# Circumstances in the Utilization of the Soil Cement In Sabo Works in Japan

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## Abstract

The Sabo Soil Cement that can effectively use excavated surplus soil generated from work sites is now utilized at sabo works in Japan. Although this method has superiority such as a reduction of excavated surplus soil and its cost compared to the ordinary concrete, it has some problems on quality control of a stability of manifest strength etc. This report introduces the state of the Japan's Sabo Soil Cement method and the influence of the grain size distribution and of the maximum grain size on the strength expressed. And the range of the grain size for soil cement is proposed to estimate the strength with cement quantity. The basic test about freezing and thawing was also implemented on site. It is clear that external protection materials are useful to prevent the freeze-thaw effect against the quality of the soil cement. It is proposed as future research directions in Sabo Soil Cement method.

**Keywords:** soil cement, excavated surplus soil, sabo works, cost reduction, quality control

## 1. Introduction

Soil Cement was first executed by the U.S. Bureau of Reclamation at the Bonny Dam in 1951[1)], then spread throughout the U.S. In Japan, it began to spread following its first use for dam construction in 1987 by the Japan Water Resources Development Public Corporation (name at that time).

Soil Cement is defined in many different ways by different users, but generally, it refers to material made by stabilizing soil produced at a construction site by mixing it with cement. At sabo works in Japan, materials made by adding cement milk instead of cement are also called Sabo Soil Cement[2)]. It can be a classified as the In-situ Mixing (ISM) method that means executing sabo facilities by mixing and agitating soil and cement milk using a "twin header" which is a two-blade-agitator and mounted onto the tip of the arm of a backhoe and the In-situ Stabilized Excavation Materials (INSEM) method that is constructing a structure by compacting the material with a vibrating roller (Fig.1). The materials used to execute the ISM method are soil and cement milk produced by a simple cement plant, but that used to execute the INSEM method is a super thick consistency material that is so thick that it does not slump and is produced by mixing soil with cement. Sabo works in Japan have, since the end of World War II, been the construction of structures such as sabo dams made of concrete, but in recent years, the use of Sabo Soil Cement has spread. The following are cited as reasons for this change. First, at a sabo works site, the excavation produces a large quantity of excavated surplus soil, and its disposal is very expensive and causes environmental problems including noise and vibration when the excavated surplus soil is transported. The construction of a soil disposal area itself undermines the environment in its vicinity. And the gravel around sabo work sites has often good quality for the utilization for the aggregates, and its use is thought to be effective and important way not only to benefit the environment, but also to lower costs[2)].

The characteristics of soil cement material are that it is intermediate between concrete and soil (Fig.2), and that its mix proportions can be set according to its purpose. But because its abrasion resistance and its resistance against the deterioration of concrete due to the freeze — thaw cycles are inferior to those of concrete, it should not be applied to the parts that will be subject to the impact of a debris-flow, but should be combined with recently developed exterior protective material. The present standards for Sabo Soil Cement in Japan[2)] stipulate the desired strength level and the portions to which Sabo Soil Cement is applied as shown in Table 1. The concrete strength that has been used for sabo structures in Japan is often approximately 18N/mm$^2$.

Below, the state of Sabo Soil Cement in Japan, related technological challenges and state of studies of the method are introduced.

 

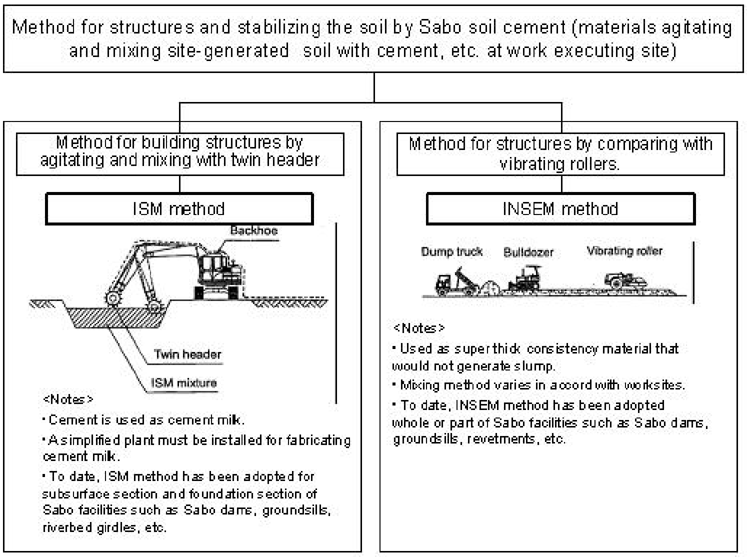


**Fig. 1.** Classification of methods of using Sabo Soil Cement.

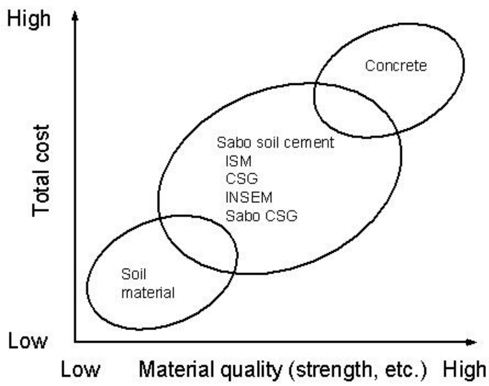


**Fig. 2.** Quality-Cost relationship.

## 2. Use of Sabo Soil Cement in Japan

Table 2 shows the number of structures built using Sabo Soil Cement (below called, "soil cement") as part of sabo works in Japan.

An examination to clarify which portions of sabo structures are made of soil cement shows that it is most commonly used to build the foundations of sabo dams, followed by the main body of these dams (Fig.3). The entire bodies of sabo dams with height of 5m or more have still rarely been made of soil cement. It seems that this trend results from the fact that because soil cement related technology is still under development, clients intend to firstly try to apply it to constitute the portions not subject to the impact of debris flows, and from the problems with the abundance of soil and the ease of execution. Therefore, it is predicted that even when its use has progressed, the number of sabo dams which material of upper part is concrete, material of lower part is soil cement.

Recently, methods of covering the surface of soil cement with steel or with concrete blocks have been developed by private companies (Fig.4).

At the beginning of the development of soil cement, many were covered with ordinary concrete etc., but in recent years, methods of protecting it from the impact of debris flows and other stress by covering its surface with the material mentioned above have come into use.

**Table 1.** Desired strength level — applied member relationship.

| Desired strength | | Typical Applied Members |
|---|---|---|
| Desired strength level I | 0.5-1.5N/mm$^2$ | Embanking material and earth retaining work |
| Desired strength level II | 1.5-3.0N/mm$^2$ | Foundations of sediment check dams |
| Desired strength level III | 3.0-6.0N/mm$^2$ | Interiors of sediment check dams |
| Desired strength level IV | 6.0-18.0N/mm$^2$ | Sediment check dams unlikely to be struck by a debris flow |
| Desired strength level V | 18.0-21.0N/mm$^2$ | Sediment check dams likely to be struck by a debris flow |
| Desired strength level VI | over 21.0N/mm$^2$ | Spillway of sediment check dams |

**Table 2.** Executions of the INSEM and ISM methods (Unit: structures).

| Project group | INSEM | ISM |
|---|---|---|
| MLIT sabo works (1995-2004) | 38 | 24 |
| Prefectural sabo works (2003-2004) | 14 | 1 |

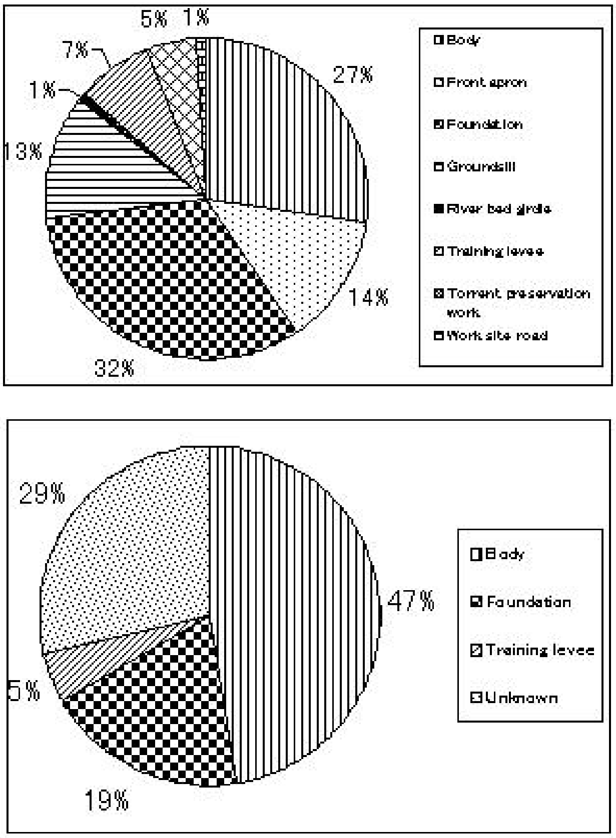


**Fig. 3.** Portions made of soil cement (Top : MLIT works, Bottom : Prefectural Sabo works).

## 3. Studies of technological problems with design and construction

The use of Sabo Soil Cement for construction work has revealed the following technological problems that have been studied as outlined below. In Japan, concrete is transported to work sites after passing a specified quality inspection in the factory, but Sabo Soil Cement is made by agitation and mixing with soil on site, so it is difficult to ensure it has consistent strength as in the case of concrete, and its strength may fluctuate according to its water content and the grain size distribution of its soil. In the case of the large-scale construction like water storage dam, the strength of soil cement is confirmed by performing a number of preliminary mix proportion tests, but at sabo works, it is difficult to perform preliminary tests at the same level as being executed at an ordinary water storage dam because each sabo work is much smaller than that of

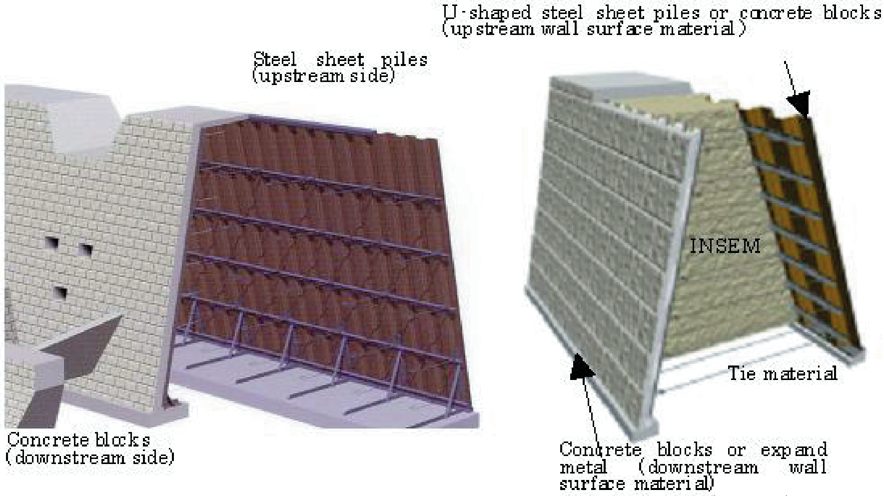


**Fig. 4.** Covering the surface with steel sheet piles (image).

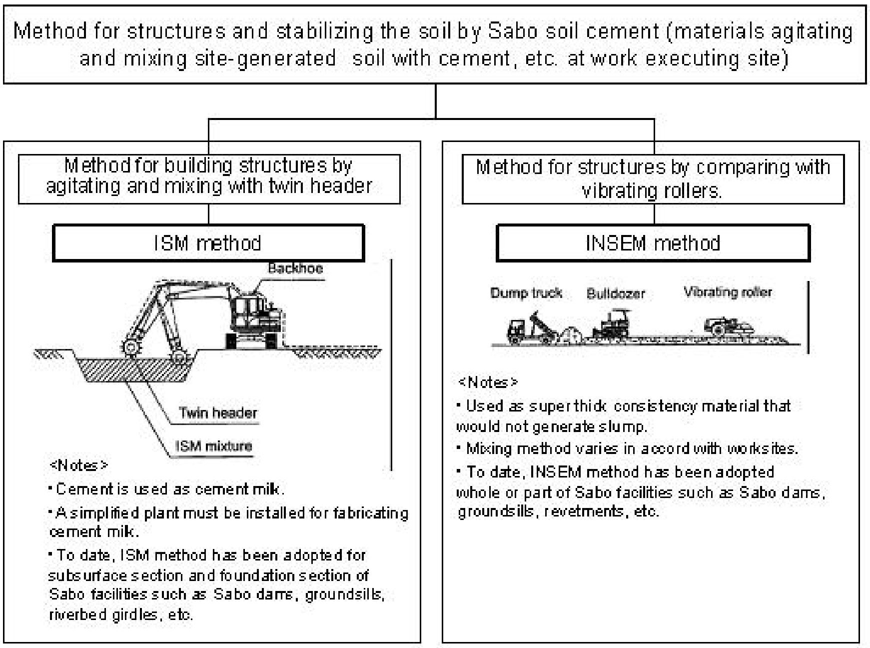


**Fig. 5.** Unit weight-strength relationship.

water storage dam. When handling soil cement, it is necessary to be aware that it is not construction material that can be supplied with stable uniform quality.

(1) Unit weight

Its unit weight is an important value necessary from the preliminary design stage. At this stage, other work methods can be adopted instead of making a final decision whether or not to use soil cement. Under the present standards, the unit weight is set according to a mix proportion test, but at this stage, the work could be done efficiently if it were possible to use the minimum unit weight for each desired strength level based on the past data instead of performing the tests in parallel. Generally, the unit weight tends to be proportional to the strength, and Fig.5 shows the relationship of the unit weight of actual soil cement with the mix proportion strength.

Fig.5 shows a tendency for the unit weight to be proportional to the strength. This figure also reveals that it is possible to set the unit weight for each strength level as shown in Table 3.

(2) Method of estimating the desired strength level based on grain size distribution.

It is stipulated by the present standard that the desired strength should be set according to a mix proportion test. Like the unit weight, to perform preliminary design efficiently, the desired strength level should be estimated in advance based on its grain size distribution.

**Table 3.** Setting the unit weight according to the desired strength.

| Desired strength level | Design strength $N/mm^2$ | Brend proportion strength($N/mm^2$) | Unit weight ($N/m^3$) |
|---|---|---|---|
| Level I | 0.5～1.5 | 0.75～2.25 | 17.5 |
| Level II | 1.5～3.0 | 2.25～4.5 | 17.8 |
| Level III | 3.0～6.0 | 4.5～9.0 | 18.2 |
| Level IV | 6.0～18.0 | 9.0～27.0 | 19.0 |
| Level V | 18.0～21.0 | 27.0～31.5 | 22.2 |
| Level VI | 21.0 or more | 31.5 or more | 23.0 |

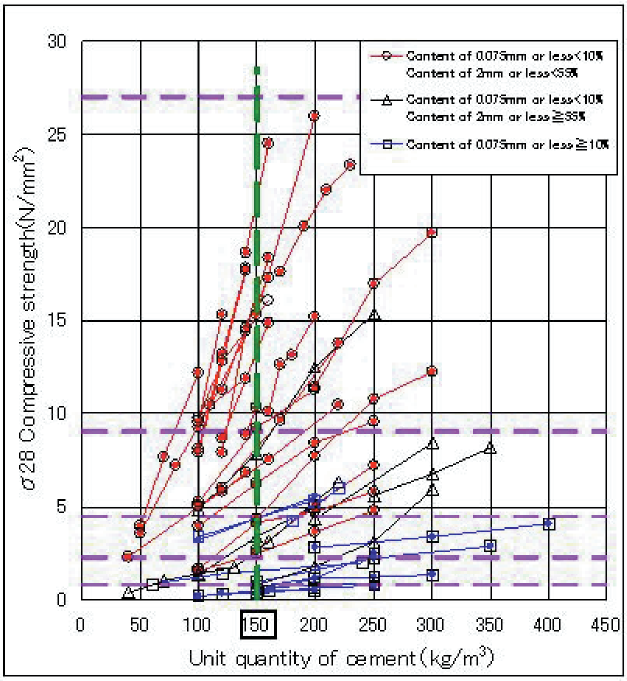


**Fig. 6.** Categorization based on desired strength and strength expressed.

Fig.6 shows the cement content — strength relationship based on the results of laboratory mix proportion tests performed throughout Japan, revealing that the higher the cement quantity, the greater the strength. It also reveals that the strength depends on the grain size distribution. Fig.7 shows a grain size distribution based organization of the strength level that, based on these data, can be counted on to appear at a unit cement quantity of $150kg/m^3$. Fig.8 shows a flow chart to which Fig.7 is converted. According to this figure, it is possible to estimate the approximate strength level based on the grain size distribution. And because the strength of soil cement is dependent on water contents, it seems that in the case of soil with high optimum water content (approximately 15% or more), the strengths shown in Fig.6 to 8 will not be expressed.

(3) Shear strength

In Japan, joints in soil cement are either not treated or else they are treated by scattering cement or bedding mortar. Comparative data concerning the compressive strength of soil cement have been obtained, but there are few data about shear strength. At a multipurpose dam, the shear strength of concrete is assumed to be between 1/7 and 1/10 of the compressive strength[5)].

Therefore, trial constructions were performed by varying the soil cement joint treatment of sabo structures to measure the shear strength, obtaining the following results.

The shear tests were performed using cores with age of 35 days obtained at a trial construction executed using the INSEM method. The basic mix proportion of the INSEM was unit cement quantity of $80kg/m^3$ and design strength of $3.0N/mm^2$ or more. Table 4 shows the test cases.

Table 5 shows the test results. The compressive strength was obtained as $4.53N/mm^2$ by an unconfined compressive test of the core. According to Table 5, the shear strength was between 1/9 and 1/25 of the

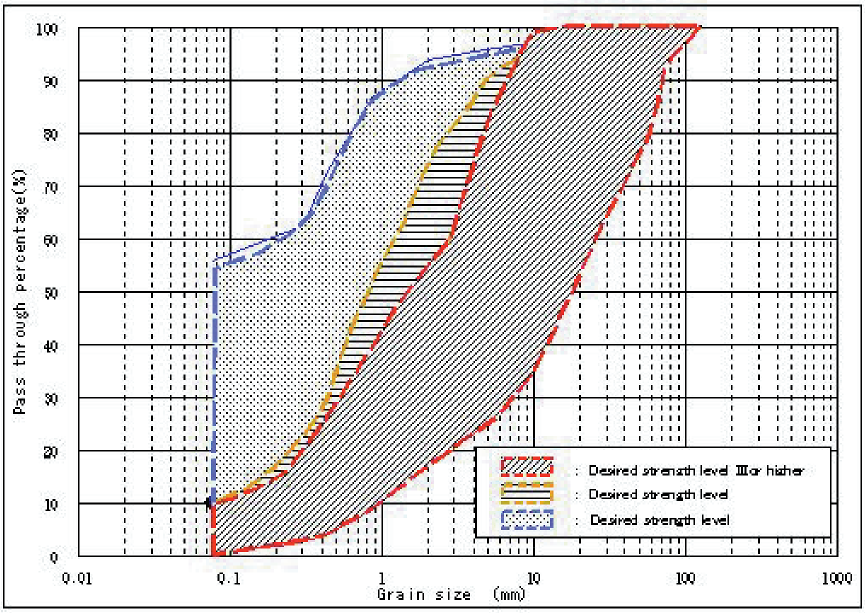


**Fig. 7.** Grain size distribution by category based on desired strength.

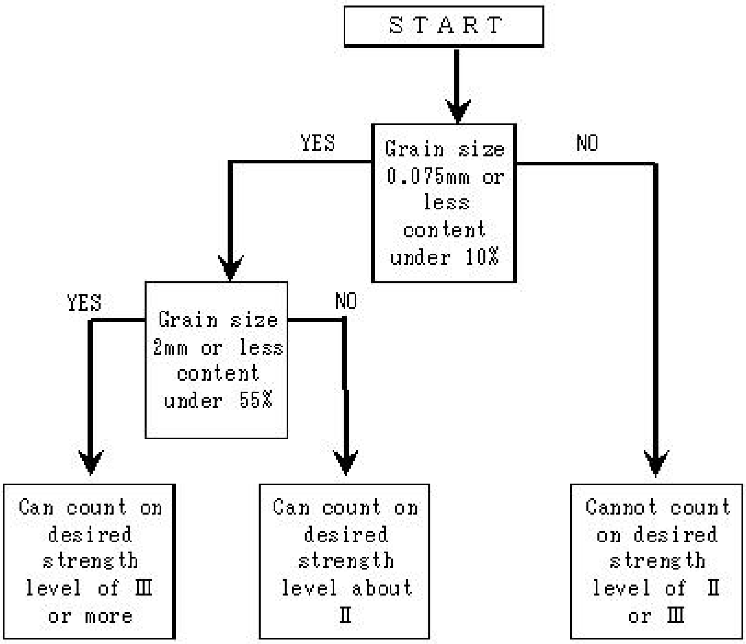


**Fig. 8.** Flow chart of the application of soil produced on site.

compressive strength, and the highest shear strength is in case of bedding mortar. It reveals that the shear strength varies greatly according to the joint treatment method. An early report has been made of the most recent of these tests, but the test results will be analyzed again and reported in the future.

(4) Hexavalent chromium

Generally, during a cement manufacturing process, trivalent chromium in raw materials used to make cement is oxidized to form hexavalent chromium that remains in the cement. The cement causes a hydration reaction that eludes the hexavalent chromium in the cement in a liquid phase, but because at the same time the products of hydration that are precipitated are hardened, its elution above the standard level from the hardened mortar or concrete is not found. But in the case of cement improved soil on the other hand, the formation of products of hydration is impeded by the effects of clay minerals and the organic substances in the improved soil, resulting in the elution of the hexavalent chromium that has not been hardened by the products of hydration[3)], so the elution of hexavalent chromium during execution of soil cement may occur.

**Table 4.** Test cases

| Case | Completed thickness | Max grain size | Joint surface treatment method | Material used |
|---|---|---|---|---|
| Case1 | 300mm × 2 layers | 80mm | Joint cleaning(sprinkled water) | Soil cement |
| Case2 | | | Blast furnace cement:classB | |
| Case3 | | | Laying and smoothing mortar | |
| Case4-1 | | | Raking(with cleaning) | |
| Case4-2 | | | Raking(without cleaning) | |
| Case5 | Soil:300mm × 2 layers<br>Concrete:150mm × 1 layers | 40mm | Joint cleaning(sprinkled water) | Soil cement + Concrete |

**Table 5.** Test results.

| Case | Compressive strength ($N/mm^2$)① | Pure shearing strength② | | ②/① |
|---|---|---|---|---|
| | | ($kN/m^2$) | ($N/mm^2$) | |
| Case1 | 4.53 | 177 | 0.18 | 1/25.2 |
| Case2 | | 261 | 0.26 | 1/17.4 |
| Case3 | | 494 | 0.49 | 1/9.2 |
| Case4 | | 199 | 0.2 | 1/22.7 |
| Case5 | | 404 | 0.4 | 1/11.3 |

Under the Japanese standards, the hexavalent chromium elution is stipulated as 0.05mg/liters or less. But within the range of the cases collected so far, some cases are found to be beyond the standard. In one case, the test before the execution of sabo works revealed that hexavalent chrome levels is above the standard so it was treated by mixing crusher run stones until it fell below the standard value, and in two cases, the work method was changed because the preliminary test showed that the hexavalent chromium value was exceeded the standard value. These problems were confirmed by such pre-work testing and dealt with by appropriate treatment. In Japan, a method of testing for hexavalent chromium4) has been established, so the test is done based on this method, then according to the test results, the type of cement is changed or crusher run stones are mixed in to treat it appropriately. In order to avoid the danger of having to redo the design, it is considered rational to perform the hexavalent elution test at the initial stage of the soil cement planning.

(5) Quality in cold regions

In cold regions, it is feared that the quality of the soil cement may be reduced by freezing and thawing of water in the soil cement. The Japanese standard stipulates that when it is covered with concrete as its external protective material, the criterion is thickness from 50cm to 100cm[2)] according to the size of the structure, but it does not provide specific provisions concerning its relationship with the outside air temperature. Therefore, thermometers were installed inside of the existing concrete gravity sabo dams to measure the exterior air temperature and the internal temperature. Examples of the results of the measurements are shown in Fig 9.

The minimum temperature recorded during the observation period was $-8.5°$, but a thermometer installed at depth of 50cm from the concrete surface did not record any temperature below 0°C. Judging from this result, if the exterior protective layer is approximately 50cm, it may very effectively prevent freezing and thawing. Such temperature monitoring is now being done at several locations in Japan, and treatment methods to provide protection from freezing and thawing will be clarified based on the results.

## 4. $CO_2$ reduction effects

The effects of soil cement are, as stated in the introduction, environmental and cost reduction. One of the environmental effects is the reduction of the production of $CO_2$, but no quantitative calculations of this effect have been made so far. Therefore a trial calculation was done to clarify the extent that the INSEM method lowers $CO_2$ emissions comparing to those in the case of using concrete. For the concrete, the calcu-

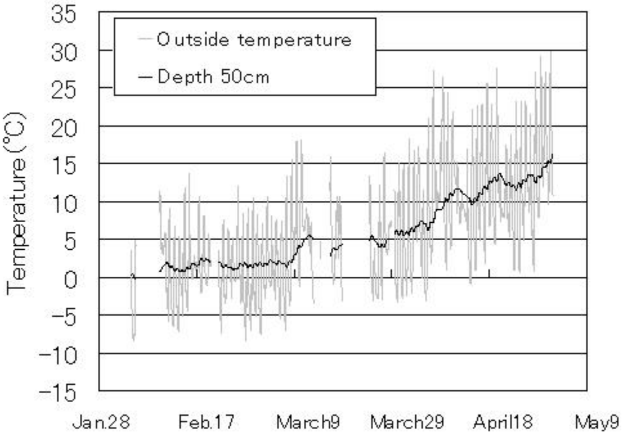


**Fig. 9.** Behavior of the temperature inside (depth 50cm) a sabo dam.

**Table 6.** Trial calculation $CO_2$ emissions.

| Sabo dam | INSEM quantity (kg/m³) | Unit cement quantity (kg/m³) | $CO_2$ emissions per INSEM 1m³① | Unit cement quantity using the concrete method (kg/m³) | $CO_2$ emissions per concrete 1m³② | ①/② |
|---|---|---|---|---|---|---|
| Sabo dam1 | 165,000 | 80 | 45.07 | 237 | 129.55 | 0.35 |
| Sabo dam2 | 20,959 | 170 | 90.12 | 242 | 135.00 | 0.67 |
| Sabo dam3 | 1,674 | 130 | 74.07 | 247 | 139.55 | 0.53 |
| Sabo dam4 | 2,790 | 160 | 84.45 | 244 | 134.32 | 0.63 |
| Sabo dam5 | 6,811 | 100 | 57.14 | 224 | 204.32 | 0.28 |

lation considered its transport from a nearby ready-mix concrete plant to the final construction site, and the INSEM calculation considered the excavation, mixing, and agitation on-site to the final construction. The calculations were done by accumulating the $CO_2$ emissions of each step in the process based on the machinery fuel consumption and the $CO_2$ emission unit of the cement and other materials. The calculation results are shown in Table 6.

The details are omitted here, but it showed that approximately 90% of $CO_2$ emissions were produced by cement. Because there are big differences in the quantity of $CO_2$ emissions per $1m^3$ as shown in Table 6, it can be stated that as long as the size of the structure made by INSEM is not very much larger than that of a concrete structure, the $CO_2$ emission effects of soil cement are dominant.

## 5. Use of large diameter gravel

Soil cement is a method that effectively uses excavated surplus soil produced by construction, but because of issues related to roller compaction, the maximum diameter of the useable gravel is stipulated between 80mm and 150mm. Although there are larger gravels at work sites, the spreading thickness is 30cm, and if soil cement is made using gravel larger than 150mm, gravel may be dislodged from the poured surface obstructing the execution. Fig.10 shows a case where soil cement made using 300mm gravel is roller compacted, revealing that the vibrating roller is inclined by the impact of the large diameter gravel. In order to make greater use of large diameter gravel, it is necessary to improve the functions of compaction rollers.

On the other hand, new initiatives to use only large diameter gravels are being undertaken. Fig.11 shows a method of selecting only coarse gravel with diameter from 80mm to 500mm, transporting it to the construction location, and filling it with concrete with extremely high fluidity. Roller compaction is unnecessary, and if the gravel is high quality, it obtains strength greater than that of concrete.

In Japan, various initiatives such as this are undertaken to effectively use excavated surplus soil produced by construction.

**Fig. 10.** Inclination of the vibrating roller.

**Fig. 11.** Rubble concrete.

## 6. Conclusion

This report has discussed the present state of Sabo Soil Cement and technology problems with this method. Japan must reduce construction costs in the face of its worsening financial situation. Another problem we face is reducing the quantity of soil transported from construction sites. On the other hand, there is fear that the strength of soil cement is easily scattered, so there is a tendency for clients to be passive to use it for sabo work. This is because penalties would be imposed if the strength were not exceeded standard value. The best way to prevent this from happening is to confirm the strength by a preliminary mix proportion test and other necessary tests, but this not only has an image of being a troublesome task, it will probably take time to widely introduce the needed technology.

Sediment disasters continue to occur throughout Japan, and the costs spent for the countermeasures must be minimized by promotion of sabo project efficiently. We also wish to make efforts to collect more spent for the countermeasures foreign technological information to improve soil cement technologies.

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