usable materials to be increased, thereby reducing the cost. The same holds for the evaluation of shear strength that takes into account the conditions of constraint for fill.

2) Optimization of zoning

The measure that will contribute most significantly to the cost reduction of fill dams is to reduce the total volume of soil and rock transported. For this purpose, dam body needs to be zoned in such a manner that the volume of disposed soil and rocks is minimized. The fill dam body has been designed in accordance with classically acquired materials and there have been many cases where materials different from those originally intended were obtained in the construction phase.

In this case, the different materials were handled as the materials for disposal. With increasing momentum for cost reduction in recent years, however, there are increasing cases where zoning is corrected in accordance with a change in the materials after commencement of embankment. In most cases, zoning is corrected for individual dams. Correction of zoning in the middle of embankment term is not an easy task. It is desired to systematize techniques to facilitate the correction of zoning in each step of embankment.

(2) Efforts in the construction phase

Efforts in the construction phase are much the same as those for concrete dams. For fill dams, the following efforts in particular contribute to the cost reduction.

- A simplified classifier that classifies excavated soil and rocks (a mobile classifier and others)

- Guidelines for the quick and precise judgment of rocks at dam construction sites

- Formulation of a temporary facility plan that takes into account the diversion and temporary placement of temporary facilities from nearby construction sites

4.2 Foundation treatment

The foundation treatment cost is broken down into the costs of (1) boring, (2) permeability test, (3) grouting, and (4) grout tunnel and others. The Technical Guidelines for Grouting amended in April 2003 are commonly used. Major amendments are as follows.

- Clarification of original construction purpose and scope
- Grouting that is appropriate for the foundation ground
- Continuous verification and review during construction

These amendments are expected to significantly reduce the foundation treatment cost.

a. Consolidation grouting

Purpose	Scope of construction		Target value of improvement	
	Before amendment	After amendment	Before amendment	After amendment
Improvement of imperviousness	Entire surface of foundation	Upstream end to weep hole	5-10 Lu (gravity dam)	About 5 Lu
Reinforcement of weak portions		Around weak portions		Not more than 10 Lu

b. Blanket grouting

Purpose	Scope of construction		Target value of improvement	
	Before amendment	After amendment	Before amendment	After amendment
Improvement of imperviousness in core zone	Entire core zone	Central portion of core zone	To be set based on the properties of rocks and the characteristics of improvement	About 5 Lu
		Near filter zone		5-10 Lu

c. Target value of improvement by curtain grouting (in the case where stress relief causes high water permeation)

Depth	Gravity dam		Fill dam	
	Before amendment	After amendment	Before amendment	After amendment
0-H/2	1-2 Lu	About 2-5 Lu	2-5 Lu	About 2-5 Lu
H/2-H		5-10 Lu		5-10 Lu

(1) Cost reduction by appropriate review of the scope of foundation treatment and the target value of improvement

Amendments to the scope of construction and the target value of improvement for consolidation grouting, blanket grouting and curtain grouting are as listed in the tables above.

The volume of consolidation grouting and curtain grouting can be reduced by a factor of about 0.4 and 0.6, respectively, depending on the scale of dams.

(2) Cost reduction by rationalization of construction specifications

The Technical Guidelines for Grouting suggest that test grouting should be carried out based on a grouting plan in the block that represents the geological section to study the appropriateness of the plan and review the plan as required before starting grouting work in full swing and that a cycle consisting of construction, analysis of data, and verification and review of the grouting plan should be repeated during construction.

The best-suited grouting specifications are selected at construction sites by carrying out test grouting and making improvements on a routine basis. As a result, cost reduction effects, including shortened grouting term, are expected.

4.3 Pre-cast concrete material

As a rationalization technique, attention is given to the use of pre-cast inspection galleries.

Economical reasons for precluding the use of precast galleries are that the portions of dams where pre-cast galleries can be used are limited, the forms for production of pre-cast galleries are very costly, and as a result the construction of galleries using ordinary forms is economically more advantageous than the use of pre-cast galleries. For these reasons, the use of pre-cast galleries has been limited to large dams with long galleries that have the advantage of being cheaper to construct than the galleries constructed by using ordinary forms. However, the forms for production of precast galleries can be used repeatedly and diverted to other dams if the shape of galleries is standardized. As the number of reuses increases, the use of pre-cast galleries for dams becomes more economical than the construction of galleries using ordinary forms.

(1) Expected effects

The use of standardized pre-cast galleries instead of the galleries constructed at dam sites makes it possible to shorten work periods, reduce construction cost and work-related accidents while assuring the quality of dams.

1) Assurance of quality

Potential problems associated with the construction of dams using pre-cast galleries were the structural strength of the galleries, the property of the galleries to follow the behaviors of a dam, and the reliability of construction. The construction of a large dam proved that these problems did not occur.

2) Shortening of work periods

Placement of concrete was often restricted during the construction of galleries particularly in the horizontal section by the conventional formwork methods. The concrete placement periods can be shortened by the use of pre-cast galleries, which are manufactured in advance at factories, and installed at dam sites.

3) Reduction of construction cost

The standardization of forms for pre-cast galleries according to slope, type and others makes it possible to use the formsthem for the galleries for other dams and reduce the productionconstruction cost of the galleries. Further, because work periods are shortened, due to reductions in the price per unit length of gallery andthe rental rates of temporary facilities, such as aggregate production equipment, concrete placing equipment, and turbid water treatment equipment, . can be reduced, resulting in total construction cost reduction.

4) Reduction of work-related accidents

In the conventional method, skilled workers, including reinforcing-bar placers, welders and special labors, were needed for the construction of galleries. The pre-production of pre-cast galleries makes it possible standardize the work skill level of skilled and other workers at dam construction sites. In addition, this reduces the formwork in high workplaces, resulting in a reduction of work-related accidents.

(2) Effects of introduction of pre-cast galleries

Effects of reducing the construction cost and the number of workers were 9% and 67% on the average at six dam construction sites into which pre-cast galleries were introduced.

(3) Analysis of the effects

Although it is difficult to unequivocally discuss the effects of introduction of pre-cast galleries because the effects depend on the scale of dam, the length of inspection galleries in the horizontal section, the scale of temporary equipmentpresence or absence of aggregate production equipment and other factors, the effects at the example construction sites are summarized as follows.

1) Effect of reducing the construction cost

The gallery construction cost is reduced by 10% as compared with the conventional construction methods.

2) Effect of reducing the number of workers

The number of workers is reduced to about 30% as compared with the conventional construction methods. The number of work-related accidents is expected to be reduced, although the number of work-related accidents is not necessarily proportional to the number of workers.

3) Effect of shortening work periods

The effect of shortening work periods seems to increase dramatically as the scale of dams increases.

Chapter 5 Conclusion

Concrete measures to reduce the construction cost of individual dams need to be taken in each phase of dam construction projects. Because the measures are interrelated, it is necessary to study the measures and make advance preparations for the measures at an early stage.

On that occasion, it is important to have a good understanding of the items specific to the dam by referring to the results of the analyses in this paper.

* Explanation of terms

(*1) New RCD construction method

The new RCD construction method refers to an improved RCD construction method. Research and development is being carried out in the name of thin-layer RCD construction method. The thin-layer RCD construction method is the same as the RCD construction method in that the concrete for RCD is used and concrete is compacted using a vibratory roller, but different from the RCD construction method in that the thickness of concrete per lift is thin, about 40 cm, a layer of concrete is placed on the entire face without dividing the face of dam body, and it is possible to simplify the treatment of horizontal construction joint face for 48 hours until concrete is placed in contact with hardened concrete.

Source: Japan Dam Engineering Center, Advancements in RCD Construction Method and Technology, Dec. 2005

(*2) Trapezoidal CSG construction method

The trapezoidal CSG construction method is a method of constructing trapezoidal CSG dam, or a new type of dam. The trapezoidal CSG dam exploits the characteristics of the trapezoidal dam and the CSG dam construction method as well achieves three rationalizations, mainly the rationalization of materials, and the rationalization of design and construction, thereby reducing the effects on the environment.

The CSG construction method is a method of mixing base materials, such as riverbed gravel, with water and cement without making adjustments, such as classification, to the materials. The manufactured mixture is called CSG (Cemented Sand and Gravel.) The trapezoidal dam is a dam having a trapezoidal cross section that was proposed as a design of dam using the CSG.

Source: Committee on Preparation of Technical Information on Trapezoidal CSG Dam, Technical Guidelines for Trapezoidal CSG Dam, Nov. 2003

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