Sustainable and Safe Dams Around the World – Tournier, Bennett & Bibeau (Eds)

Development and application of various new technologies for construction of Yamba Dam

T. Hiratsuka
Shimizu Corporation, Naganohara Town, Gunma Prefecture, Japan

N. Yamashita & T. Kase
Shimizu Corporation, Chuo Ward, Tokyo, Japan

ABSTRACT: The Yamba Dam is the concrete gravity dam under construction of 116m high and about 1,000,000m³ in volume on the Agatsuma River nearby Tokyo. Concrete placement was mainly executed by compacting zero-slump-concrete with vibration rollers in summer time, and by the extended layer construction method with slump-concrete in winter time. Also, three conduit spillways with large radial gates were installed in the dam. In order to cope with these backgrounds, we developed "Backhoe with vibrator" with the compaction gauging function of slump-concrete and improved the construction quality. Vibrating rollers can grasp the position information and control the number of rolling compaction for placement of the zero-slump-concrete. In addition, we simulated the construction process by using the Virtual Reality system for the conduit spillways with complicated structure within the dam body. In the 10km-transportation of graded concrete aggregates by belt conveyor, we developed a system for continuously grasping the aggregate grading on the belt conveyor.

RÉSUMÉ: Sur la rivière Agatsuma, près de Tokyo, le barrage de Yamba est un barrage-poids en construction de 116 m de hauteur et faisant environ 1 000 000 m³ de volume de béton. La mise en place du béton a été réalisée en été en compactant principalement le béton sans affaissement avec des rouleaux vibrants. En hiver, le procédé de construction par couches a été réalisé en utilisant surtout du béton avec affaissement. De plus, l'évacuateur de crue du barrage comprend trois passages dotés de grandes vannes radiales. Afin de faire face à ces conditions, une rétro-excavatrice munie d'un vibrateur permettait de mesurer la compaction du béton avec affaissement; cet appareil a amélioré la qualité de la construction. Les rouleaux compacteurs vibrants peuvent connaître leur position et contrôler leur nombre de passages lors de la mise en place du béton sans affaissement. De plus, le processus de construction a été simulé en utilisant un système de réalité virtuelle pour les passages de l'évacuateur de crue caractérisé par une structure complexe incorporée dans le corps du barrage. Pour le transport sur 10 km par convoyeur à courroie des agrégats du béton, un système permettant de mesurer en permanence la granulométrie a été mis au point.

1 INTRODUCTION

The Yamba Dam is a multi-purpose dam currently under construction in the middle reaches of the Agatsuma River in the Tone River upstream of the Tokyo area. It is a concrete gravity dam of 116 m high, 290.8 m long, volume of about 1,000,000 m³ and reservoir capacity of 107,500,000 m³.

We commenced work on excavation of the main dam on January 2015. As of the end of October 2018 concrete placement in the dam has proceeded to a height of 110 m and a volume of 952,000 m³.

2 PURPOSES OF YAMBA DAM

2.1 *Flood control*

Agatsuma River is one of the main tributaries of the Tone River that flows through the north of the Tokyo area. But to date there has not been flood control system, such as flood control dam, etc., installed on this river. This flood control function of Yamba Dam will enable flood damage to be reduced not only in the Agatsuma River catchment area, but also over wide areas in the Tokyo region

2.2 *Stable supply of municipal water, etc.*

In the downstream Tone River basin that includes the capital area there is a tight supply of water, and in the past 10 years restrictions on water intake have been imposed three times. It will be possible to increase the supply of municipal water as well as industrial water to the Tokyo area, and it is expected to stabilize the water use in the Tone River basin.

2.3 *Hydropower generation*

Hydropower plant which is 11,700 kW output is under construction at just downstream area.

For the above reasons it is desirable for the Tokyo area that the dam will be completed as soon as possible. In addition, the Tokyo Olympics will be held soon, so all those involved in the project are working hard to complete.

3 DEVELOPMENT AND APPLICATION OF NEW TECHNOLOGIES FOR YAMBA DAM

The Yamba Dam is a large dam with more than 100m high, so it is important that concrete placement is efficiently carried out. In summer, zero-slump-concrete compacted with a vibrating roller is mainly used, in order to efficiently place the interior concrete, which accounts for most of the volume in the dam body. In winter, a concrete placement method using slump-concrete with a higher cement content to promote heat generation was adopted to deal with the low external air temperatures. Also, three conduit spillways with large radial gates are provided in the center of the dam, so the structure within the dam is complex.

3.1 *Details of the development and application of new technologies for Yamba Dam*

Based on the above points, new technologies were introduced for the construction of the main body of the Yamba Dam as follows.

3.1.1 *Development of the concrete compaction control system*

It was planned to use a layer construction method for rational construction of Yamba Dam. In this plan, in summer zero-slump-concrete is used for the internal concrete for efficient construction, and slump-concrete is used for the external concrete. In winter to deal with the lower external air temperature, it was planned to also use slump-concrete with a higher cement content for the internal concrete. Therefore slump-concrete is placed throughout the year. To ensure quality of concrete, the backhoe with vibrator (Information Technology (IT)-enabled "Vibe-back") was developed with the function of recording the compaction positions and judging when compaction was completed. For the zero-slump-concrete, bulldozers and vibrating rollers with a Global Navigation Satellite System (GNSS) were introduced.

With the IT-enabled Vibe-back, 3-dimensional (3D) positional information is determined for the locations of vibrators using GNSS installed in the cabin and displacement sensors installed on the boom and the arm as shown in Figure 1. The adequate compaction of the compacted concrete can be confirmed by the surface condition such as no exposed course aggregate, existing mortar and stiffness as much as withstanding the loads by humans (JSCE 2013). This situation stands for the flatness of the concrete compaction surface. When the flatness is checked then it is possible to judge the adequate compaction, because there is no segregation of the coarse aggregate and the mortar sufficiently surrounds the aggregate. Therefore, flatness of the surface (smoothness/irregularity of the surface) was adopted as an index for judging completion of compaction. The irregularity of the surface was measured using a 3D laser scanner installed in the cabin as shown in Figure 1.

Completion of compaction was determined by the following procedure.

1) Three-dimension positional information of the vibrator was determined by the GNSS and displacement sensors
2) Vibrations were detected by the oil flow rate meter installed on the vibrator hydraulic pressure piping, and the 3D position of the vibrator was displayed on a mesh (50 cm x 50 cm) in monitor.
3) When the flatness (roughness) measured by the 3D laser scanner was within ±2 cm it was judged that compaction is completed, and that area in the mesh was colored.

In the actual concrete placement, in some cases one lift was placed in 2 layers, so a "2-layer placement control system" was developed that judges completion of compaction separately for the first and second layers, and this was implemented as shown in Figure 2.

Also, in some cases multiple IT-enabled Vibe-backs were used, so a "Multiple vehicle coupling system" was developed that collected the compaction data from each layer transmitted to a control PC via a network. These data are integrated so that the compaction locations of another Vibe-back could also be checked as shown in Figure 3.

In summer zero-slump-concrete is used in the interior, divided and leveled in 4 layers (25 cm× 4 layers) by a bulldozer, and compacted by a vibrating roller. GNSS was installed on each of the machines, and systems were introduced for controlling the height of leveling by the bulldozers and for control of the track of the compacted positions of the vibrating rollers as shown in Figure 4.

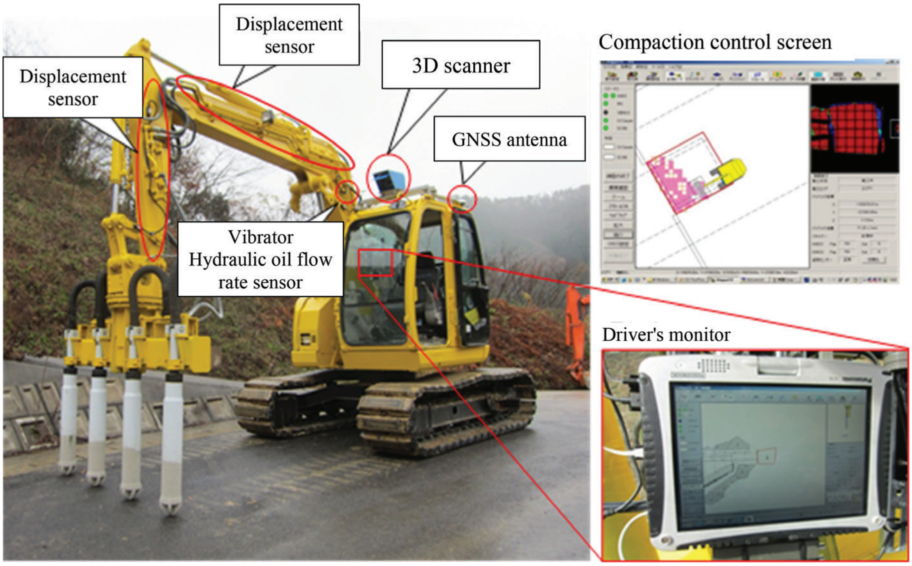

Figure 1. IT-enabled Vibe-back

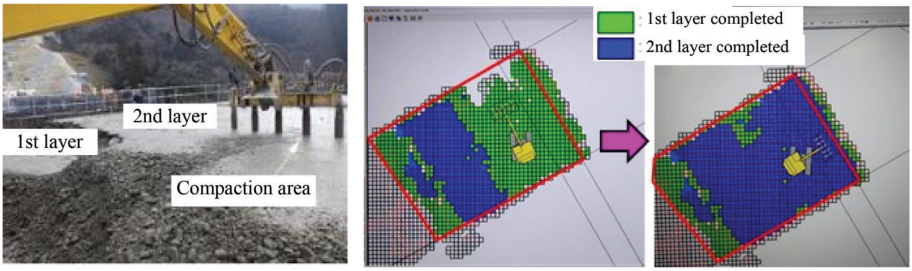

Figure 2. Two-layer placement control system

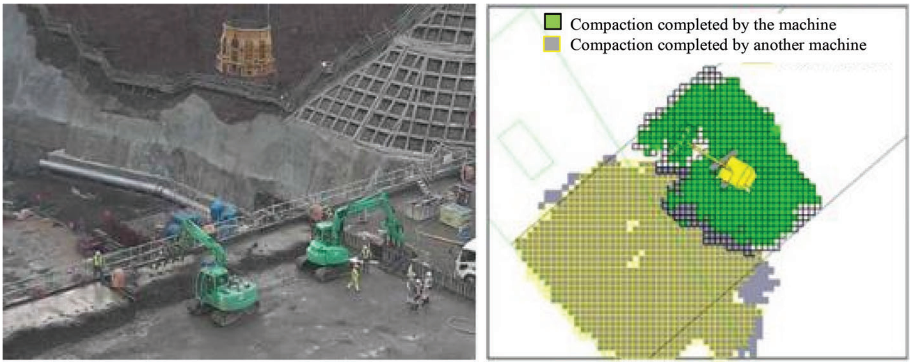

Figure 3. Multiple vehicle coupling system

Figure 4. Bulldozer and vibrating roller with GNSS

In the case of the bulldozer, the elevation of the machine determined by GNSS and the height of the blade was indicated to the operator on machine guidance. This method controlled the layer thickness to be 25 cm.

In the case of the vibrating roller, control of the track of the compacted positions determined by GNSS and the number of compaction passes was displayed. The number of compaction passes was colored for each number of passes up to 10 passes as determined from a construction test, the compaction was reliably carried out thereby preventing insufficient compaction, and it was confirmed that compaction was completed over the whole surface of the zero-slump-concrete as shown in Figure 5.

3.1.2 *Introduction of virtual reality (VR) system*

The center of Yamba Dam has three spillways with large radial gates with a complex structure, so it was important to check the construction procedures for interference between the

Figure 5. Screen for controlling the number of vibrating roller compaction passes

gate and the reinforcement or the gate hardware. Therefore, the dam body structure, reinforcement, gate equipment, etc., at this location was modeled in 3-dimensions (3D), to produce a 3D virtual space. Construction machinery and the workers were arranged in this virtual 3D space, to visualize the status of interference between the various embedded objects and the status of construction as shown in Figures 6 and 7.

By wearing VR goggles it was possible to enter this virtual space and check with one‘s own eyes for interference between the reinforcement and hardware and the arrangement of the construction machinery. Also, by using the VR system at meetings, the construction procedures and the arrangement of machinery, etc., were discussed in advance.

3.1.3 *Development of the system for determining grading of aggregates*

The aggregates for Yamba Dam are excavated at a quarry 10 km from the dam, crushed in an aggregates production plant near the quarry, and sieved. The aggregates production plant is about 10 km distant from the concrete production plant at the dam site, and the aggregates are transported over this long distance by the belt conveyor. In order to shorten the transport time over this long distance, the speed of the belt conveyor was increased to 165 m/min., from the normal speed of 80 m/min.

At Yamba Dam the coarse aggregates are divided into 3 grades: G1 (80 to 40 mm), G2 (40 to 20 mm), and G3 (20 to 5 mm), and a stock is maintained of each grade. Each of the coarse aggregates is transported by the belt conveyor to a position close to the dam and placed in a storage bin for each grade. However, if the grades are mixed by error then it would not be

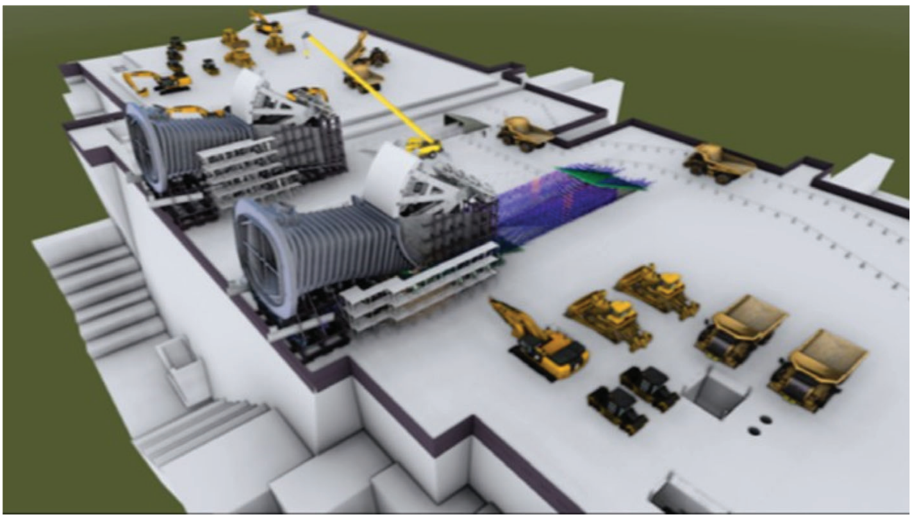

Figure 6. VR system image

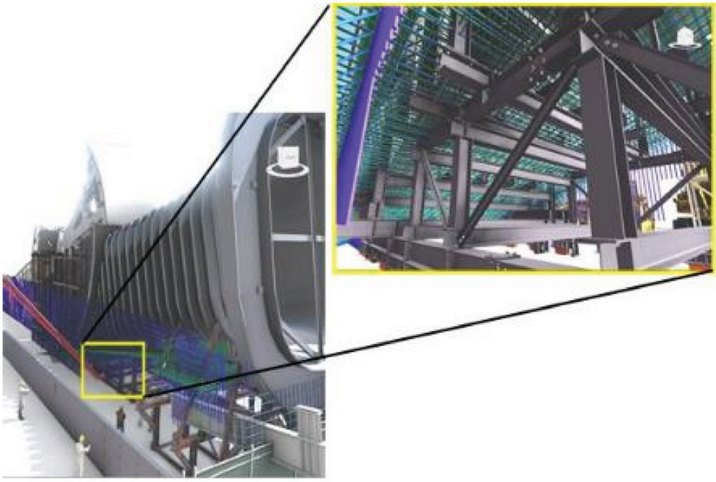

Figure 7. VR system image

possible to mix the concrete appropriately. Also, if the incorrect aggregates were placed in a storage bin, then the aggregates in that bin would have to be removed, which would cause a problem for the construction schedule. In order to prevent such problems, the system was developed for measuring the size of the aggregates on the aggregates transport belt conveyor. A 3D laser scanner installed above the belt conveyor as shown in Figure 8 emitted the laser on the conveyed aggregate and simultaneously detected the reflection beam that is distributed by the irregularity of the conveyed aggregate surface as shown in Figure 9. The aggregate grading can be analyzed using the relation between these. During development of the system, the

Figure 8. 3D laser scanner above the belt conveyor

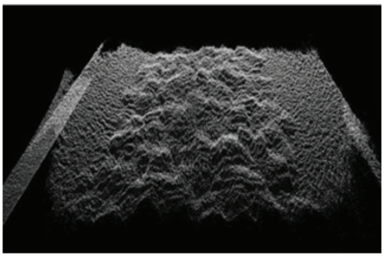

Figure 9. Reflection beam obtained from 3D laser scanner G1 (80 to 40 mm)

irregularity of aggregates was obtained more than 10,000 times, and the system was established by setting judgment criteria using machine learning. For judgment on site artificial intelligence (AI) was introduced, and automatically judgment carried out. During construction, if there was a difference between the aggregate grade determined and the bin to which the aggregates will be loaded, the belt conveyor was forcibly stopped, which prevents incorrect insertion of the aggregates.

3.1.4 *Introduction of CIM for dam construction and foundation treatment*

The Ministry of Land, Infrastructure, Transport and Tourism is currently promoting data sharing coupled with 3D models, using Construction Information Modeling (CIM), which is Building Information Modeling (BIM) applied to the civil engineering project. CIM also enables coupling and collection of information to the same 3D model through each of the stages of planning, construction, and maintenance, and sharing of this information among those involved in the whole project. CIM was introduced from the start of construction at Yamba Dam, and construction information has been accumulated on a 3D model.

At Yamba Dam, the focus was on the main body concrete construction information and the foundation treatment information necessary for dam construction, and this information was managed on a 3D model. The construction information was as shown below in Table 1. By clicking the location on the CIM 3D model where construction information is to be checked, it is immediately possible to view the quality control documents and as-built control documents.

Table 1. Construction information management using CIM

Concrete placement control	Placement plan Witness inspection (reinforcement, formwork, water bar, precast inspection galleries, precast formwork, placement surface, bedrock) Information and Communication Technology (ICT) machinery Measuring instrument data
Concrete quality control	Compressive strength tests, x-Range successive (Rs)-Range measured (Rm) control chart Radioactive Isotope (RI) density tests, various photographs Quality control daily reports (slump, vibration compaction value, air content tests, etc.) (Figure 10)
Foundation treatment control (curtain grouting, consolidation grouting)_	Grouting daily reports, probability of exceedance graphs (Figure 11) Rock grade, rock quality (initial + correction reflecting pilot cores)

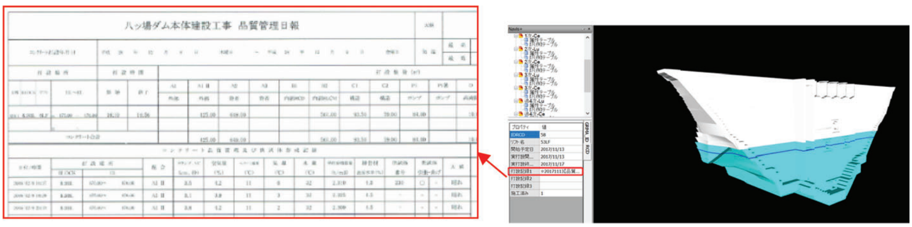

Figure 10. Information control linked to dam 3D model

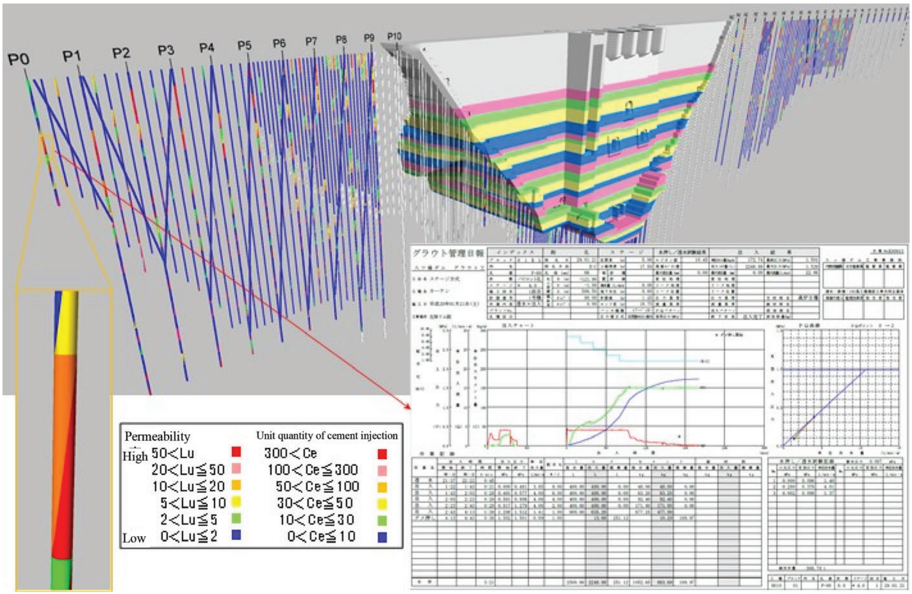

Figure 11. Information control linked to foundation treatment 3D model

3.1.5 *Calculation of earthwork volume by UAV photogrammetry*

In recent years there has been remarkable improvement in the technology for taking images using an unmanned aerial vehicle (UAV) on which a digital camera is mounted as shown in Figure 12, and these are being utilized in many fields. In the field of construction survey by the utilization of UAVs is progressing, and it was utilized for measurement of excavation shape and calculation volume.

Conventionally earthwork volume was estimated based on cross-sectional drawings, obtained by the survey using optical instruments. However, on this project the volume was calculated using photogrammetry by the UAV. By analyzing images taken by a UAV, excavation 3D data having contour lines (height data) is generated as shown in Figure 13. This data is incorporated into 3D Computer-Aided Design (CAD) for calculating the earthwork volume. It has been confirmed that the both volume by cross-sectional survey and the photogrammetry using the UAV are virtually equivalent.

Figure 12. Surveying UAV

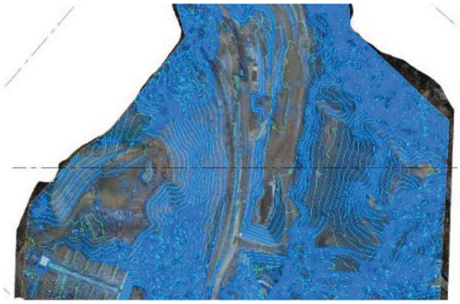

Figure 13. Contour data based on analysis of photographs

3.1.6 *Calculation of concrete volume down to bedrock using 3D laser scanner*

The foundation excavation for the concrete gravity dams is occasionally modified from the defined figures since adequate rock foundation would be secured earlier than expected or an additional meticulously excavation for a weak stratum or loose foundation would be forced. Both situation also require the re-estimation of concrete volume placed as well as the excavated volume. For this purpose, cross-sectional survey conventionally should be carried out for preparing cross-sectional drawings prior to concrete placement. However, when the bedrock surface is much irregular, the ordinal survey executed at every 5m is not enough for accurate estimaton. In additon, there are other difficulties that such estimation should be completed prior to placement schedule. In recent years 3D scanners have become common and their handling is also comparatively easy, so they are being utilized in various fields. Therefore, point group data for the rock surface was obtained using a 3D scanner as shown in Figure 14. To solve above difficulties the 3D scanner technology was incorporated. By using 3D scanner, the concrete volume is estimated based on the scanned data of the objectives area before and after the concrete placement.

The measurement accuracy of the 3D scanner has been confirmed to have an error of about 1 cm, comparing to the conventional method at multiple arbitrary points. This is sufficient accurate

3.2 *Effect of the development and application of new technologies for Yamba Dam*

The new Technologies above-mentioned enables high quality construction of the dam as described below, comparing the conventional manner.

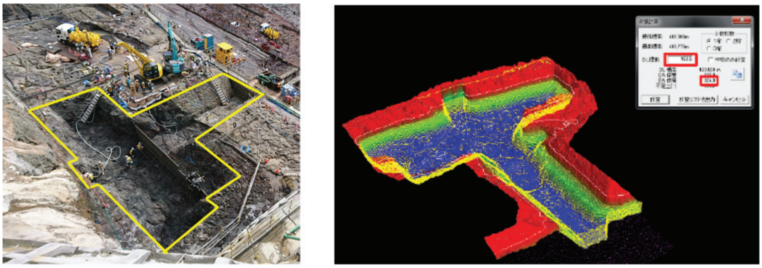

Figure 14. 3D scanned data at a concrete placement location

3.2.1 *Development of the concrete compaction control system*

The judgement of the completion of the compaction for slump-concrete can be controlled based on numerical indices by the concrete compaction control system, while it was conventionally judged qualitatively and visually by the backhoe operator and the site controller. Also, it is possible to check the locations where compaction is insufficient using this system. The compaction is reliably carried out over the whole surface. It is possible to avoid reduction in quality and delay of the construction time due to excessive compaction.

The GNSS system installed on the bulldozer enables the thickness control of the spread concrete by the blade height based on the GNSS data, while it was carried out by the measurement by the site manager. The construction is reliably carried out with accurate layer thicknesses of 25 cm. Regarding the compaction passes, the tracking of the vibrating roller using GNSS counts specified number over the whole surface, while these were confirmed by the operator and the site manager.

In this way, the new system realizes reliable dam construction, resulting high quality compaction, accurate layer thickness and compaction passes and avoidance of less quality as well as the construction delay due to excessive compaction.

3.2.2 *Introduction of the Virtual Reality (VR) system*

The VR system makes possible to avoid interference in structures and the construction. It is utilized in the meeting at the construction site for the easier coordination with the designers before construction. The construction procedures can be checked in advance, thereby avoiding works losses due to errors in the construction procedures and preventing delays against the construction schedule.

3.2.3 *Development of the aggregate grade judgment system*

It can constantly and automatically determine the aggregate grade. It can completely prevent erroneous storage of aggregates in specific bins.

3.2.4 *Introduction of CIM for construction of the dam body and foundation treatment*

In the dam construction, CIM system using a 3D model can carry out integrated management of the data of all stages of inspection, construction, and quality control. For example, in the case of foundation treatment, the grouting daily reports, geological data, etc., are managed in an integrated manner in the 3D model. The permeability characteristics of the bedrock is visually identified. Note that that these data can be utilized for the Yamba Dam operating and maintenance stage.

3.2.5 *Calculation of earthwork volume using UAV photogrammetry*

UAV photogrammetry provides equivalent earthwork volume to conventional cross-sectional surveying using optical instruments. It is considered that it will replace the conventional surveying and achieve significant rationalization. Also, it can carry out the surveying that requires about 2 days by conventional methods in about 1 hour.

3.2.6 *Calculation of concrete volume using 3D laser scanner*

A 3D laser scanner correctly surveys figures of the rock foundation or the structural surfaces. When concrete placement was carried out, the concrete volume calculated by a 3-D laser scanner was equivalent to the actual volume placed. It requires extremely less hours of about 30 minutes comparing to about a day by the conventional method. It is considered that it will achieve significant rationalization.

4 CONCLUSIONS

Various technologies and new technology described in this paper have been introduced for the Yamba Dam in order to improve quality and shorten the construction time.

For the concrete quality, the compaction control system was developed so that the status of compaction could be judged and recorded. The aggregate grading judgement system was developed to prevent incorrect placement of aggregates.

To shorten the construction time, a VR system was introduced to reproduce the 3D virtual space of complex structures, in order to study in advance the status during construction, and to determine the ideal construction procedures. Also, UAV photogrammetry and 3D laser scanning were introduced, which achieved labor-saving on surveying work. Introduction of these technologies realized shorter construction time and no delays on the schedule.

Also, CIM, which is being promoted by the Ministry of Land, Infrastructure, Transport and Tourism, was introduced, so that construction information could be stored on a 3D model, and the information shared with the client. This construction information is planned to be utilized in the maintenance stage in the future.

On Yamba Dam it was verified that these technologies are effective for improving quality and shortening construction time in dam construction. We intend to continue to apply these on dam constructions to achieve further improvements.

REFERENCE

JSCE. 2013. *The Standard Specifications for Concrete Structures. Dam Concrete*. (in Japanese)