National University of Civil Engineering (NUCE) in Vietnam, Saitama University, The Center for Environmental Science in Saitama (CESS), National Institute of Environmental Studies (NIES) in Japan

SATREPS Report on Waste Composition Survey at Construction and Demolition Waste Landfills in Vietnam

July 2020

SATREPS (Science and Technology Research Partnership for Sustainable Development) is a Japanese government program that promotes international joint research targeting global issues. Global challenges cannot be met by a single country or region acting on its own, so engagement by the international community is essential. To address these issues, SATREPS works through three- to five-year projects involving partnerships between researchers in Japan and developing countries. SATREPS projects are expected to lead to outcomes with potential for practical utilization, and to enhance the research capacity in the developing country.

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Preface

Based on the agreement between the Socialist Republic of Vietnam and Japan, a JST-JICA SATREPS (Science and Technology Research Partnership for Sustainable Development) project began in February 2018. The SATREPS project targets the establishment of environmentally sound management of construction and demolition waste and its wise utilization for control of environmental pollution and production of new recycled construction materials; it will continue until March 2023.

This publication is the SATREPS Report on Waste Composition Survey at Construction and Demolition Waste (CDW) Landfills in Vietnam. The survey was carried out at two CDW landfills in Hanoi, Thanh Tri and Vinh Quynh, as a part of SATREPS project activities from 2018 to 2019. The objective of the survey was to provide technical guidance by a waste composition survey at CDW landfills and to identify the composition and grain size distribution of dumped waste materials.

We would like to take this opportunity to thank the Department of Construction (DOC) of Hanoi City, Hanoi Urban Environment Company (URENCO), and Ministry of Construction (MOC) for their kind cooperation to promote the survey and thank the staff of the JICA Vietnam Office and the respective coordinators from the JICA headquarter and the JST for their continuous support on the SATREPS project.

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1. Summary

Concrete and clay brick waste generated from construction and demolition sites as well as concrete and clay brick waste dumped at construction and demolition waste (CDW) landfills has a high potential as recyclable and reusable materials for construction after performing suitable treatment and quality control. Due to the lack of waste segregation, however, unrecyclable and/or hardly recyclable materials as well as hazardous and toxic materials are dumped together with concrete and clay brick waste at CDW landfills. As a result, the insufficient waste segregation becomes being one of the obstacles to recycling and reuse of the concrete and clay brick waste dumped at CDW landfills. In this SATREPS report on waste composition survey at construction and demolition waste landfills in Vietnam, we report i) a technical guidance to characterize the waste composition and grain size distribution of dumped waste at CDW landfills, and ii) results from case studies carried out at two CDW landfills in Hanoi, Thanh Tri and Vinh Quynh.

The technical guidance provides the survey methodology from preliminary survey to data analysis and reporting via implementation of waste composition survey, divided into six steps. Necessary procedures and processes, equipment and items as well as examples of record sheets to analyse the waste composition and grain size distribution are given in this part (Section 3). The section on case studies (Section 4) reports the survey results at two CDW landfills, providing measured data on waste composition and grain size distribution. Major results from case studies are i) the measured water content increased with decreasing grain size for both Thanh Tri and Vinh Quynh CDW landfills. In particular, the water contents of “Concrete” and “Clay bricks” depended highly on the grain size. On the other hand, the water contents of other materials did not vary depending on the grain size, ii) the major components of dumped materials were different between Thanh Tri and Vinh Quynh CDW landfills. For the Thanh Tri CDW landfill, “Concrete” and “Clay bricks” were the major components and the sum of these materials was 68.5%. On the other hand, the major component of dumped material at Vinh Quynh CDW landfill was “Concrete” at 53.8%, iii) for both Thanh Tri and Vinh Quynh CDW landfills, the grain size was distributed broadly up to the maximum diameter of 600 mm, and there was only a small difference in the grain size distributions on a wet mass basis and on a dry basis. It is worth noting that there were no hazardous and toxic materials dumped at either CDW landfill.

In addition, information on sampling methods, waste classification for dumped materials at CDW landfills, and determination of grain size distributions using an image analysis technique, data analysis on the relationship between mass distributions of sorted materials and grain size, and comparison of grain size distributions of concrete and clay bricks (≥ 10 mm) to the gradation of graded aggregates for road subbase construction in Vietnam (TCVN 8859:2011) are given in the Appendices.

2. Background and Objectives

In recent years, the numbers of building and construction works as well as demolition works have been growing rapidly in Vietnam. The expansion of the construction sector causes simultaneously the generation of construction and demolition waste (CDW). The generated CDW has not been fully recycled in Vietnam, and most CDW is used as a material for ground levelling on-site and dumped in ponds and on vacant land without any treatment. Some part of the generated CDW is brought to the designated dumping site for landfilling (hereafter, CDW landfill).

The generated as well as dumped concrete and clay brick waste at CDW landfills has a high potential as recyclable and reusable materials for construction after performing suitable treatments and quality controls like crushing and grading by grain size. Due to the lack of waste segregation at construction and demolition sites, however, unrecyclable and/or hardly recyclable materials such as ceramics, glass, and plastic are dumped together with concrete and clay brick waste at CDW landfills. In addition, hazardous and toxic materials such as gypsum board and asbestos, paint (volatile), and oil are sometimes dumped illegally at CDW landfills. As a result, the insufficient waste segregation becomes being one of obstacles to promoting the recycling and reuse of the dumped concrete and clay brick waste at CDW landfills.

In order to examine the potential use of dumped concrete and clay bricks at CDW landfills for recycling and reuse, it is important to identify the waste composition and grain size distribution of dumped waste. However, till now there has been no reliable data on the waste composition and grain size distribution at CDW landfills in Vietnam and no methodology and technical guidance have been proposed. The actual data obtained from a reasonable method is important to discuss the sustainable CDW management and to develop a future recycling strategy of CDW among stakeholders in Vietnam. Therefore, the objectives of this report are i) to provide the technical guidance of a waste composition survey at CDW Landfills in Vietnam and ii) to report the survey results from two CDW landfills in Hanoi as case studies.

3. Technical Guidance of Waste Composition Survey at CDW Landfills

3.1 Overall procedure of waste composition survey

The overall procedure of the waste composition survey at CDW landfills is shown in Fig. 1. The survey consists of a total of six steps. Step 1 is the “Preliminary survey” including a site visit to check the site condition and to collect site information through an interview of the site manager. If necessary, a trial excavation of the site (either by hand or using an excavator) should be done to check the dumped CDW materials on the site. Step 2 is “Planning” to decide the location of the excavation pit and working space, excavation and sampling methods, sorting materials, grading of material sizes, working schedule, and safety measures at the site. Step 3 is the “Preparation” that is necessary for the survey, such as obtaining equipment and items for excavation, sorting, weighting, sampling, recording, and safety measures. The preparation of a working station and recruitment of human resources are also organized. Step 4 is “Implementation” of the survey on the site including excavation, sorting and grading of materials, weighing of sorted materials, and bag sampling. After completion of the survey, backfilling of the excavated pit and cleaning are necessary tasks to restore the site to its condition before the excavation of the pit. Step 5 is “Laboratory testing”. The water contents are measured to determine the dry-basis weight of sampled materials. It is also useful to measure other physical and chemical properties, water and acid extractable ions to characterize the environmental safety of sampled materials. Step 6 is “Data analysis and reporting”. By analysing the collected data, the composition of sorted materials and particle size distributions of dumped waste materials can be summarized in the report.

3.2 Preliminary survey: Step 1

The preliminary survey is important to check the site condition and to collect site information. The site condition should be recorded as memos with photos. It is useful to bring an earth view from Google Earth (https://www.google.com/earth/) when we visit the site to see an overall view of land. To collect the site information details, it is also important to interview the site manager. An example of the questionnaire is shown in Table 1. In the table, basic information of the site can be recoded as well as the management condition of the site. Photos of site visits for preliminary surveys and interviews about site management are shown in Fig. 2. In addition, a trial excavation of the site either by hand or using an excavator should be done, if necessary, to identify the dumped CDW materials on the site (see Fig. 17).

Step 1: Preliminary survey

- Site visit (site condition)
- Site information (interview questionnaire)
- Trial excavation (if necessary)

Step 2: Planning

- Location of excavation pit and working space
- Excavation and sampling method
- Sorting of materials
- Grading of material size
- Working schedule
- Safety measures

Step 3: Preparation

- Equipment and items (excavation, sorting, weighting, bag sampling, recording, safety measures)
- Preparation of working station
- Recruitment of human resources
- Others

Step 4: Implementation

- Excavation
- Sorting of materials and grading of material size
- Weighting sorted materials (wet mass)
- Bag sampling (for laboratory tests)
- Backfilling of excavated pit and cleaning

Step 5: Laboratory testing

- Water content measurement (convert to dry mass)
- Other measurements (physical and chemical properties, water and acid extractable ions, and so on)

Step 6: Data analysis and reporting

- Water composition of sorted materials (wet or dry mass basis, total and each size range)
- Particle size distribution of sorted materials (total and each material)
- Analysis of other measurements

Fig. 1. Flow chart of overall procedure for waste composition survey at CDW landfill.

Fig. 2. Site visit for preliminary survey at CDW landfill and interview of site manager.

Table 1. Questionnaire sheet for waste composition survey at CDW landfill.

Site name / Address		/
Date		/ /
Investigator		
Site Information:		
1	GPS location	
2	Estimated area (m^2)	
3	Landowner	
4	Operation company/institute	
5	Number of workers	
6	Intake per day/week/month	
7	Operation years	
8	Estimated life years	
9	Photo	
10	Groundwater level	
11	Acceptable waste	
12	Previous land use	
13	Height of dumped waste	
14	Surrounding environment	
15	Accessibility	
16	Workability	
17	Weather	
18	Remarks	

Licensing		Yes	No	Remarks
18	Do you have official approval for accepting CDW? (If yes, describe)	☐	☐	
Rule and staff training		☐	☐	
19	Do you have any internal rules about management of the site? (If yes, describe)	☐	☐	
20	Do staff and workers understand and comply with the rules?	☐	☐	
21	Do staff and workers receive proper training on CDW handling? (If yes, describe)	☐	☐	
22	Do you provide proper safety equipment for site staff and workers? (If yes, list items)	☐	☐	

Recording				
23	Do you have and keep records of accepted amount of waste? (If yes, describe)	☐	☐	
24	Do you have and keep records of contracting agencies and companies that come to dispose of CDW? (If yes, describe)	☐	☐	
Site utilities				
25	Does the landfill site have proper waste handling devices and machineries (such as mechanical lifting devices, excavator, etc.)? (If yes, list items)	☐	☐	
26	Do you have access to electricity and water onsite? (If yes, list items)	☐	☐	
Others				
27	Have you ever refused to accept waste? (If yes, specify reason)	☐	☐	
28	Do you sort and recycle accepted waste on-site? (If yes, describe)	☐	☐	
Additional remarks: Estimated depth of buried (dumped) waste, sanitary condition (inside), tipping fee, design drawing of site (if possible), Google earth map, and so on.				

3.3 Planning: Step 2

"Planning" consists of deciding the location of the excavation pit and working space, sorting materials, grading material sizes, working schedule, and safety measures on the site. In this survey, we applied a sampling method from an excavated pit based on the judgement design (so called "Pit sampling") because the method is easy to implement and is able to secure the work safety on the site (see Appendix 1). An example of excavated pit is shown in Fig. 3. The size of excavated pit is recommended to be ~2.5–4 m in length and width, and ~1 m of depth down to the original soil ground depending on the site condition. At least 10,000 kg is necessary to characterize the waste composition and grain size distribution of dumped CDW on a site.

Based on the results of a preliminary survey and the definition and classification system of CDW reported in the literatures and reports (see Appendix 2), we decided to sort the excavated materials into ten categories in this survey: 1) concrete, 2) clay bricks, 3) ceramics, 4) glass, 5) plastics, 6) metals, 7) wood, 8) stones, 9) miscellaneous (including paper, rubber, leather, and textiles), and 10) soil-like material (typically, <10 mm). The typical sizes of sorted materials with remarks are shown in Table 2. Except for the soil-like material, the size is normally ≥10 mm. Photos of sorted materials are shown in Fig. 4. In this survey, a total of eight sieve sizes was applied to investigate the grain size distribution of dumped CDW on the site, as shown in Table 3. The fractions with ≤100 mm (labelled as "Over 10" and "Under 10") were measured by using a sieve, and the fractions >100 mm (labelled as "Over 100") were measured by using an image analysis technique (see Appendix 3). Photos of sorted materials of different sizes are shown in Fig. 5.

An example of the working schedule is shown in Table 4. In the table, a total of 7 days work is scheduled from the mobilization of survey items in Step 3 to the calculation of water content in Step 6.

Fig. 3. Example of excavated pit for waste composition survey.

(a) Concrete

(b) Clay bricks

(c) Ceramics

(d) Glass

(e) Plastics

(f) Metals

(g) Wood

(h) Stones

(i) Miscellaneous

(j) Soil-like

Fig. 4. Examples of sorted materials for waste composition survey.

(a) > 300 mm

(b) 106 – 300 mm

(c) 53 – 106 mm

(d) 26.5 – 53 mm

(e) 9.5 – 26.5 mm

(f) 4.75 – 9.5 mm

(g) 2 – 4.75 m

(h) < 2 mm

Fig. 5. Sorted materials of different sizes.

Table 2. Sorted materials for waste composition survey.

No.	Material	Size	Remarks
1	Concrete	≥ 10 mm	including concrete and cement blocks
2	Clay bricks		including mortar binders
3	Ceramics		including tiles made of ceramics
4	Glass		
5	Plastics		Soft plastics (e.g., PET bottles), hard plastics (e.g., PVC pipes),
6	Metals		Steel, copper cable, etc.
7	Wood		
8	Stones		
9	Miscellaneous		Paper, rubber, leather, textiles, etc.
10	Soil-like	< 10 mm	Fine fraction including sludge, ash, and miscellaneous

Table 3. Sieve sizes for waste composition survey.

No.	Sieve size (mm)	Name	Measurement method
1	> 300	> 100 mm (Over 100)	Image analysis
2	106 – 300		
3	53 – 106	≥ 10 mm (Over 10)	Sieve analysis
4	26.5 – 53		
5	9.5 – 26.5		
6	4.75 – 9.5	< 10 mm (Under 10)	
7	2 – 4.75		
8	< 2		

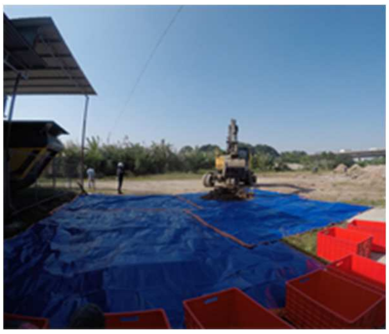
Table 4. An example of working schedule: From the mobilization of survey items in Step 3 to the calculation of water content in Step 6.

Activity	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Step 3: Preparation • Mobilization of survey items • Preparation of working station							
• Guidance and training of workers							
Step 4: Implementation • Excavation							
• Sorting of materials and grading of size • Weighting of sorted materials • Bag sampling							
• Backfilling of excavated pit and cleaning							
Step 5: Laboratory testing • Measuring water content (bag samples)							
Step 6: Data analysis and reporting • Calculation of water content (bag samples)							

3.4 Preparation: Step 3

"Preparation" consists of preparation of necessary equipment and items for the survey, working station on the site, and recruitment of human resources. Necessary equipment and items for the survey are listed in Table 5. The equipment and items are categorized into 1) mobilization and transportation, 2) excavation of the pit, 3) working space, 4) sorting and weighing materials, 5) recording, and 6) safety measures. Photos of equipment and items for the survey are shown in Fig. 6. A suitable working station is important to carry out the sorting and weighing of excavated samples from the pit, to store the samples, and to secure rest space for labours and survey members. An example of a working station is shown in Fig. 7. The land area of ~20 m of length and ~15 m of width should be prepared for the survey work. A list of required personnel for the survey is given in Table 6. The personnel include a supervisor, logistic personnel, full-time and part-time workers, driver(s), and operator of the excavator. The duty and responsibility of the personnel is also given in the table.

(a) Excavator



(b) Tarpaulins

(c) Sun shield

(d) Containers

(e) Sieve (large size)

(f) Platform scale

(g) Plastic bags

(h) Ladder

Fig. 6. Photos of equipment and items for waste composition survey.

Table 5. Equipment and items for waste composition survey.

1. Mobilization and transportation	- Truck - Vehicle
2. Excavation of pit	- Excavator - Wheelbarrow trolley
3. Working space	- Tarpaulins (or waterproof aluminium foil mat): To store the excavated samples - Sun shield (Canopy) - Storage station (if necessary, to store the tools)
4. Sorting and weighing of materials	- Shovels (normal and hand shovels) - Rake tool: to sort samples - Containers (plastic containers): To store sorted materials, 10–20 pieces - Boxes: To store and ship samples, ~10 pieces - Sieves (large size): Aperture sizes of 300, 100, 30, 10-mm - Hand sieves (laboratory size): For small particles under 5 and 2 mm - Platform scales: To weight samples (spring balance scale can be an option as well) - Plastic bags: To take samples for laboratory tests (various sizes are preferable. Ziplock bags are also useful) - Sand bags: To take large-scale samples - Measuring tapes (open reel tapes): To measure the pit scale, etc. - Robust laminate signs and posters: To identify the place of containers (sorted materials) - Ladder: To take photos for image analysis - Scissors (or cutter) - Black Marker pens
5. Recording	- White board: To draft daily work schedule, etc. - Whiteboard marker - Notebooks: To keep a record of each working day - Pens - Normal tape (Scotch tape) - Digital camera - GPS device
6. Safety measure	- Hard hat/helmet - Safety gloves - Face and eye masks - Rubber boots - One-piece construction work outfit - Raincoat (in case of rain) - Safety tapes (Safety masking tapes in different colours for identification) - Garbage bin (temporary garbage bin for onsite trash)

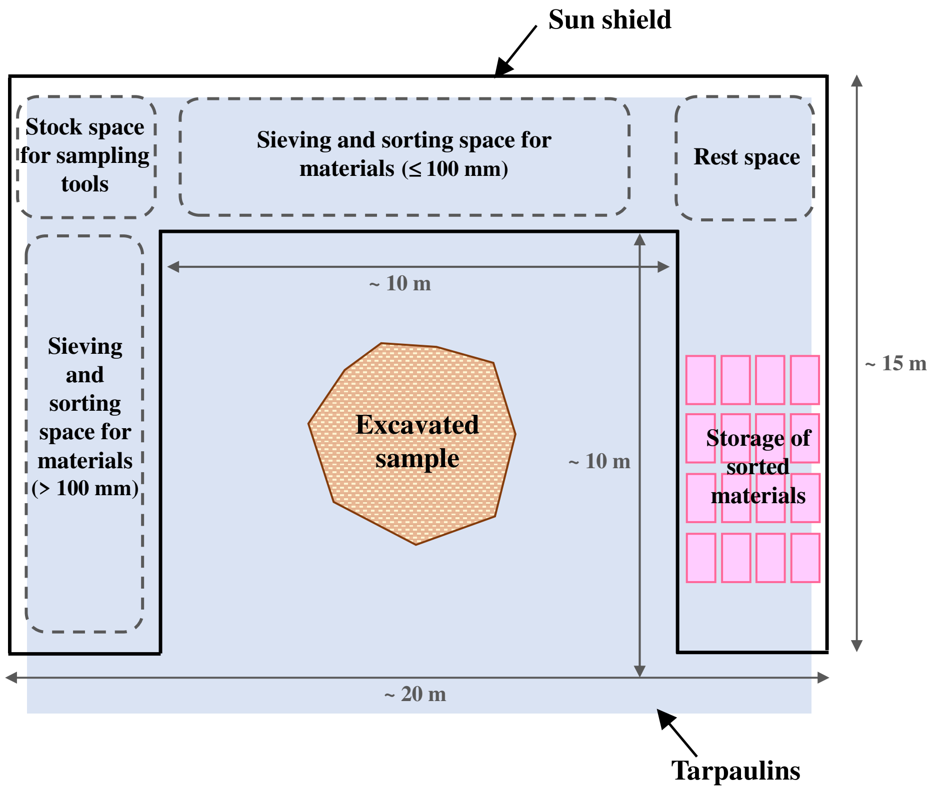


Fig. 7. Illustration of working station for waste composition survey.

Table 6. List of required personnel for waste composition survey.

	Category	Number	Duty and responsibility
1	Supervisor	1	Person who takes charge of the whole survey work and operation
2	Logistics personnel	1	Person who makes survey schedule and takes charge of the logistics
3	Full-time workers	3	Sort materials, and grade material sizes, and packaging of samples. Training of part-time assistant workers
4	Part-time assistant workers	5~10	Assist sorting of materials, grading of material sizes, and packaging of samples
5	Driver of truck	1	Mobilization of equipment and items, transport of samples to the laboratory
6	Operator of excavator	1	Excavation of pit and backfilling of pit after the survey
	Total	12~17	

3.5 Implementation: Step 4

The overall scheme for sorting material and grading by size is shown in Fig. 8, and an example of a recording sheet for the waste composition survey is given in Table 7. On the recording sheet, 1) size of excavated materials, 2) mass of each size fraction after sieving, and 3) mass of each material for each size fraction can be recorded on a single sheet.

After the excavation of samples from a pit, the samples are transferred to the working station. There, the samples are sieved with 300-mm and 106–300-mm sieves to separate the materials into "Over 100" and ≤100 mm. Next, the sieved samples "Over 100" are sorted by material, and the mass of each sorted material is measured. The sorted materials of "Over 100" are photographed for image analysis in the laboratory and the size and fraction of each material is sampled (~10 kg for each).

The samples with ≥10 mm ("Over 10") are sieved with a total of 6 sieves of 53–106, 26.5–53, 9.5–26.5, 4.75–9.5, 2–4.75, and 2-mm sieves to separate the materials into "Over 10" and "Under 10" mm. The sieved "Over 10" samples are sorted by material, and the mass of each sorted material is measured (~2 kg for each). The mass of the sieved samples of "Under 10" (only soil-like) is measured, and the bag sampling is used to take each size fraction (~30 kg for each). All bags of samples taken on the site are brought to the laboratory to measure the water content in the laboratory (Step 5). Some photos of the waste composition survey are shown in Fig. 9. After completion of the survey, backfilling of the excavated pit and cleaning are necessary to restore the site.

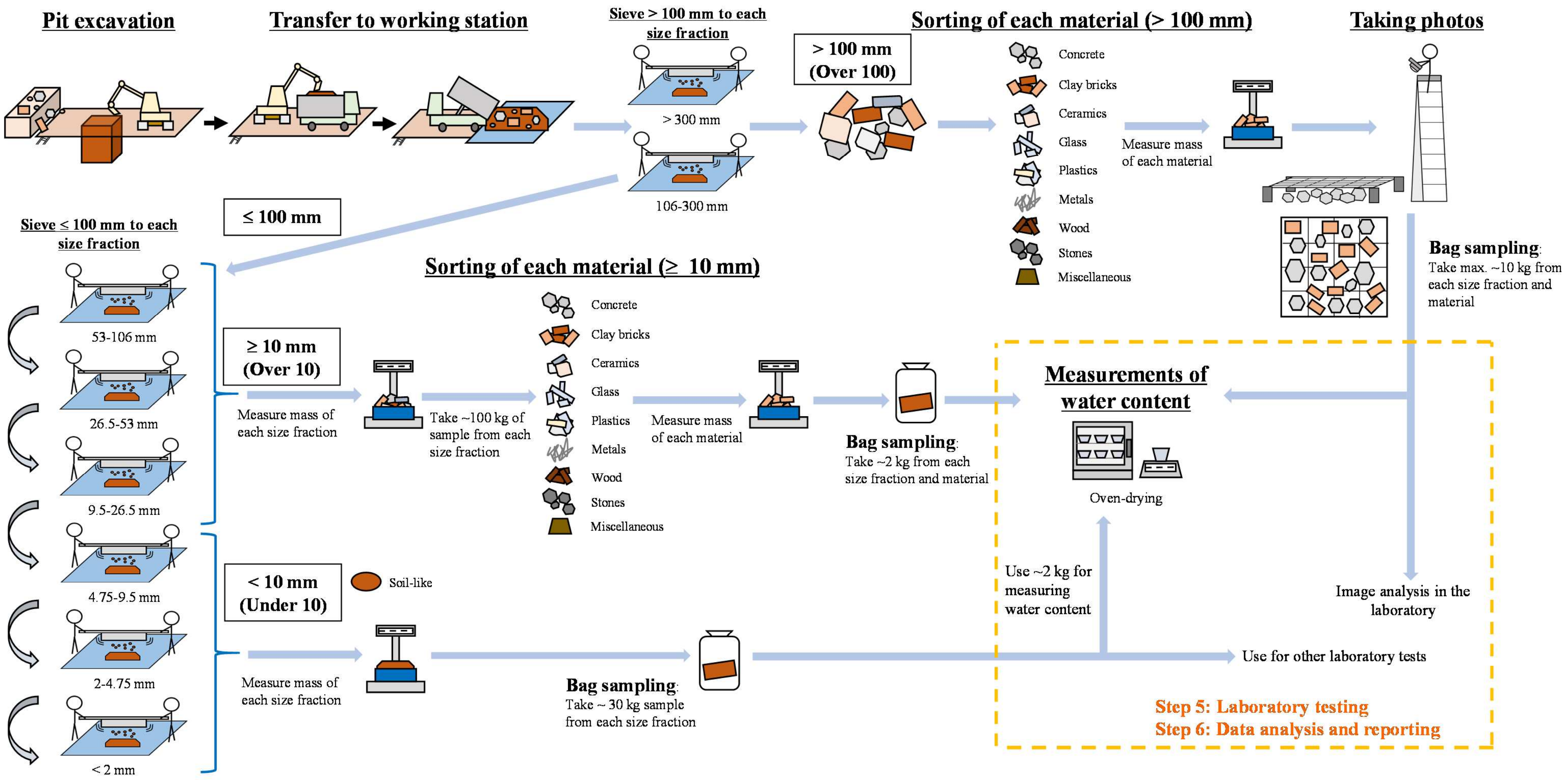


Fig. 8. Overall scheme for material sorting and grading of material size in Step 4.

(a) Measuring size of excavated pit

(b) Placement of excavated samples

(c) Sorted materials by sieving

(d) Recording mass of sorted materials

(e) Sorted materials (ceramics)

(f) Image analysis (samples >100 mm)

Fig. 9. Photos of implementation of waste composition survey.

Table 7. Recording sheet for sorted and graded materials in the waste composition survey.

1. Size of excavated pit		
	Length (mm)	/ /
	Width (mm)	/ /
	Depth (mm)	/ /

2. Mass of each size fraction after sieving		
No.	Sieve size (mm)	Mass (kg)
1	> 300	
2	106 – 300	
3	53 – 106	
4	26.5 – 53	
5	9.5 – 26.5	
6	4.75 – 9.5	
7	2 – 4.75	
8	< 2	

3. Mass of each material for each size fraction					
[Grain size: > 300 mm]		Mass (kg)	[Grain size: 26.5-53 mm]		Mass (kg)
1	Concrete		1	Concrete	
2	Clay bricks		2	Clay bricks	
3	Ceramics		3	Ceramics	
4	Glass		4	Glass	
5	Plastics		5	Plastics	
6	Metals		6	Metals	
7	Wood		7	Wood	
8	Stones		8	Stones	
9	Miscellaneous		9	Miscellaneous	
[Grain size: 106-300 mm]		Mass (kg)	[Grain size: 9.5-26.5 mm]		Mass (kg)
1	Concrete		1	Concrete	
2	Clay bricks		2	Clay bricks	
3	Ceramics		3	Ceramics	
4	Glass		4	Glass	
5	Plastics		5	Plastics	
6	Metals		6	Metals	
7	Wood		7	Wood	
8	Stones		8	Stones	
9	Miscellaneous		9	Miscellaneous	
[Grain size: 53-106 mm]		Mass (kg)			
1	Concrete				
2	Clay bricks				
3	Ceramics				
4	Glass				
5	Plastics				
6	Metals				
7	Wood				
8	Stones				
9	Miscellaneous				

3.6 Laboratory testing: Step 5

The water content of samples of each size fraction and material taken from the site were measured. Oven drying at 110°C with 24 hours was commonly applied (Fig. 10). The photos of "Over 100" were used to determine the grain size distribution based on the image analysis technique (Appendix 3). In addition, measuring other physical and chemical properties, water and acid extractable ions, especially for "Under 10" samples, was useful to characterize the environmental safety of fine fractions on the site.

Fig. 10. Water content measurement in the laboratory (oven-drying method).

3.7 Data analysis and reporting: Step 6

By analysing the collected data, the composition of sorted waste materials and particle size distributions of dumped materials can be summarized in the report. (See next sections for case studies at CDW landfills in Thanh Tri and Vinh Quynh.)

4. Case Studies of Waste Composition Survey

4.1 CDW landfill in Thanh Tri, Hanoi

4.1.1 Basic information of site

Basic information on the site is summarized in Table 8, and earth views are shown in Fig. 11. The Thanh Tri CDW landfill is under operation in Hanoi City and located about 7 km southeast of City Center (close to Red River). The site has been in operation since 2017 and is operated by an appointed private company under management of the Hanoi Department of Construction. Photos of site are shown in Fig. 12. For more information, refer to "SATREPS Baseline Survey Report on Construction and Demolition Waste Landfills in Hanoi, Vietnam. 2019".
(http://park.saitama-u.ac.jp/~vietnam_satreps/content/files/SATREPS_Baseline_Survey_Report_Oct_2019. pdf).

Table 8. Basic information survey for Thanh Tri CDW landfill.

Item no.	Content	Thanh Tri
1	GPS location	20° 59' 21.6" N, 105° 53' 58.1" E
2	Estimated area (m^2)	29,000
3	Landowner	Hanoi People's Committee (public land)
4	Operation company/institute	Waste Treatment & Investment for Development of Hanoi Environment Joint Stock Company
5	Number of workers	4 guards
6	Intake per day/week/month	Unknown (fluctuated)
7	Operation years	Since 2017 to date
8	Estimated life years	5 years (up to 2022)
9	Photo	(See Fig. 12)
10	Groundwater level	5–10 m from the ground surface
11	Acceptable waste	CDW (brick, concrete, tile, stone, wood, glass, plastic, steel, soil)
12	Previous land use	Vacant land (free area formed by sedimentation of Red River)
13	Height of dumped waste	~10 m in height, 1 m in depth
14	Surrounding environment	Red River, agricultural field, river sand-stock company
15	Accessibility	Good (~20–30 min from NUCE)
16	Workability	Enough space to work
17	Weather	Wet season: May - October, heavy rain Dry season: November - April, little rain
18	Remarks	● Under operation with 2 guards. ● Available for visit. ● Type of waste: CDW mixed with a lot of soil ● Additional information: 01 crushing machine on display.

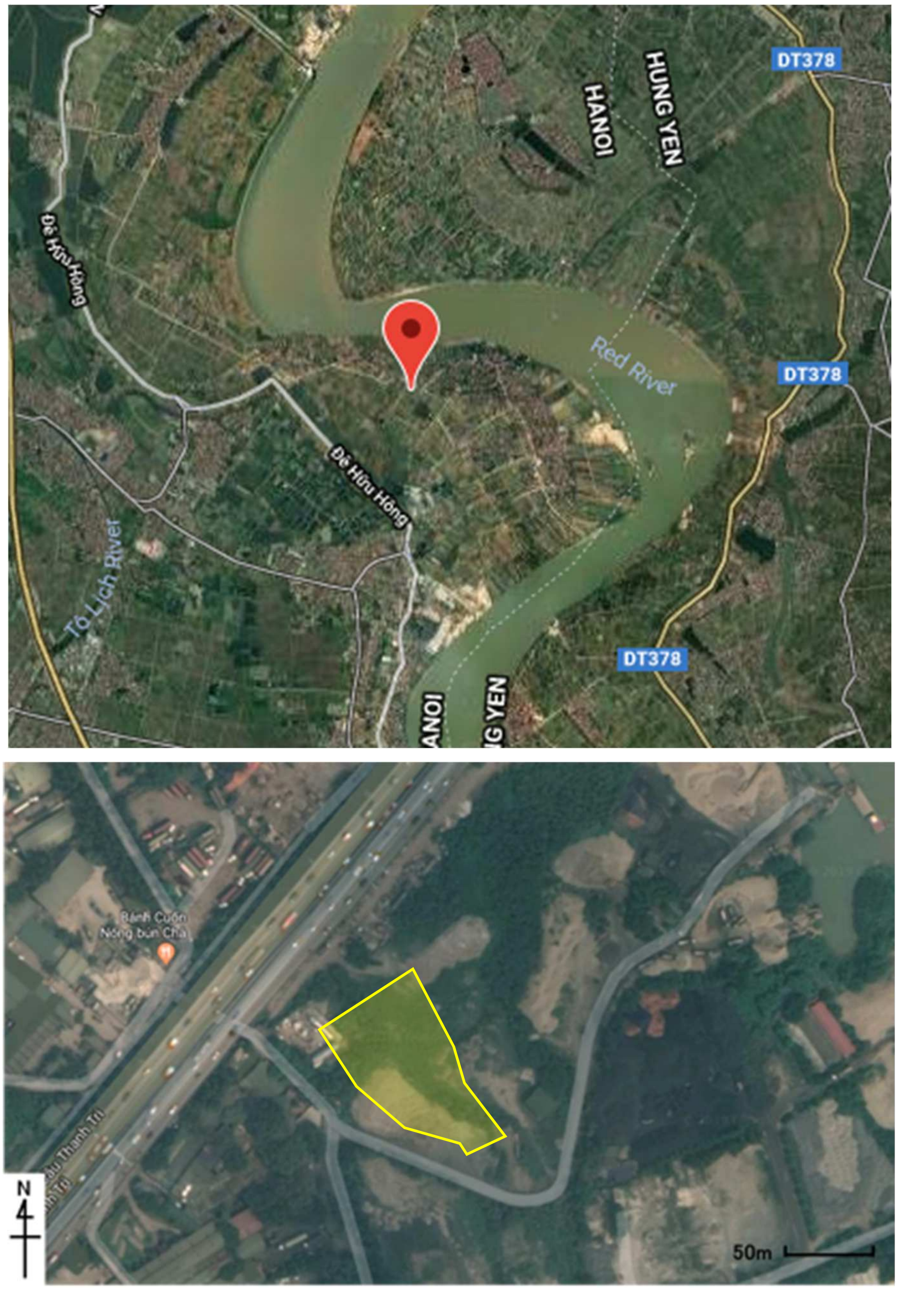


Fig. 11. Earth views of Thanh Tri CDW landfill (Google Inc. Dated July 01, 2019)

Fig. 12. Photos of Thanh Tri CDW landfill. Dumped waste piles (left) and ground surface (right).

4.1.2 Sampling pit and recording sheet

At the Thanh Tri CDW landfill, the dumped waste layer was around ~8–10 m deep from the ground surface. The size of the excavated pit is shown in Fig. 13. A total volume of 7.6 m^3 was excavated and the material was sorted and graded. The record of the waste composition survey is shown in Table 9. It is noted that the mass (in kg) recorded on the sheet is given on a wet basis (actual mass of kg at the site).

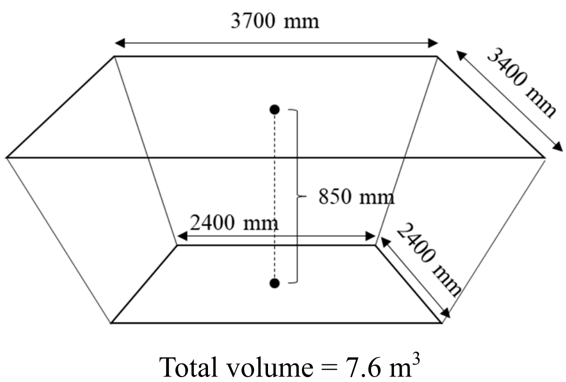


Fig. 13. Sampling pit at Thanh Tri CDW landfill. Photo (left) and scale of pit (right).

Table 9. Recording sheet for sorted and graded materials in the waste composition survey at Thanh Tri CDW landfill.

2. Mass of each size fraction after sieving		
No.	Sieve size (mm)	Mass (kg)
1	> 300	55+62+31=148
2	106 – 300	254+273+233+289+308+466=1823
3	53 – 106	271+295+291+321+279+303+303=2061
4	26.5 – 53	359+383+385+371+245=1743
5	9.5 – 26.5	517+485+489+493+679=2663
6	4.75 – 9.5	177+296+358=831
7	2 – 4.75	122+221+289=632
8	< 2	347+258+223+230=1058

3. Mass of each material for each size fraction					
[Grain size: > 300 mm]		Mass (kg)	[Grain size: 26.5-53 mm]		Mass (kg)
1	Concrete	10.2+6.4=16.6	1	Concrete	179+109+125.2=413.2
2	Clay bricks	57+30+44.4=131.4	2	Clay bricks	303+288+211.8+357=1159.8
3	Ceramics	–	3	Ceramics	99+60.9=159.9
4	Glass	–	4	Glass	–
5	Plastics	–	5	Plastics	–
6	Metals	–	6	Metals	–
7	Wood	–	7	Wood	–
8	Stones	–	8	Stones	–
9	Miscellaneous	–	9	Miscellaneous	10
[Grain size: 106-300 mm]		Mass (kg)	[Grain size: 9.5-26.5 mm]		Mass (kg)
1	Concrete	233+189.2+327+166.9=915.9	1	Concrete	279+301+288+206+259.7=1333.7
2	Clay bricks	177+247+180.5+226.8=831.3	2	Clay bricks	59+104+388.1=461.1
3	Ceramics	4.3	3	Ceramics	40.7+49=89.7
4	Glass	–	4	Glass	20.8
5	Plastics	–	5	Plastics	–
6	Metals	–	6	Metals	–
7	Wood	–	7	Wood	9.9
8	Stones	6.8	8	Stones	53+29.3=82.3
9	Miscellaneous	32.5+32.3=64.8	9	Miscellaneous	177+208+280.4=665.4
[Grain size: 53-106 mm]		Mass (kg)			
1	Concrete	350+377+289+435.5=1451.5			
2	Clay bricks	156+294.2=450.2			
3	Ceramics	50+78.3=128.3			
4	Glass	–			
5	Plastics	–			
6	Metals	–			
7	Wood	–			
8	Stones	–			
9	Miscellaneous	31.3			

4.1.3 Water content

After the measurements of water content in the laboratory, the measured mass of each grain size and sorted material was converted from the mass on wet basis (in kg) to the mass on dry basis (in kg). The measured water content for each grain size is shown in Table 10. The measured water content increased with decreasing in the grain size: the water contents became ~4.3–4.7% for "Over 100", ~5.4–10.3% for "Over 10", and ~16.8–27.8% for "Under 10" (means "soil-like"). The average water content of the excavated pit (all grain sizes) was 12.5%.

The measured water content of each sorted material by each grain size as well as % of dry mass for each grain size is summarised in Table 11. It can be observed that the water content of "Concrete" and "Clay bricks" depended on the grain size. For "Concrete", the water increased with decreasing grain size and ranged from 2.3% (>300 mm) to 11.4% (9.5–26.5 mm). For "Clay bricks", the water contents increased with decreasing grain size and ranged from 4.9% (>300 mm) to 9.4% (9.5–26.5 mm). On the other hand, the water contents of "Ceramic" did not vary depending on the grain size and was ~6.6–7.6%. Among the "Over 100" and "Over 10", the water contents of "Miscellaneous" was the highest and ranged from 8.9 to 17.5%.

Table 10. Mass on wet and dry basis and water content for each grain size at Thanh Tri CDW

No.	Grain size (mm)	Mass on wet basis (kg)	Mass on dry basis* (kg)	Water content** (%)
1	> 300	148	141	4.7
2	106 – 300	1823	1744	4.3
3	53 – 106	2061	1951	5.4
4	26.5 – 53	1743	1606	7.9
5	9.5 – 26.5	2663	2388	10.3
6	4.75 – 9.5	831	691	16.8
7	2 – 4.75	632	456	27.8
8	< 2	1058	764	27.8
	Total (kg)	10960	9741	12.5***

* Mass on dry basis was estimated measured mass on wet basis and measured water content.

** Water content was measured by using a bag sample

*** (10960-9741)/(9741) x 100 = 12.5%

Table 11. Water content of each sorted material in each grain size at Thanh Tri CDW landfill.

Grain size (mm)	Material	Water content (%)	% of dry mass
> 300	Concrete	2.3	11.3
	Clay bricks	4.9	88.7
	Ceramics	–	–
	Glass	–	–
	Plastics	–	–
	Metals	–	–
	Wood	–	–
	Stones	–	–
	Miscellaneous	–	–
		Total	100
106 – 300	Concrete	2.5	51.2
	Clay bricks	5.9	44.8
	Ceramics	6.6	0.2
	Glass	–	–
	Plastics	–	–
	Metals	–	–
	Wood	–	–
	Stones	7.2	0.3
	Miscellaneous	8.9	3.4
		Total	100
53 – 106	Concrete	4.6	71.0
	Clay bricks	6.9	21.5
	Ceramics	7.6	6.1
	Glass	–	–
	Plastics	–	–
	Metals	–	–
	Wood	–	–
	Stones	–	–
	Miscellaneous	9.2	1.4
		Total	100
26.5 – 53	Concrete	8.8	23.5
	Clay bricks	7.5	66.8
	Ceramics	7.6	9.2
	Glass	–	–
	Plastics	–	–
	Metals	–	–
	Wood	–	–
	Stones	–	–
	Miscellaneous	17.5	0.5
		Total	100
9.5 – 26.5	Concrete	11.4	49.5
	Clay bricks	9.4	17.5
	Ceramics	5.1	3.6
	Glass	0.4	0.9
	Plastics	–	–
	Metals	–	–
	Wood	19.0	0.3
	Stones	2.8	3.4
	Miscellaneous	10.7	24.9
		Total	100
4.75 – 9.5	Soil-like	16.8	100
2 – 4.75	Soil-like	27.8	100
< 2	Soil-like	27.8	100

4.1.4 Waste composition

Waste compositions of sorted material on a dry mass basis at the Thanh Tri CDW landfill are shown in Fig. 14. The major components of dumped materials were "Concrete" and "Clay bricks," and the sum of these materials became 68.5% of the total. The secondary components were "Soil-like (19.6%)", "Miscellaneous (7.1%)", and "Ceramics (3.7%)". Other materials were very small and varied from ~0.00.2%. It is worth noting that hazardous and toxic materials were not found in the survey at Thanh Tri CDW landfill.

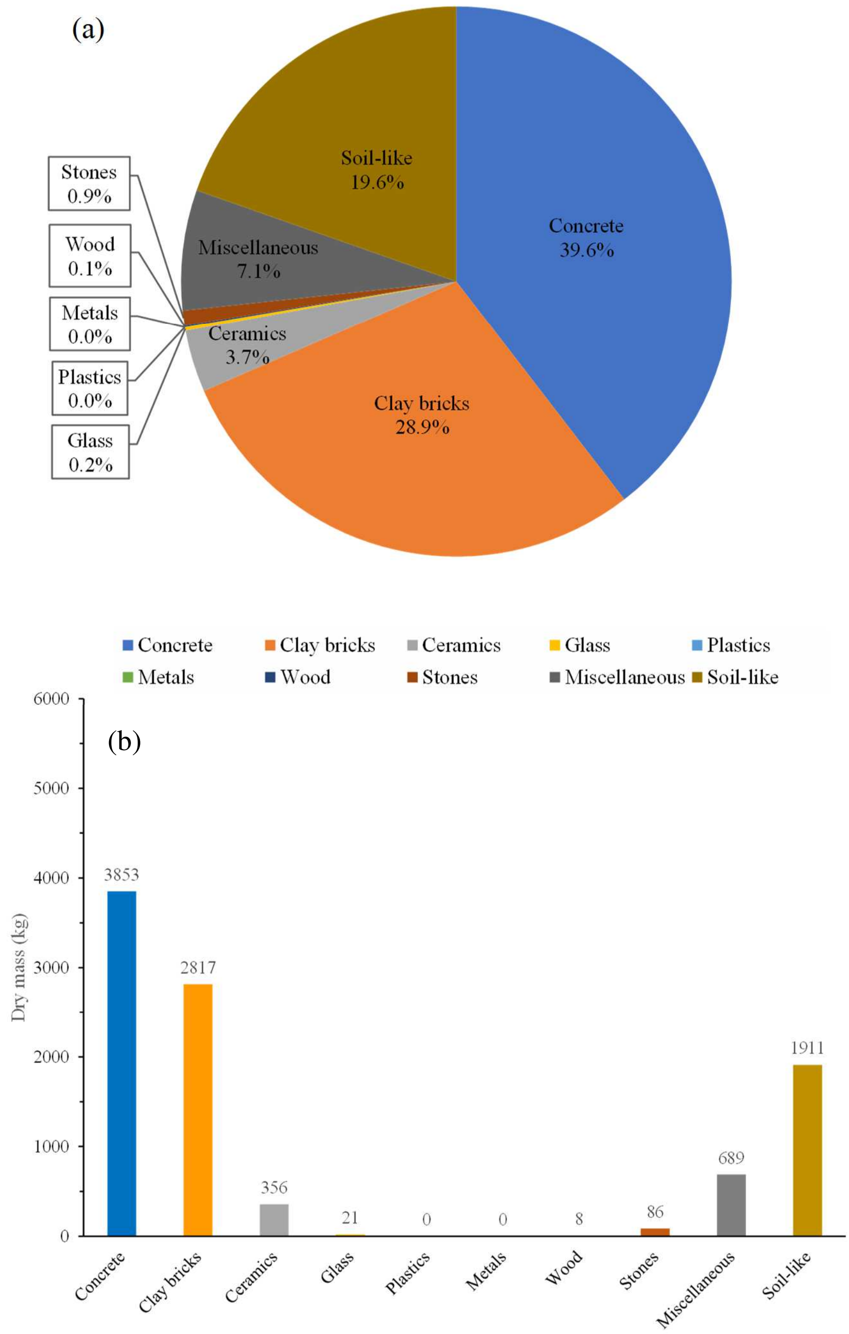


Fig. 14. Waste composition on dry mass basis at Thanh Tri CDW landfill. (a) % on dry mass basis of each sorted material. (b) Dry mass of each sorted material in kg.

4.1.5 Grain size distribution

Measured grain size distributions of all sorted materials on both wet and dry mass bases at Thanh Tri CDW landfill are shown in Fig. 15a. The grain size was distributed broadly up to the maximum diameter of 600 mm. It can be seen there was a small difference in the grain size distributions between wet mass and dry mass. The grain size distributions of “Concrete”, “Clay bricks”, and “Concrete + Clay bricks” (≥ 10 mm) are shown in Fig. 15b. The grain size of “Clay brick” was bigger than that of “Concrete” at the site.

The relationship between mass distributions of sorted materials and grain size is shown in Appendix 4. The comparison of grain size distributions of concrete and clay bricks (≥ 10 mm) to the gradation of graded aggregates for road subbase in Vietnam (TCVN 8859:2011) is shown in Appendix 5.

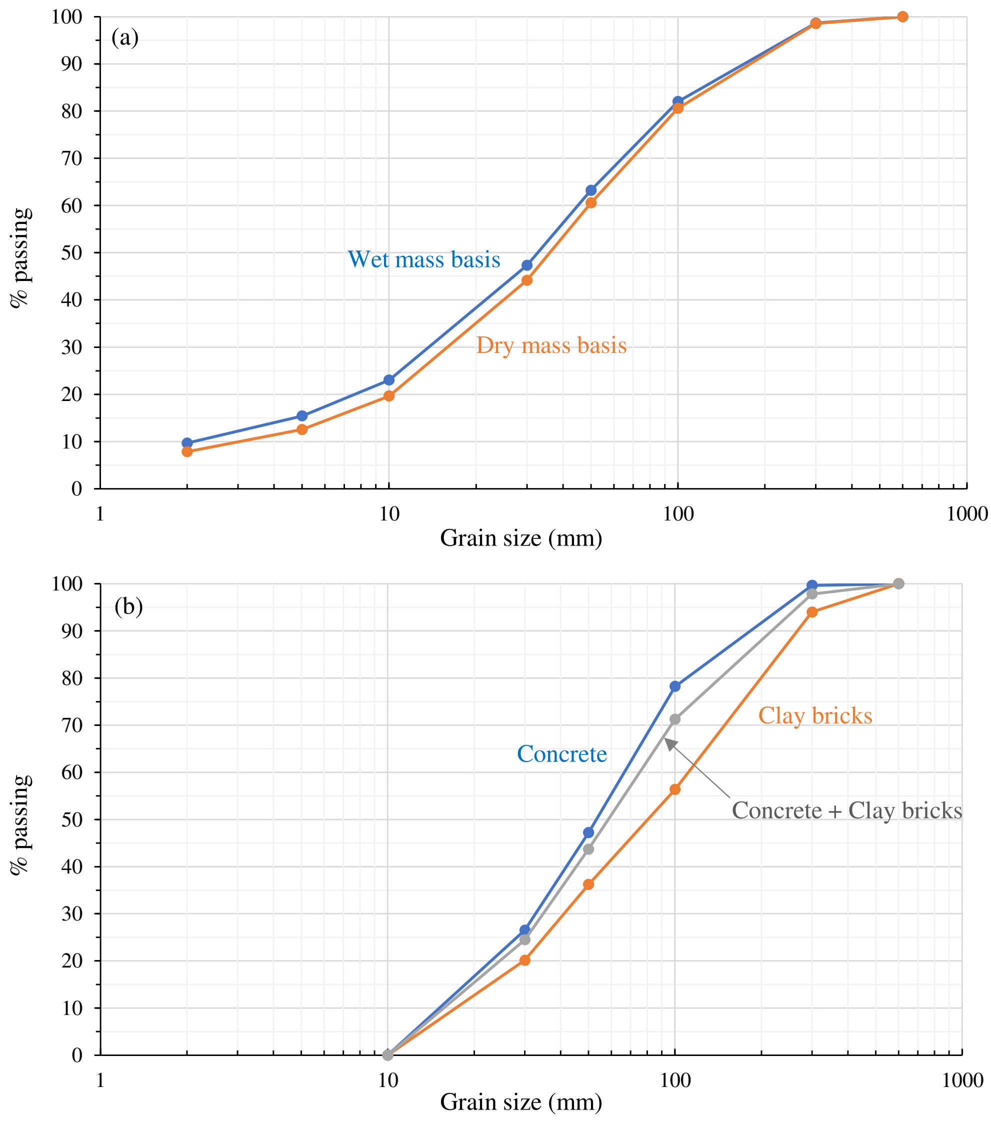


Fig. 15. Grain size distribution at Thanh Tri CDW landfill. (a) Total materials (b) Concrete, Clay bricks, and Concrete + Clay bricks (≥ 10 mm) on dry mass basis.

4.2 CDW landfill in Vinh Quynh, Hanoi

4.2.1 Basic information of site

Basic information of the site is summarized in Table 12, and earth views are shown in Fig. 16. The Vinh Quynh CDW landfill was operated from 2013 to 2018 and is now closed. The site is located about 12 km south of the City Center. The site was operated by an appointed private company under the management of the Hanoi Department of Construction. Photos of the pre-excavation are shown in Fig. 17. For more information, refer to "SATREPS Baseline Survey Report on Construction and Demolition Waste Landfills in Hanoi, Vietnam. 2019".
(http://park.saitama-u.ac.jp/~vietnam_satreps/content/files/SATREPS_Baseline_Survey_Report_Oct_2019.pdf)

Table 12. Basic information survey for Vinh Quynh CDW landfill.

Item no.	**Content**	**Vinh Quynh**
1	GPS location	20° 56' 31.632" N, 105° 49' 41.52" E
2	Estimated area (m^2)	44,000
3	Landowner	Hanoi People's Committee (public land)
4	Operation company/institute	Environmental Technology and Ecology Joint Stock Company
5	Number of workers	1 guard
6	Intake per day/week/month	20–30 trucks (1.25 tons)
7	Operation (years)	6 years from 2013 to 2018
8	Estimated life years	None (Closed)
9	Photo	(See Fig. 4)
10	Groundwater level	2.5–3.5 m from ground surface
11	Acceptable waste	CDW (brick concrete, tile, stone, wood, plastic, soil), domestic waste
12	Previous land use	Pond
13	Height of dumped waste	3.5–4.0 m from ground surface
14	Surrounding environment	Pond, channel, agricultural field
15	Accessibility	Good (30 min from NUCE)
16	Workability	Enough space to work
17	Weather	Wet season: May - October, heavy rain Dry season: November - April, light rain
18	Remarks	● Under limited operation (ALMOST FULL). The land usage is scheduled to change in 2019 by Hanoi People's Committee. ● Available for visit with an official document from local government. ● Type of dumped waste was different at different points inside.

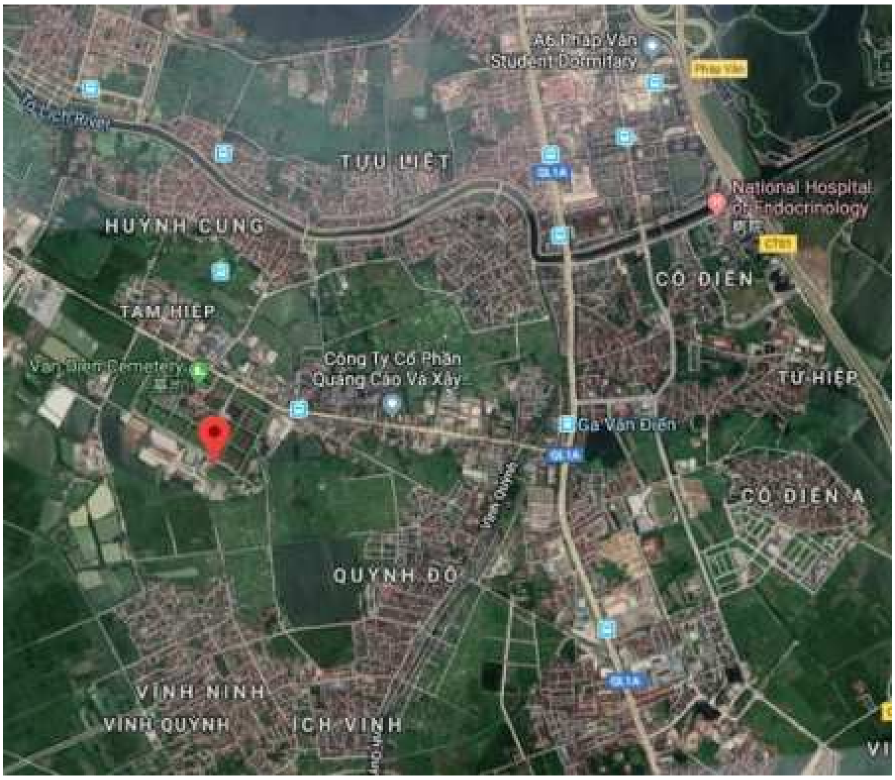


Fig. 16. Earth views of Vinh Quynh CDW landfill (Google Inc. Dated July 01, 2019).

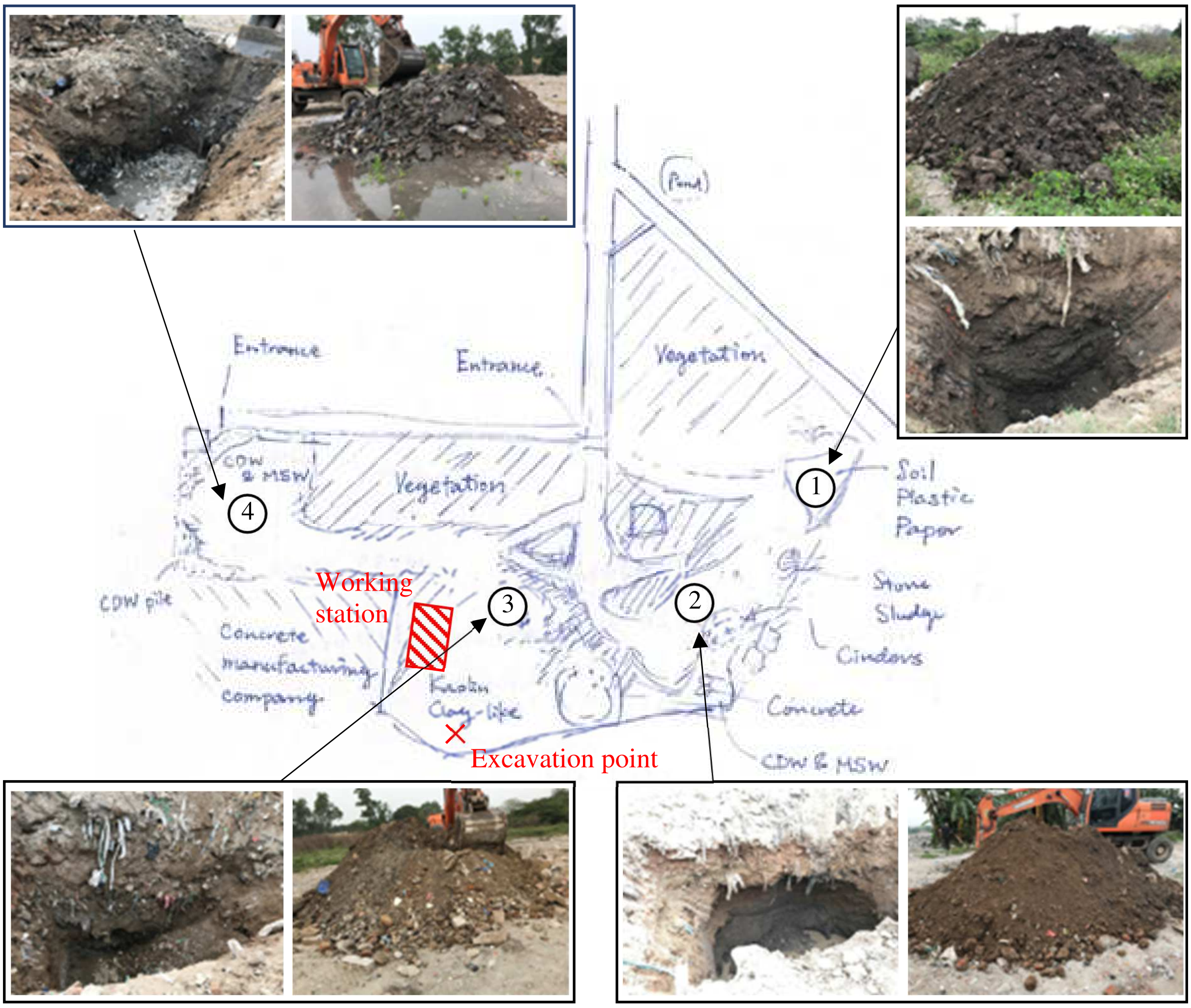


Fig. 17. Sketch of Vinh Quynh CDW landfill. To decide the point of excavation at the site, trial excavations were carried out at 4 points (①~④).

4.2.2 Sampling pit and recording sheet

At the Vinh Quynh CDW landfill site, the dumped waste layer was a maximum depth of 4 m from the ground surface. The dumped waste layer was ~1.3 m at the excavation point. The size of the excavated pit is shown in Fig. 18. A total volume of 6.6 m^3 was excavated and subjected to the material sorting and grading. The record sheet of the waste composition survey is shown in Table 13. It is noted that the mass (in kg) recorded in the sheet is given on a wet basis (actual mass of kg at the site).

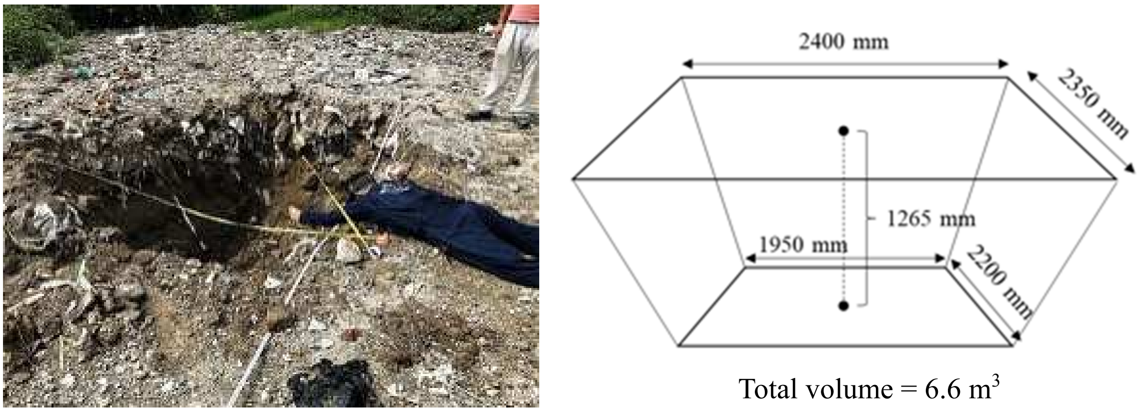


Fig. 18. Sampling pit at Vinh Quynh CDW landfill. Photo (left) and scale of pit (right).

Table 13. Recording sheet for sorted and graded materials in the waste composition survey at Vinh Quynh CDW landfill.

1. Size of excavated pit		
	Length (m)	(2410+2400+2390)/3=2400 (top) / (2000+2010+1840)/3=1950 (bottom)
	Width (m)	(2340+2340+2370)/3=2350 (top) / (2210+2220+2170)/3=2200 (bottom)
	Depth (m)	(1260+1261+1274)/3=1265

2. Mass of each size fraction after sieving		
No.	Sieve size (mm)	Mass (kg)
1	> 300	405+349+329+201+427=1711
2	106 – 300	539+215+477+324+287+449+524=2815
3	53 – 106	370+326+320+266+149=1431
4	26.5 – 53	243+244+320+273=1080
5	9.5 – 26.5	500+292+365+341+391+387=2276
6	4.75 – 9.5	333+345+547=1225
7	2 – 4.75	264+201+309+302=1076
8	< 2	299+443=742

3. Mass of each material for each size fraction					
[Grain size: > 300 mm]		Mass (kg)	[Grain size: 26.5-53 mm]		Mass (kg)
1	Concrete	405+349.4+329+591=1674.4	1	Concrete	247+300+104.5=651.5
2	Clay bricks	36.5	2	Clay bricks	66+79.9=145.9
3	Ceramics	–	3	Ceramics	–
4	Glass	–	4	Glass	0.9
5	Plastics	–	5	Plastics	–
6	Metals	–	6	Metals	–
7	Wood	–	7	Wood	3.2
8	Stones	–	8	Stones	17+17.9=34.9
9	Miscellaneous	–	9	Miscellaneous	188+55.5=243.5
[Grain size: 106-300 mm]		Mass (kg)	[Grain size: 9.5-26.5 mm]		Mass (kg)
1	Concrete	539+215+477+324+362.3=1917.3	1	Concrete	207+233+198+238.8=876.8
2	Clay bricks	108+173.2=281.2	2	Clay bricks	108.8
3	Ceramics	55	3	Ceramics	19
4	Glass	–	4	Glass	13.5
5	Plastics	–	5	Plastics	–
6	Metals	–	6	Metals	–
7	Wood	–	7	Wood	–
8	Stones	21.5	8	Stones	92+100.9=192.9
9	Miscellaneous	233.6+306.3=539.9	9	Miscellaneous	277+301+290+197=1065
[Grain size: 53-106 mm]		Mass (kg)			
1	Concrete	268.2+320.1+280.3=868.6			
2	Clay bricks	108+167=277			
3	Ceramics	40+5494			
4	Glass	–			
5	Plastics	–			
6	Metals	–			
7	Wood	20.1			
8	Stones	29.6			
9	Miscellaneous	76+65.4=141.4			

4.2.3 Water content

After the measurements of water content in the laboratory, the measured mass of each grain size and sorted material was converted from the mass on a wet basis (in kg) to the mass on a dry basis (in kg). The measured water content for each grain size is shown in Table 14. Like the results from the Thanh Tri CDW landfill (shown in section 4.1.3), the measured water content increased with decreasing grain size: the water contents became ~6.1_14.6% for "Over 100", ~14.4–19.4% for "Over 10", and ~26.4–29.2% for "Under 10" (means "Soil-like"). The average water content of the excavated pit (all grain size) was 21.3% (it is 1.7 times higher than that of Thanh Tri CDW landfill).

Measured water content of each sorted material in each grain size as well as % of dry mass for each grain size were summarised in Table 15. Like the results from Thanh Tri CDW landfill (shown in section 4.1.3), it can be observed that the water contents of "Concrete" and "Clay bricks" depended on the grain size. For "Concrete", the water contents increased with decreasing in grain size and ranged from 6.0% (> 300 mm) to 12.9% (9.5–26.5mm). For "Clay bricks", the water contents increased with decreasing in grain size and ranged from 10.5% (> 300 mm) to 16.1% (26.5–53 mm) and 15.6% (9.5–26.5 mm). On the other hand, the water contents of "Ceramic", "Glass", and "Stones" did not vary depending on the grain size and was ~0.3–0.5% for "Ceramic" and "Glass" and ~19.0–24.2% for "Stones". The water contents of "Wood" and "Miscellaneous" categories were higher than those of other sorted materials and became ~84.9–111% for "Wood" and ~26.6–46.2% for "Miscellaneous".

Table 14. Mass on wet and dry basis and water content of each grain size at Vinh Quynh CDW landfill.

No.	Grain size (mm)	Mass on wet basis (kg)	Mass on dry basis* (kg)	Water content** (%)
1	>300	1711	1607	6.1
2	106 – 300	2815	2403	14.6
3	53 – 106	1431	1224	14.4
4	26.5 – 53	1080	897	16.9
5	9.5 – 26.5	2276	1834	19.4
6	4.75 – 9.5	1225	902	26.4
7	2 – 4.75	1076	791	26.5
8	<2	742	525	29.2
	Total (kg)	12355	10183	21.3***

* Mass on dry basis was estimated measured mass on wet basis and measured water content.

** Water content was measured by using a bag sample

*** (12355-10183)/(10183) x 100 = 21.3%

Table 15. Water content of each sorted material in each grain size at Vinh Quynh CDW landfill.

Grain size (mm)	Material	Water content (%)	% of dry mass
> 300	Concrete	6.0	97.9
	Clay bricks	10.5	2.1
	Ceramics	–	–
	Glass	–	–
	Plastics	–	–
	Metals	–	–
	Wood	–	–
	Stones	–	–
	Miscellaneous	–	–
		Total	100
106 – 300	Concrete	8.2	73.2
	Clay bricks	12.0	10.3
	Ceramics	0.5	2.3
	Glass	–	–
	Plastics	–	–
	Metals	–	–
	Wood	–	–
	Stones	19.0	0.7
	Miscellaneous	40.0	13.5
		Total	100
53 – 106	Concrete	9.4	64.3
	Clay bricks	13.3	19.6
	Ceramics	0.5	7.7
	Glass	–	
	Plastics	–	
	Metals	–	
	Wood	84.9	0.2
	Stones	19.7	2.0
	Miscellaneous	46.2	6.2
		Total	100

Grain size (mm)	Material	Water content (%)	% of dry mass
26.5 – 53	Concrete	9.2	66.0
	Clay bricks	16.1	13.6
	Ceramics	–	
	Glass	0.3	0.1
	Plastics	–	
	Metals	–	
	Wood	111	0.0
	Stones	24.2	2.9
	Miscellaneous	35.8	17.4
		Total	100
9.5 – 26.5	Concrete	12.9	41.7
	Clay bricks	15.6	5.6
	Ceramics	0.3	1.0
	Glass	0.4	0.7
	Plastics	–	
	Metals	–	
	Wood	–	
	Stones	20.1	8.4
	Miscellaneous	26.6	42.6
		Total	100
4.75 – 9.5	Soil-like	26.4	100
2 – 4.75	Soil-like	26.5	100
<2	Soil-like	29.3	100

4.2.4 Waste composition

The waste composition of material sorted on dry mass basis at the Vinh Quynh CDW landfill is shown in Fig. 19. The major component of dumped materials was "Concrete (53.8%)" and the secondary components were "Soil-like (21.8%)", "Miscellaneous (13.1%)", and "Clay bricks (7.3%)". The minor components were "Ceramics (1.6%)" and "Stones (2.2%)". Other materials were very scarce and accounted for ~0.0–0.1%. Like the Thanh Tri CDW landfill, it is worth noting that hazardous and toxic materials were not found in the survey at the Vinh Quynh CDW landfill.

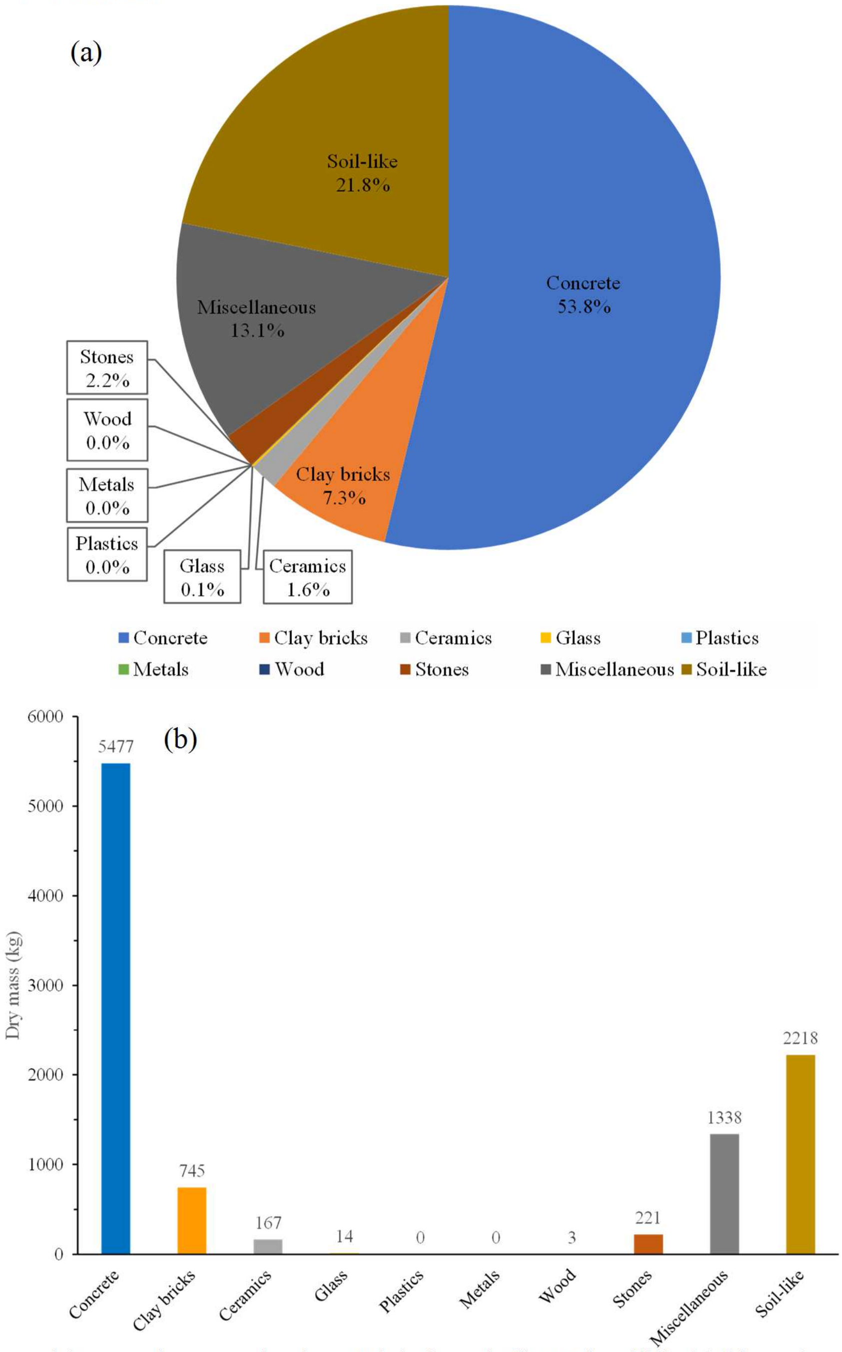


Fig. 19. Waste composition on dry mass basis at Vinh Quynh CDW landfill. (a) % on dry mass basis of each sorted material. (b) Dry mass of each sorted material in kg.

4.2.5 Grain size distribution

Measured grain size distributions of all sorted materials on both a wet and dry mass basis at the Vinh Quynh Tri CDW landfill are shown in Fig. 20a. Like the results from Thanh Tri CDW landfill (Fig. 15a), the grain size was distributed broadly up to the maximum diameter of 600 mm, and there was a small difference in the grain size distributions between wet mass and dry mass. The grain size distributions of "Concrete", "Clay bricks", and "Concrete + Clay bricks" (≥ 10 mm) are shown in Fig. 20b. In contrast to the results from the Thanh Tri CDW landfill (Fig. 15b), the grain size of "Concrete" was bigger than that of "Clay bricks" at the Vinh Quynh CDW landfill. The relationship between mass distributions of sorted materials and grain size is shown in Appendix 4. The comparison of grain size distributions of concrete and clay bricks (≥10 mm) to the gradation of graded aggregates for road subbases in Vietnam (TCVN 8859:2011) is shown in Appendix 5.

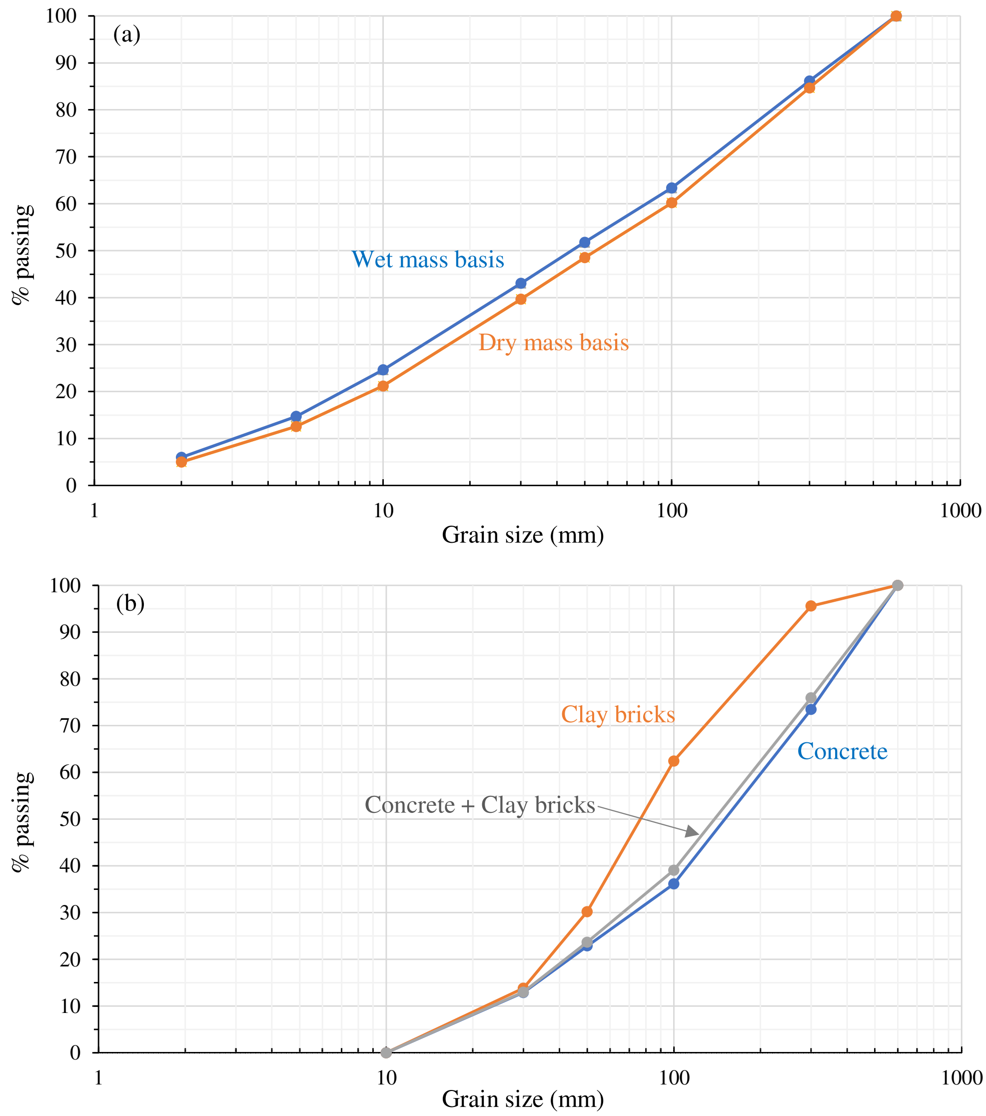


Fig. 20. Grain size distribution at Vinh Quynh CDW landfill. (a) Total materials (b) Concrete, Clay bricks, and Concrete + Clay bricks (≥ 10 mm) on dry mass basis.

Appendix 1: Sampling methods

In general, data collection and sampling are implemented based on either probability-based or judgemental designs (e.g., EPA 2002). For the probability-based design, the sampling unit is chosen from the statistical population (each group in the statistical population has a known probability of selection). A simple random, stratified, systematic grid sampling can be applied typically to collect samples from the statistical population. However, it is normally difficult to adopt a pure probability without selection bias, non-response bias, or estimation (Deming, 1950). For the judgemental sampling, on the other hand, the sampling unit is chosen based on knowledge, experience, and the site characteristics and/or the condition after a preliminary survey by experts and professionals, not considering the statistical population and probability of selection. From this viewpoint, the judgemental sampling cannot avoid the selection bias. Table A1 summaries typical advantages and disadvantages of the probability-based and judgmental sampling designs.

In this survey, a pit sampling (e.g., Petersen and Calvin, 1986; Ayres et al., 2016) based on the judgement sampling design was applied to decide the location and size of a sampling pit at each CDW landfill site, fully considering the results of a pre-survey, experience of experts and professionals, safety of workers, and limitations of time and cost. Therefore, it is noted that we cannot analyse the spatial variation of waste composition and grain size distribution at the investigated site because of the unknown statistical population.

Table A1. Advantages and disadvantages of probability-based and judgmental sampling designs (refer to EPA, 2002).

	Probability-based	Judgmental
Advantage	· Able to calculate uncertainty associated with estimate · Reproducible within uncertainty limits · Able to make statistical inferences · Able to handle decision error criteria	· Less expensive than probabilistic designs · Easy to decide the size and scale of sampling · Easy to implement
Disadvantage	· Difficult to design random locations · Optimal design depends on an accurate conceptual model	· Depends on expert knowledge and personal judgement including the data interpretation · Not reliable to evaluate precision of estimates

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Appendix 2: Waste classification of dumped materials at CDW landfill

Construction and demolition waste (CDW) consists of materials such as concrete, clay bricks, asphalt pavement, wood, plastic, ceramics, and other materials generated during the construction, renovation, and demolition of buildings and structures. At CDW landfill sites, in general, not only such bulky materials but also stones and soil-like materials (debris) generated during the construction and demolition works are commonly dumped together. In addition, the waste generated at construction and demolition sites contains hazardous waste such as asbestos, solvents, coal tar, and so on. Due to the lack of segregation, hazardous waste is often dumped at CDW landfill sites together with non-hazardous CDW in developing countries (Abarca-Guerrero and Leandro-Hernandez, 2017).

The definition of CDW varies depending on country, region, and local conditions such as construction materials and structural styles (e.g., EPA, 1998; Construction Material Recycling Law in Japan, 2005; European Commission, 2016). The classification and category of hazardous waste also vary depending on the country, region, and its hazardous properties. In Vietnam, CDW is also called Construction Solid Waste (CSW), and the definition and classification as well as separation, reuse, and recycling methods shown in technical standards (TCVN), and legal documents (Decree and Circular) are summarized in Table A2. The list of hazardous wastes from CDW including excavated soil from contaminated sites is given in the attached document Decision No.23/2006/QD-BTNMT.

On the other hand, a number of classification systems for municipal solid waste (MSW) have been proposed based on waste type, materials groups, degradability of organic compounds, and so on (e.g., Landva and Clark, 1990; Dixon and Langer, 2006). These classification systems can be applied to classify the typical dumped materials at CDW landfills in Vietnam and are shown in Table A3. The dumped CDW consists of non-hazardous and hazardous waste and the non-hazardous waste is classified into inorganic and organic materials. The inorganic materials consist of non-degradable ones such as concrete, clay bricks, ceramics, glass, stones, and soil-like, and degradable (corrosive) materials like metals. The organic materials are further classified into putrescible and non-putrescible, but most non-hazardous CDW is categorized as non-putrescible (i.e., wood, plastic, paper, and so on). Except for the soil-like material, the size of non-hazardous CDW at CDW landfill sites is normally >10 mm. Even though the amount dumped was very small, some hazardous wastes such as gypsum, asbestos, and paint were found at investigated CDW landfills investigated in this survey. Those hazardous materials are also classified in Table A3.

The STREPS project surveyed seven CDW landfills in Hanoi in 2019 (SATREPS report, 2019). The survey results showed that typical dumped materials were classified into ten categories: 1) concrete, 2) clay bricks, 3) ceramics, 4) glass, 5) plastics, 6) metals, 7) wood, 8) stones, 9) miscellaneous (including paper, rubber, leather, and textiles), and 10) soil-like (typically, <10 mm). Based on the investigated results, we classified the sorted materials into ten categories in this composition survey.

Table A2. Definition, classification, separation, reuse, and recycling methods shown in technical standards and legal documents in Vietnam.

TCVN/Decree/Circular	Definition	Classification	Separation, reuse, and recycling
TCVN 6705: 2009	Waste from construction activities: Waste discarded by dismantling or renovating old construction works, or new works in process of construction (house, bridge, road, etc.) such as mortar, broken brick, concrete, ceramic water pipeline, roof, gypsum and other materials.		
Decree No.38/2015/ND-CP	Solid waste from construction activities (including renovation and demolition of works)	a) Soil, sludge b) Gravelly soil, solid waste from construction materials (brick, tile, grout, concrete, adhesives materials overdue) c) Recyclable solid waste such as glass, steel, wood, paper, plastics	a) Soil, sludge from excavation, dredging topsoil, digging the foundation piles shall be used to cultivate the crop land or suitable land areas. b) Gravelly soil, solid waste from construction materials (brick, tile, grout, concrete, adhesives materials overdue) shall be recycled as construction materials or reused as backfill materials for buildings or buried in construction solid waste landfill. c) Recyclable solid waste such as glass, steel, wood, paper, plastics shall be recycled and reused.
Circular No. 08/2017/TT-BXD	Construction Solid Waste (CSW) is solid waste generated during surveying and constructing the construction works (including new construction, renovation, improvement, rehabilitation, recovery, and demolition)	a) Recyclable solid waste. b) Solid wastes can be reused at the construction site or in other construction sites. c) Wastes that cannot be recycled, reused is required to be landfilled. d) Hazardous waste is separated and managed following the regulations in Decree No. 38/2015/ND-CP and other guiding legal documents on hazardous waste management.	a) Concrete and brick debris can be recycled to produce coarse aggregates, to manufacture brick, wall panel, floor brick, other building materials, and leveling the ground surface. b) Wood and paper, they can be recycled mainly to produce paper, wood, and burning materials. c) Mixtures of bitumen can be recycled to produce bituminous concrete (aggregate form). d) Steel and other metal, they can be reused or used for metal production. e) Other construction materials--the recycle and reuse depends on their characteristics and compositions.

Table A3. Classification of dumping materials at CDW landfill.

[Non-hazardous waste]

	Inorganic		Organic	
Size	[Degradable]	[Non-degradable]	[Putrescible] Readily biodegradable	[Non-putrescible] Slowly biodegradable
≥ 10 mm	• Metals (corrosive)	• Concrete • Clay bricks • Ceramics • Glass Asphalt • Stones		• Wood • Plastic Paper, Rubber, Leather, Textiles → • Miscellaneous
< 10 mm		• Sol-like (including sludge and ash)		

[Hazardous waste]

	Gypsum (containing hazard; under reducing condition)	Asbestos (fibres) Glass fibres Mercury (volatiles) Waste acid Waste alkali	Paint (volatile) Detergents Solvents (volatile)	Oil Lubricants Coal tar (containing hazard)

• Materials sorted in the waste composition survey

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Appendix 3: Determination of grain size distribution using an image analysis technique

In this waste composition survey, an image analysis technique was applied to determine the distribution of grain sizes >100 mm (e.g., Ibekken and Schleyer, 1986; Mora et al., 1998; Shanthi et al., 2014). This is because the image analysis technique is simple and easy to apply on-site. On the other hand, mechanical sieving and measurement of raw weights of coarse fractions on-site require heavy work, a long time, and a balance with a high capacity.

For image analyses, samples were placed on a tarpaulin as a flat plane and photographed horizontally (Fig. A1), and photos of samples were taken from the top of the placed samples (around 1.5 to 2 m height) as vertically as possible to avoid image distortion (see Fig. 6h). The photo image was analysed using image processing software. In this survey, Adobe Illustrator (Adobe Inc.) was used to correct the distortion of images, and ImageJ was used to calculate the grain size. After correcting the distortion of the image, it was first binarized with a thresholding value that shows a clear edge of each sample. Then, the best-fit ellipse major axis, minor axis, and Feret's diameter (maximum calliper) were calculated automatically (Fig. A1), and the volume and equivalent diameter of each sample were estimated from the measured ellipsoid. Next, the estimated volume was converted to weight by multiplying it by the density of the material. Finally, the dataset consisting of the estimated weight and equivalent dimeter (grain size) was used to plot the grain size distribution.

To evaluate the results of the grain size distribution from the image analysis technique, we compared the analysed grain size distributions of concrete and clay bricks to those measured by mechanical sieving. As shown in Fig. A2, the image analysis technique gave similar results for both concrete and clay bricks at Thanh Tri and Vinh Quynh CDW landfills. This indicates that a simple and easy image analysis technique is applicable to measure coarse fractions (> 100 mm) of dumped materials at CDW landfills.

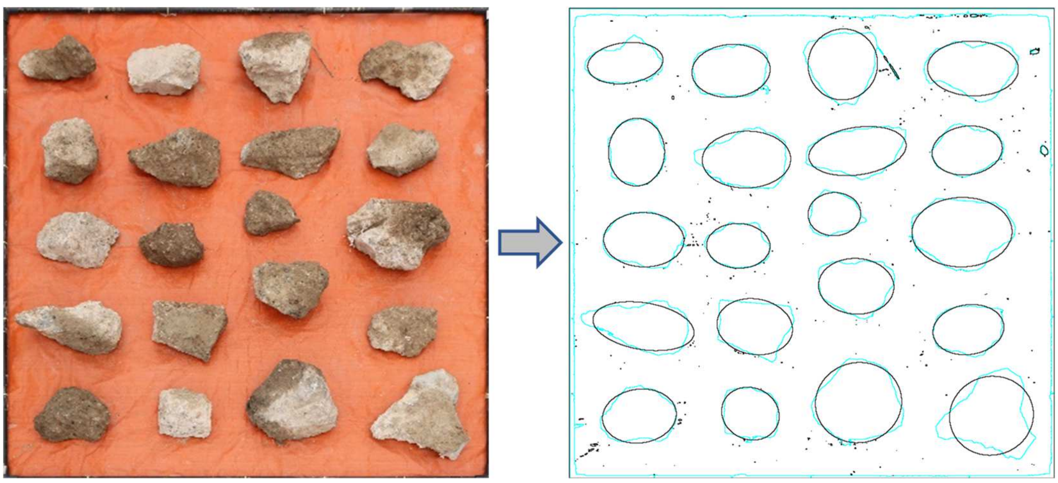

Fig. A1. Image analysis for determining grain size. Left: original samples, Right: Image trace (blue) and ellipses (black).

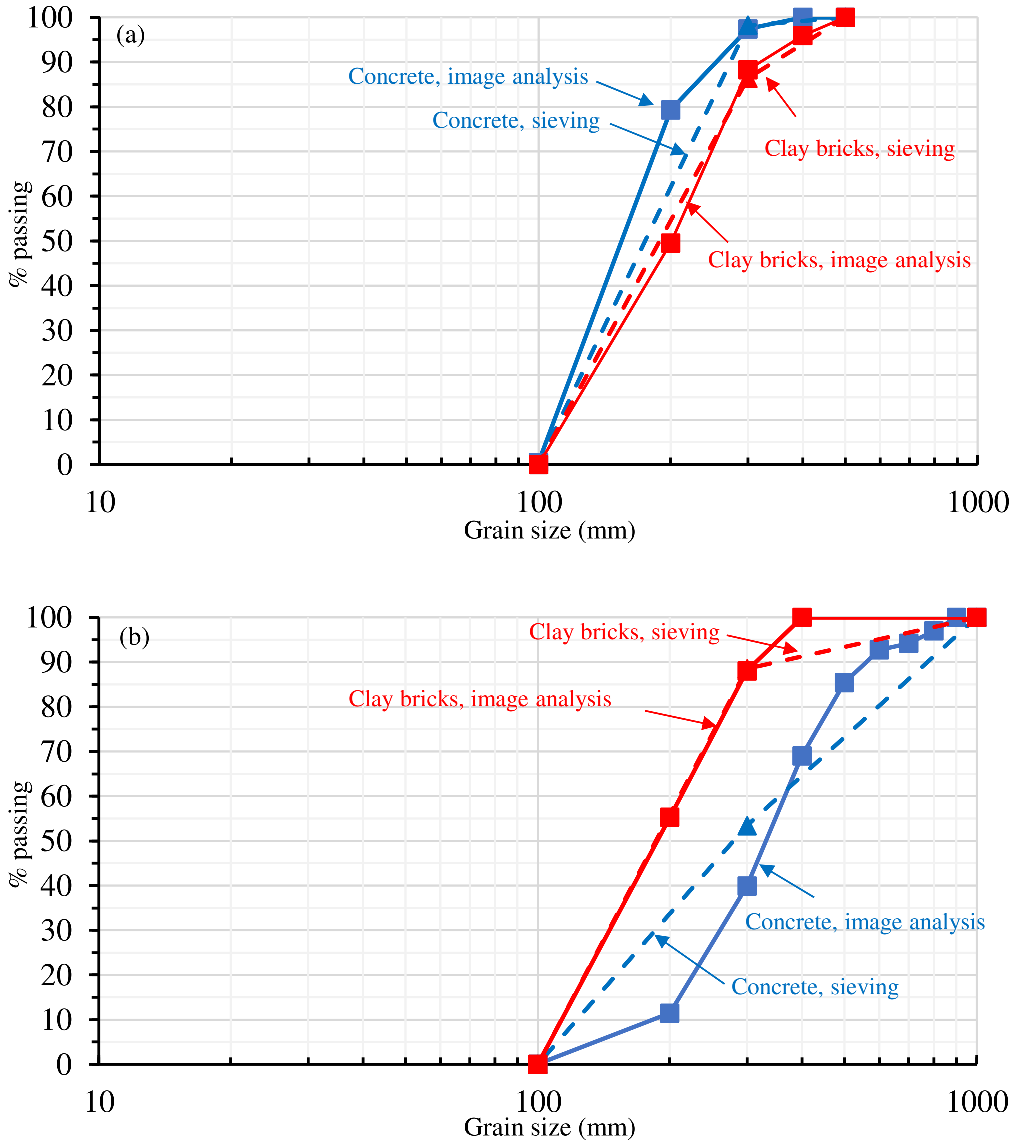

Fig. A2. Comparison of grain size distributions for concrete and clay bricks (>100 mm) measured by image analysis and mechanical sieving. (a) Thanh Tri CDW landfill, (b) Vinh Quynh CDW landfill.

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Appendix 4: Relationship between mass distribution of sorted materials and grain size

The relationship between dry-mass distribution and grain size of sorted materials is shown in Fig. A3. For Thanh Tri CDW landfill site, it can be seen that the major materials were concrete and clay bricks >10 mm, and soil-like <10 mm (Fig. A3a). For Vinh Quynh CDW, on the other hand, the major materials were concrete and soil-like, and the percentage of clay bricks was smaller compared to the Thanh Tri CDW landfill (Fig. A3b). For the Vinh Quynh CDW landfill, two clear peaks of concrete can be seen within the ranges of 106–300 and >300 mm, indicating that coarser fractions of concrete were dumped compared to the Thanh Tri CDW landfill. For both landfills, miscellaneous materials were mostly in the range of 9.5–26.5 mm. In addition, a relatively high amount of ceramics within the ranges of 9.5–26.5, 26.5–53 and 53–106 mm was found at the Thanh Tri CDW landfill, but very little ceramics was found at the Vinh Quynh CDW landfill.

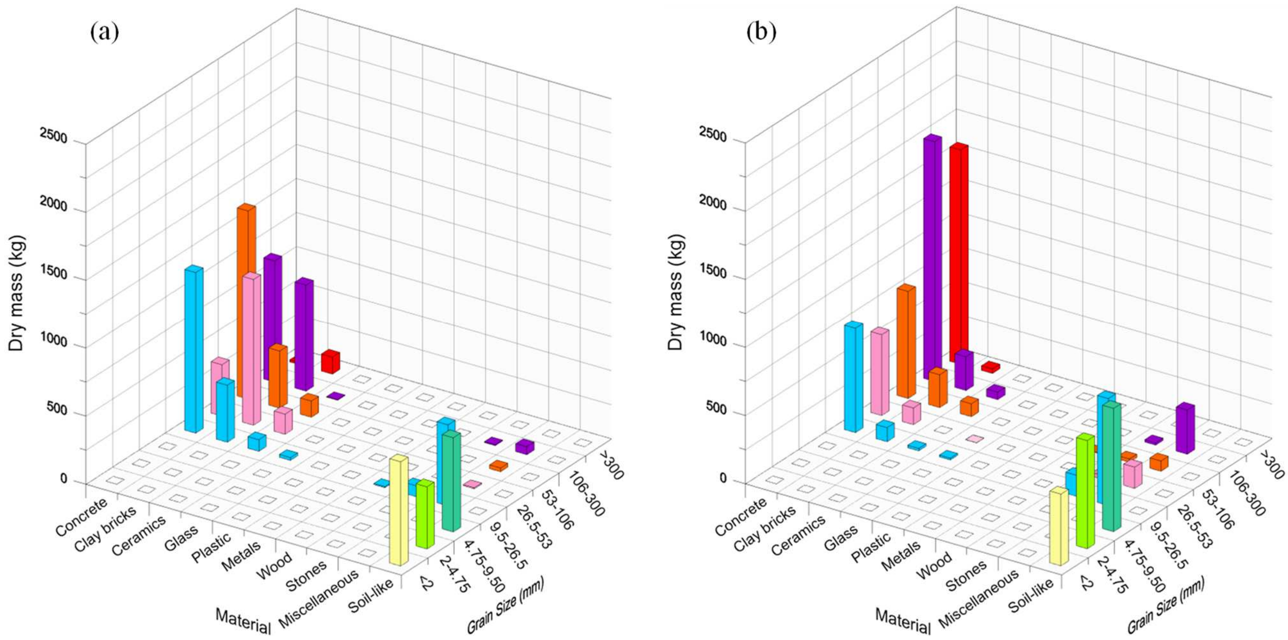

Fig. A3. Relationship between dry-mass distribution of sorted materials and grain size. (a) Thanh Tri CDW landfill (b) Vinh Quynh CDW landfill.

Appendix 5: Comparison of grain size distributions of concrete and clay bricks (≥10 mm) to the gradation of graded aggregates for road subbase in Vietnam (TCVN 8859:2011)

Measured grain size distributions of concrete, clay bricks, and concrete + clay bricks were compared to those of graded aggregates for roadbed materials (D_{max} = 37.5 mm) in TCVN 8859 (2011) and are shown in Fig. A4. The grain size distribution of graded aggregates for roadbed materials in TCVN 98859 is given by the range of percent of screened through sieving by weight, and upper and lower ranges are given in the figure. Measured D_{max}, D_{75}, D_{50}, and D_{25} for concrete, clay bricks, and concrete + clay bricks are summarized in Table A4. Basically, the measured grain sizes of concrete, clay bricks, and concrete + clay bricks for both CDW landfills was larger than those upper and lower sizes in TCVN 8859, indicating that suitable crushing and grading are necessary to use the dumped concrete and clay bricks for roadbed materials. Especially, the control of D_{max} (the maximum grain diameter) and the control of grading (grain distribution), i.e., the control of diameters such as D_{75} (coarse), D_{50} (mean), and D_{25} (fine) are highly required.

Table A4. Measured D_{max}, D_{75}, D_{50}, and D_{25} for concrete, clay bricks, and concrete + clay bricks at Thanh Tri and Vinh Quynh CDW landfills.

(mm)	Concrete	Clay bricks	Concrete + Clay bricks	Graded aggregated with D_{max} = 35 mm (TCVN 8859:2011)
Thanh Tri CDW landfill				
D_{max}	600	600	600	35
D_{75}	94.8	199	128	17.5 ~ 27.5
D_{50}	54.5	84.2	61.4	7.4 ~ 15.0
D_{25}	28.9	36.1	30.6	1.5 ~ 5.1
Vinh Quynh CDW landfill				
D_{max}	600	600	600	35
D_{75}	317	176	295	17.5 ~ 27.5
D_{50}	174	80.7	159	7.4 ~ 15.0
D_{25}	58.1	43.6	54.3	1.5 ~ 5.1

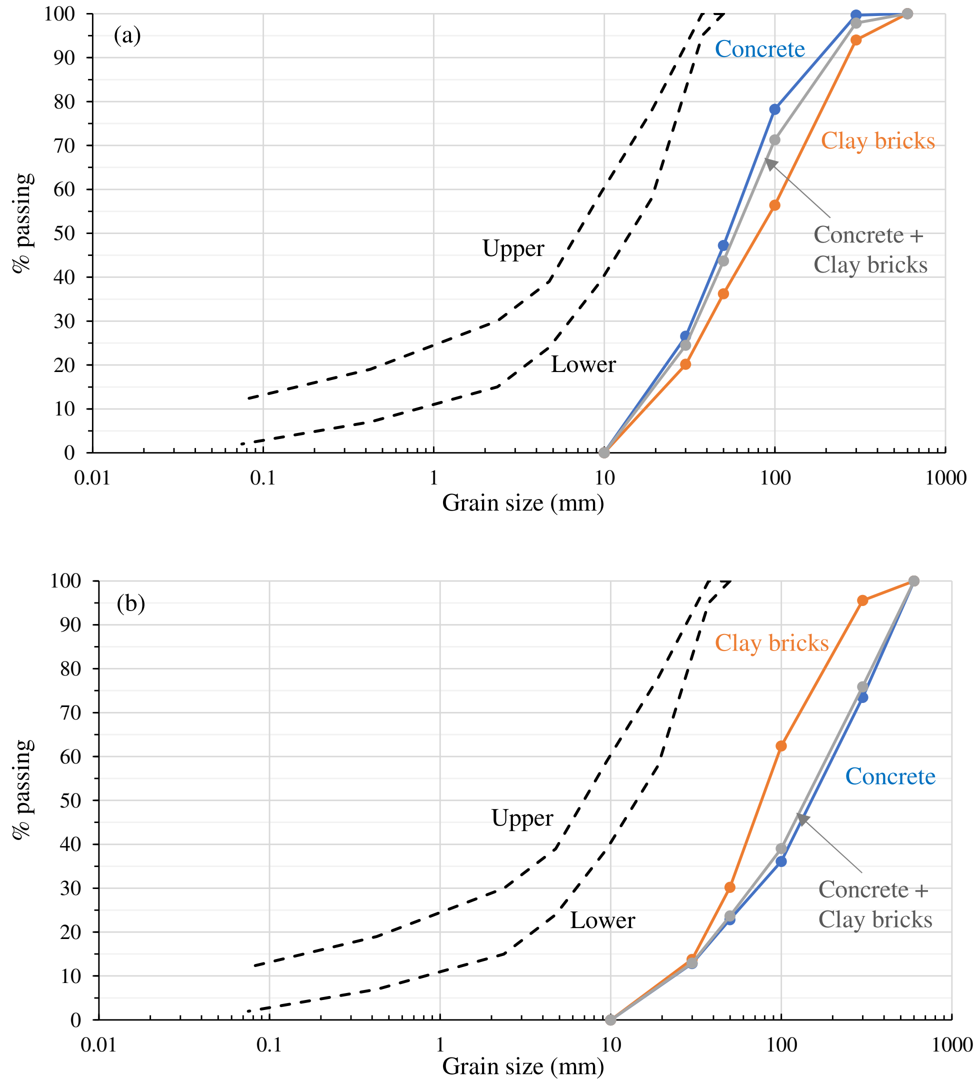

Fig. A4. Comparison of grain size distributions of concrete, clay bricks, and concrete + clay bricks with those of graded aggregates for roadbed materials (D_{max} = 37.5 mm) in TCVN 98859: 2011. (a) Thanh Tri CDW landfill (b) Vinh Quynh CDW landfill.

[Reference]

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