Semi-aerobic Landfill Concept

Guide to Introducing The Fukuoka Method

< Semi-Aerobic Landfill Method >

for Final Waste Disposal Sites

Fukuoka Prefecture

Introduction

In order to contribute to resolving environmental problems in the Asian region, Fukuoka Prefecture is utilizing the environmental technologies and know-how it has built up in the process of overcoming pollution in the past to implement international environmental cooperation with Vietnam, Thailand, China, and other countries.

Especially in Vietnam and Thailand, support has been provided for a series of processes ranging from selection of suitable sites for introduction of the Fukuoka method (semi-aerobic landfill method) for final waste disposal sites (hereinafter, the “Fukuoka method”) through to their design, construction, and maintenance management. This guide has been created based on these experiences and accomplishments.

This guide has been created to help local government officials overseas better understand the Fukuoka method and as an opportunity to consider the introduction of this method. For this reason, it includes not only technical content such as design, construction, and maintenance management related to the introduction of the Fukuoka method, but also examples of the method’s introduction both in Japan and overseas (in the Asian region).

Please note that this guide describes some basic and general aspects of the Fukuoka method. Accordingly, when actually designing, constructing and maintaining Fukuoka method landfill, while referring to this guide, it will also be necessary to discuss with experts and undertake extensive consideration bsed on the design criteria, environmental conditions, any presumed properties of landfill waste, local site regulations, and so on.

It is hoped that this introductory guide will encourage overseas local governments to consider introducing the Fukuoka method, and that the Fukuoka method will spread to more areas and help to alleviate environmental issues related to final waste disposal sites.

Table of Contents

1. Overview of the Fukuoka method

1.1. History of the Fukuoka method

The Fukuoka method (semi-aerobic landfill method) for final waste disposal sites (hereinafter, the “Fukuoka method”) was invented by Professor Emeritus Masataka Hanashima of Fukuoka University and put into practical application in cooperation with Fukuoka University and Fukuoka City. In Japan, the Fukuoka method was first put into practical application in 1975 at the Shin-Kamata landfill site in Fukuoka City, and in 1979 it was adopted as the standard design for Japan's final landfill site guidelines.

1.2. Structural overview of the Fukuoka method

Fig. 1 shows a structural diagram of the Fukuoka method and the anaerobic landfill method. The Fukuoka method is a final waste disposal site mainly composed of a gas venting system, leachate collection and discharge system, leachate treatment system, rainwater collection, and drainage system, and groundwater collection and discharge system. In this method, a leachate collection and discharge system consisting of stone rubble and perforated pipes are installed at the bottom of the landfill, so leachate in the waste layers is promptly drained to the leachate treatment system, and thermal convection occurs due to fermentation heat generated by decomposition of waste inside the layers.

This design reduces the moisture content inside the layers, with air being naturally supplied from the leachate collection/discharge pipes, which promotes decomposition of waste while maintaining the interior in anaerobic state.

In other words, compared to conventional anaerobic landfill methods, this technique improves the water quality of leachate, suppresses greenhouse gas emissions, reduces the amount of hydrogen sulfide and volatile organic compounds generated, and enables early stabilization of landfills.

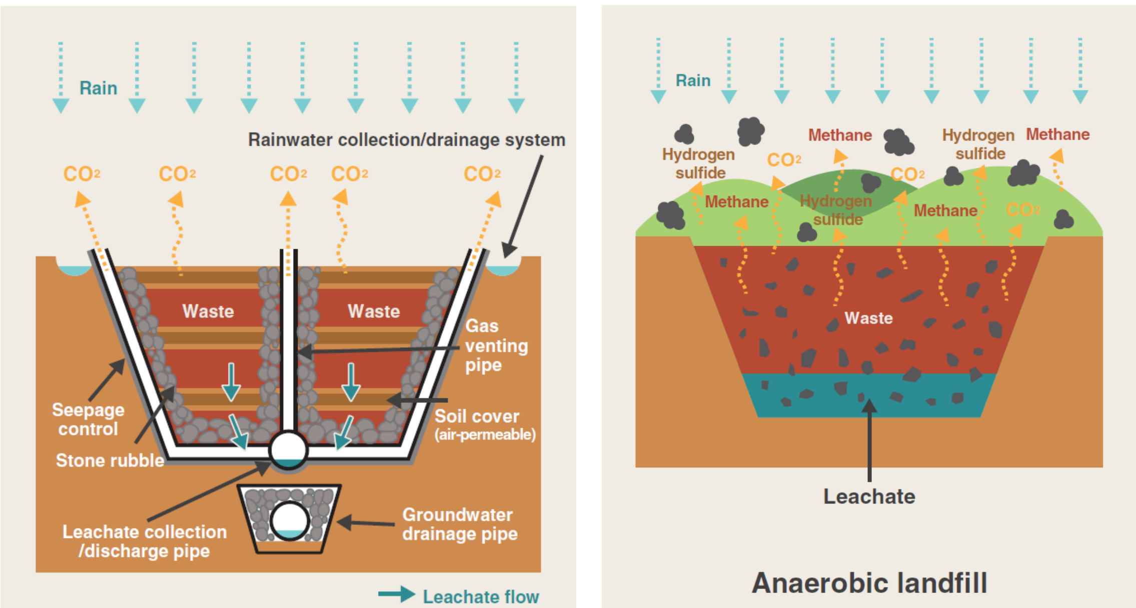


Fig. 1 Structural diagrams of the Fukuoka method and anaerobic landfill method
(created by Fukuoka Prefecture)

1.3. Advantages of the Fukuoka method

As shown in Fig. 1, in the anaerobic landfill method, which is widely used in developing countries, the landfill layer has an anaerobic atmosphere, there are not only problems in terms of sanitation, such as deterioration of leachate water quality and odors caused by generation of hydrogen sulfide—there is also the risk that generation of methane gas will trigger fires or explosions in the landfill. However, with the Fukuoka method, air naturally flows into the landfill layer through the leachate collection/discharge pipes, so that aerobic atmosphere is maintained, and generation of methane gas and hydrogen sulfide is suppressed by vigorous microbial activity. As a result, an odor-improving effect can be expected and the landfill can be stabilized at an earlier stage. In addition, since the design prevents leachate accumulating inside the landfill layer, this method can be expected to improve the water environment both inside and outside the disposal site, compared to the anaerobic landfill method.

Furthermore, by undertaking appropriate maintenance management, the final waste disposal site can be stabilized at an earlier stage and the costs of spraying chemical agents as part of maintenance management can be reduced.

1.4. The Fukuoka method deployed outside Japan

After the Fukuoka method was adopted as the standard design for final disposal sites in Japan, the overseas deployment of this method commenced, starting with Malaysia. To date, the Fukuoka method has been introduced in more than a dozen countries. In 2011, the method was recognized as one of the Clean Development Mechanisms (CDM) under the United Nations Framework Convention on Climate Change (UNFCCC).

As part of its commitment to international environmental cooperation, in response to requests from overseas, Fukuoka Prefecture has been providing support for the introduction and maintenance of the Fukuoka method, which is the standard method for final disposal sites in Japan. To date, support has been provided in the city of Hanoi in Vietnam and the district of Sikhio in Thailand. In addition, Fukuoka Prefecture operates a chemical analysis training program at Fukuoka City Institute for Hygiene and Environment, which invites government officials engaged in environmental measures to Fukuoka Prefecture, mainly from regions with existing friendship agreements, to tackle pollution issues and take part in seminars on environmental technologies and policies, as well as site visits.

2. Current situation and issues related to final waste disposal sites in Asia

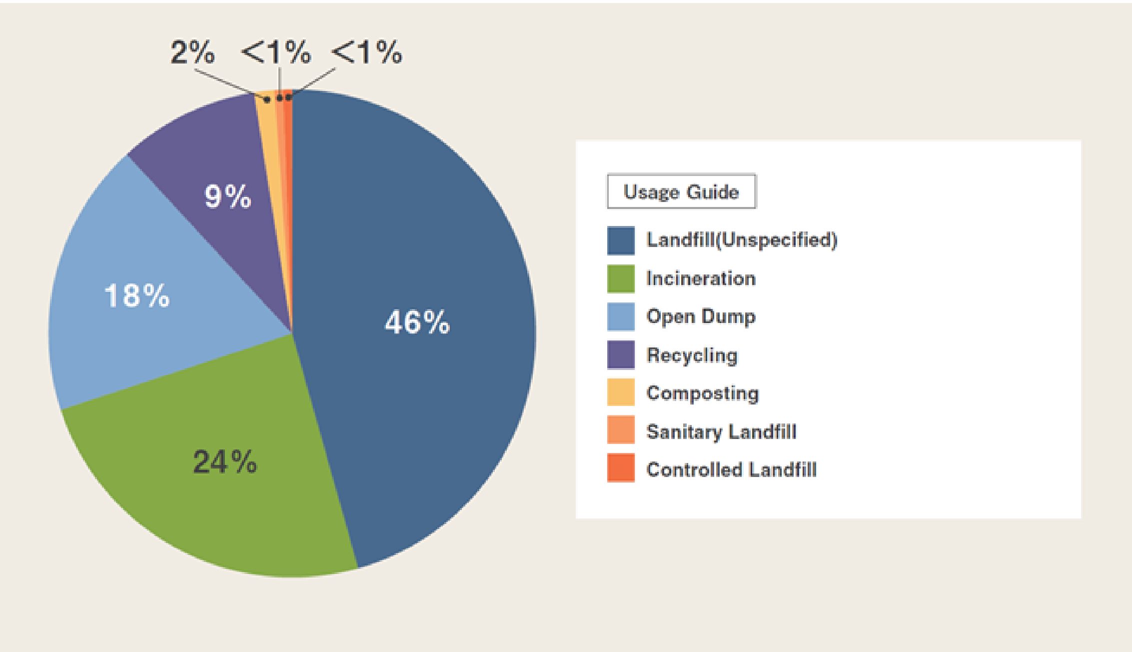
2.1. Summary

The amount of waste generated in the Asian region is increasing due to rapid population growth and economic development. In countries and regions where generation of waste has increased sharply, cases of environmental pollution and associated health damage at disposal sites have been observed due to lack of proper waste management.

This chapter first outlines the current status of landfill disposal in the Asian region. Next, as specific examples, it describes the waste disposal methods and status of final waste disposal sites in Vietnam and Thailand where Fukuoka Prefecture is providing support for the introduction and development of the Fukuoka method.

2.1.1. Status of landfill disposal in the Asian region

In the Asian region, the state of implementation of waste-related legal systems differs according to each individual country or local authority, and the status of various disposal methods also differs. The graph below shows the status of waste management in East Asia and Oceania. Disposal methods such as recycling, incineration, and other means account for only 35% of the total, and the majority of waste goes to landfill. Overall, direct landfill (method unspecified) accounts for 46% of the total and open dump accounts for 18%.



* Both "Open Dump" and "controlled landfill" are classified as anaerobic landfills. In open dump, waste is simply piled up on land, while in controlled landfills, land is excavated, then backfilled after waste is dumped. See Table 3 (p. 10) for the features of these and some aspect of sanitary landfills.

Fig. 2 Status of waste management in East Asia and Oceania
Created by World Bank Group (2018), based on the amended What A Waste 2.0

2.2. Vietnam

2.2.1. Composition of waste

The composition of household waste in Vietnam is as outlined below, taking the city of Hội An in central Vietnam as an example. The proportion of kitchen waste and plants (organic waste) is extremely high, accounting for 67.2% of the total.

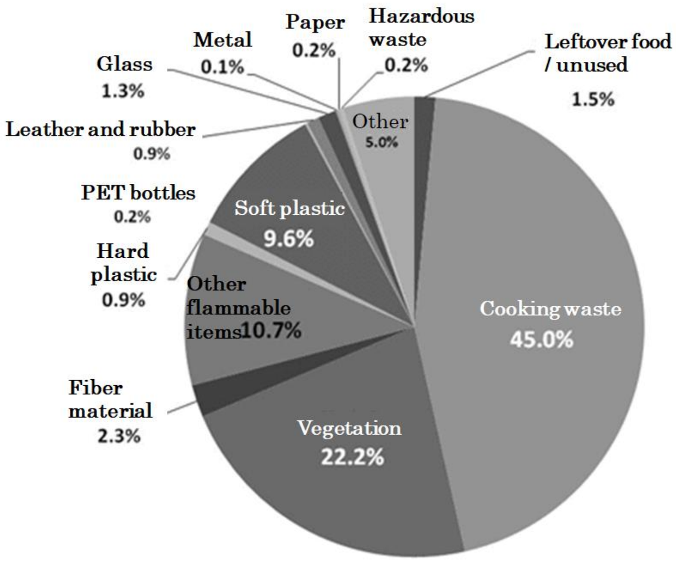
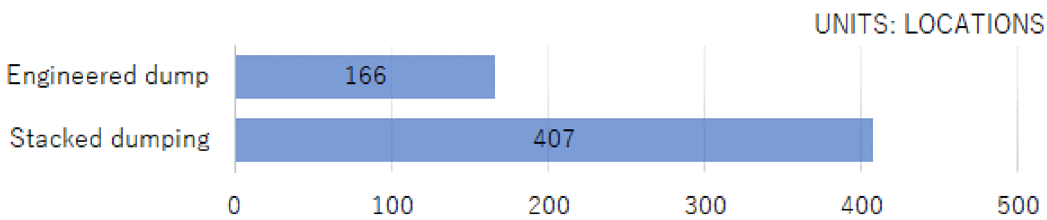


Figure 3 Hội An City Waste Composition Survey Results

Source: Dynax Urban Environment Research Institute ; Composition and Discharge of Household Waste in Hội An, Vietnam

2.2.2. Main disposal methods

The composition of final disposal sites for urban solid waste in Vietnam is as follows, based on trial calculations from the *General Overview on Solid Waste Management in Vietnam* as announced by Vietnam's Bureau of Technical Infrastructure in 2016.



	Stacked dumping	Engineered dump
Landfill method for municipal waste	407	166

"Sanitary landfills" refers to landfills where measures are taken to prevent the occurrence of unsanitary pests, etc. by covering with soil, in contrast to open dump landfills.

Fig. 4 Composition of final disposal sites in Vietnam

Source: Created based on the *General Overview on Solid Waste Management in Vietnam*, Bureau of Technical Infrastructure

It was reported that Vietnam has 573 final waste disposal sites, of which about 71% are open dumps and about 29% are engineered dumps. Semi-aerobic landfill systems, which the Fukuoka method represents, are not mentioned in this guidebook.

2.2.3. Status of disposal sites

According to Prime Minister's Decision No. 64/2003/QD-TTg (the plan for thoroughly handling establishments which cause serious environmental pollution) (hereinafter, “Prime Minister's Decision No. 1788/2013/QD-TTg”), which indicated the policy for responding to facilities causing environmental pollution confirmed within Vietnam, Vietnam recognizes that existing disposal sites are facing problems of environmental pollution.

For example, problems such as the following have been confirmed, and the following methods have been implemented as countermeasures.

Table 1 Problems and major countermeasures undertaken at disposal sites in Vietnam (one example)

Classification	Problem areas	Measures
Odors	● Unpleasant odors are diffused to some distance from the disposal site. ● Odors not only adversely affect quality of life for residents, but also promote the awareness that disposal sites are unpleasant facilities to be avoided.	● Spray with chemical agents. ● Cover over with soil.
Water pollution	● Leachate flows into surface water and groundwater and becomes an epidemiological source of various pathogens, which can adversely affect the health and hygiene of the surrounding population. ● Waste pickers igniting fires to extract metallic materials bring about pollution of soil and groundwater.	● Cover disposal site with plastic sheets. ● Designate permitted times for waste pickers to enter and exit, or comprehensively prohibit this activity.
Noxious pests, birds	● Occurrence of noxious pests and birds (see Photo (1)). Noxious pests and birds carry pathogens from disposal sites to human habitats. ● Many wild dogs have settled in to live at disposal sites. Uncontrolled dogs carry pathogens.	● Spray with chemical agents. (see Photo (2)) ● Cover over with soil.
Landfill fires	● There is the risk of ignition from neglected waste. ● There is the risk of ignition due to methane gas generated from waste.	● Separate different types of waste. Manage and recover methane gas generated.
Dispersal of waste	● Waste may be dispersed to residential housing in the surrounding area.	● Cover disposal site with plastic sheets. ● Cover over with soil.

Sources: August 2019 Survey of Disposal Sites in Vietnam / Ministry of Economy, Trade and Industry (2017) Vietnam: FS Project to Construct Oil Recycling Systems in Developing Countries / Independent study by NTT Data Institute of Management Consulting

Photo (1): This is an engineered dump site, but many pests occur here, mainly in puddles of water	Photo (2): Chemicals sprayed at a disposal site

Even if it is nominally a proper landfill site, the aforementioned problems may occur because sanitary treatments are not actually performed. Also, depending on the disposal site, even if a problem occurs, in some cases countermeasures are not taken and problems cannot improve. This situation has led to opposition campaigns by residents.

2.3. Thailand

2.3.1. Composition of waste

The composition of household waste in Thailand is as outlined below. The proportion of organics is extremely high, accounting for 64% of the total.

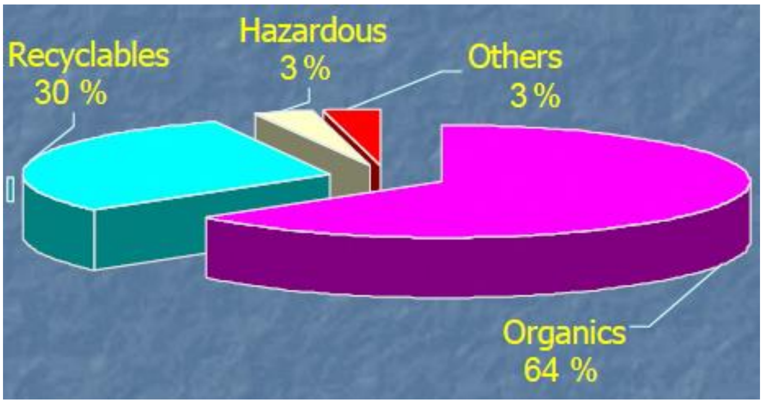
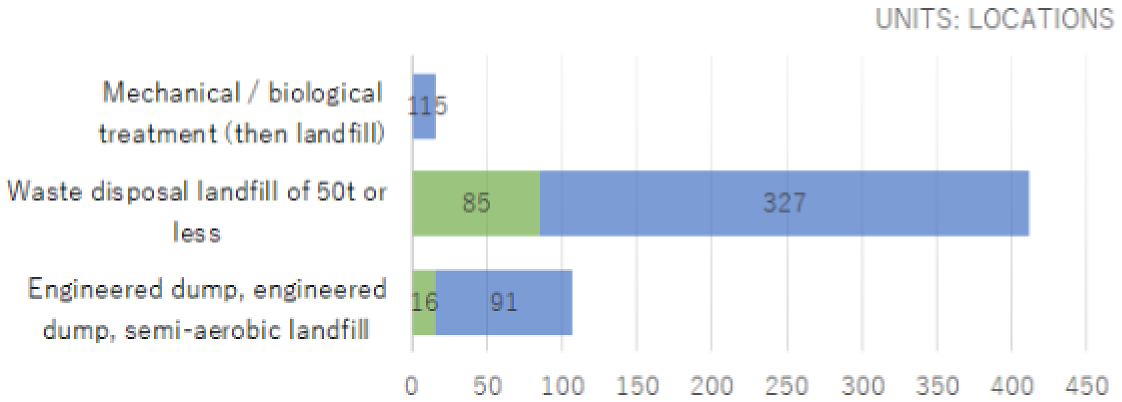


Figure 5: Waste composition in Thailand

Source: Pollution Control Department, Ministry of Natural Resources and Environment, Thailand, Thailand's Waste Minimization

2.3.2. Main disposal methods

According to the *2018 Annual Report of Waste Disposal Sites Status in Thai*, the composition of final disposal sites in Thailand was as follows.



	Engineered dump, engineered dump, semi-aerobic landfill	Waste disposal landfill of 50t or less	Mechanical / biological treatment (then landfill)
Privately operated	16	85	1
Operated by local government	91	327	15

Fig. 6 Composition of final disposal sites in Thailand
Source: Created based on the *2018 Annual Report of Waste Disposal Sites Status in Thailand*, Pollution Control Department

Most final waste disposal sites in Thailand are operated by local governments. About 76% of these disposal sites are open dumps. Disposal of waste in semi-aerobic landfills (the Fukuoka method), engineered dumps, and sanitary landfills account for about 20% of the total.

2.3.3. Status of disposal sites

For example, the following problems have been confirmed mainly in dumping-type landfills, which represent the majority, and the following methods have been implemented as countermeasures.

Table 2　Problems and major countermeasures undertaken at disposal sites in Thailand

Classification	Problem areas	Measures
Odors	● Unpleasant odors are diffused to some distance from the disposal site. ● Odors not only adversely affect quality of life for residents, but also promote the awareness that disposal sites are unpleasant facilities to be avoided.	● Spray with chemical agents. ● Cover over with soil.
Water pollution	● Leachate flows into surface water and groundwater (see Photo (1) below) and becomes an epidemiological source of various pathogens, which can adversely affect the health and hygiene of the surrounding population. ● Waste pickers igniting fires to extract metallic materials bring about pollution of soil and groundwater.	● Cover disposal site with plastic sheets. ● Designate permitted times for waste pickers to enter and exit, or comprehensively prohibit this activity.
Noxious pests, birds, wild dogs	● Occurrence of noxious pests and birds. Noxious pests and birds carry pathogens from disposal sites to human habitats. ● Many wild dogs have settled in to live at disposal sites (see Photo (2) below). Uncontrolled dogs carry pathogens.	● Spray with chemical agents. ● Cover over with soil.
Landfill fires	● There is the risk of ignition from neglected waste. ● There is the risk of ignition due to methane gas generated from waste.	● Separate different types of waste. ● Manage and recover methane gas generated.
Dispersal of waste	● Waste may be dispersed to residential housing in the surrounding area.	● Cover disposal site with plastic sheets. ● Cover over with soil.

Sources: October 2019 Survey of Disposal Sites in Thailand, Independent study by NTT Data Institute of Management Consulting

Photo (1): Water leaching from waste

Photo (2): Wild dog at the site

In some landfills, garbage may continue to build up because the amount of garbage dumped is beyond the capabilities of the local government to handle. Moreover, since garbage may pile up without a covering of soil, the aforementioned problems of odors and pests are likely to occur.

3. What is the Fukuoka method?

3.1. Positioning of final waste disposal sites

Except in cases of illegal dumping, etc., waste is collected and disposed of by recycling (material recycling), converting into fuel (thermal recycling), incineration, and other methods. The final waste disposal site ultimately receives and disposes of any residue remaining after such disposal methods, as well as items that are difficult to recycle.

3.2. Landfill classification

（1） Site classifications

Final landfill sites can be classified into “land-based landfill” and “water surface landfill” sites. Land-based landfills can be further divided into "mountainous landfills" and "flat landfills." Mountainous landfills are disposal sites located in mountainous areas or valleys, while flat landfills are disposal sites located on flat land. Water surface landfills are disposal sites located on the surface of seawater or inland waters.

（2） Structural classifications

The design of final disposal sites can be principally divided into four types: anaerobic landfill, improved anaerobic sanitary landfill (engineered dumps), semi-aerobic landfill, and aerobic landfill. The structural features of each structure and the advantages and disadvantages of introducing it are shown in Table 3 below.

Table 3 Main features of each landfill method, and advantages & disadvantages of introduction

Landfill classification	Features	Advantages (+) & disadvantages (-)
Anaerobic landfill (open dumps, controlled dumps, sanitary landfills)	● Maintained in an anaerobic state, with no air (oxygen) supplied to the landfill interior ● Flat land is excavated, or waste is dumped into valley areas. ● Waste is soaked in water.	(+) The construction method is simple. (-) Generates a large amount of gas, including methane, hydrogen sulfide, and carbon dioxide. (-) High BOD and COD values of leachate.
Improved anaerobic engineered dumps (sanitary landfill)	● In addition to seepage barrier works, collection pipes are installed in the bottom layer of the anaerobic sanitary landfill.	(+) Since groundwater and leachate in the landfill layers are drained through the collection pipes, when the water treatment system is functioning effectively, this type of landfill is effective in preventing groundwater contamination. (-) Since air (oxygen) is not supplied into the landfill's interior, the landfill enters an anaerobic state, just like an anaerobic landfill.
Semi-aerobic landfill	● A gas venting and leachate collection/discharge pipes with a sufficiently large cross-section is installed, with its opening in contact with the atmosphere, and the area surrounding the collection/discharge pipes are packed with stone rubble or similar filter material. ● The moisture level inside the waste layers is low, and air is naturally supplied into the waste layers via the collection/discharge pipes.	(+) Promotes decomposition of landfill waste and improves leachate quality. (+) Suppresses generation of methane gas, contributing to prevention of fires and prevention of global warming. (+) Promotes the stabilization process, enabling earlier use of landfill sites. (+) Comparatively lesser quantities of sprayed chemicals are needed for sterilization, deodorization, and control of unsanitary insects. (-) This structure is designed to lower the BOD value of leachate, so it is not suitable for landfills of waste such as glass or ceramics.
Aerobic landfill	● In addition to the collection/discharge pipes, semi-aerobic landfills are equipped with air inlet pipes, through which air is forced to create a more aerobic state inside the waste layers.	(+) The interior of the landfill is in a more aerobic state than the semi-aerobic type, leading to earlier stabilization of the landfill. (-) It is necessary to introduce equipment such as blowers to force the air to flow in, which entails additional costs.

3.3. Structural features of the Fukuoka method

A structural overview of the Fukuoka method was outlined in Chapter 1, but the structural characteristics of the Fukuoka method will be explained here in greater detail.

The Fukuoka method has two principal structural features. These are prevention of seepage of leachate into landfill foundation ground and inflow of air into the landfill layers due to fermentation heat, following the installation of the collection/discharge pipes.

3.3.1. Prevention of seepage of leachate into landfill foundation ground

Fig. 7, in the Fukuoka method, perforated pipes and seepage barrier sheets are laid at the bottom of the landfill, with stone rubble packed around them. In this method, leachate is drained to the leachate regulating pond and to treatment facilities outside the landfill via the collection/discharge pipes without seeping outside the landfill. Another feature of this structure is that not only is leachate not retained in the landfill layer, but also that the aerobic region is expanded by increasing the gas phase gap in the layer.

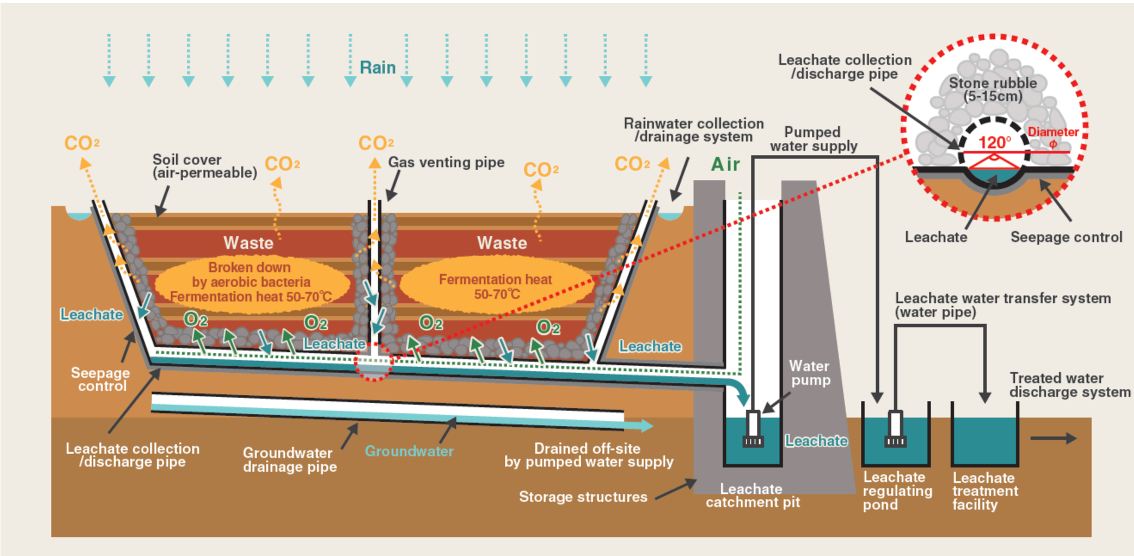


Fig. 7 Structural diagram of the Fukuoka method (created by Fukuoka Prefecture)

3.3.2. Inflow of air into interior layers caused by fermentation heat in the landfill

The temperature inside the landfill rises (to 50–70°C) because fermentation heat is generated in the landfill layers by microbial decomposition of waste. As shown in Fig. 7, in the Fukuoka method, the installation of the collection/discharge pipes causes thermal convection due to the temperature difference between the inside and outside of the landfill, with air (oxygen) flowing inward through the collection/discharge pipes, in the opposite direction to the leachate flowing out into the leachate collection pit. Maintaining the landfill layers in an aerobic state stimulates the activity of microorganisms inside the layers, promoting aerobic microbial decomposition.

For this reason, it is very important to constantly keep the water level in the leachate collection pit at a lower elevation than the end of the leachate collection/discharge pipes, so that air can always flow in from the outlet of the collection/discharge pipes.

Further, since the Fukuoka method creates both an aerobic state and an anaerobic state in the landfill layer, nitrification and denitrification reactions are more likely to occur. Under these conditions, the nitrogen contained in leachate is easily removed, which is advantageous.

3.4. Usefulness of the Fukuoka method

This section explains the usefulness that can be expected when the Fukuoka method is introduced, in comparison with anaerobic landfill methods.

3.4.1. Reduction of costs related to leachate treatment facilities

(1) Stabilization of waste through effective use of the purification capacity of nature

In order to decompose waste more quickly as well as improve the water quality of leachate in the landfill and discharge it off-site, it is necessary to make the interior of the landfill layer aerobic. In the Fukuoka method, thermal convection occurs due to the temperature difference between the landfill's interior (fermentation heat from microorganisms) and exterior (ambient air temperature), with air (oxygen) naturally flowing inside through the collection/discharge pipes. Additionally, leachate generated from disposal sites using this method has a lower concentration of organic pollutants than anaerobic landfill methods, which leads to reduction of costs related to leachate treatment facilities.

3.4.2. Purification of water environment & atmospheric environment

（1） Purification of water environment

Table 4 compares the quality of leachate in the Fukuoka method with anaerobic landfill methods. When landfilling is continuous, BOD and COD values for leachate under both landfill systems increase to around 40,000–50,000 mg/L, respectively, and the pH becomes around 6.0. At this point, there is no difference in water quality between the anaerobic landfill method and the Fukuoka method; however, the Fukuoka method promotes decomposition of waste in the interior layers after landfill, which improves the quality of leachate. Water quality under the anaerobic landfill method 6 months after dumping is almost the same as for continuous landfill, whereas under the Fukuoka method, BOD value decreases to 5,000–6,000 mg/L and COD value decreases to 10,000 mg/L, while pH increases to around 8.0. Moreover, two years after landfill is complete, improvements in the water environment at disposal sites are evident and even faster with the Fukuoka method than with anaerobic landfill.

Table 4 Landfill method and leachate water quality

Category		Continuous landfill	6 months after landfill is complete	1 year after landfill is complete	2 years after landfill is complete
Anaerobic landfill method	BOD (mg/L)	40,000–50,000	40,000–50,000	30,000–40,000	10,000–20,000
	COD※ (mg/L)	40,000–50,000	40,000–50,000	30,000–40,000	20,000–30,000
	NH_3-N (mg/L)	800–1,000	1,000	800	600
	pH	Around 6.0	Around 6.0	Around 6.0	Around 6.0
	Degree of transparency	0.9–1.0	1–2	2–3	2–3
The Fukuoka method (Semi-aerobic landfill method)	BOD (mg/L)	40,000–50,000	5,000–6,000	100–200	50
	COD※ (mg/L)	40,000–50,000	10,000	1,000–2,000	1,000
	NH_3-N (mg/L)	800–1,000	500	100–200	100
	pH	Around 6.0	Around 8.0	Around 7.5	7.0–8.0
	Degree of transparency	0.9–1.0	1–2	3–4	5–6

* Analysis by $K_2Cr_2O_2$ method

Source: Masataka Hanashima, Koreyoshi Yamazaki, Yasushi Matsufuji (1981) *Excerpt from experimental research on waste landfill structures*

（2） Purification of atmospheric environment

The Fukuoka method generates lower quantities of hydrogen sulfide and volatile organic compounds than anaerobic landfill methods, and therefore can be expected to reduce odors that might cause troubles with local residents. Local governments that have actually introduced the Fukuoka method have reported improvement of unpleasant odors.

3.4.3. Reduction of greenhouse gases

（1） Theory of greenhouse gas reduction

Greenhouse gases are generated in the process of waste decomposition at final disposal sites. The principal gases generated include carbon dioxide (CO_2) and methane (CH_4). Methane has a Global Warming Potential (GWP) of 25, which is 25 times the greenhouse effect of carbon dioxide (which has a Global Warming Potential of 1).

The design of the anaerobic landfill method allows very little air to flow into the waste layers, so that oxygen levels are often insufficient and carbon dioxide and methane are more easily generated. The semi-aerobic design of the Fukuoka method promotes aerobic decomposition of waste. The carbon in the waste combines with the oxygen supplied through the collection/discharge pipes to produce carbon dioxide, suppressing the generation of methane. Carbon dioxide thus generated is discharged externally through gas venting facilities installed in on-site. Adopting the Fukuoka method for landfill enables reduction of greenhouse gas emissions compared to anaerobic landfill methods. As outlined above, the Fukuoka method is a technique that suppresses generation of methane gas from landfills and contributes to climate change countermeasures.

（2） Certified as a CDM method

At the United Nations CDM Executive Board meeting held in Morocco in July 2011, use of the Fukuoka method was recognized as a CDM method (AM0093: Avoidance of landfill gas emissions by passive aeration of landfills) to suppress methane gas emissions from existing landfill sites. The CDM is a project to reduce greenhouse gas emissions in developing countries through funding and technical assistance from developed countries. This system can be used to achieve reduction targets for developed countries, as it enables developed countries to acquire, as emission quotas, amounts equivalent to the reductions generated by the project, either in whole or in part.

3.4.4. Earlier use of former landfill sites

One advantage of the Fukuoka method is that sites can be used earlier because the period until stabilization is shorter than with other landfill methods (anaerobic landfill methods, etc.). In Japan, this method is used not only for greening, but also for public facilities, including sports facilities and multipurpose plazas, and sites for solar power generation.

Photo: Example utilization of former landfill site (Solar power plant: DINS Mega Solar)

Photo courtesy of Daiei Kankyo Holdings

4. Basic conceptual points for introducing the Fukuoka method

4.1. Methods of managing final waste disposal sites

Final waste disposal sites are owned, financed, designed/constructed, operated, and dismantled by governments (including local governments) or private companies.

Public-private partnerships that provide public services are also known as PPP. PFI (Private Finance Initiative) is a typical PPP method. It intends to provide efficient and effective services by having the private sector take a leadership role in ownership, financing, design/construction, operation, and dismantling of public facilities and other facilities.

As shown in Table 5, the PFI business method can be further subdivided depending on the jurisdiction over ownership, financing, design/construction, operation, and dismantling of facilities.

Table 5 Comparison of PFI business methods

Method	Facility ownership	Financing	Design/construction	Operation	Facility dismantling
BOO (Build Operate Own)	Private	Private	Private	Private	Private
BOT (Build Operate Transfer)	Private	Private	Private	Private	Public
BTO (Build Transfer Operate)	Public	Private (public)	Private	Private	Public
DBO (Design Build Operate)	Public	Public	Private	Private	Public

* DBO is a PFI method, but it is also known as a "quasi-PFI business method" because it does not use private funds.

Created by the Japan Waste Management Association (2010), based on planning, design, and management guidelines for the development of final waste disposal sites

The selection of potential final waste disposal sites varies from country to country.

In Vietnam, final waste disposal sites in many cases have adopted the DBO method, in which the local government raises funds and the private sector designs, constructs, and operates the facility. On the other hand, in Thailand, final waste disposal sites have adopted the BOO method in many cases, in which private companies are responsible for all aspects, including facility ownership and financing.

4.2. Steps and procedures for establishing final waste disposal sites

Since the procedures related to final waste disposal sites will vary depending on the implementing country, please refer to the legal system, etc. for more details.

In Japan, consideration moves forward as shown in Fig. 8. The procedures for setting up a final waste disposal site can be broadly classified into the planning/concept stage, the scheduling/project stage, the business provider selection stage, the (design) construction stage, and the shared use stage. The main procedures for construction of disposal sites include the formulation of a basic plan for general waste treatment based on the Waste Disposal Act, the implementation of an environmental impact assessment, and the ordering of facility construction work.

This guide explains some basic policies and points for consideration in the planning, design, construction, and maintenance of the Fukuoka method landfills, and introduces some cases from Japan, Vietnam, and Thailand.

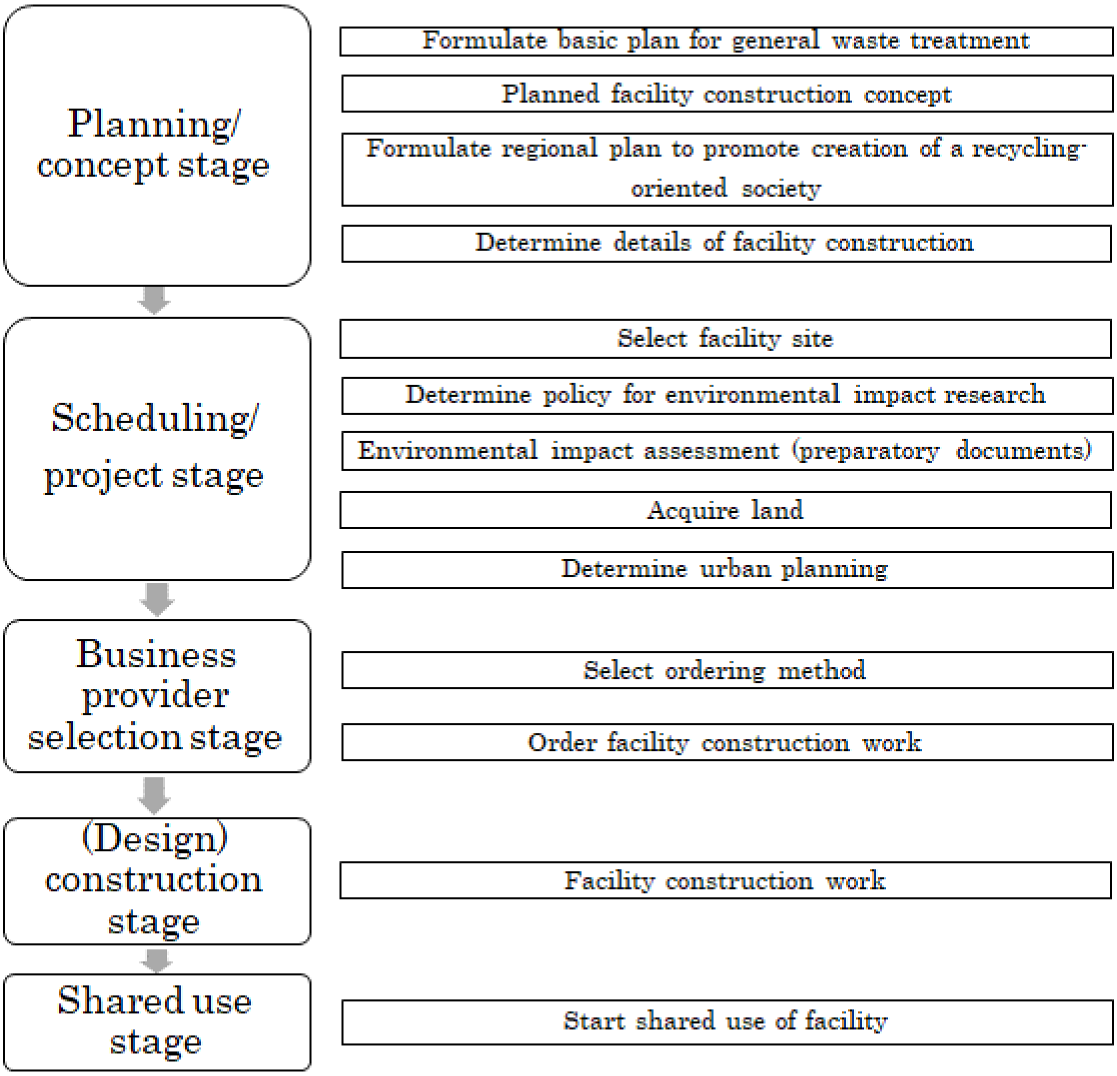


Fig. 8 Items and details for implementation of final waste disposal site facilities improvement in Japan
Created by the Japan Waste Management Association (2010), based on the amended 2010 planning, design, and management guidelines for the development of final waste disposal sites improvement

In the case of Thailand, the steps differ for (1) public construction of sites and (2) the PFI method. Procedures for establishing final disposal sites are specified in the Public Health Act, the Maintenance of Cleanliness and Orderliness of the Country Act, and the Determining Plans and Processes for Decentralization Act, among others.

(1) In the case of public construction, the local government acquires land, conducts site surveys, carries out detailed design, and then conducts public hearings. A request is made to the Office of Natural Resources Environmental Policy and Planning (ONEP) for the budget, and if the requirements are met, the central government will allocate the budget to the local government. After that, the local government will undertake the bidding process for construction.

(2) In the case of PPP, after the land is acquired, the implementing entity conducts a field survey to confirm whether the financial situation is likely to be adequate, and obtains approval from the prefectural waste management committee and the Central Committee for Solid Waste Management under the jurisdiction of the Ministry of Interior. After that, the local government prepares the terms of reference, then conducts legal checks with the national law office. After that, bidding for construction is conducted.

In the case of Vietnam, all are public. When setting up a final waste disposal site, before implementing the project, an environmental impact assessment should be conducted based on the "Circular on Strategic Environmental Assessment, Environmental Impact Assessment and Environmental Protection Plans" (27/2015 / TTBTNMT). At this time, it is essential to obtain consent from residents. After that, the next stage is deciding on the specific area for the final waste disposal site, the project design, and review and examination of the project. These implementation procedures are based on governmental decisions such as ND 68/2019/ND-CP 01/10/2019 Decision 59 (Decision on Management of Construction and Investment projects).

4.3. Site selection

An example of suitable site selection survey flow is shown in Fig. 9 below. When selecting a suitable site in Japan, the legal and regulatory status of land use should first be checked and the candidate facility sites extracted. Based on the results of this first stage, candidate sites that satisfy the geographical conditions are extracted into the second stage. In the third stage, any candidate sites that present planning difficulties are excluded, taking into account field surveys, economic evaluations, etc. Finally, each of the extracted candidate sites is evaluated, and a final candidate site is selected.

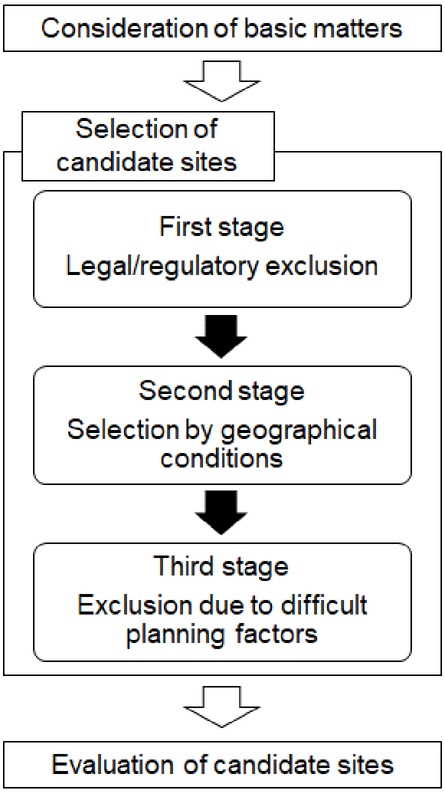


Fig. 9 Example procedure for selecting candidate sites

Created by the Japan Waste Management Association (2010), based on the amended 2010 planning, design, and management guidelines for the development of final waste disposal sites improvement

Looking at overseas cases, regarding regulations for surveying suitable sites, as well as design, construction, and management, Vietnam has established relevant standards, including solid waste burial site design standards (TCXDVN 261: 2001) and standards of waste water of solid waste burial sites (TCVN 7733: 2007 Water quality), etc.

In Thailand, the relevant laws include provisions for considering suitable sites based on public advice from the Pollution Control Department regarding "Regulations on examination of suitable sites and design, construction, and management of engineered dump sites created by sanitary landfill methods," as well as “Regulations for selecting landfills for sanitary landfill sites” announced by the Ministry of Health (2017).

As described above, the laws and regulations relating to the selection of suitable sites vary from country to country. Therefore, when planning a final waste disposal site, it is essential to check local laws and procedures for selecting suitable sites before proceeding. Information and items for consideration helpful in selecting candidate sites are shown from 4.3.1 to 4.3.5 below.

4.3.1. Consideration of basic aspects

When considering basic aspects, assessment items related to waste collection/transport conditions, surrounding area conditions, terrain topology/geology, safety in case of disasters, etc. all need to be organized in advance. In addition, when selecting a final waste disposal site, it is necessary to calculate the amount of landfill waste and to understand the properties of this waste.

(1) Calculation of landfill waste

When calculating the amount of landfill waste, the expected amount of waste and soil cover quantity (same-day soil cover, interim soil cover, final soil cover) need to be considered.

(2) Understanding the properties of waste

When planning a final waste disposal site, it is important to have an understanding in advance of the properties of presumed waste materials in the area. Items sent to the Fukuoka method disposal sites should not include hazardous waste items, such as medical waste. It is also desirable that garbage such as food waste is mainly treated as raw waste, and also that waste does not contain a significant proportion of plastic, glass, ceramics, or the like. In addition, sharp objects should be removed because these can damage the seepage barrier sheeting.

To this end, depending on the properties of the waste, it is effective to introduce a waste separation process before burial at the final disposal site, and to carry out awareness-raising activities among local residents for waste separation.

4.3.2. First stage (exclusion due to laws and regulations)

In the first stage, the scope of selection for candidate sites is set, and any areas where location of a final disposal site would prove legally difficult are excluded. Basic information is gathered on laws and regulations related to licensing examinations, as well as social aspects.

4.3.3. Second stage (selection based on geographical conditions)

In the second stage, candidate sites having suitable topography for a final disposal site are selected from the regions extracted in the first stage. For reference, points for confirmation are listed below.

- Whenever possible, construction on non-permeable ground is ideal.
- The surface soil conditions are confirmed.
- Soft ground and places where uneven ground subsidence is a possibility are avoided, in favor of sites where load-bearing capacity and safety can be expected.
- Areas at risk of landslides or landslips are avoided.
- Areas of frequent storm water spillover, irrigation water sources, and locations where water intakes are directly downstream are avoided.
- The presence or absence of groundwater in the rainy season and dry season is confirmed, with reference to existing literature.
- Groundwater availability (water level, flow direction) around the proposed disposal site is estimated by site surveys.

4.3.4. Third stage (exclusion due to difficult planning factors)

In the third stage, for the candidate sites extracted in the second stage, land use status, siting, water use status, landscape, etc. are confirmed by means of field surveys. Also, in considering landfill area, landfill capacity, economic aspects, etc., candidate sites that include difficult planning factors are excluded.

4.3.5. Evaluation of candidate sites

Finally, to evaluate the candidate sites, the candidate sites extracted in the third stage are each ranked in priority based on the established evaluation criteria. Methods for ranking priority might include displaying each evaluation item as ○, △, or ×, then assessing by a comparison table, or else assessing the total of weighted scores for each evaluation item, etc.

4.4. Environmental impact assessment

The objective of conducting an environmental impact assessment is to assess the potential impact on surrounding areas that may arise from the construction of a treatment facility. For environmental impact assessments, the basic flow involves conducting surveys during the construction period, the landfill implementation period, and after the landfill is completed; however, the surveyed items will vary depending on the country and local authority, and each country’s standards should be met. This section will introduce some examples from Thailand and Vietnam.

4.4.1. Implementing environmental impact assessments

(1) Thailand

In Thailand, impact assessments are conducted regarding the following four aspects of environmental resources. Analysis is conducted based on these aspects, and the impact on the surrounding environment is evaluated.

- Physical Environmental Resources
  - Air quality, surface water quality, groundwater sources, topography, etc.
- Biological Environmental Resources
  - Forest resources, wildlife, etc.
- Human Use Values
  - Land use status, public transportation, use values of water sources, etc.
- Quality of Life
  - Economic status, neighboring communities, workplace safety, public health, landscape and recreation, etc.

The scope of the environmental impact assessment should conform to the assessment policy laid forth by the Department of Environmental Quality Promotion. Within environment conservation areas, it is necessary to carry out an EIA (Environment Impact Assessment) if more than 50 tons will be transported there per day, and an IEE (Initial Environmental Evaluation) if less than 50 tons will be transported per day. Subsequently, when explaining to local residents, an agreement will be reached.

(2) Vietnam

Chapter Ⅲ: Environmental Impact Assessment in Vietnam's basic law regarding waste (Law on Environmental Protection: Law No. 55/2014/QH13) stipulates the items for impact assessment and prediction as follows.

- Natural environmental conditions
  - Climatic and weather conditions, hydrological and marine conditions, soil, water, and atmospheric environment quality, biological resources, etc.
- Socio-economic conditions
  - Economic conditions, social conditions
- Environmental impact prediction
  - Predictions of impact during the project's preparation, construction, operation, and any other phases (dismantling, renovation, etc.)
  - Prediction of project risks and impact due to incidents

4.4.2. Measures to reduce the adverse effects of environmental impact assessment

Based on the results of the environmental impact assessment, for any items deemed harmful to the surrounding environment, a countermeasure plan is considered to minimize the impact. Table 6 shows examples of measures to reduce adverse effects during the construction period and the landfill implementation period.

Table 6 Measures to reduce adverse environmental effects associated with construction of final disposal sites (example)

Item	Example measures to reduce adverse environmental effects	
	Construction period	Landfill implementation period
[Aspects related to physical resources]		
Ground water sources		● Installing leachate treatment facilities ● Maximizing the utilization of treated water within disposal site (watering trees in and around the site, etc.)
Groundwater		● Laying down seepage barrier materials on the bottom of the landfill ● Reinforcing the ground foundation beneath the landfill
Atmosphere	● During transport, completely covering earth and sand loaded on trucks with tarpaulins, etc., and avoiding overloading.	● To prevent dust being dispersed by moving vehicles, spreading gravel to smooth out road surfaces and spraying water regularly.
[Aspects related to human use values]		
Traffic	● Ensuring that material delivery routes avoid local community areas ● Ensuring that transport avoids times when traffic is heavy ● Installing road signs and signals on the roads used ● Requesting police cooperation	● Installing signs on roads leading to the disposal site to limit traffic speeds. ● Completely covering waste materials during transport
[Aspects related to quality of life]		
Economic-social	● Employing people who reside nearby ● Preparing welfare and benefits for workers	
Public health	● Conducting health check-ups for employees ● Conducting training on potential health hazards associated with construction work. ● Setting up a first-aid room ● Scattering water on roads to prevent dust	● Conducting annual health check-ups for employees
Landscape	● Installing fences around the construction site	● Completing landfill work each day ● Closing gates after end of work each day
Noise	● Setting up delivery routes that are considerate of local residents ● Setting speed limits for transport vehicles ● Informing local residents in advance when noise will occur at night	● Performing regular equipment maintenance ● Tree planting
Unpleasant odors		● Completing landfills on a daily basis to prevent stagnant water pooling around landfills ● Covering over with soil

Source: JICA (2019) The Fukuoka Method Development Guidelines for Thailand (created by JICA Grassroots Cooperation Project)

4.5. Building consensus with neighboring residents

It is assumed that obtaining the approval of local residents at the final disposal site will be difficult, due to environmental and technical concerns, among others. Accordingly, it is important to explain to the residents the details of the plan, methods of introduction, environmental impact, countermeasures against environmental impact, etc., and to reach consensus. In actual consensus building, responses should follow the deliberative process of each local authority.

Different countries have different laws. For example, Vietnam has Government Decision 40/2019/ND-CP (No. 40/2019) under the Environmental Law, which is a law about explaining to residents. In Thailand, details of conducting public hearings with residents are stipulated in the Special Item 55 of 122 of Royal Thai Government Gazette.

5. Sequence of points and items to implement from initial design to use of former landfill site

5.1. Design

When designing and constructing sites following the Fukuoka method, various consideration is required in advance to prevent any impact on public health, hygiene, and the environment surrounding the disposal site. This section outlines the considerations required during the design stage.

5.1.1. Estimation of required landfill capacity

Estimation of the required capacity of the landfill is calculated based on the area of the project site and the volume of waste.

5.1.2. Basic structural design

The basic structural design should comply with each country's design standards for final landfill sites.

For example, in Vietnam, TCVN (National Standard) 6696: 2000 exists as a general requirement for solid waste landfills.

(1) Construction design

① Basic principles

The landfill design should be considered after first examining the properties of the waste going to landfill, as well as the topography, geology, surrounding environment, and construction costs of the planned site. However, depending on the topographical conditions, the points to keep in mind for the construction design will vary. Points to keep in mind when designing embankments and earth cuts are shown below.

② Points to keep in mind about embankments

(A) Embankments on sloping ground

- In the case of embankments built on sloping ground (such as mountainous sites), foundations may be unstable and the design may involve creating many high embankments facing the valley side. This will require drainage countermeasures such as underground drainage, drainage installed at the base of inclines, etc., as well as cutting of steps.

(B) Embankments at cut-and-fill boundaries

- At the boundaries between earth cuts and filling, embankments may sink, causing a level difference to occur after work is complete. For this reason, countermeasures should be taken, such as underground drainage channels, rounding work on cut and fill boundaries, step cutting, and compaction of thinner layers.

(C) Step cutting

- If the embankment foundation ground is inclined, design should allow for step-shaped cuts to be made on the inclined ground.

③ Points to keep in mind about earth cutting

(A) Earth cutting in terrain prone to landslides or collapsing

- Care should be exercised when cutting in terrain prone to landslides or collapsing, as excavation can disrupt the balance of the land.

(B) Earth cutting in areas with water sources

- If a water source is found on sloping land, the water should be drained near the source to avoid deterioration of ground.
- If the quantity of spring water is large, vertical drainage channels should be installed.
- Advance consideration of treatment or cleaning of this spring water should be carried out after it has been directed to drainage channels.

(C) Long or massive earth cuts

- Since areas where long or massive earth cuts are performed will have large inclined surfaces, the geology of the entire slope will rarely be uniform.
- Preliminary surveys should be carried out to determine whether the cut slope contains unstable ground (expanding materials such as Neogene mudstone or serpentine).
- Be careful when cutting earth along the groundwater level before excavation, as groundwater levels may be out of balance.

(2) Design of gas venting equipment

The main objectives of installing gas venting equipment are: (1) Treating landfill gas; (2) Supplying air to promote landfill stabilization; and (3) Collecting and draining leachate through perforated pipes. Regarding specific designs, please consider the following points.

- From start to completion of landfill, it should have the capacity to treat gas generated inside the landfill layers and on the surface of the landfill layers.
- The layout and structural design should not obstruct landfilling of waste or use of the site.
- The structure should promote stabilization of the landfill layer.
- It should have a complementary role as a collection/discharge pipes.

In addition, in order to stabilize the final waste disposal site as soon as possible, additional introduction of gas venting equipment should be considered (depending on the status of gas discharge after landfill), and the plan should move forward in consideration of the impact on the environment surrounding the disposal site.

① Configuration of gas venting equipment

Gas venting equipment consists of incline gas venting equipment and vertical gas venting equipment. As it is possible that the gas venting equipment may be damaged during landfill work, it is important to adopt a design that is easy to install and reduces costs.

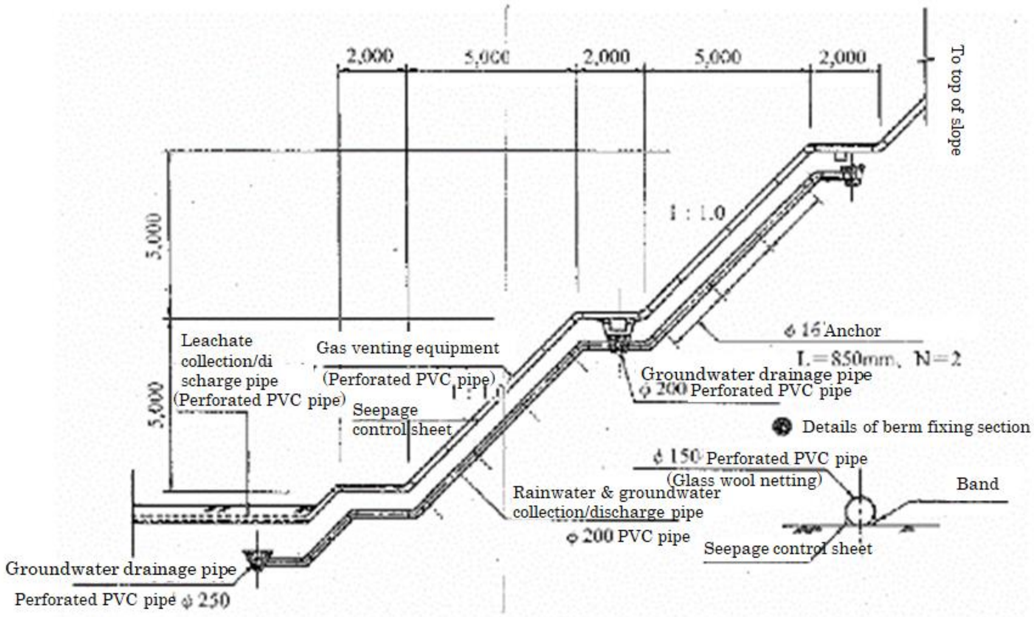


Fig. 10 Example of incline gas venting equipment

Created by the Japan Waste Management Association (2010), based on the amended 2010 planning, design, and management guidelines for the development of final waste disposal sites improvement

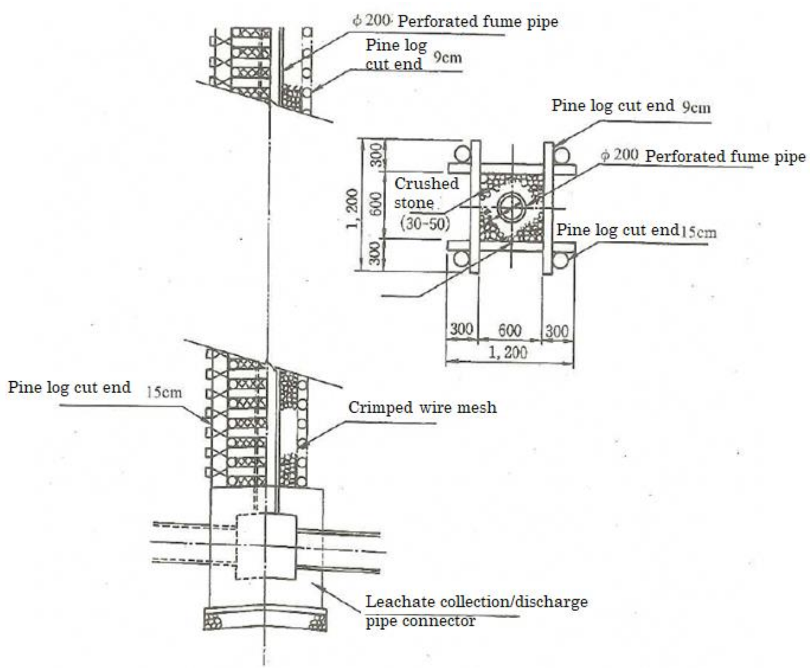


Fig. 11 Example of vertical gas venting equipment

Created by the Japan Waste Management Association (2010), based on the amended 2010 planning, design, and management guidelines for the development of final waste disposal sites improvement

② Materials of gas venting equipment

Usually, gas venting equipment is composed of perforated pipes and gabions (cages woven with steel wire or similar material and filled with stone rubble). Materials for the perforated pipes include Hume pipes, PVC pipes, polyester pipes, steel pipes, or the like.

③ Points to keep in mind

In the design of gas venting facilities, appropriate equipment should be selected and its layout considered, taking into account the properties of the landfill gas and any changes over time, the thickness of the landfill layer, the landfill method, the environment surrounding the landfill, and landfill working conditions. In particular, for the purpose of early stabilization of the disposal site and to prevent fires and workplace accidents, the design should prevent the generation of malodorous gases such as methane and hydrogen sulfide as far as possible.

In addition, due to the accumulated weight of waste, soil covering, and heavy equipment as the landfill progresses, the design should adequately take into account the heavy load applied to the parts connecting the bottom leachate collection/discharge pipes and the vertical gas venting equipment. One example of countermeasure might be reinforcing strength by laying stone rubble around the parts connecting the bottom leachate collection/discharge pipes and the vertical gas venting equipment.

(3) Design of leachate collection and discharge equipment

The main purpose of the leachate collection/discharge pipes are to quickly drain the leachate from the landfill to outside the site and supply air into the landfill's interior. For this reason, an appropriate pipes diameter should be determined also in consideration of air supply. In addition, the scale of the leachate treatment facility and the scale of the leachate regulating pond should be considered regarding past rainfall data so that appropriate wastewater treatment can be performed.

① Structure of leachate collection and discharge equipment

The leachate collection and discharge system consists of five elements: (1) Bottom collection pipes, (2) Sloping collection/discharge pipes, (3) Vertical collection/discharge pipes, (4) Water catchment pit, and (5) Water pipes. The functions that each has are shown in Table 7 below.

Table 7 Structural components of collection/discharge pipes and their functions

No.	Item	Main functions
①	Bottom collection pipes	・Collection of leachate ・Drainage to (4) Water catchment pit
②	Sloping collection/discharge pipes	・Vertical collection and drainage of leachate to landfill ・Discharge of generated gas
③	Vertical collection/discharge pipes	・Vertical collection and drainage of leachate to landfill ・Discharge of generated gas
④	Water catchment pit	・Sending water to leachate treatment facility ・Allowing inflow of air from outside
⑤	Water pipes	・Leachate from the water catchment pit is pumped and sent to the leachate drainage facility

② Materials of leachate collection/discharge pipes

Example materials for leachate collection/discharge pipes include lightweight, easily machined, and highly corrosion-resistant materials such as high-density polyethylene pipes.

③ Points to keep in mind

Leachate collection and discharge equipment is difficult to repair after landfill work commences. Accordingly, conditions for the leachate collection/discharge pipes such as clogging or subsiding of leachate collection/discharge pipes, internal storage conditions, facility operation periods, and the collection/discharge pipes always being exposed to the atmosphere, as well as the properties of waste, pipes construction materials, etc. need to be considered in advance when designing.

Also, when designing in areas where intensive rainfall due to sudden squalls, etc. can be expected, the leachate collection and discharge equipment, pipe diameters, etc. should be capable of handling the maximum daily rainfall (during sudden squalls, etc.) rather than the average daily rainfall.

（4） Design of leachate regulating pond

The purpose of the leachate regulating pond is to ensure the stable operation of the leachate treatment facility. Although the treatment capacity of the leachate treatment facility is constant, any increases in amount of rainfall and leachate due to heavy rain or the like can be handled by installing a leachate regulating pond. A leachate regulating pond should have the main functions listed below.

- Countermeasures against sudden increase of leachate due to heavy rainfall, etc., and adjusting for seasonal water quality fluctuations
- Standardization of leachate water quality
- Storage of leachate when leachate treatment facility is shut down (for inspection, maintenance, etc.)
- Pre-treatment function for leachate treatment facility

In Japan, it is common to use excavated ponds and dams fitted with surface seepage barrier works, or concrete water tanks. Whichever design is adopted, it is important that the structure should be able to withstand water pressure.

Leachate is affected by rainfall and it varies depending on regional characteristics (meteorological conditions, location conditions, waste properties). Therefore, it is necessary to design the equipment capacity based on the regional characteristics near the disposal site.

(5) Design of leachate treatment facilities

The objective of installing leachate treatment facilities is to treat leachate on-site so that it does not contaminate groundwater or the area where water is discharged. Since the design direction of the treatment facility depends on the quality and location of leachate, this should be determined in consultation with experts who are well-versed in groundwater and water treatment. Fig. 12 shows the basic treatment flow of leachate treatment in Japan. However, the configuration of whichever treatment process is adopted should be changed depending on water quality conditions and the like.

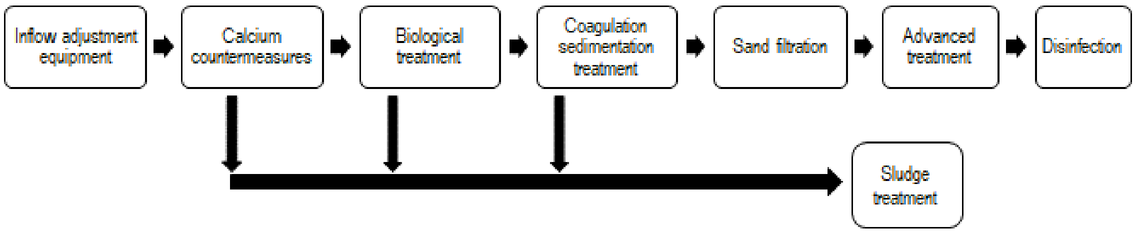


Fig. 12 Basic treatment flow of leachate treatment in Japan.

Created by the Japan Waste Management Association (2010), based on the amended 2010 planning, design, and management guidelines for the development of final waste disposal sites improvement

In Japan, the Ministerial Ordinance Stipulating Technical Standards for Final Landfill Site for Municipal Solid Waste and Industrial Waste provides the following standards for leachate drainage.

Table 8 Leachate drainage standards at general final waste disposal sites (in Japan / partial extract)

Target item	Drainage standard
Biochemical oxygen demand (BOD)	60 mg/L or less (when discharged into public waters other than seas and lakes)
Chemical oxygen demand (COD)	90 mg/L or less (when discharged into seas or lakes)
Alkyl mercury compounds	Should be not detected.
Mercury, alkylmercury, and other mercury compounds	Mercury 0.005 mg/L or less
Cadmium and its compounds	Cadmium 0.03 mg/L or less
Lead and its compounds	Lead 0.1 mg/L or less
Organic phosphorus compounds	Organic phosphorus compounds 1 mg/L or less
Hexavalent chromium compounds	Hexavalent chromium compounds 0.5 mg/L or less
Arsenic and its compounds	Arsenic 0.1 mg/L or less
Cyanide compounds	Cyanide 1 mg/L or less
Polychlorinated biphenyl	Polychlorinated biphenyl 0.003 mg/L or less

Source: Excerpted from the Ministerial Ordinance Stipulating Technical Standards for Final Landfill Site for Municipal Solid Waste and Industrial Waste (Excerpt from Appendix 1)

(6) Design of rainwater collection and drainage facilities

The objective of installing rainwater collection and drainage facilities is to reduce the amount of leachate by collecting and draining rainwater from areas outside landfills. Separating solid waste and rainwater inside the landfill is also an important objective of the facility. To achieve these objectives, rainwater collection and drainage facilities need to have the following three functions.

- Preventing inflow of rainwater from the surrounding area into the landfill
- Preventing inflow of rainwater from unfilled areas and from existing landfill areas to other landfill areas
- Preventing drained rainwater from affecting the surrounding area

① Structure of rainwater collection and drainage facilities

There are two types of rainwater collection and drainage facilities: collection/drainage channels and disaster prevention regulating ponds. Drainage channels can be further classified into upstream area diversion channels, peripheral collection/drainage channels, landfill interior collection/drainage channels, and landfill surface collection/drainage channels. Collection/drainage channels play a role in collection and drainage, while the function of disaster prevention regulating ponds is storage of collected rainwater.

② Points to keep in mind

When designing rainwater collection and drainage facilities, the following four points should be kept in mind.

- Gradient: As a general rule, the gradient should be gentler the further downstream
- Flow velocity: Set to prevent occurrence of sedimentation and wear caused by running water
- Cross-section: Cross-section design should take into account the risks of sedimentation and overflow
- Structure: The equipment should be very durable

(7) Design of groundwater collection and drainage facilities

In landfills where seepage barrier works are in place, it is necessary to properly treat groundwater and spring water. If these are not properly excluded, there is a risk that seepage barrier works will be damaged or that the ground will loosen, collapse, or slide when the groundwater level around the landfill rises. The purpose of groundwater collection and drainage facilities is to eliminate groundwater promptly to reduce these risks.

① Structure of groundwater collection and drainage facilities

The structure of groundwater collection and drainage facilities will differ, depending on the bottom layer and inclined areas.

(A) Bottom layer

Generally, a culvert drainage structure should be considered, in which perforated pipes are covered with a filter material such as stone rubble or crushed stone. If gas is generated from the ground, gas venting pipes may be installed as required. In such cases, the gradient of the bottom layer should also be considered.

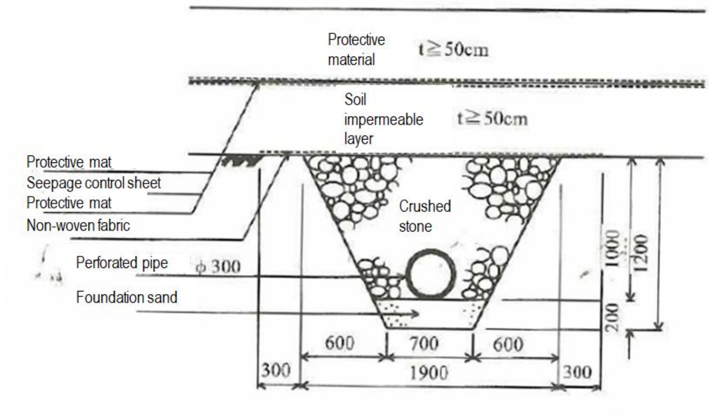


Fig. 13 Example of groundwater collection and drainage pipe structure

Source: Japan Waste Management Association (2010), Planning, design, and management guidelines for the development of final waste disposal sites (revised edition)

(B) Inclined areas

Just as with the bottom layer, collection and drainage is carried out using a culvert drainage structure. Culvert drainage installed at the base of inclined areas should connect to the main line and any branch lines of the collection/drainage facilities on the bottom layer.

(8) Seepage barrier works design

① Types of seepage barrier works

The objective of seepage barrier works is to prevent leachate from flowing out of the landfill. There are two types of seepage barrier works: surface seepage barrier works and vertical seepage barrier works, as shown in Table 9. The main types of seepage barrier materials include synthetic rubber (synthetic resin), asphalt, and bentonite, among others.

Table 9 Classifications & characteristics of seepage barrier works

Classification	Features
Surface seepage barrier works	● Sealing the bottom layer and inclined areas of landfill ● Use of seepage barrier sheeting, cohesive soil, etc.
Vertical seepage control works	● A method of seepage control when there is an impermeable layer or cohesive soil layer at the planned site ● Seepage control installed either vertically or inclined for the lower levels, bottom layer, or surrounding area of landfill ● Uses curtain grouting, underground continuous barriers, waterproof pipes, sheet piles, waterproof cores, vertical sheets, etc.

② Points to keep in mind

When choosing seepage control works, since seepage control works cannot be repaired after landfill work, it is necessary to consider the characteristics and environmental conditions (degree of seepage prevention, retention period, etc.) shown in Table 9.

Protective mats (non-woven fabric), installed at the upper layer of seepage control sheeting, function to prevent damage to seepage control sheeting caused by traveling vehicles and to prevent deterioration caused by direct sunlight.

(9) Storage structures

The purpose of installing storage structures is to prevent runoff and collapse of landfill layers and to safely manage waste.

① Type of storage structures

Storage structures can be broadly classified into three types: concrete gravity dams, embankment dams, and retaining walls (Fig. 14). Concrete gravity dams and embankment dams can be used for large-scale storage, and retaining walls are basically used for small-scale storage. In addition, when selecting the type and design of the storage structure, the decision should take into account the state of the foundation ground.

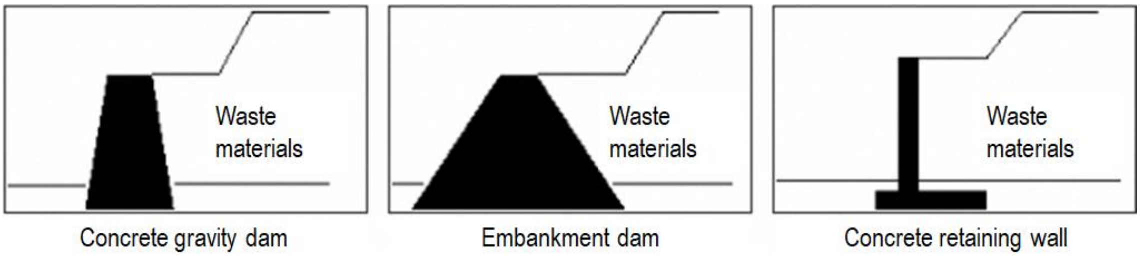


Fig. 14 Main types of storage structures
Source: Website of NPO/LSA: Landfill Systems & Technologies Research Association of Japan

② Points to keep in mind

When designing a storage structure, it can be assumed that the main loads applied to the storage structure will be the weight of the structure itself and the pressure of waste, as well as load generated by earthquake vibrations. Since the load applied to the storage structure will depend on the characteristics of the final landfill site (scale of landfill, properties of waste, landfill period, topography, geology, etc.), sufficient consideration is needed when setting conditions.

(10) Countermeasures for impact on local communities

It is best to ensure that waste treatment areas inside final disposal sites are not visible from the outside. In addition, monitoring systems should be introduced to avoid impact on local communities.

5.2. Construction

This section explains the points to be kept in mind when constructing the final disposal sites, and presents some examples of such construction in Japan.

5.2.1. Construction on sloping areas

Before construction work starts, a wooden frame is set up and the angle and position of the excavation are indicated to the heavy equipment operator, so that excavation work can be performed accurately. It may also worth measuring the gradient of the incline after construction using a gradient rule, and confirming quality as appropriate.

5.2.2. Ground survey

The ground survey confirms the load-bearing capacity of the foundation ground, ensuring that the ground will not settle unevenly due to the combined load of stone rubble and the leachate collection/discharge pipes. If the load-bearing capacity is insufficient, the ground should be improved. In Japan, heavy machinery and hydraulic jacks are used to carry out standard loading tests (actual load is applied and the amount of ground subsidence is measured).

5.2.3. Ground improvement

As indicated in 5.2.3 when it is recognized that the foundation's load-bearing capacity is insufficient, it is necessary to improve the ground so that the necessary load-bearing capacity can be obtained. However, since the characteristics of the construction method will vary depending on the depth of the target ground, the construction method should be considered in light of local circumstances.

In Japan, after soil is removed from soft ground with low basic load-bearing capacity, it is replaced with stone rubble and soil that improves the load-bearing capacity. Examples of suitable replacement soil include natural soil and cement-mixed soil.

5.2.4. Groundwork shaping

In groundwork shaping, it is important to form smooth ground. If the work is not carried out adequately, when heavy equipment or other loads are applied to installed seepage control sheets, these sheets may be damaged. Damage to seepage control sheets may also involve risks such as leakage of leachate away from the site and inflow of groundwater into the landfill interior. For this reason, it is important to pay attention to the following points.

- In the bottom layer, when laying multiple seepage control sheets step-by-step, each sheet needs to be shaped.
- On inclined areas, if soil breaks away even when fixed in place and thus cannot be shaped, cement is used to repair it.
- If geological conditions (such as rocks) make it difficult to smooth the ground, soil should be applied by spraying to smooth it.

5.2.5. Groundwater drainage system

If groundwater sources are confirmed during construction, groundwater drainage pipes should be installed as necessary, even if not previously anticipated at the design stage. If groundwater is still present, the soil behind the seepage control sheets may be scoured away, leading to damage to sheets or the collection/discharge pipes.

In Japan, the groundwater level is checked visually when the ground is excavated to the supporting layer, during the rainy season when groundwater levels are high. However, if excavation work is not completed by the rainy season, it is also effective to dig down to the support layer both upstream and downstream of the groundwater source and confirm both these groundwater levels. The following construction guidelines are assumed after the groundwater level is confirmed.

Table 10 Support for expected construction after confirmation of groundwater level

	Response
If there is no groundwater	Carry out construction as designed
If there is groundwater	Carry out construction as designed if the design's drainage pipes can handle it
	If there are water sources in some parts, add groundwater pipes
If groundwater is at high levels	Significant design changes are required, such as raising the elevation of the support layer

In addition, when constructing the groundwater drainage system, the following points should be kept in mind.

（1） Preparatory work

At the preparatory stage, a pipe layout plan is created together with materials manufacturers based on the design drawings. By preparing machined items (joints connecting pipes of different diameters, bent pipes, etc.) in advance according to the pipe layout plan, construction on site can progress smoothly.

（2） Pipeline excavation

Excavation for pipelines should be carried out in accordance with the pipeline elevation and cross-sections as per the design drawings, to ensure the correct shape of excavated cross-sections and to secure adequate flow capacity.

（3） Discharge pipes

Discharge pipes are connected by joints. When connecting, check the installation elevation of pipelines and whether there is any sediment inflow into the pipeline.

5.2.6. Seepage control

As the function of seepage control is to prevent leachate from flowing away from the site, the following points should be kept in mind when carrying out construction.

(1) Preventing damage to seepage control sheets

Using protective mats is an effective way to protect seepage control sheets from external forces. Generally, the materials of protective mats can be classified into non-woven fabrics and geosynthetics (made of composite materials). By laying protective mats over the upper surface of the seepage control sheet, it is possible not only to protect the seepage control sheets, but also to prevent deterioration caused by direct sunlight.

Since workers need to work on top of seepage control sheets, reconsider the working conditions, such as use of rubber-soled shoes to avoid damaging seepage control sheets. If seepage control sheets need to be temporarily fixed in place partway through the construction process, stack concrete or similar materials on top of sheets and avoid using piles, etc. Moreover, to prevent damage to seepage control sheets, check that there are no protruding objects such as tree roots, shoots, or rocks during construction.

(2) Understanding environmental conditions

When constructed under high-temperature conditions, seepage control sheets may contract when the temperature later drops. For this reason, environmental conditions should be factored in, such as carrying out construction during lower temperatures. In addition, work should not be carried out when the surface of seepage control sheets is wet due to rainfall. Work should be carried out when moisture is not present. If the results of shaping are poor due to inflow of rainwater, etc., it is better to start over shaping again.

5.2.7. Leachate collection/discharge pipes

It is necessary to construct the leachate collection/discharge pipes not only so that the leachate can be discharged, but also that air can be supplied into the landfill interior. Some points to keep in mind during construction are shown below.

(1) Securing gradient

As with the construction of a groundwater drainage system, the elevation of the base layer and the designed gradient should be secured based on the survey results. When securing a drainage gradient proves difficult due to deterioration of the foundation ground, work should be carried out to improve the foundation ground.

(2) Carrying out strength testing

After perforation of the leachate collection/discharge pipe, a strength test should be performed as appropriate.

(3) Checking the shape of the protective stone rubble layer

Check whether the gradient and length are in accordance with the planned design.

(4) Laying down protective stone rubble

The size of the stone rubble will affect the activity of microorganisms in the tube and the flow of water and air. As clogging can occur, careful attention should be paid to construction methods and quality assurance when installing the leachate collection/discharge pipes. At time of construction, relatively fine stone rubble is laid around the collection/discharge pipes, while stone rubble will become coarser the further it is laid from the center of the pipes. In addition, using stone rubble of mixed sizes will cause the gaps between the stones to be larger.

During transport of materials, rubble stones may be worn down by colliding with each other, which can change the stones' diameter. As part of quality assurance, when materials arrive on site, it is necessary to confirm that stones are of the specified diameter.

(5) Protection of seepage control sheets

When laying stone rubble, take care to prevent any damage to seepage control sheets. Since vehicles are not allowed to pass through sections where the seepage control sheets have been laid, the collection/discharge pipes should be installed simultaneously alongside these sheets. Laying of seepage control sheets and the collection/discharge pipes should be performed in the following order: downstream, mid-stream, upstream.

In order to protect seepage control sheets, besides transporting these manually using wheelbarrows, etc. when laying down stone rubble, avoid placing stones on top of these sheets even temporarily. In addition, the collection/discharge pipes and stone rubble are not laid right to the end of each sheet, but are installed with care to secure the joints between sheets.

5.2.8. Gas venting equipment

The main points to consider for gas venting equipment in general are preventing detachment or disconnection of any connecting sections, securing an adequate cross-section shape, and preventing damage to seepage control sheets. In addition, since installation of gas venting equipment on inclined surfaces is essentially performed manually, consideration should be given to ease of construction.

5.2.9. Water catchment pit (penetration through seepage control sheets)

Protective concrete should be laid from the landfill site to the leachate pit, and the collection/discharge pipes should be constructed to fulfill its functions of leachate drainage and air supply. In particular, since the water catchment pit lacks any structures such as seepage control sheets, special attention should be paid to any leakage of leachate from connecting sections.

5.2.10. Stormwater drainage ditch

The points to keep in mind when constructing storm water drainage channels are the same as when constructing general drainage channels. Attention should be paid to achieving the designed gradient and preventing water leakage from connecting sections, and construction work should be carried in accordance with the design drawings.

5.3. Maintenance management

At disposal sites using the Fukuoka method, it is necessary to maintain aerobic atmosphere in the landfill layers by draining leachate and to carry out appropriate maintenance to lower the BOD value of leachate, thus stabilizing the landfill as soon as possible. The leachate collection/discharge pipes, which facilitates ventilation, water flow, and drainage, and the stone rubble layers, are important elements of maintenance management. This section describes implementation policies and points to keep in mind when undertaking maintenance management.

5.3.1. Intake management

The following measures should be put in place for intake of waste.

- The properties of the incoming waste (such as its composition and shape) should be understood
- Guidance of incoming vehicles
- Use truck scales to ascertain the amount of incoming load

5.3.2. 5Landfill

When bagged waste is received, the bags need to be opened and sorted out in advance, after which the operation proceeds to landfill work. This operation can be performed using a backhoe or similar equipment.

Landfilling work is performed by pushing waste from the bottom of roads on-site using bulldozers etc., to secure enough space to work. When heavy equipment passes by or makes turns during landfill work, care should be taken to avoid damaging the leachate collection/discharge pipes or seepage control sheets. An example countermeasure to prevent damage to seepage control sheets is laying down elastic bed matting or slush along the seepage control sheet on the gradient.

5.3.3. Soil cover

Soil cover prevents unpleasant odors, prevents dispersal or outflow of waste, prevents breeding of unsanitary pests, prevents ignition and spread of fires, and preserves the surrounding environment by improving the landscape, etc. It also helps in management of disposal sites, as it helps with intake of waste and ground leveling/compacting and prevents seepage of leachate. Soil cover is classified into same-day soil cover, interim soil cover, and final soil cover, according to its purpose. Different purposes and timings of use are shown in Table 11 below.

Table 11 Purposes and timings of use of soil cover

Type of soil cover	Purpose	Overview
Same-day soil cover	・Prevents dispersal of waste ・Prevents occurrence and spread of odors ・Prevents occurrence of unsanitary pests	Carried out when the landfill layer reaches a certain level of thickness, or when a day of landfill work is completed
Interim soil cover	・Secures road area for waste transport vehicles to travel ・Removes rainwater in landfill areas	Carried out as landfill progresses
Final soil cover	・Improves the landscape ・Use of site ・Reduces leachate quantity	Carried out when landfill work is complete

Since using large amounts of soil leads to a reduction in the amount of waste landfill and deterioration of air permeability, it is necessary to select the soil cover material, soil cover amount, construction method, etc. according to the intended purpose.

5.3.4. Installation of ground subsidence plates

Measurement data on ground subsidence serve as the basic data for confirming the stability of landfills and conventional ground, accurately understanding the landfill period, planning for the use of the site, and overall design. For this reason, it is best to manage this by undertaking periodic measurements. The timing of installation of ground subsidence plates is determined based on the landfill situation at the disposal site.

5.3.5. Monitoring

It is essential to check the situation through regular monitoring so that waste, leachate, gases, etc. from the landfill do not affect the surrounding environment. Monitoring items are set and carried out based on the relevant laws and regulations, such as wastewater standards, of each country. Table 12 shows examples of monitoring items.

Table 12 Example items for monitoring

Target	Measurement item	Measurement location
Leachate	● Water temperature ● pH ● BOD ● CODcr ● T-N ● NH_4^+ ● Chloride	Leachate catchment pit
Groundwater	● pH ● BOD ● NH_4^+ ● Chloride	Groundwater catchment pit
Generated gas	● Methane ● Carbon dioxide ● Hydrogen sulfide	Gas venting equipment

5.3.6. Water level control of leachate catchment pit

The water level in the leachate catchment pit is controlled so that air always flows in from the leachate collection/discharge pipes outlet. When managing the water level, periodically check whether dirt or sand has accumulated in the leachate catchment pit, and perform cleaning using high-pressure water, etc. when necessary. Also, if a worker intends to enter the leachate collection pit to perform cleaning, etc., the interior atmospheric environment (concentrations of oxygen, hydrogen sulfide, etc.) should first be measured to ensure safety.

5.3.7. Prevent clogging of stone rubble and leachate collection/discharge pipes, and eliminate landfill gases

When carrying out maintenance of leachate collection/discharge pipes and gas venting pipes, the following points should be noted.

- The leachate collection/discharge pipes and gas venting pipes are surrounded by stone rubble to prevent direct contact with potentially clogging waste materials.
- The interior of the part where the leachate collection/discharge pipes are connected and installed at right angles to the gas venting pipes should be checked periodically from the gas venting pipe side. If deposited materials such as fine dust or sand are found inside, remove these using high-pressure water, etc.
- As landfill progresses, connect and extend gas venting pipes and manage to ensure they are not buried. In addition, whenever gas venting pipes are extended, gabions should also be installed around the pipes.

5.3.8. Rainwater drainage treatment

Rainwater drainage treatment at final waste disposal sites should be maintained and managed as shown in Table .

Table 13 Maintenance & management of rainwater drainage treatment at final waste disposal sites

Location for management	Management policy
Stormwater drainage ditch	• Water from rain during landfill work permeates into landfill layers • After final soil cover, plan to install drainage facilities on top of the soil cover layer
Rainwater drainage in surrounding area	• Drainage channels are always kept managed, and care is taken to avoid build-up of sediment • If the final disposal site is located in a mountainous area, and there is a danger that rainwater may flow into the final disposal site due to steep slopes, it is more economical and safer to install open pit drainage channels.

5.3.9. Emergency (heavy rain) measures

In the event of heavy rainfall, the quantity of leachate can be reduced by draining rainwater away from the site without contacting waste. This may reduce the risk of leachate leakage and lower treatment costs. It is advisable to take measures against heavy rainfall by referring to past rainfall data and clearly identifying the target period in which measures need to be taken.

The following measures should be implemented for rainwater drainage due to heavy rainfall, etc., depending on the progress of landfill work.

- Place sheets on top of soil cover.
- In order to distinguish between leachate and rainwater, a section embankment, etc. should be installed.
- Pumps installed on the section embankment will discharge drained rainwater to rainwater drains through a discharge hose.
- After rainwater removal is complete, remove sheets immediately.

Note that when rainwater is removed from landfill land higher than surrounding reservoirs (rainwater drains), the measures are basically the same as those described above. However, in some cases, a drain pump will not be required if rainwater drains away naturally.

5.4. Landfill completion, abolition, use of site

5.4.1. Environmental monitoring and safety measures

It is important to take into account that the properties of final waste disposal landfill sites will change over time due to the wide variety of landfill waste. The main expected items for monitoring after landfill is complete include leachate, landfill gases, land subsidence, surrounding groundwater, and the management status of decomposition and stabilization of waste. Continuous monitoring of these items can be expected to improve the system efficiency of the disposal site as a whole. Monitoring should be continued until it is confirmed that there is no impact on the surrounding environment.

(1) Leachate

Leachate monitoring should be ongoing even after landfill is complete, and should be continued until it is confirmed that leachate quality will not affect the environment surrounding the disposal site. Items for monitoring include leachate volume and properties, and measures such as weight reduction may also conceivably be taken where necessary, based on the collected data.

(2) Landfill gases

Regarding landfill gases, just as in the case of (1), gas emissions and properties should be continuously measured and managed after landfill is complete. In addition, measures and management of the landfill gas treatment facility are implemented in accordance with the way the site is used, to ensure that use of the disposal site will not cause any problems.

(3) Management of landfill ground subsidence

In landfill ground, subsidence occurs due to decomposition and compression of waste. It is necessary to measure and control the extent of ground subsidence so as not to hinder the use of the site, and to take appropriate safety measures.

(4) Management of surrounding groundwater

After landfill is complete, the quality of the surrounding groundwater should be managed and the presence or absence of any leachate leaking from the final waste disposal site should be checked. In the event of leaking outside the site, monitoring will be continued, and if there is any risk of damage to the living environment or human health, the causes will be investigated and measures will be taken, such as repairing the seepage control works.

（5） Management of decomposition and stabilization of landfill waste (management of temperature inside landfills)

The internal state of landfill layers is an important item to confirm when investigating the decomposition of waste and the stability of final waste disposal sites. The measurement items for managing the landfill layer include the following.

- Composition of waste
- Ignition loss
- Moisture content
- Quality of water retained in the landfill waste layer
- Dissolution testing of landfill waste
- Gas properties inside the landfill waste layer
- Temperature inside the landfill waste layer
- Other items (analysis of elements for macroscopic understanding of the decomposition status of waste, bacterial count analysis, etc.)

5.4.2. Use of site

As indicated in “3.4.4 Earlier use of former landfill sites,” former landfill sites in Japan are used as sites for athletic parks, solar energy generation plants, and temporary storage for disaster waste.

6. Overseas case studies of introduction of the Fukuoka method

6.1. Status of international cooperation

The Fukuoka method is introduced outside of Japan by dispatching experts, accepting trainees and observers, providing technical guidance, and holding seminars, whether independently or as part of international cooperation efforts. International cooperation efforts are conducted not only by Fukuoka Prefecture but also by various organizations such as Fukuoka City, the Japan Environmental Sanitation Center (JESC), and the Japan International Cooperation Agency (JICA).

Instances whereFukuoka Prefecture has supported the introduction of the Fukuoka Method as part of international cooperation efforts include the Xuân Son landfill site in Hanoi, Vietnam (completed in 2015), and the Fukuoka method waste landfill site in Sikhio District, Nakhon Ratchasima Province, Thailand. Overviews of these disposal sites and some details of introduction can be found below.

6.2. Hanoi, Vietnam

6.2.1. Background to introduction of the Fukuoka method

The background to introduction of the Fukuoka method at the Xuân Son disposal site in Hanoi, Vietnam, is as follows.

In Hanoi, waste disposal has become a serious problem following economic development, and proper waste disposal has become a priority, especially in rural areas. Ways to develop and improve sanitary final landfill sites were sought. Fukuoka Prefecture and Hanoi City signed an environmental cooperation agreement in 2010, and introduction of the Fukuoka method in Hanoi City was considered as a priority project for exchange of environmental technology. Based on this history, it was decided that a final waste disposal site in Hanoi would be constructed using the Fukuoka method under the guidance of the method’s inventor, Emeritus Professor Masataka Hanashima of Fukuoka University. Utilizing a grassroots technical cooperation program from JICA, support was provided, which involved training of staff invited from Hanoi City to Fukuoka Prefecture and dispatching Japanese experts to offer on-site guidance.

Table 14 History of introduction at the Xuân Son disposal site

Year	Event
2008	In February, a friendship agreement was signed with Hanoi City
2009	In December, an environmental study team was dispatched to propose measures to improve environmental problems in Hanoi
2010	**In October, an environmental cooperation agreement was signed with Hanoi City** * It was specified that "giving priority to introducing the Fukuoka method at a final waste disposal site in Hanoi would be considered"
2012	In February, experts conducted a field survey of candidate sites for introducing the Fukuoka method
	In July, Hanoi City made the decision to introduce the Fukuoka method
2013	**In August, a memorandum of understanding was signed with Hanoi City regarding development of the Fukuoka method waste disposal site**
	In December, JICA grassroots technical cooperation project commenced: "Project Enhancing Development of Sanitary Landfill in Hanoi" (until December 2016)
2014	In June, work on the Xuân Son disposal site commenced
2015	**In June, work on the Xuân Son disposal site was completed**
2016	In October, a seminar on the Fukuoka method waste disposal sites was held (in Hanoi)
2018	**In November, the Xuân Son landfill reached its planned capacity and landfill was complete**
To present	Implementing management and monitoring of gas venting pipes, etc. for earlier stabilization of landfill site

6.2.2. Overview of disposal site

An overview of the Xuân Son waste disposal site can be found below.

Table 15 Overview of Xuân Son disposal site

Location of disposal site	Sơn Tây district in Hanoi City Xuân Son disposal site
Scale of disposal site	Area 3 ha (Waste disposal amount 300 t/day) Landfill capacity about 240,000 m^3
Implementation status of the project	Completed in June 2015 Technical guidance provided for maintenance management and monitoring Landfill completed in November 2018
Total construction cost	54.2 billion đồng (cost borne by Hanoi City, Vietnam)

The Xuân Son waste disposal site is located about 90 minutes (about 60 km) west of Hanoi by car. The landfill area of the Fukuoka method final disposal site is 24,000 m^2 and landfill capacity is 240,000 m^3. Most waste disposal here is flammable. According to site staff, introduction of the Fukuoka method has been effective in improving unpleasant odors and pests.

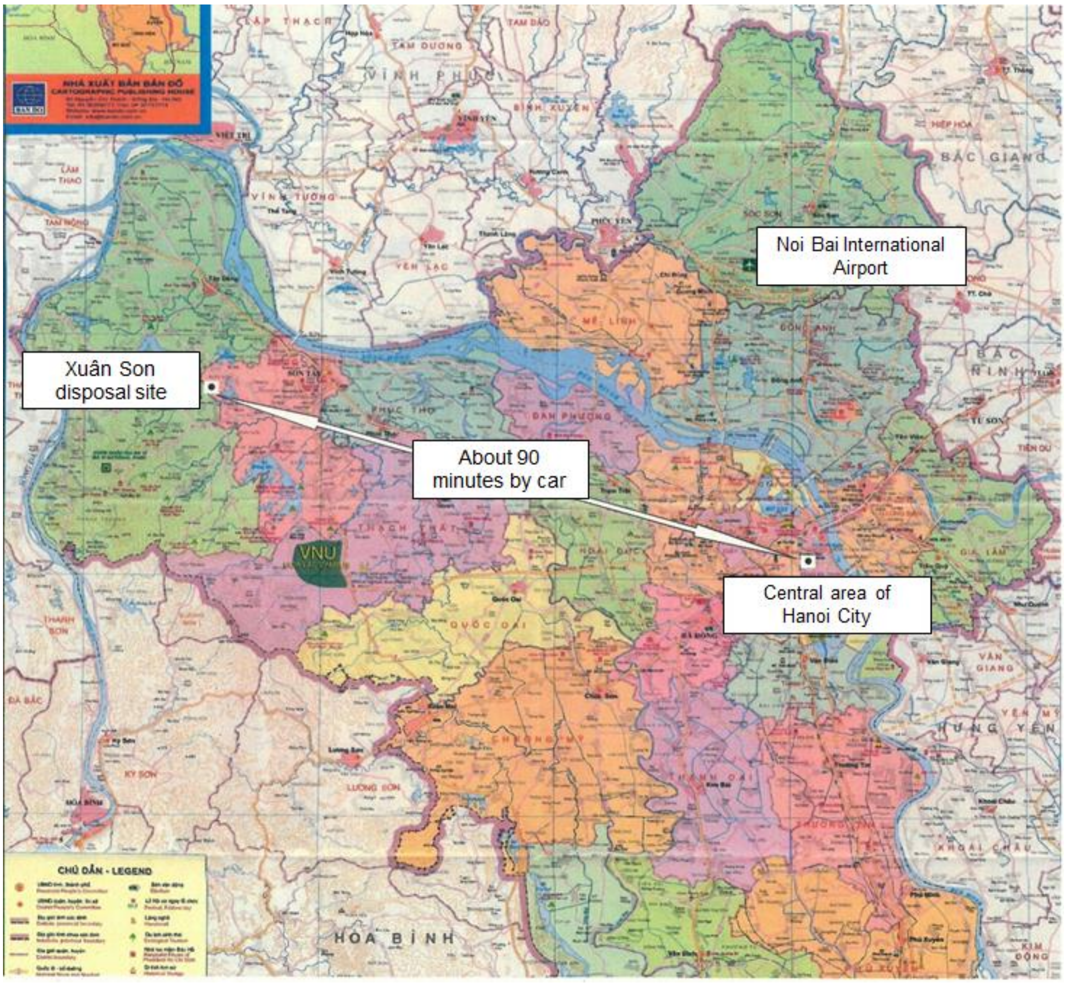


Fig. 15 Map location of disposal site (data from Fukuoka Prefecture)

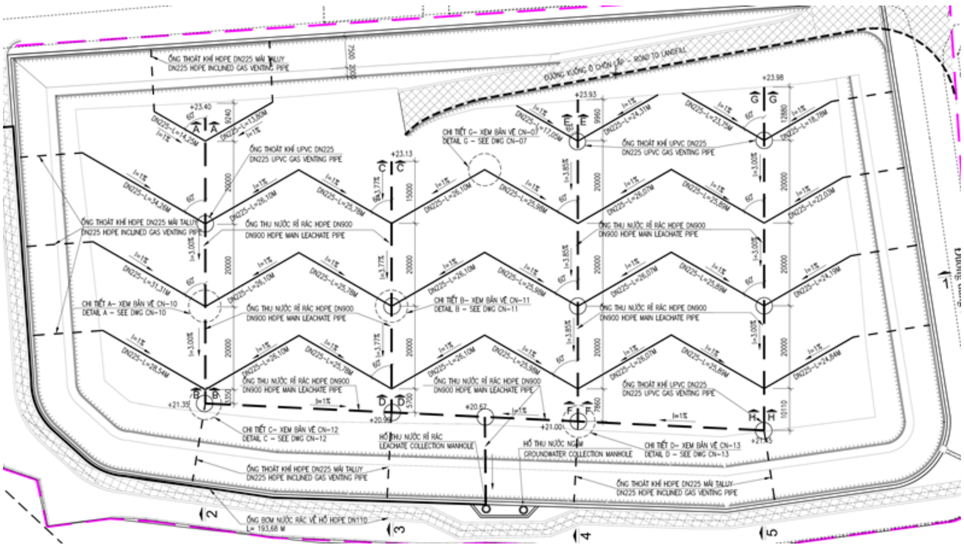


Fig. 16 Ground plan of disposal site (data from Fukuoka Prefecture)

	
Construction complete (June 2015)	Landfill complete (as at August 2019)

In June 2015, work on the Xuân Son disposal site was completed. After completion of construction, the site operated smoothly and reached its landfill capacity in November 2018. After completion of the landfill, management, and monitoring of gas venting pipes, etc. is now underway to stabilize the landfill site as early as possible.

6.3. Sikhio District, Thailand

6.3.1. Background to introduction of the Fukuoka method

The history of introducing the Fukuoka method in Sikhio District, Nakhon Ratchasima Province, Thailand, is as follows.

Since 2006, Fukuoka Prefecture has been conducting international environmental human resource development training for government officials in various Asian countries and has invited many Thai government officials as participants. Upon returning to Thailand after taking part in this training in Japan, a government official from the Pollution Control Department in the Ministry of Natural Resources and Environment proposed introduction of the Fukuoka method. Its adoption was decided by the country, and Fukuoka Prefecture was asked to provide support. In response to this, Fukuoka Prefecture provided support while utilizing the JICA Grassroots Technical Cooperation Project, including inviting Thai government officials to Fukuoka Prefecture for training and dispatching experts to offer on-site guidance.

Table 16 History of introduction at the Sikhio disposal site

Year	Event
2009	A trainee from the Pollution Control Department (PCD) in Thailand's Ministry of Natural Resources and Environment participating in the international environmental human resource development training toured the Fukuoka method disposal site. After this, the Thai government officially requested the prefecture to provide support.
2012	**In April, JICA Grassroots Technical Cooperation Project commenced: "Waste Landfill Planning Assistance for Thailand" (Phase I) (until March 2015)**
2014	In September, work on the Sikhio District disposal site commenced
2015	**In September, work on the Sikhio District disposal site was completed**
2016	In March, a plan was formulated for operation and maintenance management of the Sikhio District disposal site
	In August, an environmental cooperation agreement was signed with PCD
	In September, operations commenced at the Sikhio District disposal site
2017	**In April, JICA Grassroots Technical Cooperation Project commenced: "Support for the Construction of Proper Waste Treatment Processes in Kingdom of Thailand" (Phase II) (until March 2020)**
2018	In August, the Fukuoka Method awareness-raising seminar (hosted by PCD) was held (in Bangkok)
2019	In May, the Fukuoka Method awareness-raising seminar (hosted by Fukuoka Prefecture & PCD) was held (in Bangkok)
To present	The landfill site is properly managed and maintained and is operating smoothly

6.3.2. 6.3.2. Overview of disposal site

An overview of the Fukuoka method final waste disposal site in Sikhio District can be found below.

Table 17 Overview of the Sikhio District disposal site

Location of disposal site	Sikhio District, Nakhon Ratchasima Province * Adjacent to existing anaerobic landfill site
Scale of disposal site	Site area: 18,712 m^2 Landfill area: 2,496 m^2 Landfill capacity: 6,966 m^2
Implementation status of the project	Construction complete: September 2015 Operation started: September 2016 Landfill period: 10 years (planned)
Total construction cost	Approximately 9.2 million baht (cost borne by Sikhio District)
Landfill method	Cell method
Landfill target waste	Household waste (no incineration, waste separated)
Water treatment	Aeration method

Sikhio District is located about 350 km northeast of Bangkok, about 4.5 hours' travel by car.

The Sikhio District landfill is a small-scale experimental landfill formed of layers about 50 cm deep, with 9 layers of landfill. The city consists of 19 villages and 6 schools (approximately 20,000 people), but only 3 villages and 6 schools (approximately 11,000 people; current intake: about 1 ton/day) are eligible to bring waste to the disposal site.

According to local staff, introduction of the Fukuoka method has been effective in improving unpleasant odors, pests, and birds. Sikhio District also recognizes that it will play a role as a learning center for other municipalities based on its success story with the Fukuoka method.

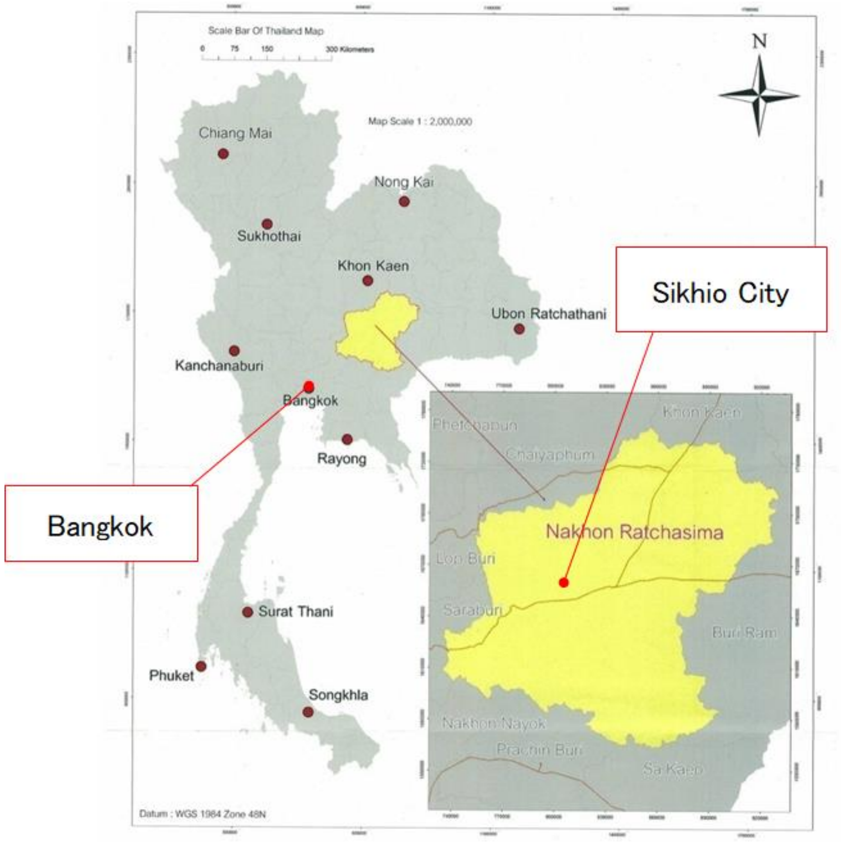


Fig. 17 Location of disposal site (data from Fukuoka Prefecture)

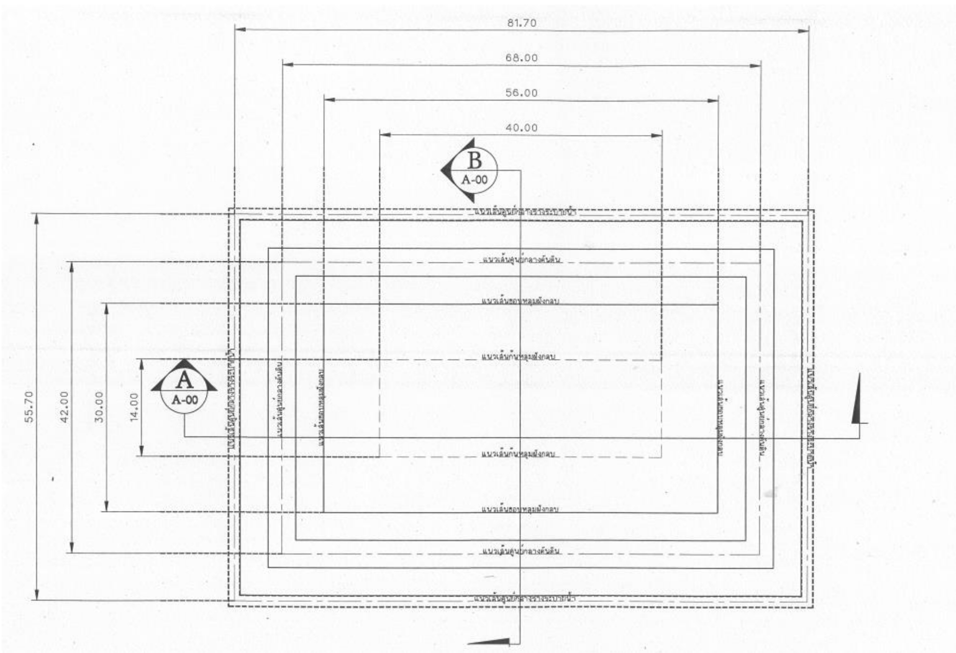


Fig. 18 Ground plan of Sikhio District disposal site (data from Fukuoka Prefecture)

	
Completion (September 2015)	Status of disposal site (as of October 2019)

After completion in September 2015, the site has been properly maintained and is operating well (as of October 2019). The Thai government, which holds a high opinion of the Fukuoka method as used in Sikhio District, intends to continue spreading the Fukuoka method throughout Thailand.

7. References

Dynax Urban Environment Research Institute, Composition and Discharge of Household Waste in Hội An, Vietnam

Ministry of Economy, Trade and Industry (2017), "Overseas Development Project for High-quality Infrastructure Systems" in 2016 (Vietnam: FS Project to Construct Oil Recycling Systems in Developing Countries)

Japan Waste Management Association (2010), Planning, design, and management guidelines for the development of final waste disposal sites (revised edition)

Ayako Tatefuji and Osamu Hirata (2009), Overseas use of semi-aerobic landfill structures (the Fukuoka method): International potential

Landfill Systems & Technologies Research Association of Japan website, Storage structures

Masataka Hanashima, Koreyoshi Yamazaki, Yasushi Matsufuji (1981), Experimental research on waste landfill structures

Bureau of Technical Infrastructure (2016), General Overview on Solid Waste Management in Vietnam

Pollution Control Department (2018), 2018 Annual Report of Waste Disposal Sites Status in Thailand

Pollution Control Department, Ministry of Natural Resources and Environment, Thailand, Thailand's Waste Minimization

World Bank Group (2018), What A Waste 2.0

Fukuoka prefectural mascot,

Ecoton

< Supervised by >

Professor Emeritus Masataka Hanashima, Fukuoka University

< Contact >

Environmental Policies Division,

Department of Environmental Affairs, Fukuoka Prefectural Government

7-7 Higashikoen, Hakata-ku, Fukuoka-shi, Fukuoka

kansei@pref.fukuoka.lg.jp

+81-92-643-3354

Report prepared by NTT Data Institute of Management Consulting, Inc.

Published March 2020