Born in Unzen
The World's First Unmanned Construction of Multilayer Sediment Control Dam Using Sediment Forms

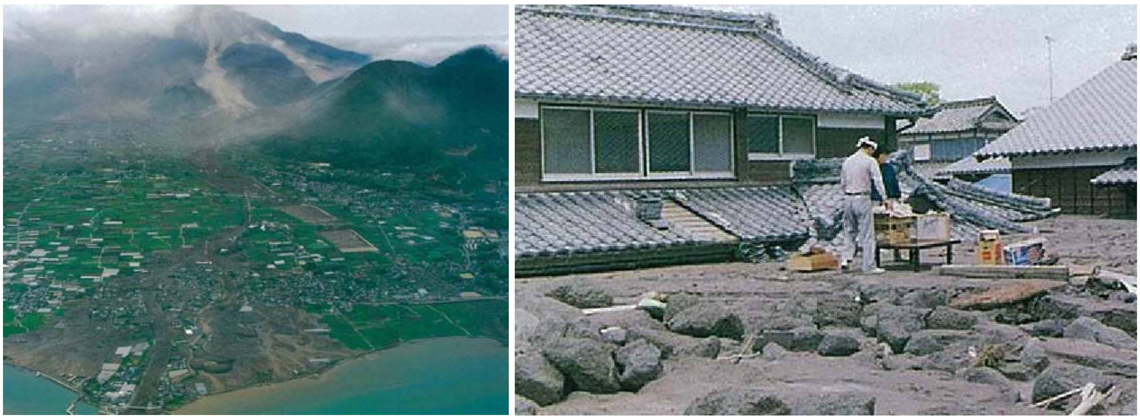
Unzen Restoration Project Office
Kyushu Regional Construction Bureau
Ministry of Land, Infrastructure and Transport

The World's First Unmanned Construction of Multilayer Sediment Control Dam Using Sediment Forms Born in Unzen
— Technological Development at Mizunashi Sediment Control Dam No.1—

1. Frequent Attacks of Pyroclastic flows and Debris flows on Housing Areas

The volcanic eruption of Mt. Unzen-Fugen caused serious damage to people and structures. A total of 44 persons were killed by pyroclastic flows and a large number of houses and lifelines such as a railway and roads were seriously damaged by pyroclastic flows and debris flows. Overall, there were 2,511 houses damaged, and almost 70%,i.e. 1,692 houses were damaged by debris flows.

Debris flows were particularly frequent during the rainy season of 1993 because of heavier rain than usual. These debris flows not only filled up the entire channel of the Mizunashi River but also flooded out of it and reached up to the sea. Sediment accumulated as much as 4-5m at some locations and gave devastating damage to the Annaka area **(Photos 1, 2 Damage due to debris flows)**



Photos 1, 2　Damage due to debris flows

Stunned by the overwhelming damage, local people who had been opposed to the sabo works master plan proposed by the Ministry of Construction (presently, the Ministry of Land, Infrastructure and Transport) began to strongly desire the construction of training dikes and the Mizunashi River Sediment Control Dam No.1 to prevent further damage. Of the proposed structures, training dikes were able to constructed by workers just like the construction of ordinary structures. But, it was impossible to construct the Mizunashi River Sediment Control Dam No.1, a core facility for disaster prevention, in the same manner as ordinary structures, because its construction site was located in the hazard area where entry was prohibited. Pyroclastic flow (Photo 3 Pyroclastic flow) might reach to the site in case of an eruption, and therefore construction by usual manner was impossible **(Fig.1 Mizunashi River Sediment Control Dam No. 1 and the hazard area)**.

As emergency measures, Nagasaki Prefectural government attempted manned construction of embankments and sheet piles conducted by the Self-Defense Forces to prevent expansion of damage. But, their effects were limited, and construction of a large-scale sediment control dam within the dangerous hazard area became the highest priority.

Photo 3　Pyroclastic flow

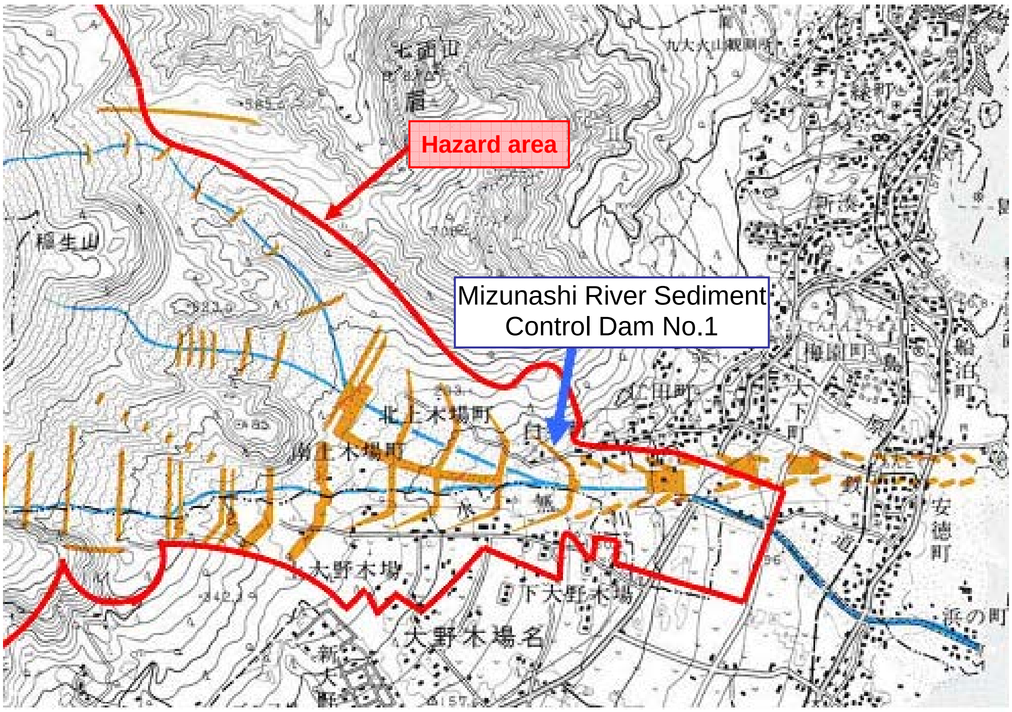


Fig. 1　Mizunashi River Sediment Control Dam No.1 and the hazard area

2. Removal of Sediment by Unmanned Construction Technique

— History of World First Technological Development —

To prevent and mitigate further damage, it was necessary to dig and carry away the deposited sediment as quickly as possible every time a debris flow occurs. But, these works should be carried within the hazard area under the threat of pyroclastic flow.

In 1993, the Ministry of Construction decided to solicit from the private sector a construction technique that can dig and carry away safely the deposited sediment from the hazard area at risk of a pyroclastic flow. The technical requirements imposed were all related to the operability of a given technique under the pyroclastic flow conditions **(Table 1)**.

	Technical Aspect	Technical Criteria
1	Digging and carrying-away of unstable gravel and sediment with occasional crushing.	Able to crush gravel 2-3 m in diameter.
2	Usable in the ambient temperature and humidity at the site.	Operable even in the conditions of 100℃ and 100% humidity temporarily.
3	Construction machines must be remote-controllable.	Remote control from 100 meters away must be possible.

Table 1 Technical requirements of the public offering

The Ministry of Construction evaluated the technical feasibility of submitted techniques and selected one technique presumed to have high applicability. The selected technique was the unmanned construction technique that can complete all the sediment removal work by remote control, from collection of sediment by bulldozer, digging and loading by backhoe, to carrying-away by dump truck.

To verify its applicability to the actual site, the Ministry of Construction conducted a field test of the selected construction technique in 1994. As a result, its applicability was verified and began to be adopted for full-scale world first sediment removal work, such as removal of sediment from a sand pocket, in the middle of the hazard area at risk of a pyroclastic flow **(Photo 4 Removal of sediment by unmanned construction technique)**.

Photo 4 Removal of sediment by unmanned construction technique

3. Further Improvement of Unmanned Construction Technique - Application to the Mizunashi River Sediment Control Dam No. 1

The sediment removal work showed a certain effect as the emergency measures for preventing and mitigating damage from debris flows. However, a strong desire for the early construction of the Mizunashi River Sediment Control Dam No. 1 as the fundamental measures against debris flows still remained. The planned construction site of this dam was located within the hazard area at risk of a pyroclastic flow and hence its construction by workers was virtually extremely difficult. A working committee consisting of experts and academics even discussed an idea of manned construction while securing an evacuation route by installing airport-type hot air shield fences or old bulldozers and tractors on the mountain side, or extending corrugated pipes from a safe place. Serious discussions continued on other ideas, such as carrying prefabricated reinforcements and tetrapods to the construction site by helicopter and dropping dry consistency ready-mixed concrete over them.

After comparing various ideas, it was decided to introduce the unmanned construction technique originally developed for sediment removal work to the construction site of the Mizunashi River Sediment Control Dam No. 1, and detailed studies for this mission began.

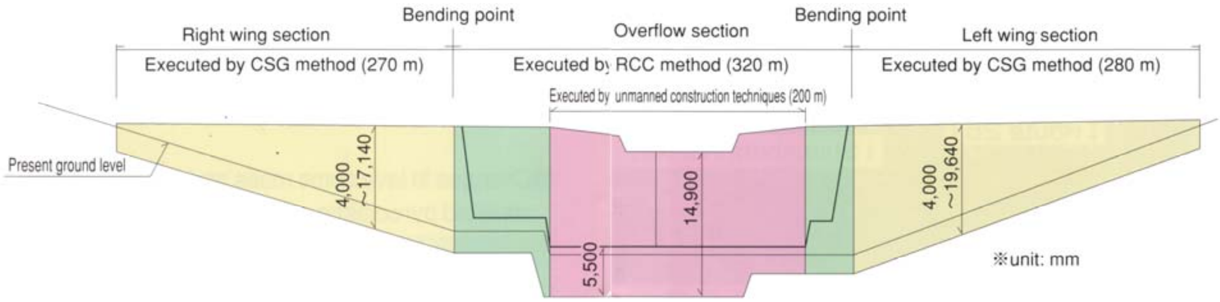
<<Selection of Construction Method>>

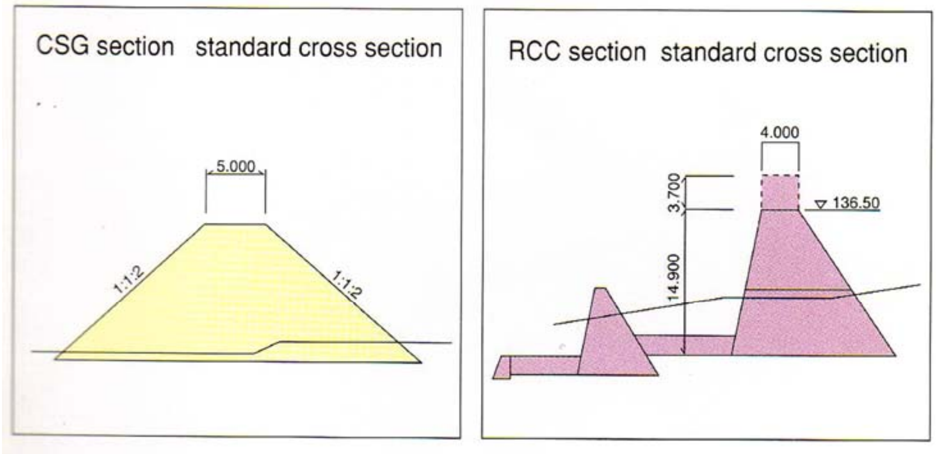
The following four conditions were established as the basic conditions for selecting a construction method for the Mizunashi River Sediment Control Dam No.1.

[1] Use of an unmanned construction technique to secure safety of workers.
[2] The structure must be safe against debris flows.
[3] The construction period must be short and show an effect as early as possible.
[4] Enormous volcanic deposits existing around the site must be utilized effectively.

Based on the overall deliberations of these conditions, it was determined to adopt the RCC (Roller Compacted Concrete) method using purchased aggregates for the dam body section, and the CSG (Cemented Sand and Gravel) method using on-site sediment for the wing sections which are not directly hit by a debris flow **(Fig. 2 Front view and side view)**. The RCC method is to transport extremely stiff consistency concrete containing a small amount of cement by dump truck, to spread and level it by bulldozer, and to compact it to a thickness of 50 cm per layer with vibration roller **(Photo 5 RCC method by unmanned construction)**.

Photo 5　RCC method by unmanned construction





Specifications

Dam height	Dam length		Dam volume	
14.9m	870m	Overflow section (RCC)320m Right bank wing section (CSG)270m Left bank wing section (CSG)280m	233,500m³	Overflow section (RCC) 70,500cubic meters Right bank wing section (CSG) 51,000cubic meters Left bank wing section (CSG) 114,000cubic meters

specified concrete mixture for RCC method

maximum size of coarse aggregate Gmax (mm)	half cycle of VC value (sec)	range of air content (%)	water / cement ratio W/C (%)	percentage of fine aggregate S/a (%)	units (kg/cubic meter)						
					water W	cement C	fine aggregate S	coarse aggregate			admixture
								80～40	40～20	20～5	
80	20±10	1.5±1	72.5	33	87	120	736	543	621	388	0.30

specified mixture for CSG method

maximum size of coarse aggregate Gmax (mm)	units (kg/cubic meter)			water content after addition of cement (%)
	cement C	water W	aggregate	
150	80	194	1,770	10±2

Fig. 2 Front view, side view and specifications

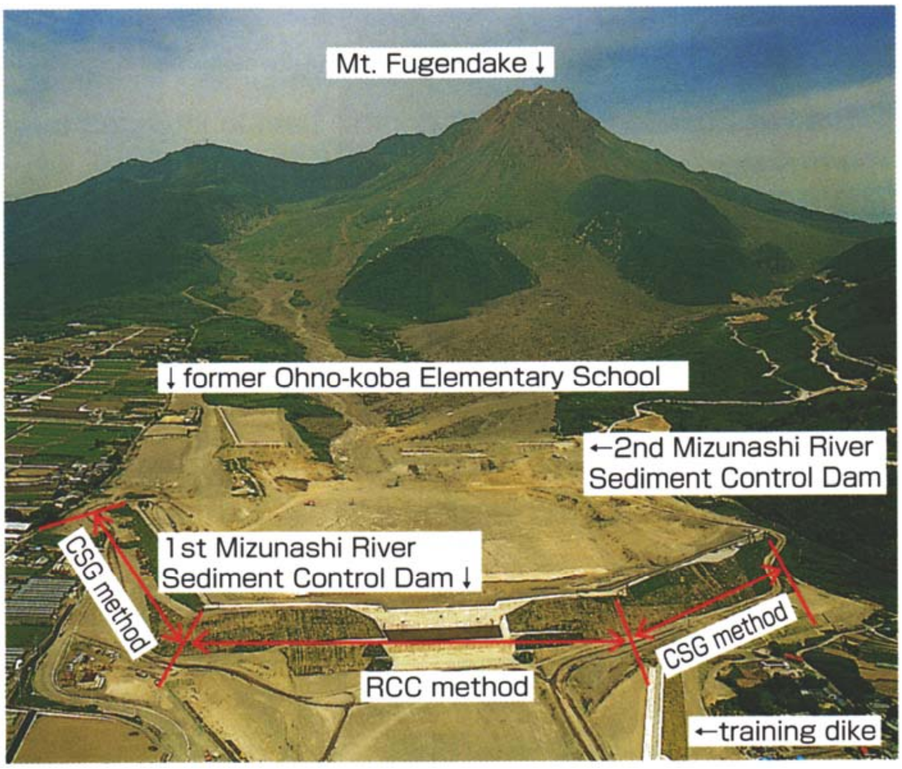


Photo 6　Bird's eye view of No.1 Sediment Control Dam（Photographed on May 1,998）

The CSG method is to carry the mixture of cement and on-site sediment (debris flow deposit) by truck up to the construction site, spread it by bulldozer, and compact it by vibration roller, so as to construct a banked-up multilayer structure. Therefore, the RCC and CSG methods are similar in their construction methods but differ in the construction materials used. The former uses the purchased aggregate and the latter uses debris flow deposits obtained at the site. But, both of them could successfully secure the strength more than expected.

4. Necessity is the Mother of Invention! A bizarre idea came out.

— Development of Sediment Forms—

The construction method of conventional forms for concrete dams is complicated and hence they were not suitable for the unmanned construction technique. In addition, the materials for the RCC and CSG methods were rather like sediment and they were to be spread by bulldozer and compacted by vibration roller. Therefore, if forms like those of ordinary concrete were used, construction work at the positions close to the forms would become difficult.

Therefore, by reversing an approach, we came up with an idea to use banked-up sediment as the forms for the RCC method, which was named the sediment forms (Fig. 3 Sediment forms). With the introduction of these forms, it became possible to construct the peripheral areas of the dam by the unmanned construction technique. They were also effective for the prevention of fall of bulldozers and vibration rollers at those areas.

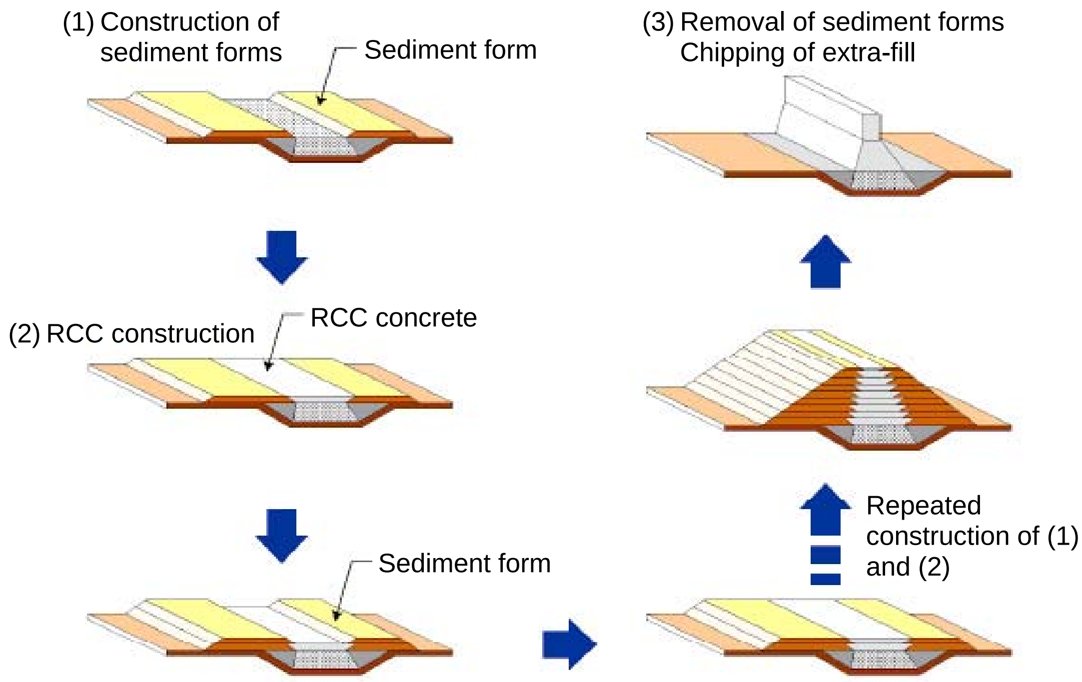


Fig. 3 Sediment forms

Sediment forms were banked up concurrently with the construction of RCC concrete.

This construction method made it possible to construct RCC concrete using the unmanned construction technique originally developed for sediment removal work, which consists of delivery of sediment by dump truck and its spread by bulldozer.

With the development of these innovative forms, construction of a sediment control dam became possible even in the middle of the hazard area at risk of a pyroclastic flow. It gave an impetus to the construction of sediment control facilities which had been much desired by the community.

Sediment forms placed at the flowing section needs to be removed after completion of the dam. But, the forms placed at the both end sections are to be used as landscaping. Sediment forms were not used for the construction of the wing sections by the CSG method. Instead, a large amount of excavated sediment was utilized to create a large cross-section with a reduced gradient on both upstream and downstream sides.

5. GPS as the Main Player

— Construction Procedure of RCC Concrete by Unmanned Technique Using Sediment Forms —

Using the innovative sediment forms, RCC concrete was constructed in the following order. Remote-control cameras were placed for traffic of construction vehicles. GPS, which is familiar to us used in car navigation systems, were utilized for spreading materials at the dam body. This made it possible to compact the concrete with an accuracy of “cm” order.

1) Delivery and unloading of RCC concrete

Photo 7　Delivery and unloading

2) Spreading（spread to 50 cm thickness per layer by bulldozer）

Photo 8　Spreading

3) Compaction（A 50 cm layer is compacted by vibration roller）

Photo 9　Compaction

4) Construction of sediment forms（use of excavated sediment as forms）

Photo 10　Delivery of sediment and spreading　（1 layer: 50 cm）

Photo 11 Shaping of sediment for use as forms

5) Construction Control Utilizing IT Technology

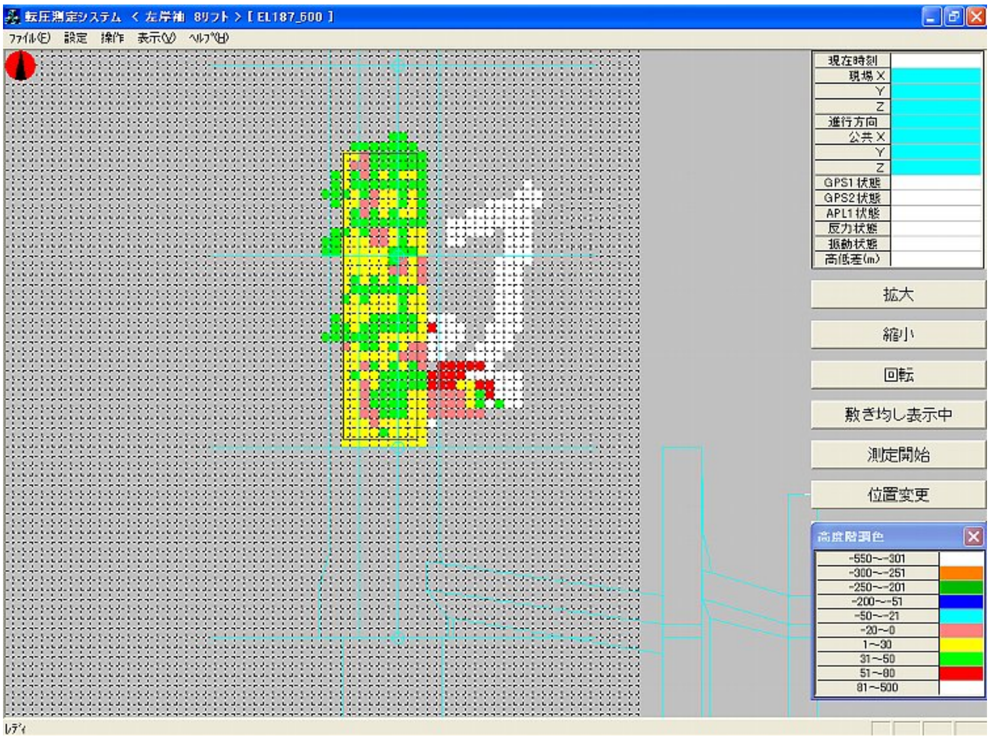


Photo 12 Control of spreading thickness using GPS (1 layer: 50 cm)

Utilizing GPS data, the spreading thickness was controlled by displaying thick and thin areas in different colors on the monitor screen.

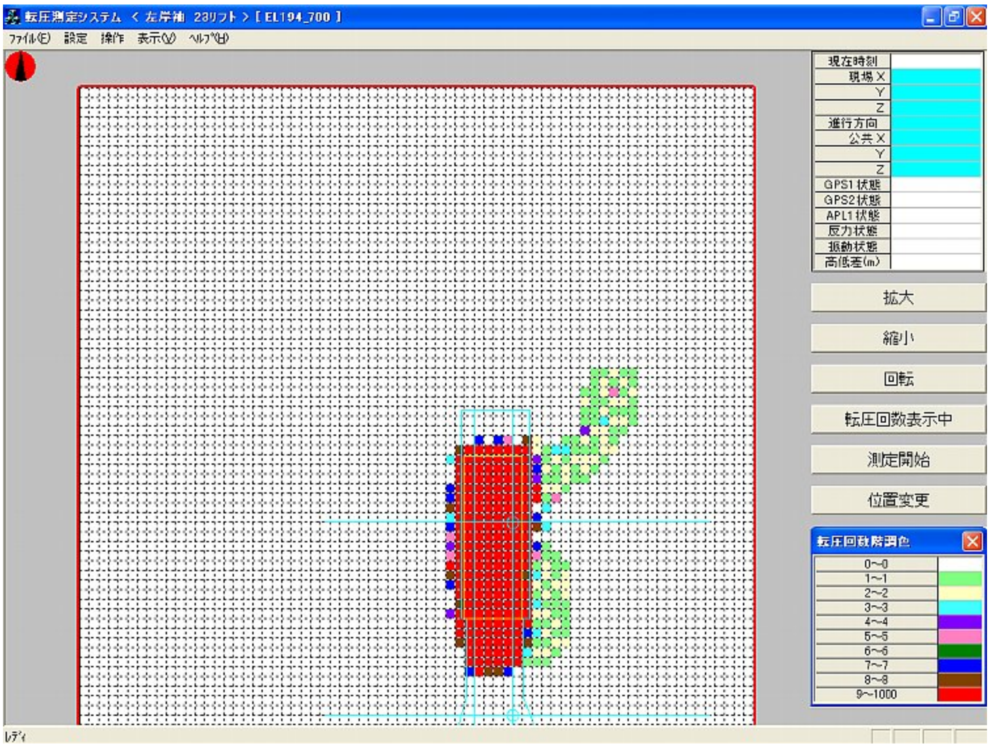


Photo 13　Control of rolling times using GPS

Utilizing GPS data, completion of the required rolling times was indicated by red color.

6) Completion

Photo 14　Completion (present situation, taken Oct. 2007)

The Mizinashi River Sediment Control Dam No. 1 was started its construction in

September 1995 and completed in February 1998. With the completion of this dam, the safety in the downstream area of the Mizunashi River increased significantly. This dam is located at the most downstream side among the several sediment control dams planned for the upstream area of the Mizunashi River. This dam, 870 m long and 14.5 m high with a sand storage capacity of 1 million m^3, is one of the largest among the sediment control dams in Japan.

6. Sediment Control Works in the 'Remote Control' Age

—Technological Progress of Unmanned (Remote Control) Construction Technique—

The unmanned construction technique developed at the disaster site in Unzen has since been applied to other volcanic disaster sites, such as the sites of Mt. Usu eruption and Miyake Island eruption in 2000. In recent years, its use has been extended to not only the volcanic disaster sites but also other dangerous work sites where manned work should be avoided for safety.

Even at Unzen, this construction technique has since been significantly improved, as seen in the application to complex construction processes, such as conveyance and installation of steel structures by remote control. It is hoped that the unmanned construction technique will be further improved and utilized for the mitigation of sediment-related disasters in Japan and overseas.

Downstream area of the Mizunashi River
(photographed on May 27, 1998)

Taken 5th, Jul. 2006

Editor and Production

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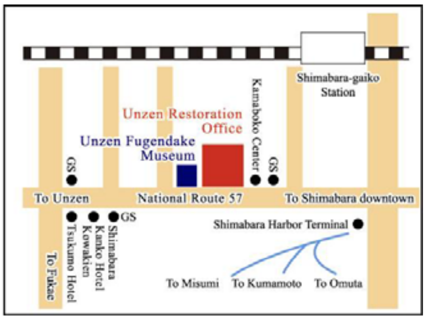

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