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Study of Present Situation and Future Prospect of Environmental and Safety Measures in Suburban Aggregate Mines in Japan

by

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Abstract

Development of aggregate resources for use in structural concrete has been encouraged in Japan to support infrastructure improvement and national land conservation. Natural aggregate is a valuable resource necessary for sound economic development and its importance is growing. However, against the backdrop of the ongoing depletion of resources, growing concern over nature conservation and increasingly tightened control over resource use, the supply of natural aggregates such as sea/river/pit sand and sea/river gravel has been decreasing.

The number and scale of public works and construction of buildings have been decreased due to the recent recession and the critical public opinion about public works. However, the necessary public works have been done as in the past. The lack of high quality aggregates has become a serious problem in Japan. Dredging of sea floor sand and development of new sand quarries for securing good quality sand have become the target of criticism from the viewpoint of environmental protection.

This paper describes the present situation and future prospects of environmental and safety measures in suburban aggregate mines in Japan.

Keywords: Natural aggregate, Pit sand and gravel, Slope stability, Heavy rain, Planting and afforestation

1. Introduction

Natural aggregate resources used in the production of structural concrete are indispensable for infrastructure improvement and national land conservation. They are truly valuable resources.

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However, the supply of aggregates resources has been decreasing year after year due to the exhaustion of economically viable aggregate resources, the increasing concern over the natural environment, and rises in the prices of raw materials [1)].

Japan is now faced with uncertainties in terms of maintaining a stable long-term supply of aggregate resources. On the other hand, because of the rise in demand for high-strength concrete, high-grade aggregates are increasingly needed. The current situation underlines the importance of efficient, environment-friendly and safe exploitation of aggregate resources as well as a stable supply of high-grade aggregate supported by reliable quality control. Maximum exploitation of finite aggregate resources should be pursued in a secure manner while minimizing environmental impact.

Additionally, as show in **Fig. 1**, it has become difficult to win the understanding of local residents regarding exploitation of aggregate resources because residents in the vicinity of excavation sites have experienced noise, dust and road accidents caused by dump trucks, illegal dumping of industrial waste at excavation sites, and large-scale soil runoff due to heavy rainfall. Accordingly, development of aggregate resources should be pursued while placing greater importance on ensuring the understanding and cooperation of local residents.

Fig. 1 A sign put up by local residents protesting a new aggregate resources development.

2. Aggregate Resources in Japan

2.1 Aggregate Types

Aggregate is a broad category of material mixed with cement and water for making mortar or concrete. It includes sand, crushed sand/stone, gravel, slag and others. It is roughly divided into coarse aggregate and fine aggregate according to its grain size. There are natural, synthetic and recycled aggregates. Natural aggregate is classified according to extraction sites, namely river sand/gravel, land sand/gravel, pit sand/gravel, and sea sand/gravel.

2.2 Distribution of Aggregate Resources

Land/pit sand and gravel are extracted from quaternary sedimentary rocks which are distributed in a wide area in eastern Japan. Due to a decrease in the number of sites where extraction activities are economically viable, aggregate production is dwindling. In other areas west of Osaka, very little land/pit sand and gravel is distributed due to the lack of quaternary sedimentary rock formations. Sea sand and gravel are found in many places in the coastal waters and in the Seto Inland Sea. In the seas of Kyushu and Seto, where extraction condition is favorable, sand and gravel have been exploited for many years, and thus further development of aggregate resources is not expected. **Figure 2** shows the production of sand and gravel according to the area in fiscal year 2009 $^{2)}$.

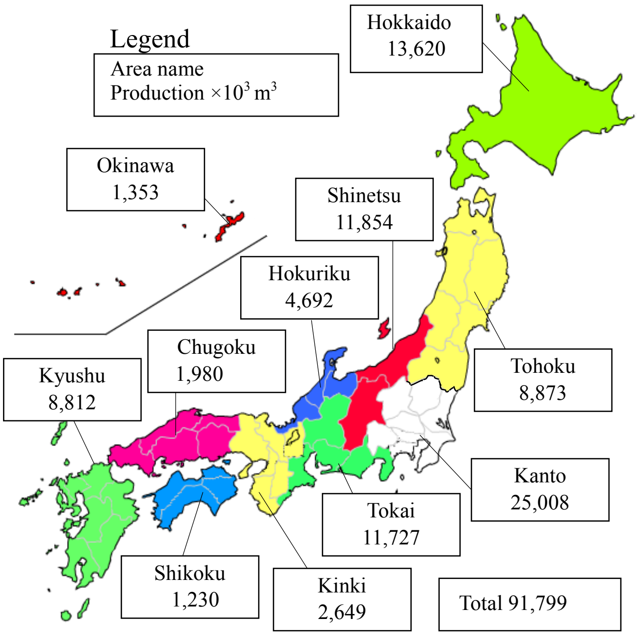


Fig. 2 Area-wise natural sand and gravel production in 2009 $^{2)}$.

On top of this, many prefectures have banned extraction of sea sand and gravel as part of their efforts for environmental conservation. In these circumstances, alternative aggregate resources are urgently needed. On the other hand, hard rock available for extracting crushed sand and stone is distributed across Japan. Such hard rock includes sandstone, shale and limestone, formed in the Palaeozoic and Mesozoic Eras, rhyolite, formed at the end of the Mesozoic Era, and andesite and basalt, formed between the Neogene Period and the Quaternary Period.

2.3 The Past and Present Situations of Aggregate Resources Development

The high economic growth in the past resulted in a rapidly increasing demand for aggregate. To satisfy the demand, resources such as land/pit/sea sand and gravel and crushed stone were exploited. Prior to the steep rise in demand, river sand and gravel accounted for much of the aggregate supply. However, with the increase in aggregate production, extraction of river sand and gravel was gradually brought under control because problems such as bridge pier scouring became serious. As shown in **Fig. 3**, the annual supply of natural aggregate increased to about 350 million tons to meet the rising demand $^{1)}$. To make up for a supply deficiency caused by the continuing increase in demand, production of crushed stone increased remarkably. The consumption of aggregate peaked at 949 million tons in 1990. Since the collapse of the asset-inflated bubble economy, however, the demand for aggregate has been decreasing.

Particularly in fiscal 2009, the global financial crisis caused a decline in personal consumption as well as a decrease in the number of public works projects, which helped to reduce consumption of aggregate to 390 million tons, less than 50% of the peak consumption $^{1)}$.

The current consumption stands at around 390 million tons per year, of which one-third is natural aggregate. The past heavy consumption of aggregate now poses an increasingly serious problem, namely the insufficiency of quality sand. Additionally, restrictions on the extraction of sea sand and gravel are being strengthened for the purpose of advancing environmental measures. Use of recycled aggregate has been promoted, but it is not sufficient to meet the demand. In the past, use of crushed stone was effective in satisfying the increasing demand for aggregate.

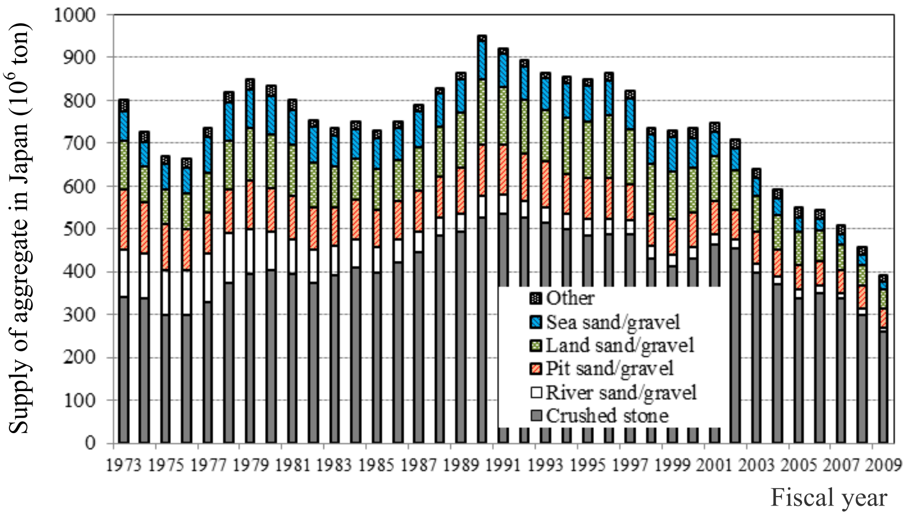


Fig. 3 Changes in the supply of aggregate in Japan [1].

However, resources available for long-term production of crushed stone in an economically viable manner are diminishing because suitable rock deposits are already exploited and awareness with regard to the need for land conservation is growing. Production of crushed stone has become difficult also because a large amount of energy is needed for crushing hard rock and control of dust and powder is required in the production process. While quality aggregate resources are becoming scarce, high-quality aggregate is increasingly needed due to the rise in demand for high-strength concrete. Under the circumstances, therefore, a stable supply of high-quality aggregate is a high-priority issue. In order to address this issue, the supply of aggregate must be increased by promoting research and development concerning recycled aggregate production, as well as by advancing efficient extraction of natural aggregate in an environment-friendly manner. Reliable quality control is also necessary for ensuring a supply of high-quality aggregate.

The following sections describe the current situation and some challenges of natural aggregate exploitation with a focus on Chiba Prefecture. In Chiba, pit sand and gravel have been extracted for many years to supply aggregate to the entire Kanto area, including the Toyo metropolitan district which has high demand for concrete.

2.4 Aggregate Mining Sites near the Tokyo Metropolitan District

In Chiba Prefecture, which is adjacent to the Tokyo metropolitan district where concrete is consumed in large quantities, 120 pit sand/gravel mining sites are operated for exploiting natural aggregates [2]. Chiba is endowed with one of the largest deposits of sand and gravel in Japan. Having a physical advantage of adjoining the metropolitan district that has a strong demand for concrete, the prefecture has long been a place of active extraction of pit sand and gravel, which are mainly supplied to Tokyo and other places in the Kanto area. The natural aggregate resources available in Chiba are mostly pit sand/gravel. Chiba leads other prefectures in the production volume of natural aggregates, and 16,382,000 m^3 of sand and gravel were extracted in 2009 as compared to the national total extraction of 108,595,000 m^3 2).

As shown in **Fig. 4**, the geological features in Chiba are distinctive in three different areas, namely, the hilly district of Bousou in the south, the Shimousa highlands extending from the central part to the northern part of the prefecture, and the Kujukuri plains along the Pacific coast in the east3).There are Neogene and Quaternary sedimentary layers in the northwestern part of the Bousou hilly district. The Neogene sedimentary rocks include sandstone, mudstone and conglomerate, among which sandstone and conglomerate are excavated in the form of pit sand/gravel for use as aggregate. Excavation of pit sand and gravel has been particularly actively conducted in Ichijuku and Mandano Formations, which contain relatively coarse, quality sand. The strike and the dip of these formations are N 56°E and N5°. The formations consist of layers of muddy sand (20 m thick), medium sand (40 m thick), sand gravel (10 m thick) and fine sand (20 m thick) from the top 4).

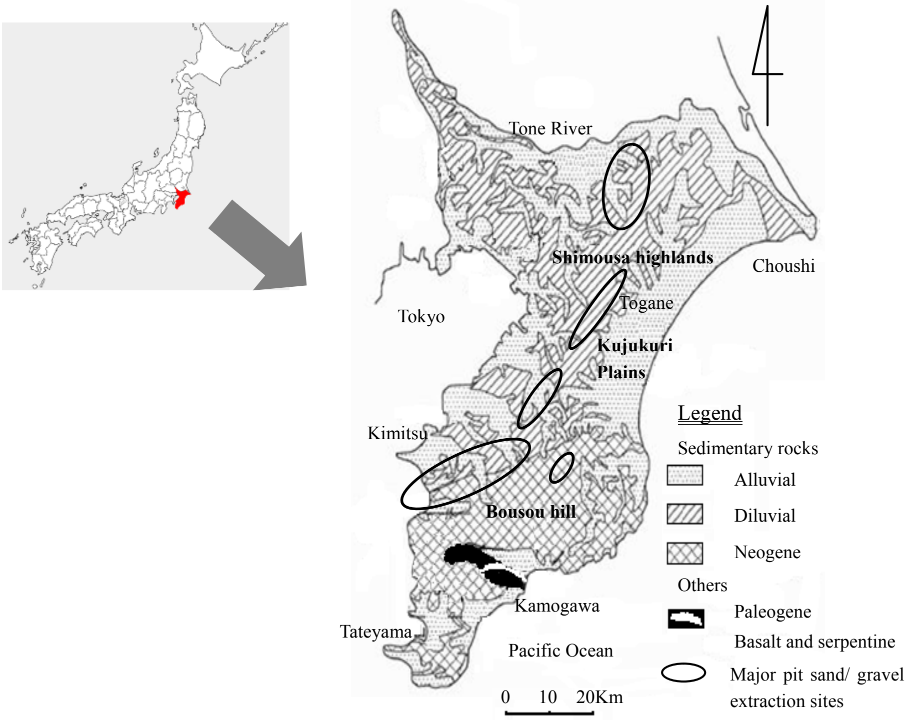


Fig. 4 Geological features and major pit sand/gravel mining sites in Chiba 3).

Blasting work is not necessary because no hard rock layers are included, and the bench cut method is applied instead. In this method, power shovels and bulldozers are used for cutting out steps on the top of the slope in the first place, and the excavation progresses downward. Starting in the topsoil, excavation proceeds to layers of pit sand, sand containing pumice, raw sand, base rock and raw stone. **Figure 5** shows the pit sand and/gravel mining working faces in Mandano Formation. Efficiency in the exploitation of aggregate has been promoted by improving excavation techniques and equipment. As natural aggregate resources are finite and a stable supply of high-quality aggregates will be increasingly important in the future, it is necessary to ensure efficient, environment-friendly and safe exploitation of aggregates as well as more stringent quality control.

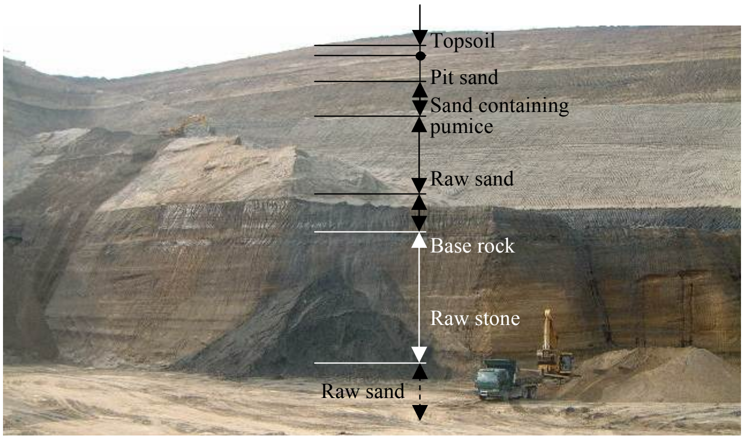


Fig. 5 Working face and excavation layers at Y mine in Mandano Formation.

3. Safety Measures

3.1 Preventing Failures of Artificial Slopes

One of the concerns at pit sand/gravel excavation sites is a disaster caused by failures of slopes used for mining and land filling. As shown in **Fig. 6**, slope failure modes are primarily divided into toppling failures and sliding failures. Toppling failures can be prevented by implementing adequate execution management according to the design of each working face, because toppling failures are mostly caused by excavation on an extremely steep slope. Thus, a disaster caused by toppling failures is actually a man-made disaster. On the other hand, sliding failures are caused by a discontinuous geological surface, groundwater or erosion due to rainfall.

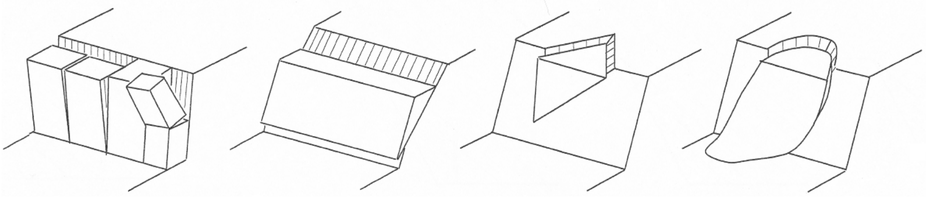

(1) Toppling failure (2) Sliding failure
(a) Plane failure (b) Wedge failure (c) Circular failure

Fig. 6 Slope failure modes 5).

Prevention of sliding failures requires detailed understanding of working faces in terms of the mechanical properties of the ground, and analysis of slope stability is also needed. Development of aggregate resources, however, is mostly conducted on a small or medium scale, and thus it is not easy to ensure such detailed understanding and analysis for preventing slope failure disasters in view of the time and funds necessary for research and analysis.

Currently, mining engineers visually inspect slope stability, and slopes are managed on the basis of the recommended stable gradients for pit sand/gravel excavation according to the Gravel Gathering Act and the Forestland Development Act. In the future, by ensuring simple methods for understanding mechanical properties of the mining ground, as well as for analyzing slope stability, techniques for preventing slope failures should be introduced for optimizing and stabilizing artificial slope configurations to suit to the condition of each excavation site. Pre-excavation assessment of slope stability will greatly help to ensure safe and efficient operation as well as to reduce the effects of excavation on the environment.

3.1.1 Tests for Assessing the Mechanical Properties of the Ground

The mechanical properties are necessary at first for cut slope stability assessment. In order to analyze the bearing capacity of soil, an in-site plate bearing test [6] was conducted. The test results are shown in **Table 1**. This test method is used extensively because the uncomplicated test procedure makes it relatively easy to understand the bearing capacity of the foundation ground. The dynamic deformation modulus (E_{vd}) obtained by the test suggests that the ground is mostly made up of sandy soil. Formulas (1) ~ (4) were used to estimate the parameters [7] for analyzing the bearing capacity of the ground. These parameters are shown in **Table 2**.

$$E_{vd} = 21 \times N \tag{1}$$

$$E = 14 \times N \tag{2}$$

$$\varphi = \sqrt{20N} + 15^\circ \tag{3}$$

$$q = 40 + 5N \tag{4}$$

where, Evd is the dynamic deformation modulus, N is the N value, E is the young's modulus, φ is the internal friction angle, and q is the uniaxial compressive strength.

Table 1 Plate bearing test results.

Layers	Dynamic deformation modulus, E_{vd} (MPa)
Topsoil	15.9
Pit sand	27.0
Sand containing pumice	41.6
Raw sand	22.3
Base rock	38.9
Raw stone	52.9

Table 2 Mechanical parameters used for analysis.

	Young's modulus (MPa)	Internal friction angle (°)	Cohesion (kPa)	Compressive strength (kPa)	Density (kN/m^3)
Topsoil	10.6	18.9	4.70	43.8	16.4
Pit sand	18.1	20.1	8.04	46.4	16.9
Sand containing pumice	27.7	21.3	12.4	49.9	17.4
Raw sand	14.8	19.6	6.64	45.3	16.7
Base Rock	25.9	21.1	11.6	49.3	17.3
Raw stone	35.3	22.1	15.7	52.6	17.9
Surrounding rock	20.0	35	10.5	40.0	27.0

3.1.2 Numerical Analysis and Interpretation of Analysis Results

Numerical analysis was conducted by means of Phase 2 [8], a two-dimensional elasto-plastic finite element stress analysis program, for assessing the stability of artificial slopes under various conditions. Before examining various slope designs, changes in the slope stability were assessed in relation to varied configurations of excavated slopes and finished steps. The mechanical parameters shown in **Table 2** were used for the assessment and these values were estimated on the basis of the plate bearing test results. **Figure 7** shows the distribution of safety factors around an excavated slope which is 100 m high and has a gradient of 45 degrees.

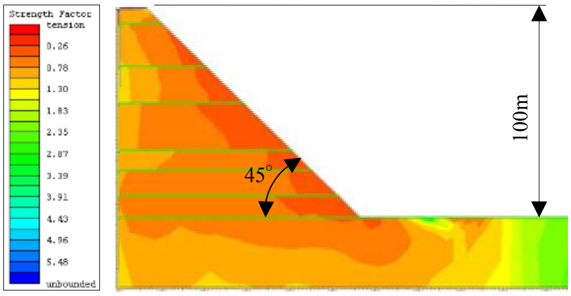


Fig. 7 Distribution of safety factors around the excavated slope surface
Height: 100 m; Gradient: 45°.

This slope gradient has been considered to be a stable gradient in the excavated site. The safety factors are determined on the basis of the Mohr-Coulomb failure criterion. It is shown in **Fig. 7** that the safety factor is as low as 0.5 on and immediately beneath the excavated surface. Accordingly, the analysis result suggests a possibility of slope failures or landslides. On the other hand, the working face and the steps in the excavated site are very stable, as shown in **Fig. 5** above, with no slope failures and landslides taking place to date. Thus, it can be considered that the results of the numerical analysis overestimate the risk of slope failures and landslides, and thus do not show a precise assessment of the actual conditions.

The actual ground properties were underestimated by the numerical analysis partly because the result of the in-site plate bearing test used for the analysis was peculiar to the soft ground on and immediately beneath the soil surface. Thus, in order to enhance the accuracy of the stability assessment, a constant-pressure direct box shear test and a uniaxial compression test were conducted with the soil samples collected on the excavated slope for understanding the actual mechanical properties of the ground. Each of the samples was compacted by applying a load which corresponded to the weight of the earth cover at each point of sample collection.

As shown in **Fig. 8**, in the direct box shear test, which is also called a direct shear test, the sample in the shear box is divided into two parts by the shear plane. The upper part and the lower part are contained in a movable frame and a stationary frame, respectively.

The sample is sheared as a normal stress is applied and the upper frame moves. The cohesion (C) and the internal friction angle (φ) are calculated on the basis of the normal stress (σ) and the strength in shear (τ). This test does not require a large quantity of a sample and is characterized by its relatively simple test procedure. Core samples were taken from the base rock layer. The current direct box shear test apparatus was not adequate for the raw stone layer [9)] because it contained sand gravel in a large quantity, and thus the soil grain size was large. Regarding these two layers, a uniaxial compression test was conducted (see **Fig. 9**).

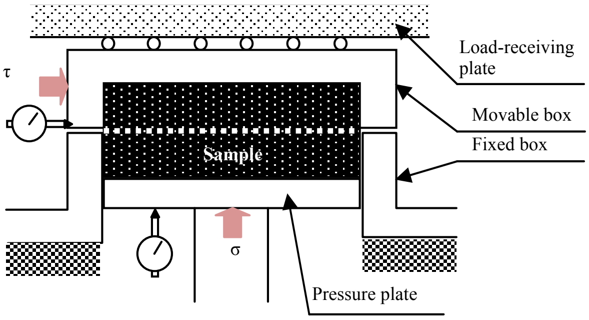


Fig. 8 Mechanism of the direct box shear test.

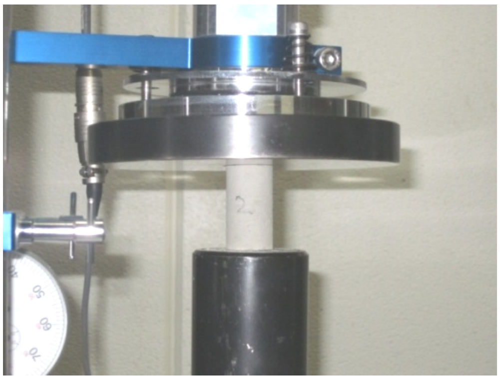


Fig. 9 Uniaxial compressive test.

The mechanical parameters obtained from the two tests mentioned above are shown in **Table 3** for each layer. These parameters were used for calculating the safety factors on and beneath the excavated slope. **Figure 10** shows the distribution of safety factors.

As shown in **Fig. 10**, the slope stability around the excavated slope is much higher than the one shown in **Fig. 7**, and it represents the actual conditions more precisely. When the slope gradient is increased to 60°, as shown in **Fig. 11**, although the stability of the slope is slightly decreased, sufficient stability is still observed at the slope toe. Accordingly, it can be said that the slope at large is stable at a gradient of 60°.

Table 3 Mechanical parameters of each layer obtained by a direct box shear test and a uniaxial compression test.

	Young's modulus (MPa)	Internal friction angle (°)	Cohesion (kPa)	Compressive strength (kPa)	Density (kN/m^3)
Topsoil	24.9	21.0	48.9	74.7	16.4
Pit sand	250.0	33.9	37.6	129.1	16.9
Sand containing pumice	369.0	38.0	36.3	171.7	17.4
Raw sand	217.0	32.6	21.1	117.6	16.7
Base Rock	405.0	20.0	240.0	645.0	17.3
Raw stone	61.2	25.0	35.0	52.6	17.9
Row sand	65.8	24.7	49.5	63.5	17.0

On the basis of the analysis results described above, it was confirmed that sufficient stability of an excavated slope is ensured when the slope is 100 m high and has a gradient of 60° instead of 45° which is the standard gradient currently adopted for ensuring slope stability. **Figures 11** and **12** show the analysis results for a slope which is 120 m high and has a gradient of either 45° or 60°, respectively.

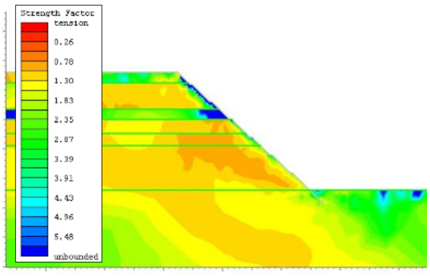


Fig. 10 Distribution of safety factors around the excavated slope surface
Height: 100 m; Gradient: 45.

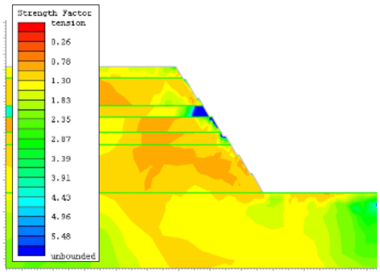


Fig. 11 Distribution of safety factors around the excavated slope surface
Height: 100 m; Gradient: 60°.

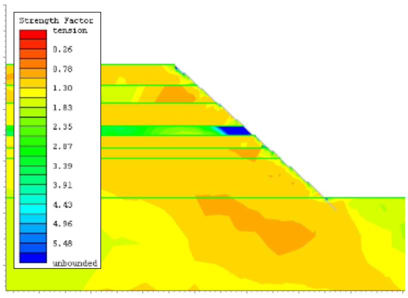


Fig. 12 Distribution of safety factors around the excavated slope surface
Height: 120 m; Gradient: 45°.

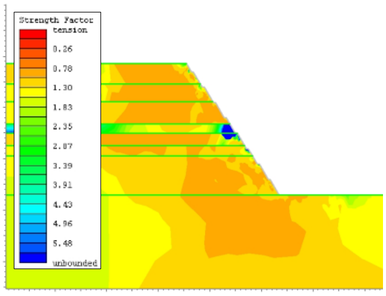
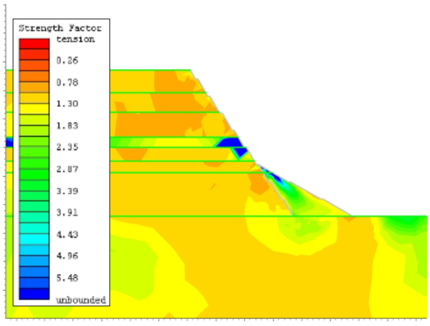


Fig. 13 Distribution of safety factors around the excavated slope surface
Height: 120 m; Gradient: 60.

According to **Fig. 10** to **13**, it is determined that a slope as high as 120 m is stable at a gradient of 45°, although the safety factor is lower in general than the slope 100 m high. At a gradient of 60°, the safety factor is further reduced on the entire slope, particularly around the toe. A failure of the slope toe may lead to the collapse of the entire slope. Thus, to assess the measures for preventing failures of the slope toe, analysis was conducted regarding a slope (height: 120 m; gradient: 60°) with a fill slope (height: 40 m; gradient: 30°) constructed at the slope toe. The analysis result in **Fig. 14** shows that the fill slope is effective in remarkably improving the safety factor at the slope toe as well as in the entire area of the slope. Accordingly, it was confirmed that the slope stability is ensured by applying a fill to the slope toe after the completion of mining even when the slope is built as high as 120 m at a gradient of 60°.



Height: 120 m; Gradient: 60°
After excavation, a fill slope was built at a height of 40 m and at a gradient of 30°

Fig. 14 Distribution of safety factors around the excavated slope surface.

However, when the excavated slope is affected by rainwater or spring water for a prolonged period after the completion of excavation, the physical properties of the ground is adversely affected, and the stability of the slope might be reduced. This underlines the need for adequate planning for the finishing of a slope in view of the slope's configuration, construction of berms for water discharge, and tree planting.

3.2 Prevention of Disasters Caused by Heavy Rain

A survey was conducted of the disasters [10] that had occurred at sites for excavating pit sand and gravel in Chiba Prefecture between April 2000 and October 2011. The causes of these disasters are shown in **Fig. 15**. There were 24 cases of disasters in the past ten years, and 84% of them were caused by heavy rains. These 24 cases are mostly characterized by runoff of soil or slag used for road construction (70%) or working face/slope failure (25%).

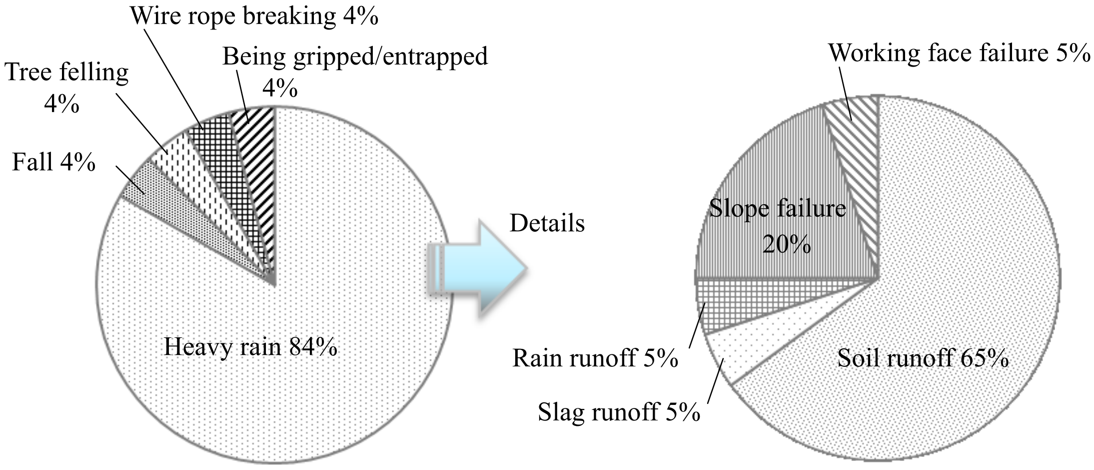


Fig. 15 Characteristics of disasters at mining sites in Chiba [10].

It is presumed that these disasters were partly caused by the fact that each mining area is not large enough to make it possible to take measures for preventing excavated sand and gravel from flowing out of the mining sites. The mining area is limited because excavation can be done only on a small- or medium-scale in Chiba Prefecture, which is adjacent to the Tokyo metropolitan district where aggregates are in high demand.

It was assumed in the past that most of the heavy rains were caused by typhoons. Recently, however, seasonal rain fronts have brought torrential rains, and localized heavy rains, which are hardly forecastable, have become more frequent. In an event of localized heavy rain, the rainfall is concentrated on an area as small as 100 km^2. The precipitation is 100 mm or more per hour but stops in about an hour. This precipitation pattern is distinctly different from the usual torrential rains caused by cumulonimbus clouds which are formed one after another along a cold front. It has been noted that both the heat-island phenomenon and the local winds peculiar to urban neighborhoods help develop cumulonimbus clouds which cause the type of heavy rainfall that has been increasing in recent years [11].

Prevention of landslide disasters caused by rainfall is among the priority matters in the design and operation of mines for exploiting pit sand and gravel. Rainwater in excavation sites should be collected in settling basins or regulating ponds so that it will seep underground without flowing out of the mining sites.

The volume of rain runoff and the capacity of a reservoir necessary for adequate design of an excavation site can be obtained by the following formula [12]:

$$Q = 1/360 \times f \times r \times A \tag{5}$$

where, Q is volume of rain runoff, f is runoff coefficient, r is design rainfall intensity and A is water catchment area. The value of f applicable to each different surface type is shown in **Table 4.**

Table 4 Runoff coefficients used for calculating the volume of rainwater runoff [12].

	Penetration ability (Low)	Penetration ability (Medium)	Penetration ability (High)
Forest land	0.6～0.7	0.5～0.6	0.3～0.5
Grass field	0.7～0.8	0.6～0.7	0.4～0.6
Farm land	-	0.7～0.8	0.5～0.7
Bare land	1.0	0.9～1.0	0.8～0.9

The rainwater intensity assumed for the design of drainage facilities and flood control reservoirs are respectively based on ten-year probability and fifty-year probability. For the purpose of obtaining design rainfall intensity, the volume of rainwater runoff is multiplied by the flood concentration time for each catchment area. The capacity required of each settlement basin/flood control reservoir is determined by multiplying the sum of the flood control capacity per unit area and the sediment storage capacity per unit area by the rainwater catchment area. The flood control capacity per unit area used in the calculation is based on the data which are shown by region in the Guidelines for Housing Land Development prepared by the Chiba Prefectural Government. By way of explanation, the case of a mine (hereinafter, “T mine") in the city of Kimitsu, Chiba, is shown below.

In the area around T mine, the flood control capacity per hectare is 1,450 m^3, and the sediment storage capacity per hectare is 300 m^3 [13]. The total capacity for flood control and sediment storage in T mine is obtained by multiplying 1,750 m^3/ha by the total catchment area, 39.71 hectares, as shown below:

$$(1{,}450\ m^3 / \text{hectare} + 300\ m^3 / \text{hectare}) \times 39.71\ \text{hectares} = 69{,}493 m^3 \tag{6}$$

Figure 16 shows T mine with a plan for rainwater catchment and flood control reservoirs. There are eight settling basins and flood control reservoirs in total. Each of the catchment areas has one basin/reservoir that is designed to prevent rainwater runoff. The actual capacity of each basin/reservoir is shown in **Table 5**.

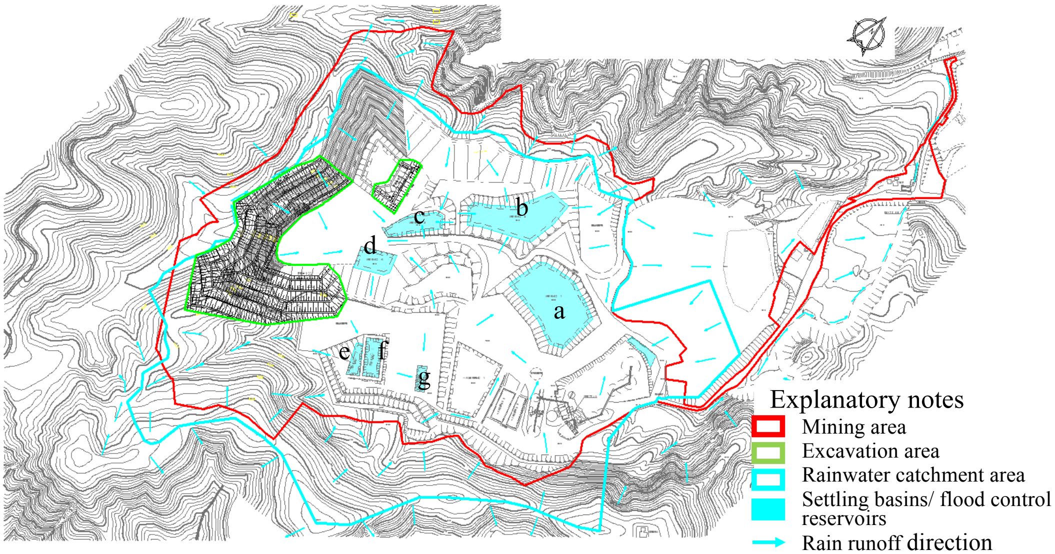


Fig. 16 Catchment areas in T mine

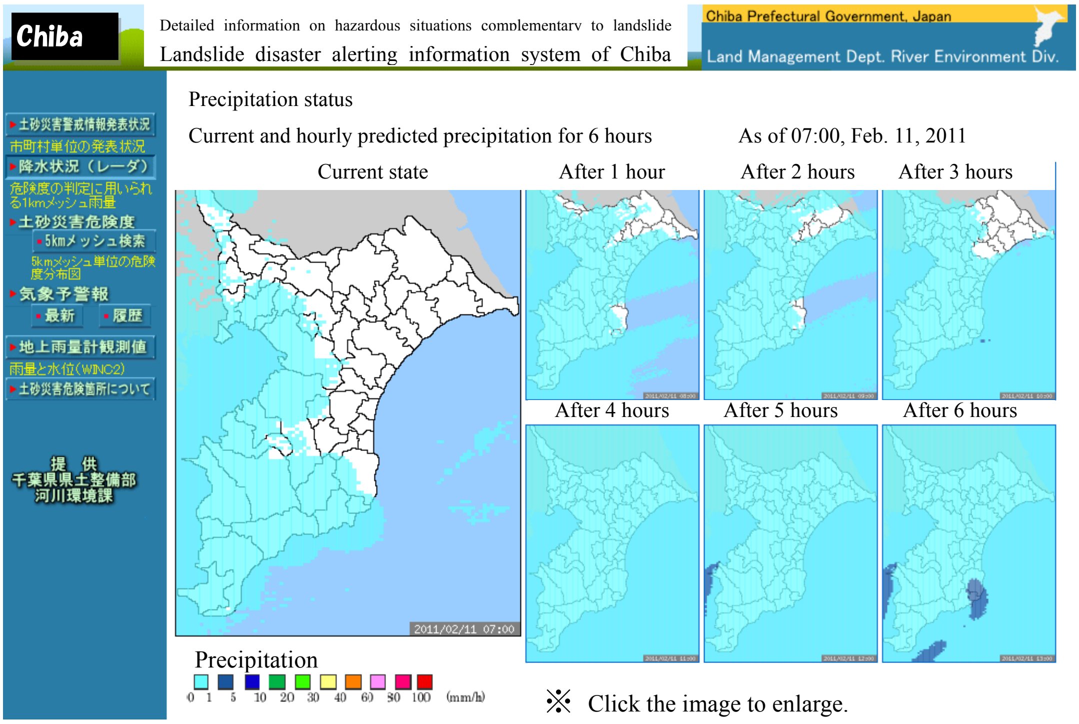
Table 5 Actual capacity and safety ratio of settling basins and flood control reservoirs.

Settling basins/ flood control reservoirs	a	b	c	d	e	f	g	Total
Actual capacity (m^3)	65,100	31,415	3,470	5,804	1,156	4,168	1,246	112,359
Safety ratio	112,359m^3 ÷ 69,493m^3 = 1.61							

Working faces are designed to prevent flooding through rainwater catchment. Additionally, it is also important to prevent disasters which might be caused by unexpected localized rainfall at an excavation site. For this purpose, the amount of rainfall must be accurately estimated for taking prompt and appropriate measures. Night-time excavation of pit sand/gravel is not permitted. At a sand and gravel production plant during the day, a large amount of water is used for sieving raw sand/gravel for producing fine aggregate. The water is supplied from sand basins and reservoirs, and well water is also used when necessary. Thus, both the water level in the basins/reservoirs and the total amount of water at a mining area changes during the day.

A practical example of T mine site is described below. At this site, weather forecast and on-site rainfall observation are effectively used for taking swift and accurate countermeasures against disasters. The T mine excavation site is located at an altitude higher than the neighboring residential area. A land features of the T mine district is the vulnerability to flooding caused by rainwater which is collected in an undeveloped area in the excavation site and runs off into mountain streams, water channels and roads to finally reach the residential area. The Prefectural Government of Chiba where T mine is located has a website for landslide disaster alerting information [14)]. This website provides information on landslide disasters which is announced jointly by the River Environment Division, Land Management Department of Chiba Prefectural Government and the Choushi meteorological observatory. Detailed supplementary information is also provided on the website. As shown in **Fig. 17**, the website shows weather warnings/advisories, the current rainfall levels obtained by the meteorological radar for the Kanto area, and hourly predicted rainfall levels for six hours. A mobile website is also available for people who need to check the website for necessary information. Information on thunder and lightning is provided by

WNI Thunder Information shown on the Disaster Prevention Website of Chiba. Tokyo Electric Power Co., Inc. also synthesizes information on thunderclouds and thunderbolts and provides information on approaching thunder.


Chiba

Detailed information on hazardous situations complementary to landslide

Landslide disaster alerting information system of Chiba

Chiba Prefectural Government, Japan

Land Management Dept. River Environment Div.

Precipitation status

Current and hourly predicted precipitation for 6 hours

As of 07:00, Feb. 11, 2011

※ Click the image to enlarge.

Fig. 17 Landslide disaster alerting information system website of Chiba Prefecture [14].

At T mine, regional information on changes in the weather is always obtained from the website. Information on precipitation is particularly important. The weather observation system shown in **Fig. 18** is also used at T mine for collecting data on the atmospheric pressure, the amount of precipitation, etc. All the information collected is used for taking quick and appropriate measures against unexpected localized rainfall and typhoons approaching the excavation site. Decisions on necessary measures are made on the basis of the information obtained from the above-mentioned website for thunder and lightning as well as on-site observation of wildfires, lightning and rolls of thunder. The data displayed on the receiver of the weather observation system include wind direction, wind velocity, air temperature, atmospheric pressure, humidity, precipitation and daily cumulative precipitation. A graphical display is available and data display and storage are available with a computer connected with the receiver.

On the basis of the information which is obtained from the above-mentioned websites and/or is collected from the weather observation system at the excavation site as well as from patrol inspection, the administrative office at the site determines the necessity for issuing one of the three types of warnings, namely a heavy rain advisory, a heavy rain warning, or a warning of record-breaking deluge in a short period. When necessary, an advisory or a warning is sent over the radio to all people working at the site. According to the manual [15] for disaster prevention, mine workers and other people are divided into groups responsible for 1) excavation, 2) hauling and plant operation, and 3) shipment, and also into other two groups of 4) office staff members and 5) visitors from outside. The manual prescribes the actions that should be taken by each group, and thus people in each group are to take shelter or to join an emergency team for taking measures for disaster prevention. **Figure 19** shows the flow of the emergency response to heavy rain at T mine.

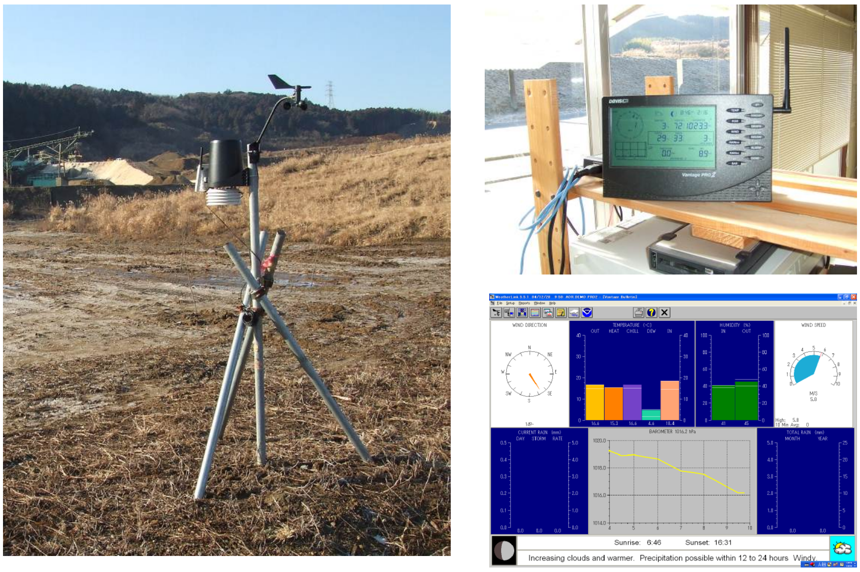


Fig. 18 Weather observation device and a receiver at T mine excavation site.

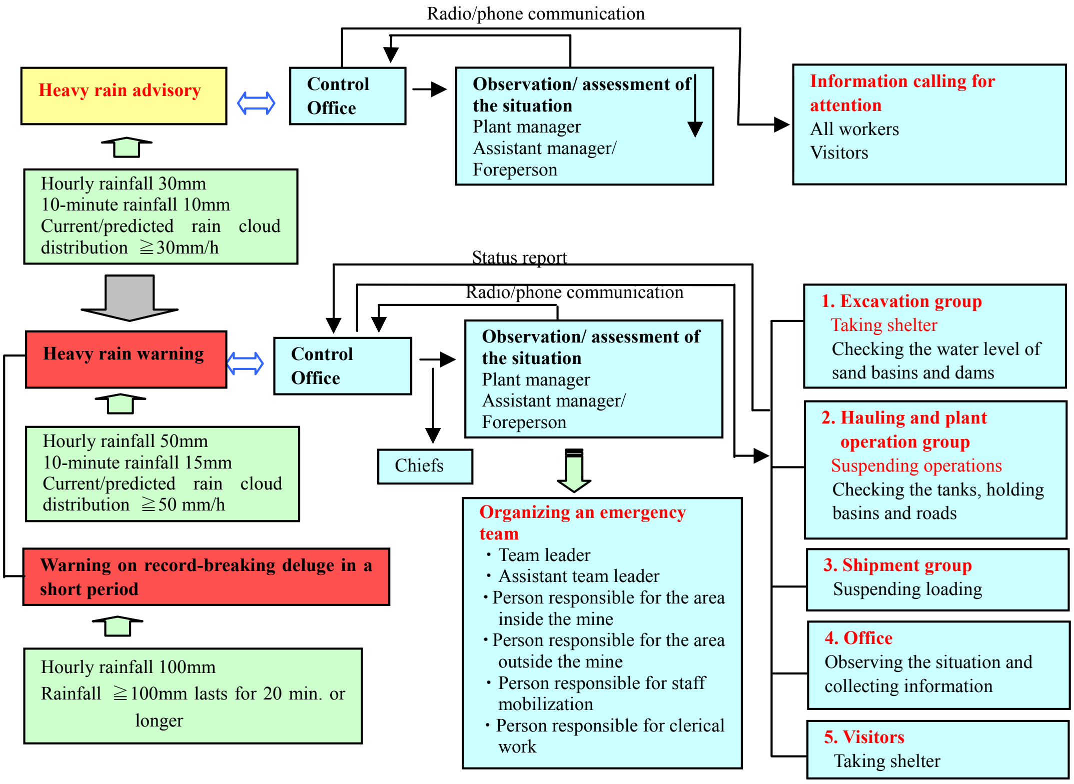


Fig. 19 Flow of emergency response during heavy rain [15].

It is desirable that the current disaster prevention scheme at the T mine excavation site be further improved to shorten the time required for processing and analyzing various weather data before making a decision on necessary measures. As the frequency of extreme weather is increasing, it is also hoped that a disaster prevention scheme will be established as a system which automatically issues an advisory or a warming to all people concerned any time, day or night, so that disasters which might be caused by extreme weather can be effectively prevented.

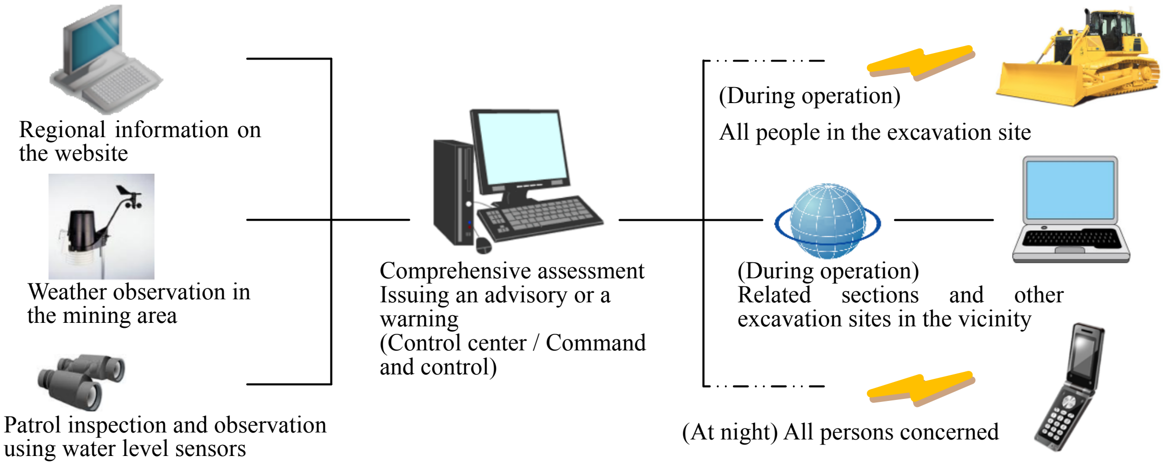


Fig. 20 Conceptual plan of an emergency response system for small and medium excavation projects.

4. Environment Protection

4.1 Prevention of Noise, Vibration and Dust

For the purpose of protecting the living environment of local residents, the Basic Law for Environmental Pollution Control stipulates that pit sand/gravel excavation operators are responsible for preventing damage to human health and living environment which might be caused by wide-ranging 1) air pollution, 2) water contamination, 3) soil contamination, 4) noise, 5) vibration, and 6) land subsidence resulting from excavation. Specific regulations are provided by the Air Pollution Control Act, the Water Pollution Control Act, the Noise Regulation Law, the Vibration Regulation Law and other laws. Construction of washing plants and other facilities at pit sand/gravel excavation sites should be reported in advance to the competent prefectural or municipal government agency, and adequate measures are taken for preventing pollution. As night-time excavation is not permitted and blasting work is not necessary for pit sand/gravel excavation, factors causing pollution are much fewer than in limestone or metal mines. However, in view of the fact that pit sand/gravel excavation sites are relatively small in scale and are often located near residential districts, adequate measures should be taken for preventing pollution. Specifically, in excavating and loading operation, low-noise machines and equipment are basically used. Force of impact is not utilized whenever possible for excavation. Workers are encouraged to use machines and equipment with great care, without unnecessary load application, high-speed operation and idling. It is also necessary to provide continuing education to heavy equipment operators so that they will take care not to cause unnecessary noise and vibration in loading sand/gravel directly from an excavating and loading machine to a truck. In order to win understanding of local residents about continued operation at an excavation site, it is necessary to minimize dust, noise and vibration caused by dump trucks which travel on public roads for transporting sand/gravel. The level of noise and vibration caused by traveling dump trucks is closely related to the surface condition of roads. However, because the level of noise and vibration is also correlated with the traveling speed of trucks, T mine has concluded an agreement with the local residents for restricting the maximum traveling speed to 20 km/h on municipal and private roads which run in residential districts to connect to prefectural highways. Furthermore, fine sand on the tires of dump trucks traveling unpaved surface in the mining area is washed away before the trucks leave for destinations outside the mining area.

Dust prevention measures are also taken under the control of the pit sand/gravel industry association. Paved roads used for sand/gravel transport are cleaned extensively with a sweeper vehicle according to a predetermined road cleaning schedule. On an as-needed basis, mine workers clean municipal and private roads in the vicinity of excavation sites.

4.2 Planting and Afforestation

4.2.1 Tree Planting at Excavation Sites

Pit sand/gravel resources are exploited by cutting down forests which are important CO_2 sinks for curbing global warming. Thus, after the completion of excavation, vegetation and the ecosystem should be restored as soon as possible. Regarding optimization of vegetation restoration at an excavation site, optimum depths of improved soil in the ground and physical/chemical properties of improved soil have been studied. The study is summarized below. A site after extraction is backfilled to a planned height. Basically, the surface soil which was removed for gravel pit development is used for backfill, and soil from other extraction sites is sometimes added to prepare land for planting. However, it is very difficult to use all soil stripped from extraction sites for backfill. First, vast land is needed for piling up and storing stripped soil and a huge budget is required to transport soil between an extraction site and a storage site as well as to ensure adequate soil management until the soil is used for covering the extraction site. Second, heavy rain or a major earthquake might cause collapse of heaped earth or soil runoff, which can cause damage to a wide area outside the extraction site. Additionally, because a 20-ton bulldozer (with a ground contact pressure of 62 kPa 16)) and/or a 40-ton power shovel (80 kPa 16)) are used for land preparation, sand and gravel of extremely small grain sizes are compacted. It is possible that the compacted sand and gravel adversely affect the growth of plants. In this respect, it is critical that covering with stripped soil is kept at a minimum and that land is improved to ensure early, optimum growth of plants. It is necessary to develop a condition which enhances deposition of organic matter and spontaneous recovery of fauna, flora and soil microbes.

4.2.2 Depth of Improved Soil in the Ground

For the purpose of understanding in more detail the thickness and the area of improved soil which are required for planting, the roots of a Japanese cypress tree (71 years old, 19.0 m high) and a Japanese cedar tree (51 years old, 16.5 m high), both of which had been felled, were plowed up for analysis. A ground-based laser scanner, which is often used for three-dimensional surveying 17) at mines, was used for scanning the roots. The cypress's rootstock after trimming and filtering (1 pixel per 1mm^3) is shown in **Fig. 21**. The rootstock was 1,800 mm long and 1,900 mm wide, having a fibrous root system developed laterally. The cedar's rootstock was 2,200 mm long and 1,200 mm wide. Judging from the age of each tree, the rootstock can be regarded as the maximum size of each species. In planting 3-year-old seedlings 500 ~ 700 mm high, pedogenic process involving soil microbes in the course of the growth of the seedlings can be taken into account. In view of this, it is assumed that growth of one seedling is ensured by applying improved soil to an area which is 1,000 mm in diameter, although the dimension of the area may be slightly different depending on tree species. In that area, 1.17 m^3 of improved soil can be applied to a depth of 1,500 mm. Thus, when an extraction site is backfilled for planting, care should be taken to prevent a bulldozer or a power shovel from compacting the soil to a depth of 1.5 m from the finished surface.

Otherwise, land should be entirely or partially cultivated to the depth of 1.5 m after the backfilling work by a bulldozer or a power shovel.

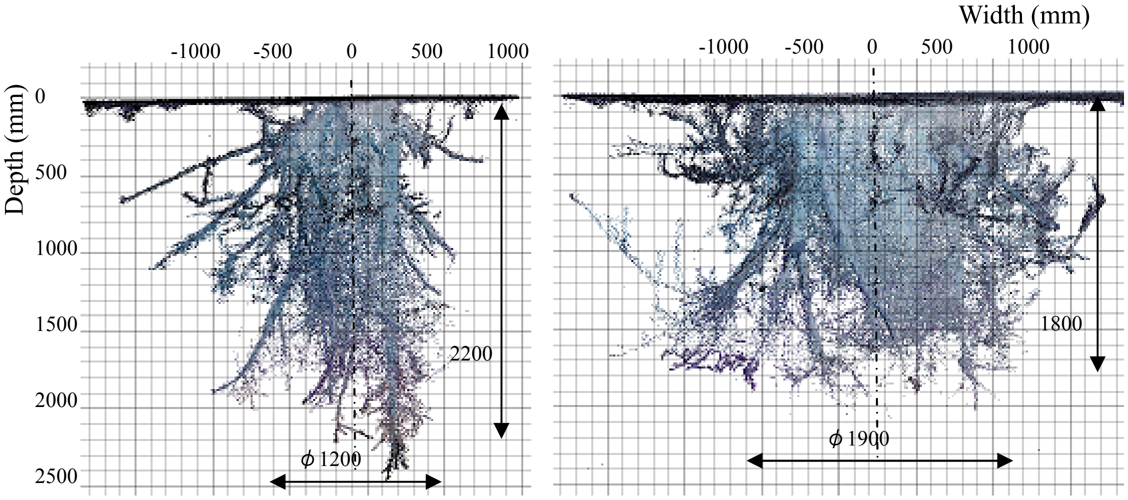


Fig. 21 Growth of the rootstock. (Left: Japanese cedar, Right: Japanese cypress).

4.2.3 Physical Conditions of Improved Soil

Water permeability of improved soil is one of the physical factors that affect the growth of plants. Poor permeability results in excess water in the ground, which causes decreased oxygen supply to roots as well as generation of harmful substances by anaerobic microorganisms. Although sandy soil is presumed to have good permeability, a field permeability test apparatus was used for determining the permeability because past experience at the extraction site had indicated the possibility of poor permeability after rain. As shown in **Fig. 22**, at a depth of 300 mm in Y mine testing ground 1) where mount-shaped organic compost had been applied and Japanese cypress trees had been growing well, the soil permeability was so high as to make it almost impossible for the test apparatus to determine the permeability. While the permeability was also good at a depth of 600 mm, it was poor at the bottom of the compost at a depth of 900 mm. This result suggests that the bottom of the compost is on the top of the backfill consisting of pit sand and others, the same type of soil used for the planting ground at Y mine 2) which is 15 m away from Y mine testing ground 1). At the afforestation site 3) of I mine, a small bulldozer had been used to modify the slope and only the surface had been prepared before planting. Thus, while the permeability was good at a depth of 300 mm, the permeability at a depth of 600 mm and deeper was as poor as at site 2) of Y mine. At the site 4) about 2 m away from site 3), the ground had been cultivated in an area 1.0 m across to a depth of 1.5 m with a power shovel for the purpose of improving the permeability. The test conducted in two months after the cultivation showed that the permeability at a depth of 600 mm and deeper had been improved to the baseline value [18], 30 mm/hour or greater.

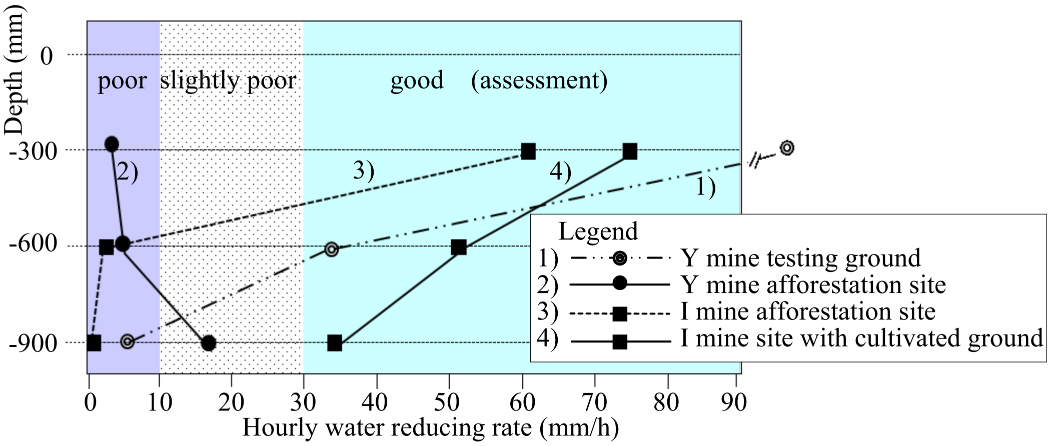


Fig. 22 Soil permeability at each afforestation site, determined by a Hasegawa system of field permeability test apparatus.

As shown in **Table 6**, the soil hardness, which affects rhizome development, was favorable at a depth of 300 mm, but the soil was so hard at depths of 600 mm and 900 mm that rhizome development was hampered or prevented roots from growing. At the latter two depths, the soil was determined to be unsuitable for plant growth [18], which suggested the need for soil improvement. After improvement, the soil did not suppress the growth of rhizomes at any depth, but it was desiccated easily, being too soft and containing too much air. In the future, it is necessary to consider the use of soil amendments, including coarse sand and fertilizer retention materials which are different in grain size from soil, for promoting formation of soil aggregate and maintaining good soil permeability after rainfalls. The water retentiveness of soil does not affect planted trees as immediately as the permeability and the hardness of soil. However, seedlings planted in soil with a high pit sand content may wither and die when the soil becomes overly dried after many precipitation-free days in summer. It seems effective to make use of xeric ground cover plants which do not compete with planted species for nutrients and water. As shown in **Fig. 23**, clovers were used as a ground cover plant at I mine on a trial basis, but it is necessary to confirm that the plant does not compete with Japanese cypress for nutrients and water.

Table 6 Soil hardness by depth at an afforestation site, measured by a Yamanaka system of soil hardness tester.

	At I mine, before soil improvement		At I mine, after soil improvement	
Depth (mm)	Hardness (mm)	Quality [18]	Hardness (mm)	Quality [18]
300	15.0	Soft ○	8.0	Too soft, too much air △
600	25.7	Hard ×	10.0	Too soft, too much air △
900	29.3	Consolidated ×	8.5	Too soft, too much air △

Fig. 23 Gravel pit before planting and after planting with ground cover application.

4.2.4 Physical and Chemical Requirements of Improved Soil

The soil for planting was analyzed in terms of its chemical properties. The results are shown in **Table 7**. As shown in **Table 7**, except for the potential Hydrogen (pH) and the electrical conductivity (EC), the values are much lower than the target values of soil applicable to landscaping or soil in woods in general in terms of the total carbon (TC), the total nitrogen (TN), the cation exchange capacity (CEC) and the available phosphoric acid. Although desirable values depend on tree species, priority should be placed on the survival and sound growth of seedlings. In this regard, it is critical to carefully plan and implement basal and additional fertilization with an aim of improving the fertility of soil through additional nitrogen, phosphoric acid and potassium.

Table 7 Chemical properties of the soil used for afforestation.

	pH (H_2O)	EC (mS-m^{-1})	TC (%)	TN (%)	CEC (Cmol(+)kg^{-1})	Available phosphoric acid (mgP_2O_5kg^{-1}) (Dry soil)
Pit sand	7.55	1.32	0.026	0.006	4.8	4.8
Target value	4.5～7.5[19)]	1～10[19)]	4～15[19)]	Less than 0.1[19)]	20～40[19)]	Less than 10[20)]

4.2.5 Species Desirable for Afforestation

In the past, three-year-old seedlings of Japanese cypress and Japanese cedar have been planted at extraction sites in consideration of the request from the site owners or because these species had grown at the sites prior to aggregate extraction. However in the future it is necessary to select tree species that can survive in the sites where Neogene sedimentary rock is predominant. Such a geological condition is not optimum for the growth of vegetation because soil is oligotrophic, being susceptible to weathering and erosion. An experiment being conducted at Y mine site shows that Alder (Alnus japonica) and Japanese green alder (Alnus firma) grow very well over a short period of time and that they rarely wither and die. Meanwhile, pine trees grow on a slope which was prepared quite some time ago in the same site. Pine seeds must have been brought there by wind and birds and germinated. As these pine trees have grown tall on the slope where the soil is hard, afforestation by seeding pine on slopes can be considered in the future.

5. Conclusion

Natural aggregates are precious resources indispensable for the sound economic development of Japan. This paper describes the current and future situations regarding aggregate resources development and the safety measures. Various studies conducted by the authors are partly presented with regard to a simple method for assessing slope stability at working faces, countermeasures against slope failures caused by extreme weather conditions such as torrential rainfall, measures for preventing pollution, and tree planting techniques for mining sites after excavation.

Under the unprecedented social situation of a declining population, it is necessary to reevaluate the role that aggregate resources development can play for supporting economic activities which help to ensure sustainable economic growth and affluence of the country. In this respect, the aggregate industry should establish itself as an environment-conscious industry as early as possible. By maintaining cooperation rather than competition among various developers for enhancing efficiency of operation, the aggregate industry as a whole can contribute to creation of a safer and more affluent society. At the same time, the aggregate industry should make efforts to gain acceptance and recognition of the local communities where the industry operates. It is strongly desired that techniques for highly efficient and environment-conscious development of aggregate resources are further improved to meet social demand for safe, responsible and environment-friendly excavation of aggregates.

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