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A CONSIDERATION OF THE TECHNOLOGICAL DEVELOPMENT OF SMALL-LOW EARTHFILL DAMS FOR THE EXPANSION OF THE RATIONAL USE OF RESERVOIRS (*)

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JAPAN

1. INTRODUCTION

In Japan, many small dams were constructed and managed for irrigation of rice paddies since ancient times. These dams are referred to as "TAMEIKE", and were frequently constructed on comparatively weak foundations using soil as the main material, such as low-lying ground, wetlands, and flood plains composed of unconsolidated sedimentary deposits (alluvium).

In new construction of irrigation dams in response to the increase in demand for water in modern times, small-low earthfill dams were adopted as a result of Japan's peculiar conditions that the majority of the national land area consists of mountains holding many small river basins with rapid flow, in order that agricultural land distributed around each small river basin is irrigated.

The number of dams in Japan with the heights over 15 m is 2,723 (the number of construction completed during or before the Edo Era is 305, construction completed during or after the Meiji Era is 2,418), with a total water storage capacity of 20.4 billion tons, but this does not equate to the water storage

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(*) *Considération du développement technologique des petits barrages en remblai pour l'irrigation et expansion de l'utilisation rationnelle des réservoirs* capacity of 40 billion tons of the Three Gorges Dam in China or the Hoover Dam in USA, which indicates that overall in Japan there are many small dams (see Fig. 1).[1]

When constructing these small fill dams, measures such as effective utilization of the soil material around the dam site are taken to reduce the construction cost, and dams are constructed after solving problems related to structural safety and water tightness function on weak foundations through governmental, academic, and private sectors' cooperative research and development.

In particular, Japan is a major earthquake country, so when constructing earthfill dams on weak foundations using mainly soil materials, concerns for liquefaction (1), settlement, and deformation of the ground due to strong seismic motions make it impossible to carry out grouting of the ground. In these cases, construction methods using a blanket of natural ground or horizontal blanket is adopted, and issues such as structural safety and water tightness are solved by countermeasures against liquefaction in the foundation soils and nearby natural ground.

Also, redevelopment of reservoirs has been implemented with levee raising or refurbishment of earthfill dams and adding a regulatory function for flooding which tends to increase with the water storage capacity growing in response to new water supply needs, and/or the development of the river basins. This redevelopment is similar to the maintenance of the water storage function of the aging small dams. In this way, the multi-faceted functions of dams and reservoirs are exhibited, contributing to the conservation of the local environment.

In these dams with low embankment heights, measuring devices are embedded to ensure safety during construction and to monitor their performance after the completion. Measurement is continued until the present.

On the other hand, there have been many cases in which these small earthfill dams have been subject to The 2011 off the Pacific coast of Tohoku Earthquake and other inland earthquakes that occurred before that. In these huge earthquakes, cracking or failures of the crest, settlement and deformation of the dam itself, etc., have been found. Apart from some very old earth dams, however, there has been no fatal damage such as large scale slides, liquefaction, or overtopping.

This document, based on examples of construction achievements, focuses on small-low earthfill dams with less than 30 m height and describes their technical

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(1) *When shearing deformation repetitively happens for a short time as it does on earthquakes, even sandy soil with high permeability temporarily becomes almost undrained and pore water pressure rises. Increased pore pressure pushes back soil particles and causes a collapse of contact among them, which renders the particles floating. This phenomenon is "liquefaction" .[2]*

characteristics, issues, and countermeasures, and consequently, we depict solutions with dams and use of reservoirs in mind.

The practical considerations will be solutions for the construction of “small scale dams” with low cost and low environmental impact in response to the need for development of water resources for the anticipated increase in population and for food safety.

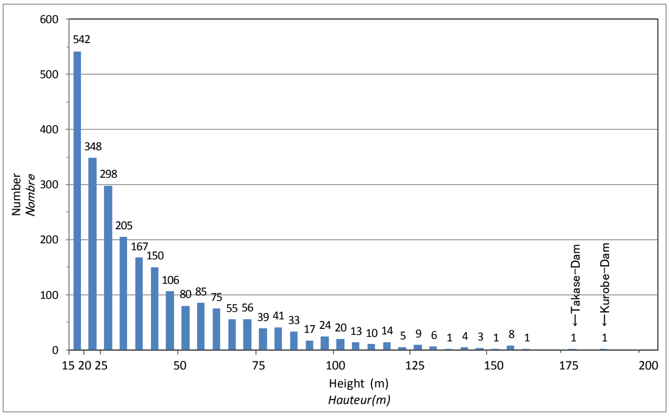


Fig.1
Distribution of dam embankment heights in Japan
Distribution des hauteurs de digues au Japon
(Dams completed in the Edo Era and earlier are not included as their embankment heights are not clear)

2. CONSTRUCTION TECHNOLOGIES OF INTEGRATED/ EXPANDED EARTHFILL DAMS

Saiku regulating dam [3], which was completed in 2010, was constructed as a fill dam through integration and expansion of two existing old small irrigation dams (TAMEIKE). The soil around them was effectively utilized to construct a safety dam on soil foundations. Also, this regulating reservoir situated at an intermediate point on the irrigation channel was constructed by expanding the dam lake while using the water for agriculture to achieve a rational increase in the water storage capacity. We, as supervising engineers, engaged in design and construction supervision. The following are the technical features.

2.1. ADOPTION OF "HOMOGENEOUS EARTHFILL DAM AND HORIZONTAL BLANKET CONSTRUCTION METHOD" UTILIZING LOCAL MATERIALS

2.1.1. Fundamental Policy

As the ground around Saiku regulating dam consists of weathered granite (depth 10 m or more) with low N-value, it was difficult to expose the sound bedrock surface over the whole site. Therefore, the dam was designed as a fill type dam. Also, in the case of the fill dam, the basic cross-section of the embankment was selected to be a homogeneous cross-section which is economical and quite safe, taking into consideration the abundance of borrow pits and the reuse of materials excavated at the site.

2.1.2. Geological Conditions

At the outcrops around the dam site, red clay masa soil due to weathered granite (referred as "Gr" hereafter) and yellow-ash-colored sandy soil were generally seen, and outcrops of unweathered rocks could hardly be seen on the surface. These weathered masa rocks (rock mass classification: D) were classified into Gr-1 (N-value: about 10 or less), Gr-2A (N-value: about 10), Gr-2B: N-value: about 20 or more), and Gr-3 (including unweathered gravel), in increasing order of N-value.

2.1.3. Adoption of Homogeneous Earthfill Dam Form

The form of the body of the dam was classified in accordance with the control level and whether coarce-particle material and fine-particle material was blended, from the following considerations using the same material. A homogeneous earthfill dam with a water tight zone (Zone1: hydraulic conductivity 1.0×10^{-5} cm/s or less) and a semi-permeable zone (Zone2: hydraulic conductivity 1.0×10^{-4} cm/s or less) was adopted.

Besides, the horizontal blanket method (described later) was adopted as the method of processing the foundations, and the water tight zone of this dam was arranged on the front surface of the dam so that the connection to the horizontal blanket would be smooth (adoption of inclined impervious core).

2.1.4. Adoption of Horizontal Blanket Method as the Method of Processing the Foundation

"Blanket method" is effective when plentiful water tight material can be obtained from the site, there are few restrictions with respect to the water storage capacity, and is used in combination with a homogeneous earthfill dam. In particular, this method is very economical as naturally-occurring materials are used.

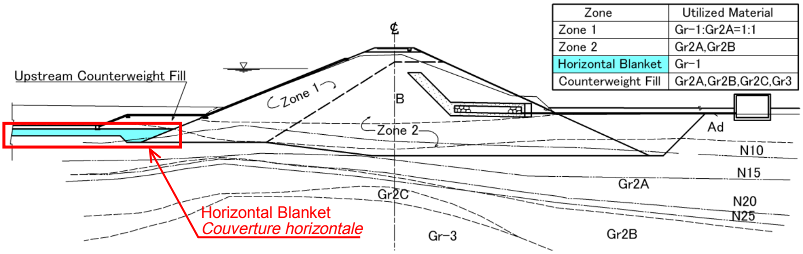
The results of an additional survey showed that the bedrock Gr-3 stratum, that was considered to be certainly capable of being water tight by the grouting method, extended from the surface of the river bed to 10 to 20 m depth or more, and extended almost horizontally in the left and right bank abutment directions.

Therefore, grouting would be applied to all the masa soil strata at the left and right abutments, which would lead to a large amount of construction work and expense based on the experience with the existing dams.

Consequently, as the concept of water tight treatment of the dam as a whole was considered appropriate, a standard cross-section of a "homogeneous earthfill dam and horizontal blanket" was adopted (see Fig. 2).

2.1.5. Scheme for Use of the Dam Construction Material

Taking the quality (particle size distribution) of the material into consideration, filter material was purchased, but all other dam construction materials were locally-occurring materials, which enabled the construction cost to be reduced.



Zone	Utilized Material
Zone 1	Gr−1:Gr2A=1:1
Zone 2	Gr2A,Gr2B
Horizontal Blanket	Gr−1
Counterweight Fill	Gr2A,Gr2B,Gr2C,Gr3

Fig. 2
Standard cross-section through the dam
Coupe standard du barrage

2.2. TECHNOLOGY FOR IMPLEMENTING THE DAM CONSTRUCTION WHILE USING AGRICULTURAL WATER

Saiku regulating dam integrates and expands two small irrigation dams (TAMEIKE) that are currently in service. The construction was carried out while supplying water for agriculture during the construction period (irrigation period $Q=5.132 m^3/s$, non-irrigation period $Q=0.243 m^3/s$), so the adopted procedure was, in the first 2-year-period, the ageing small irrigation dams (TAMEIKE) were left and the regulating reservoir on the upstream side was constructed first, and in the final 2-year-period, the ageing small irrigation dam (TAMEIKE) parts (downstream side) were completed.

During construction on the upstream side (2006 to 2007), the existing water channels were retained, and water for agricultural use flowed into existing small scale irrigation dams (TAMEIKE) in the downstream which continued to be used for agriculture.

During construction on the downstream side (2008 to 2009), the upstream reservoir was in service, so a “bottom water channel” was installed on the right bank’s temporary closure dam, and water flowed to the existing water channel on the downstream side. This way enabled the construction to be carried out while agriculture continued. Fig. 3 shows the schematic procedures of constructing of Saiku regulating dam.

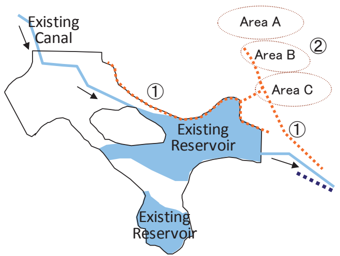
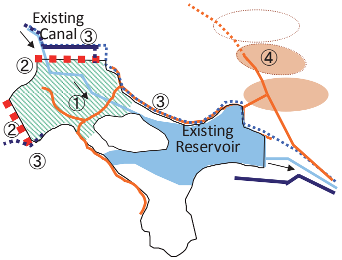
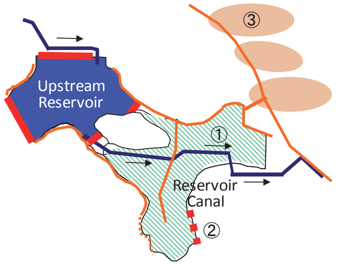
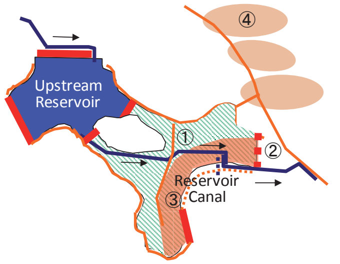
Year		2006	2007
Irrigation Period (Apr. to Sep.)	Figure	 Source: Existing Reservoir and Canal	 Source: Existing Reservoir and Canal
	Works	①Temporary Road ②Surplus Soil Treatment Place	①Excavation at Upstream Reservoir ②Secondary Dam excavation & filling ③In-flow Work & Temporary Canal ④Transport of Surplus Soil
Year		2008	2009
Irrigation Period (Apr. to Sep.)	Figure	 Source: Upstream Reservoir & Reservoir Canal	 Source: Upstream Reservoir & Reservoir Canal
	Works	①Excavation at Downstream Reservoir ②Primary Dam excavation ③Transport of Surplus Soil	①Excavation at Downstream Reservoir ②Excavation & Filling of the Main Dam ③Filling of Natural Ground & Horizontal Blanket ④Transport of Surplus Soil

Fig. 3

Schematic processes for the construction of the Saiku regulating dam

Processus schématiques de construction du barrage de régulation de Saiku

2.3. MEASURES TO INCREASE THE SEISMIC PERFORMANCE

2.3.1. Dam Construction Scheme

Masa soil is normally a material which there are concerns over settlement, reduction of strength due to permeation of and saturation with water, and liquefaction, but these concerns are reduced by increasing its density. A dam constructed on a river on Awaji Island near the epicenter of the 1995 Kobe Earthquake was constructed using masa soil as embankment material. But, as a result of taking the same measures, there was no settlement, deformation, liquefaction or other change whatsoever found after the earthquake.

Consequently, in the dam construction scheme, the seismic performance was increased by specifying that for both Zone 1 and Zone 2 material, the control standard density shall be 95% or more of 1.5Ec (compaction energy = JIS×150%).

2.3.2. Foundation Excavation Scheme

The strata at which liquefaction could potentially occur in the foundation soils in this area (strata subject to liquefaction) were the Ad stratum (alluvial) and the Gr-2A stratum (weathered masa), so the foundation excavation line was defined so that the following conditions were satisfied, and thereby safety against liquefaction was increased.

a. N-value≧10 (in this way soil with liquefaction strength 0.32 or less is excavated and removed) (2)
b. Excavation and removal of alluvial stratum

Table 1
Liquefaction strength of each stratum

Stratum	Repeated triaxial strength ratio R_L (N: N-value)	Liquefaction resistance ratio F_L (L: shear stress ratio during earthquake)
Ad stratum	0.245	F_L=0.245/L
Gr2A stratum (N-value 5 to 10 equivalent)	0.250 (N=5)	F_L=0.250/L
Gr2A stratum (N-value 10 to 15 equivalent)	0.320 (N=10)	F_L=0.320/L

(2): By eliminating N-values of 10 or less, a liquefaction strength of 0.32 or higher is ensured, and F_L ≧1.0 for the majority of the base of the dam due to the imposed load of the embankment (see Fig.4). As a result the seismic performance is ensured.

2.3.3. Loading Embankment Scheme Based on the FL Method

To ensure a resistance ratio $F_L \geqq 1.0$ with respect to liquefaction for the whole base of the dam on dam foundation soils where soils with N-value of 10 or less were removed, a loading embankment was installed at the foot of the upstream slope to increase the safety against liquefaction. The height of the loading embankment (h) necessary to ensure $F_L \geqq 1.0$ was determined by trial calculation.

<Upstream Slope>
Loading embankment height h=1.5 m (elevation of the crest EL.=24.0 m)

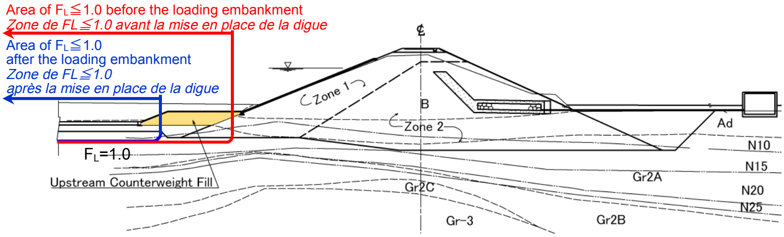


Fig. 4
Loading embankment scheme based on the FL method (main dam)
Plan de charge de la digue basé sur la méthode FL (barrage principal)
(*F_L=1.0 is the value before the embankment, F_L=1.0 is the value after the embankment)

2.4. TECHNICAL RESULTS

Fig. 5 suggests a contrast between the old dams and the completed and full regulating dam which were enlarged, using the surrounding topography to advantage. Without greatly raising the level of their crests (FWL. was raised by 40cm), many technical issues were overcome, and as a result, the water storage capacity was increased to more than tenfold (see Table 2).

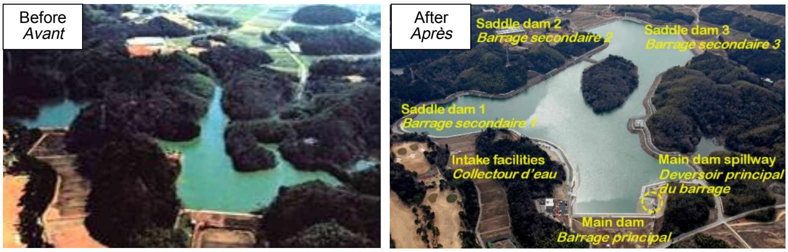


Fig. 5
The Panorama view
Vue panoramique

Table 2
Comparison between the old and new dams

	Old dams		New dam			
	Saiku	Soda	Main	Saddle 1	Saddle 2	Saddle 3
Height	10 m	5.7 m	16 m	13.5 m	14.5 m	11.5 m
Width	49 m	95 m	181 m	117 m	221 m	149 m
Volume	-	-	76,000 m^3	38,000 m^3	78,000 m^3	30,000 m^3
Water capacity	100,000 m^3	20,000 m^3	2,000,000 m^3			
Full water level	FWL. 30.00		FWL. 30.40			

3. CONSTRUCTION MANAGEMENT OF SMALL SCALE FILL DAMS USING VOLCANIC ASH SOIL AS EMBANKMENT MATERIAL

Funyuzawa dam [4], which was completed in 2009, is an example of a dam with a low embankment height, so the amount of deformation of the dam and foundations due to the embankment load was small, and highly compressible volcanic ash loam which was distributed around the dam site was used on its own as water tight material, thereby achieving a cost reduction. We, as supervising engineers, engaged in design and construction supervision.

3.1. Dam Embankment Material and Dam Form

Loam is a material which normally the relationship between strength and water content is unclear, and the strength is reduced significantly with repeated loading. The material is also highly compressible, so when used in dams with high embankment height, frequently the compressibility is improved by blending uniformly with coarse particle material for control of the embankment construction. However, the embankment height of Funyuzawa dam was low at about 15 m, so it was considered that low strength and highly compressible loam material could be used on its own as water tight material. To ensure safety of the dam (factor of safety against slip failure), a zone type fill dam form was selected in which tuff breccia (referred to as Tb. found below the loam in the borrow pits), which has a high shear strength compared with the impervious material, was placed upstream and downstream. Fig. 6 shows the standard cross-section of the dam.

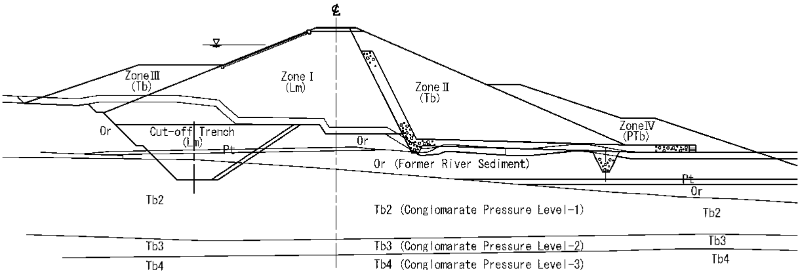


Fig. 6
Standard cross-section of the Funyuzawa dam
Coupe type du barrage de Funyuzawa

3.2. CHARACTERISTICS OF LOAM MATERIAL AS A DAM CONSTRUCTION MATERIAL

Originally loam was a name indicating the particle size distribution of soil that is a mixture of sand, silt, and clay in a constant proportion. However in geology the definition of “a stratum of volcanic ash originating from quaternary volcanic activity” was generalized as Kanto loam, so “loam” became synonymous with volcanic ash soil. The following is a description of the mechanical properties of loam material.

3.2.1. Characteristic 1. Water content and strength

In the case of normal soil materials, there is a relationship $c, \Phi = f(\rho d, W)$ between “water content/ dry density” and shear strength. Therefore, by controlling the relative density D value (Proctor density) and C value (ratio of individual water content to density), the required shear strength is ensured.

On the other hand, loam material has the characteristics that the correlation between water content and strength is poor, and that the water content required to achieve a certain level of strength (qc) varies depending on strata (e.g. depth).

Fig. 7 shows the results of arrangement of cone index (qc) of loam materials at each stratum (depth) which were from borrow pits of the Funyuzawa dam. According to the Fig. 7, correlation between water content and cone index is largely different stratum to stratum, and water content is also scattered in even the same stratum, which indicates that difficulty in quality control of embankment is obvious.

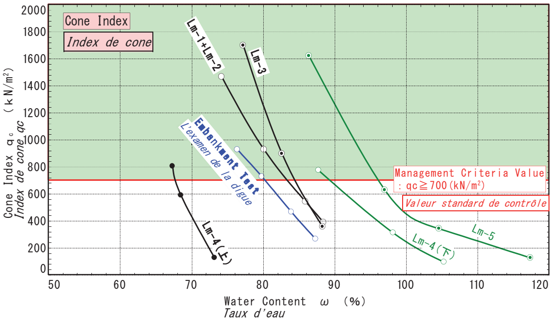


Fig. 7

Relationship between water content and strength (cone index: qc)

Relation entre le contenu en eau et la résistance (index de cône : qc)

3.2.2. Characteristic 2. Reduction in strength due to repetition

Loam has a characteristic that its strength is reduced when the water contained within the soil particles becomes freed at the surface of the soil particles due to heavy machinery operations such as roller compaction or bulldozing. Here, the results are shown for qc measured by ramming undisturbed test samples immediately after sampling, and qc measured by compacting again after separating soil that has been compacted once.

Even materials from the Funyuzawa dam borrow pit, as can be seen at the Table 3 below, the strength (cone index) is reduced by half for soil when being rammed after having been subjected to compaction energy and separation.

In compaction, careful consideration to prevention of over compaction and management of the surface of the embankment were necessary. More specifically, we decided compaction specification through embankment test analyses mentioned below, and planned a special way of quality control of embankment for the Funyuzawa dam.

Table 3
Consideration on the mold rammer at the test before transfer
(Ramming ~ Cone penetration test)

Conditions for Making Test Piece for the Cone Penetration Test (Ramming Conditions)				Cone Penetration Test			Water Content ω (%)
				After the 1st Ramming	Reduction in Strength due to Repetition →	After the 2nd Ramming	
Compaction Energy	Compaction Mold	Used Rammer	Number of Ramming	Cone Index qc (kN/m^2)		Cone Index qc (kN/m^2)	
Ec=JIS× 100%	φ200mm	10kg	20 times/layer	850	"2nd Ramming" was done after separating the same test material that had been rammed in "the 1st Ramming"	372	78.7
		2.5kg	125 times/layer	840		396	78.8
	φ100mm		25 times/layer	847		385	80.1

3.2.3. *Characteristic 3. Strength recovery and irreversibility due to drying*

Other loam material’s characteristic phenomena are “thixotropy” which is the recovery of strength with time of a material that has been remolded, and the “occurrence of cracking due to drying shrinkage” due to drying at the surface after roller compaction. Fig. 8 shows qc “immediately after roller compaction” and “after 3 days” measured in the embankment tests of the Funyuzawa dam. According to the Fig. 8, the recovery in strength due to thixotropy and drying was confirmed in the case of the materials from the Funyuzawa dam borrow pit, too.

Also, loam material with a history of drying shows “irreversibility” that even when the water content recovers to the initial water content, the initial properties are not restored.

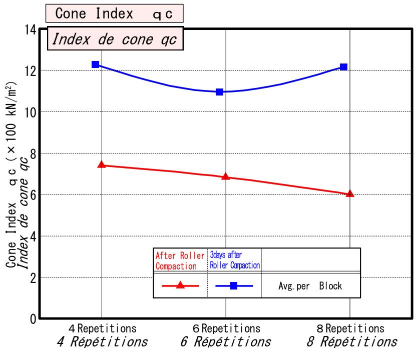


Fig. 8
Embankment test results (frequency of roller compaction – qc)
Résultat des essais sur digue (fréquence de compactage au rouleau – qc)

3.3. DETERMINATION OF CONSTRUCTION SPECIFICATION BY EMBANKMENT TEST

Strength reduction due to repetitions, a characteristic of loam, is observed in a tendency that Cone Index has decreased as compaction energy (the number of compactions) from heavy machinery has increased (see Fig. 8). Dry density becomes maximum with 6 repetitions and decreases with 8 (see left part of Fig. 9). Regarding permeability functions, it was found that the design condition (k≦1.0× 10-5 cm/sec) was satisfied with 6 or more repetitions of roller compaction (see right part of Fig. 9). We, from these findings at the embankment tests, decided that 6 repetitions is the best as a construction specification of this dam.

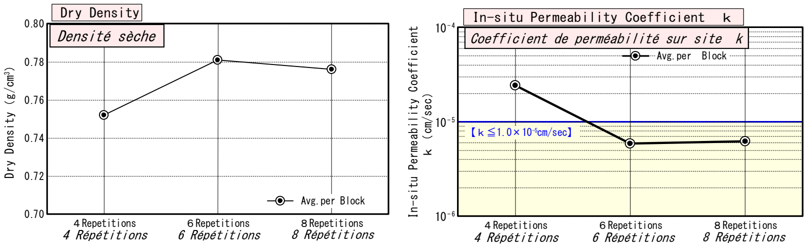


Fig. 9
Embankment test results
(frequency of roller compaction – dry density and permeability coefficient)
Résultat des essais sur digue
(fréquence de compactage au rouleau – densité sèche
et coefficient de perméabilité)

3.4. METHOD OF CONTROL OF EMBANKMENT CONSTRUCTION WITH LOAM MATERIAL

3.4.1. Obtaining Good Quality Material

When gathering the material, qc was measured immediately after compaction (standard compaction test (JIS A 1210)), and it was judged whether or not the material could be used. The criterion for selection was set as qc≧700 (kN/m^2) which incorporates a correlation with triaxial compression test results from previous years, trafficability, and the reduction in strength due to construction.

3.4.2. Measurement of the Strength of the Material

Due to the variation of the compaction energy and the compaction mechanism makes the compaction when selecting material different from that of the compaction by heavy machinery, so there is a possibility that qc in the embankment will be less than that at the soil borrow pit, Therefore, as a fundamental way, strength control shall be carried out at the surface of the embankment. Besides, relationship between in-situ qc and shear strength was confirmed by periodical uniaxial compression test and triaxial compression test results.

3.4.3. In-situ Tests

As in-situ permeability tests require a long time for measurement, they were carried out at a frequency of once a day so that exposure of the embankment surface is shortened to avoid having it dried. On the other hand, as the emphasis was placed on density control using in-situ density tests (compacted sand replacement method) carried out for each layer, and on control of the degree of saturation, we set a policy that in-situ density management complemented management data of impermeability

The density control method adopted “C-value control” which could be rapidly determined from the density (ρdL,ρtL) obtained by compacting the in-situ-sample-material excavated from the in-situ-density-hole (ρdf, ρtf).

3.5. TECHNICAL RESULTS

The embankment construction was completed in accordance with the planned embankment construction specification and embankment management method. It was confirmed that good embankment construction was achieved with little remolding as a result of selecting the material at the soil borrow pits and adoption of an appropriate rolling compaction specification.

In the test flooding, too, sound measurements were implemented for settlement, deformation, and quantity of permeation, and the safety was confirmed.

By overcoming the issues inherent in this particular loam material by construction control and effectively using the material, it was possible to achieve low cost fill dam construction, and it is expected that this information will be useful for the development of dams in the future.

4. WATER STORAGE RESERVOIR EXPANSION CONSTRUCTION LEAVING PART OF THE OLD DAM, AND RESOLUTION MEASURES TAKEN DURING THE CONSTRUCTION AND TEST FLOODING STAGES

Oyachi dam [5] was constructed to enlarge an old small scale irrigation dam (TAMEIKE), and to utilize it as a regulating reservoir. In response to the increase in water demand, Oyachi dam was constructed to expand the water storage capacity of existing Oyachi reservoir (homogeneous earthfill dam, embankment height 15 m, water storage capacity 450,000 tons) up to 1.2 million tons, while utilizing a portion of the existing structure (embankment height 23.2 m at the maximum cross-section after levee raising).

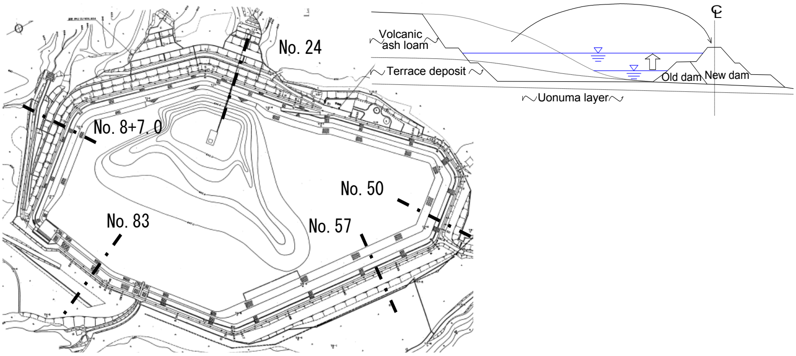


Fig. 10
Plan view of Oyachi dam
Vue en plan du barrage d'Oyachi

In order to reduce the cost, a balanced method, in which excavated soils within the existing reservoir were used for embankment, was adopted. The material excavated from the reservoir was mostly loam, so the dam type adopted was a homogeneous earthfill dam. During the long term service of this dam, we implemented stability assessments regarding dam function and earthquake resistance in 2013.

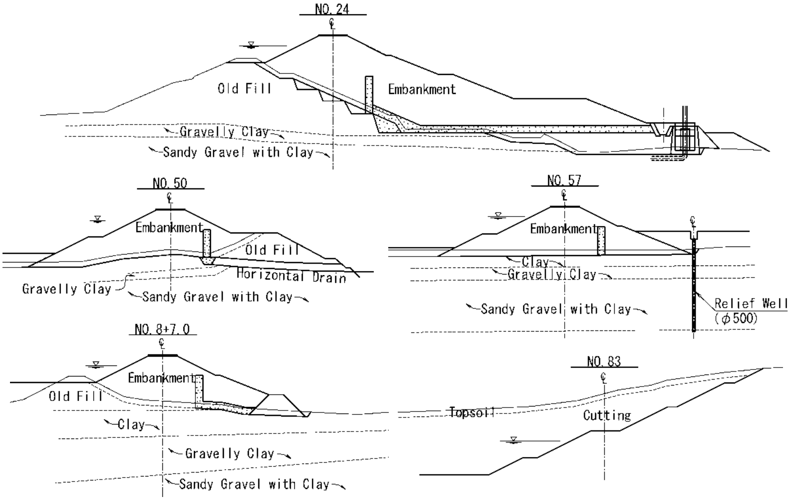


Fig. 11
Standard cross-sections of Oyachi dam
Coupes types du barrage d'Oyachi

4.1. DETAILS OF THE DESIGN AND CONSTRUCTION AND INNOVATIVE MEASURES

Oyachi dam had the following characteristics which were different from a normal river channel water storage dam.

- The water storage capacity was increased by raising the height of the old dam a nd excavating the bottom of it.
- Therefore, a cutting and embankment type regulating reservoir was formed around the whole periphery of 1,780 m.
- There were 4 types of cross-sections of main levee and secondary levee, and it was required to provide percolation channels around the whole periphery of the reservoir and to ensure safety of each area block.
- Taking into consideration that the embankment height is comparatively low, the dam foundation is a weak volcanic ash loam stratum, and the embankment is also made of loam which is difficult to control and to ensure uniformity.

As a result, due to variations in material, construction speed, changes in the direction of flow of the groundwater in the natural ground, it was necessary to carry out design changes, review the standard cross-section, and carry out additional construction, etc., during construction and during test flooding. The following is a summary of the innovative measures.

- A counterweight was installed at the feet of the upstream and downstream faces.
- Reconstruction and change in cross-section (change of slope, installation of horizontal drain) due to slide failure during construction.
- Addition of a relief well at the foot of the downstream slope and a horizontal blanket upstream, to prevent piping of the foundation soils.

4.2. ISSUES THAT AROSE DURING TEST FLOODING AND RESOLUTION MEASURES

As a result of the test flooding which commenced in 1990, leakage of water occurred from the foot of the downstream slope, which was assumed to have been caused by hydraulic failure of the foundation soils. Therefore, measurement instruments (open piezometers) were installed, and additional construction and continuous flooding test were carried out, while monitoring the amount of leakage, deformation, and seepage line.

Additional curtain grouting, additional slope grouting, and an additional horizontal blanket were gradually implemented as resolution measures until 1995, and monitoring was continued until 1999. After stable leakage (a half of the initial leakage) was observed, the flooding test was terminated.

4.3. TECHNICAL EVALUATION

To construct a normal height dam on a deep deposit of weak volcanic ash loam stratum, the deposited stratum should be removed, but this greatly increases the construction cost, so there is concern that excessive investment will be required for a facility with the objective of providing small scale water storage capacity.

Therefore, one of the options that can be evaluated is the construction of a dam under the same poor site conditions, rationally evaluating the low embankment height, and applying earthfill dam technology that effectively utilizes locally-available soils to produce a dam that is more suited to the site.

Also, during service this dam experienced comparatively large scale oscillations due to The Mid Niigata prefecture Earthquake in 2004 and The 2011 North Nagano Earthquake, but at present no major deformation has been observed. The integrity of its long term service is ensured through periodic monitoring of the behavior of measuring devices.

5. A PRACTICAL CONSIDERATION ON THE BASIS OF CHARACTERISTICS AND ISSUES OF SMALL DAMS

The common characteristics, issues, and solutions for the introduced small three dams which rationally used soil materials are shown in the following table.

Table 4
Characteristics, issues, and solutions of small dams

Technical Characteristics	Issues	Solutions
Widening and increment of water capacity of old small dams	A method for construction of new embankments and excavation of reservoir basin, while utilizing old dams	· Gradual translocation of rivers and separated construction · Usage of excavated soils as embankment material
Effective usage of surrounding soil materials	Material quality control of a heterogeneous material and soil with high water content	· Selection of a quality control method according to material characteristics · Flexible changes of cross sections in response to monitoring during construction and flooding test
Weak strata	Concerns for settlement of embankments and liquefaction	· Development of survey/ testing/ analyzing methods, based on characteristics of liquefaction · Prospects, measurements, and monitoring of settlement and deformation

We, based on these new solutions, shall consider future possibilities as follows.

- It is likely that we can achieve both renewal and water capacity increment at once through effective usage of excavated materials from the surrounding soils. This will allow us to reuse, not to just abandon, ageing earthfill dams with lowered function and the ones lacking in water capacity due to sediment.
- With proper countermeasures against weak strata and liquefaction, it is likely that we can build small earthfill dams even on the ground with weak strata that do not fit for tall dams.
- Deformation of dams can occur when soil materials that do not fit for tall dams and that have difficulties in material management are used, whether the dam is under the construction or filled with water. Then, flexible consulting services which revise standard cross-section in response to circumstances will enable us to build safe earthfill dams.

6. CONCLUSION

It has been shown from examples of technical experiences with small and low embankment height earthfill dams constructed in Japan that there are particular issues that cannot be solved by standard design.

The general rule for rational design and construction of fill dams is to utilize, to the maximum extent, soil and rock materials that can be obtained at the dam site or nearby during construction. Due to dams' social importance, however, there is emphasis and priority on securing the safe performance of dams, so embankments are frequently constructed on sound rock foundations and made from easily controlled blended cores and good quality rocks. In these cases, weak soil foundations are excavated (and disposed of), and good quality material is purchased and transported from afar, which is the main cause of cost increases.

For small scale water storage reservoirs and low embankment height dams, aspects such as the water storage energy and the load on the foundations can be dealt with more flexibly than for large scale dams, and small scale dams can be constructed on dam sites that are unsuitable for large dams, by solving their inherent technical issues.

As can be seen from the examples described, considering Japan's inherent topographical and geological conditions, dams on weak foundations and construction of dams with materials that are difficult to control such as high water content clays, etc., are probable options, however, safety can be sufficiently assured and the construction cost can be reduced by innovative measures. Moreover, integration and expansion of old reservoirs in low-lying areas by excavating the bottom of the reservoir, etc., are reasonable measures with low environmental impact.

It is considered that changing from concentrated large dams to dispersed small water storage reservoirs by applying these earthfill dam construction technologies is a sufficiently effective option in response to the anticipated future increase in demand for water on a global scale and the shortage of suitable sites for construction of dams.

REFERENCES

[1] Japan Commission On Large Dams, *Dams handbook.* Available at: http://damnet.or.jp/Dambinran/binran/TopIndex.html (Last Accessed October 7, 2014), 2014 (in Japanese).

[2] Kaida, T. & Tateishi, A., Fundamentals of earthquake resistance design, 2009 (in Japanese).

[3] Tokai Regional Agricultural Administration Office, "National irrigation and drainage project: Miyagawa irrigation's second district", *Youti Journal*, vol. 10, no. 8, pp. 28-33, 2013.

[4] Matsuura, M. et.al, "Characteristics of Funyuzawa Dam and Method of Control of Embankment Construction", *Conference of The Japanese Society of Irrigation, Drainage and Rural Engineering, Kanto Branch*, 2006 (in Japanese).

[5] Hokuriku Regional Agricultural Administration Office, *Technical Brochure on Oyachi Dam, Nakafukami-Gennaiyama regulating reservoir*, 2000 (in Japanese).

SUMMARY

Japan has 2723 dams with an embankment height of 15 m or more, of which 1816 are less than 50 m high, and 1188 (43.6%) are small-scale dams less than 30 m high; therefore roughly half of the total are low embankment height dams. The reasons for this are the national land conditions which result in small river basins with rapid flow, the demand for water resources with branch points for irrigating dispersed agricultural land, and the fact that 70% of the population lives and farms on just under 20% of the national territory consisting of weak and low lying plains.

This document summarizes the progress of the technical development of small scale fill dams in Japan and their construction results. The technical issues include the rational renewal of aging existing dams, the methods to expand reservoirs to deal with increasing water demand, design concepts for foundations that are weak and subject to liquefaction, the effective utilization of the heterogeneous soil materials that can be obtained near dams, and ensuring seismic resistance under these conditions.

For discussion purposes, we indicate herein the results of dam construction in which the reservoir bottom was excavated and the excavated soil was used for the dam embankment while ensuring water supply. This is an example of the renewal, integration, and expansion of old small-scale irrigation dams (TAMEIKE) without changing dam embankment height or the flood water level. Then issues such as material control, construction specifications, performance monitoring during construction, monitoring during flooding, etc. are discussed based on the results of trial constructions, additional measures, embedded instruments, and other methods, in order to reduce the cost by using the volcanic ash loam distributed around the dam site as the sole material.

RÉSUMÉ

Le Japon possède 2 723 digues de hauteur supérieure à 15 m. Parmi celles-ci, 1 816 font moins de 50 m, et 1 188 (43,6 %) sont des petits barrages de moins de 30 m. Ainsi, presque la moitié peuvent être considérées comme des digues basses. Les raisons sont les suivantes : configuration du territoire national avec des petits bassins versant à écoulement rapide, demande de ressources en

eau avec des points de branchement pour irriguer des champs dispersés, et 70% de la population cultivant moins de 20% du territoire consistant en des plaines fragiles à basse altitude.

Ce document résume les progrès de la technique pour les petits barrages au Japon et les enseignements tirés de leur construction. Les difficultés techniques sont liées à la rénovation rationnelle des barrages âgés et aux méthodes d'agrandissement des réservoirs afin de répondre à la demande croissante en eau, à la conception de fondations qui ne soient pas fragiles et sujettes à la liquéfaction, à l'utilisation comme matériaux de sols hétérogènes à proximité des barrages, et à la résistance aux séismes dans ces conditions.

A titre de discussion, nous présentons les résultats de construction de barrages pour lesquels les matériaux excavés du fond du réservoir sont utilisés pour la digue, tout en continuant d'assurer l'approvisionnement en eau. Nous utilisons un exemple de rénovation, d'intégration, et d'expansion d'anciens petits barrages d'irrigation (TAMEIKE) sans modification de hauteur de digue et le niveau de crue. Ensuite, les problèmes de type contrôle des matériaux, spécifications de construction, surveillance en cours de chantier et en cas de crues, etc… sont discutés à partir des résultats d'essais de constructions, mesures supplémentaires, instruments intégrés et autres méthodes, afin de réduire le coût par l'utilisation de limons de cendres volcaniques, disponibles aux alentours des sites de barrage.