横浜国立大学

Yokohama National University

Graduate School of Urban Innovation

Development of Eco-friendly Controlled Low-Strength Material Utilizing Fresh Concrete Waste and By-Products

生コンクリートの廃棄物や副産物を活用した環境負荷低減型のCLSMの開発

MASTER’S FINAL DEFENSE

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Yokohama, Japan

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CONTENTS OF PRESENTATION

- **Controlled Low-Strength Materials(CLSM):** Self-consolidating material for backfill.
- The vast global concrete production is estimated at **25 billion tons annually**.
- It is estimated over **125 million tons of returned concrete (RC)** are generated annually.
- Disposal of **RC** has a heavy impact on the environment (**267 kg of CO_2 eq./m^3**).
- The cost of disposal of RC in urban areas can range from **3500-4500** yen/m^3 [1]
- Recycling RC **conserves aggregates** and cuts **disposal costs**, offering **economic benefits**.
- The **economic** and **environmental** benefits and impact are **insufficiently quantified**.

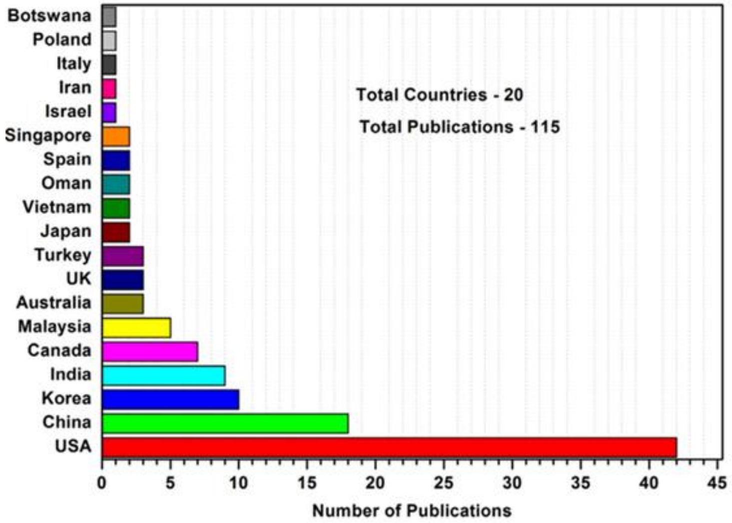

Fig. 2 Country-wise CLSM articles (Ling et al. 2018)

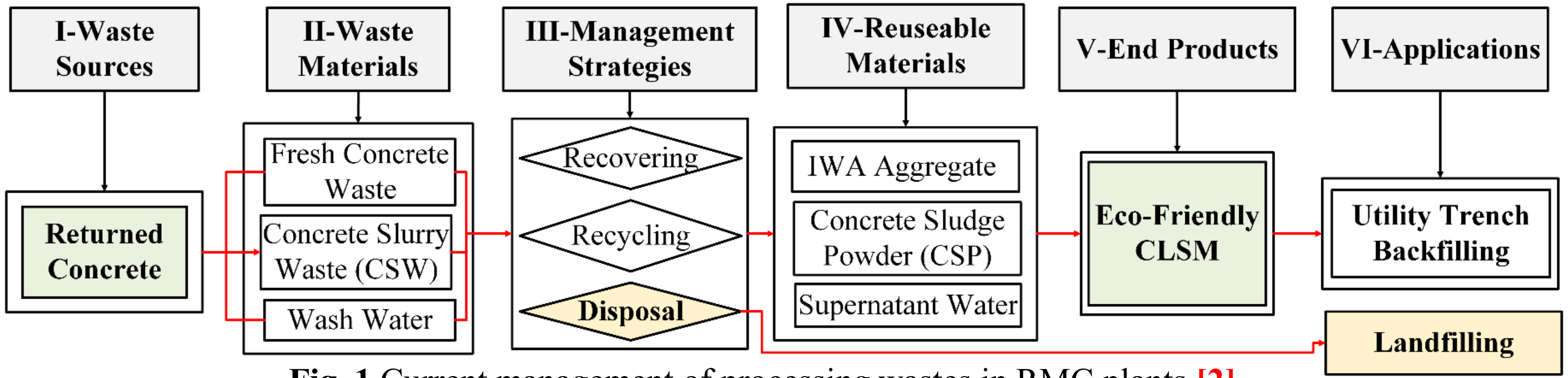

Fig. 1 Current management of processing wastes in RMC plants [2]

Fig. 3 RC and utility backfilling (NRMCA)

GENERAL OBJECTIVE

- To develop an <u>optimized</u>, <u>excavatable</u>, and <u>eco-friendly</u> **Controlled Low-Strength Material (CLSM)** for backfilling buried pipes, utilizing **fresh concrete waste** along with **industrial by-product** materials.

[1] Ferrari, G., M. Miyamoto, and A. Ferrari, New sustainable technology for recycling returned concrete. Construction and Building Materials, 2014. 67: p. 353-359.
[2] Xuan, D., Poon, C. S., & Zheng, W. (2018). Management and sustainable utilization of processing wastes from ready-mixed concrete plants in construction: A review. *Resources, Conservation and Recycling*, *136*, 238-247.

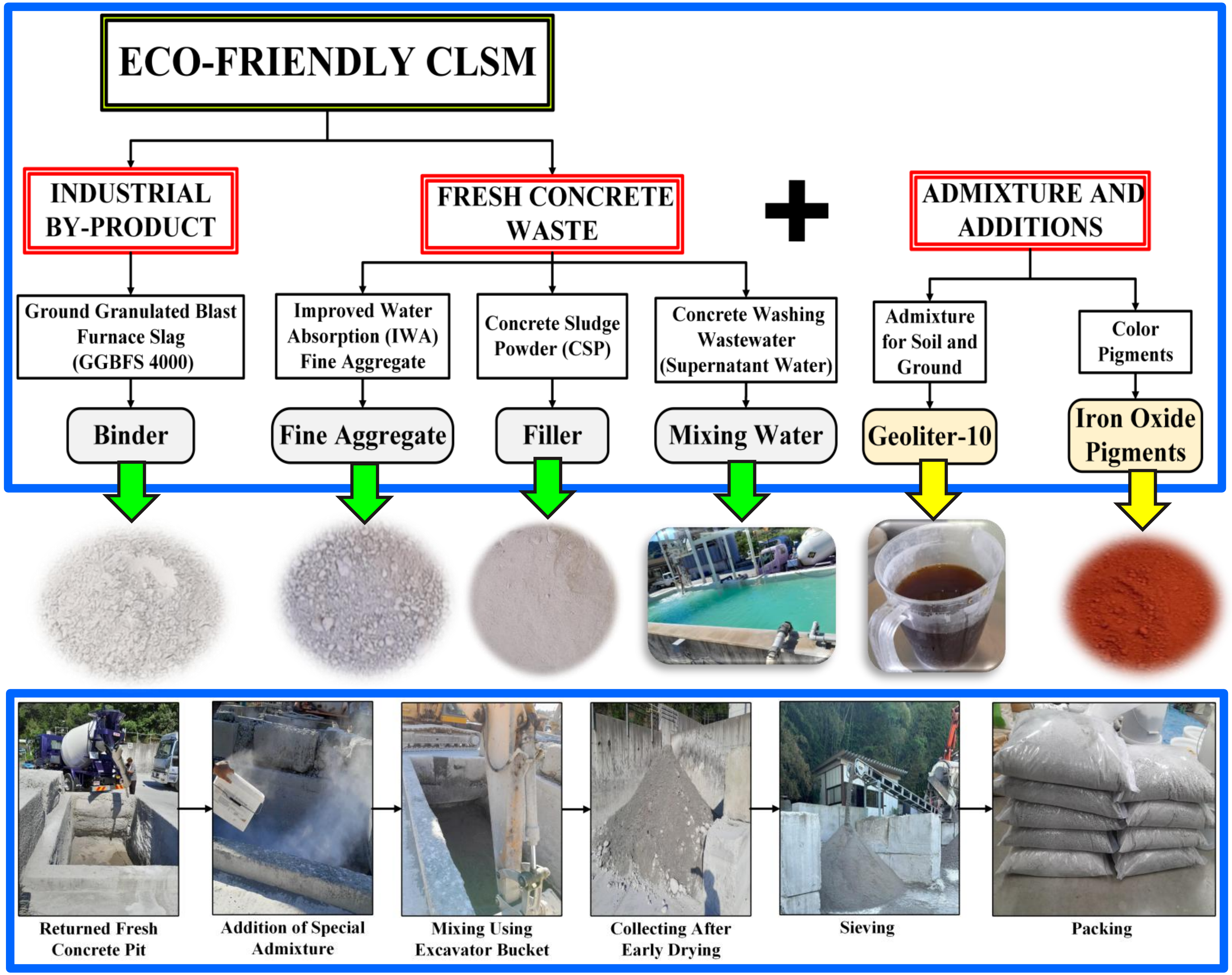

Fig. 4 IWA fine aggregate production [1]

Table 1: Test methods for **Fresh**, **Hardened** and **Durability** of eco-friendly CLSM

Categories	Property	Test Methods
Fresh CLSM Test Methods	Sampling	ASTM D 5971
	Flowability	JHS A 313-1992
	Bleeding	JSCE F 522
	Wet Density	Constant Volume Method
	Air Content	JIS A 1128
	Hardening time	JIS A 1147
Hardened CLSM Test Methods	UCS	JIS A 1216
	Excavatability	Technical Manual and ACI-229R-13
	Permeability	JIS A 1218
Durability Test Methods	Wet-dry cycles	ASTM D559
	Leaching test	JIS K 0102 65.2

[1] Ferrari, G., M. Miyamoto, and A. Ferrari, New sustainable technology for recycling returned concrete. Construction and Building Materials, 2014. 67: p. 353-359.

General criteria and requirements [1-2]

Application: Eco-Friendly Excavatable CLSM for **backfilling buried pipes**

Target Performance as per PWRI's Technical Manual For Fluidized Soil and ACI Guidelines:

- **Flowability:** 140 mm or more
- **Bleeding:** less than 3%
- **Wet density:** 1.40 g/cm³ or more
- **28-day Unconfined Compressive Strength (UCS) :** [200-600 kN/m²]
- **Backhoe excavatability UCS:** [500-1000 kN/m²]
- **Hardening:** at least 130 kN/m² under roads and 50 kN/m² under sidewalks when open to traffic
- **Maximum particle size:** 13mm
- **Easy to re-excavate**—manually or mechanically
- **Removability Modulus (RE):** 1 or less
- **Hexavalent Chromium content:** 0.05mg/L or less

GENERAL METHODOLOGY FOR THE MIX DESIGN AND MIXTURE PROPORTIONS

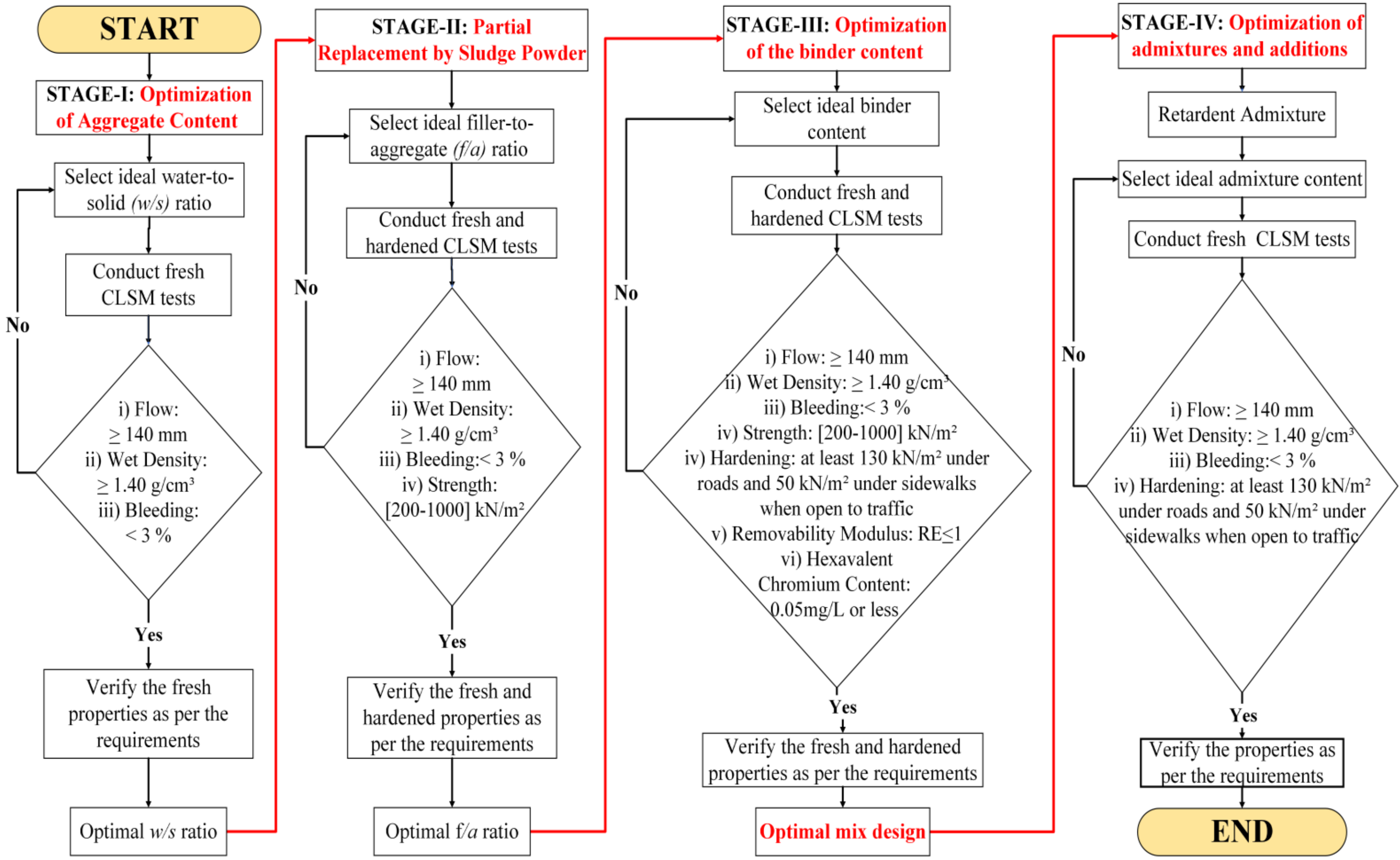

Fig. 5 General methodology for the mix design

[1] ACI 229R-13; Report on Controlled Low-Strength Materials, ACI Committee 229. American Concrete Institute (ACI): Farmington Hills, MI, USA, 2013.
[2] Public Works Research Institute; Technical Manual for Liquefied Stabilized Soil (in Japanese), 2nd ed.; Gihodo Publishing Co., Ltd.: Tokyo, Japan, 2007

STAGE-I OPTIMIZATION OF AGGREGATE

- **Maximized flow targeted** to ensure adequate water content.
- Higher *w/s* ratios **increase the average flowability.**
- As the *w/s* ratio increased, the **wet density decreased.**
- Higher *w/s* ratios resulted in an **increased bleeding rate**.
- The **bleeding rate** surpassed the target of **3%** at a ***w/s* of 24 %.**
- A ***w/s* ratio of 22%** was determined to be the **optimal *w/s* ratio.**

Table 2: Effects of *w/s* on fresh properties

w/s (%)	Stage-I Eco-Friendly CLSM Mixtures: GGBFS (kg/m³)	IWA fine aggregate (kg/m³)	Supernatant Water (kg/m³)	Air (%)	Fresh Properties: Wet Density (g/cm³)	Flow (mm)	Bleeding (%) 3hrs	Bleeding (%) 24hrs
18	50	1378	264	3.9	1.87	**192.5**	1.87	0.47
21	50	1345	286	3.4	1.84	**211**	2.41	1.92
22	50	1315	307	2.8	1.83	**223.5**	2.45	1.96
24	50	1282	326	2.5	1.81	**232.5**	3.83	3.35

STAGE-II PARTIAL REPLACEMENT BY CSP

- Targeted to **maximize CSP utilization** for improved **stability.**
- **Stage-II** focused on the **fresh** and **hardened** properties.
- Higher *f/a* **reduced flowability**, requiring additional water.
- As the *f/a* increased, **wet density decreased.**
- **Bleeding rate decreased** with higher *f/a*, fall below the target.
- Stage-II showed that up to **20% CSP filler was** utilized.

Table 3: Effects of *f/a* on fresh properties

f/a (%)	Fresh Properties: Wet Density (g/cm³)	Flow (mm)	Bleeding (%) 3hrs	Bleeding (%) 24hrs
0	**1.83**	**223.5**	**2.45**	**1.96**
10	1.81	186.5	1.92	0.96
15	1.78	174	1.55	0.52
20	**1.75**	**169**	**0.91**	**0.46**
25	1.73	109	0.48	0.00

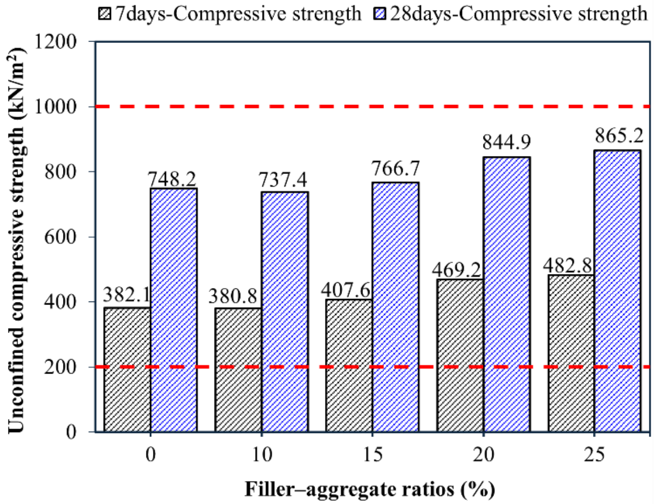

Fig. 6 Effects of *f/a* on unconfined compressive strength (UCS)

[1] Blanco, A., Pujadas, P., Cavalaro, S. H. P., & Aguado, A. (2014). Methodology for the design of controlled low-strength materials. Application to the backfill of narrow trenches. *Construction and Building Materials*, *72*, 23-30

- ➢ The eco-friendly CLSM is deemed excavable either **manually** or **mechanically**.
- ➢ **Optimal binder content** must meet all three key requirements below:

1) **A 28-day strength of 200–1000 kN/m²** was targeted to ensure re-excavation.
2) **Removability modulus (RE) ≤1** was used to assess future excavatability **(1)**
3) **Long-term strength** at **56 and 91 days** targeted to confirm excavatability.

- ❖ **30 kg/m³ binder** meets the **RE (0.46)** but fails **28-day** and **long-term strength**.
- ❖ **40 kg/m³ binder** meets **RE (0.67), 28-day (281.9),** and **long-term strength.**
- ❖ **50 kg/m³ binder** meets **28-day (835.8)** and **long-term strength,** but fails **RE.**
- ❖ **60 kg/m³ binder** fails to meet **RE(1.30), 28-day,** and **long-term strength.**

➢ The study determined that **40 kg/m³ of GGBFS was the optimal binder content.**

Source: https://shorturl.at/mV6ED
Fig. 7 Underground Leak

Fig. 8 Manual Excavation **(Nagaoka RMC)**

Fig. 9 Mechanical Excavation **(NRMCA)**

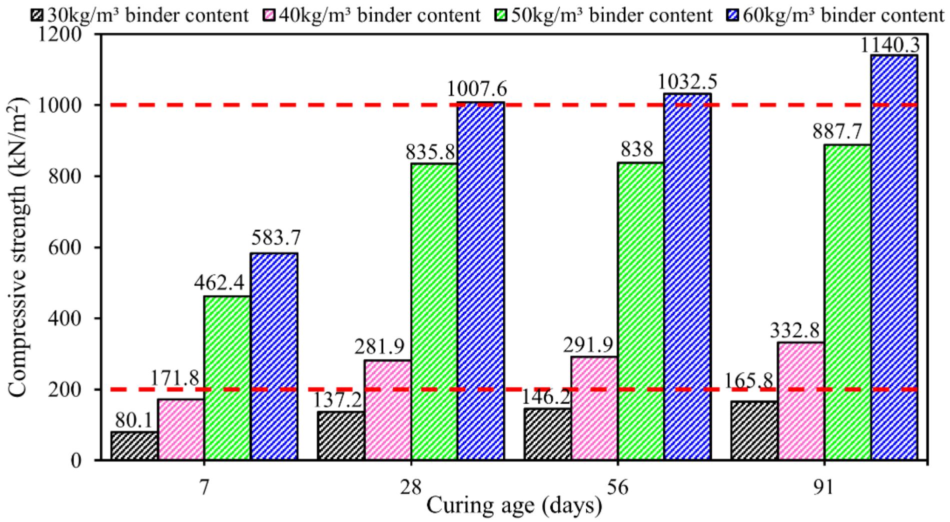

Fig. 10 Binder content effects on the UCS

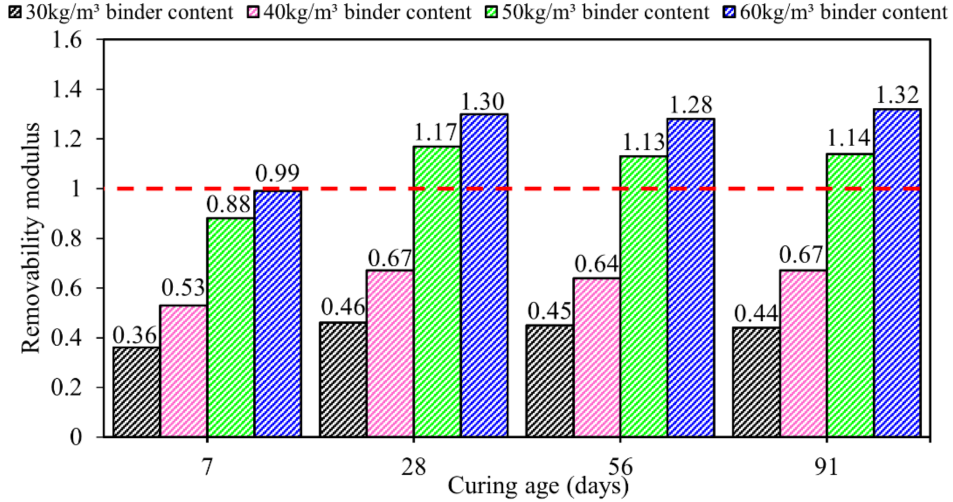

Fig. 11 Binder content effects on the RE

$$RE = \frac{W^{1.5} x 0.619 x C^{0.5}}{10^6}$$ ....Eq. **(1)**

[1] ACI 229R-13; Report on Controlled Low-Strength Materials, ACI Committee 229. American Concrete Institute (ACI): Farmington Hills, MI, USA, 2013.
[2] Public Works Research Institute; Technical Manual for Liquefied Stabilized Soil (in Japanese), 2nd ed.; Gihodo Publishing Co., Ltd.: Tokyo, Japan, 2007

- To determine the **effects of super-retardant admixture** on the workability.
- Geoliter-10 **(0%, 2.5%, 5%, 7.5%, and 10%)** of optimal binder at 1.5 hours.
- As the Geoliter-10 admixture dosage increased, the **hardening was delayed**.
- Its dispersing effect **enhances the workability** by **reducing the viscosity.**
- Improving **flow and wet density** without significantly increasing **bleeding**.
- Geoliter-10 can effectively control hardening delay by adjusting the dosage.

Table 4: Mixture proportions of Stage-IV

Geoliter-10 content (%)	Eco-Friendly CLSM Mixtures				
	GGBFS	CSP	IWA Fine Aggregate	Supernatant Water	Geoliter-10 (Binder*%)
	(kg/m^3)				
0	40	246	984	347	-
2.5	40	246	984	346	1
5	40	246	984	345	2
7.5	40	246	984	344	3
10	40	246	984	343	4

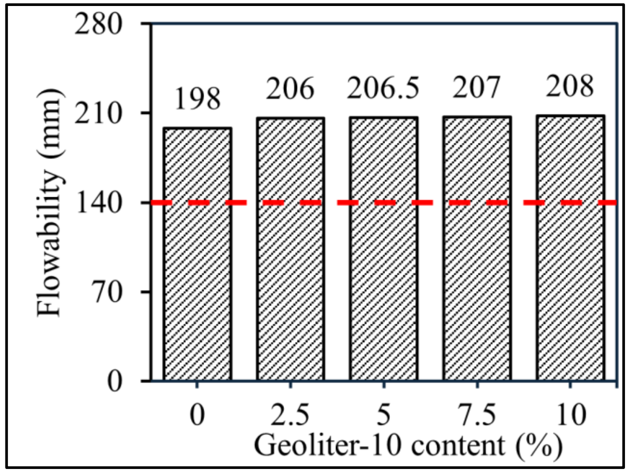

Fig. 12 Effects of geoliter-10 content on flowability

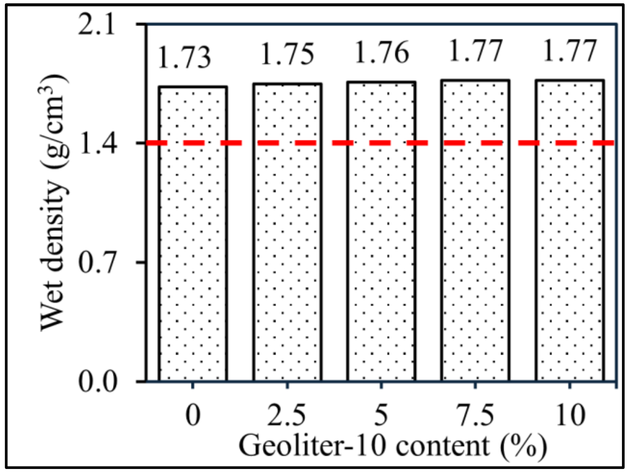

Fig. 13 Effects of geoliter-10 content on wet density

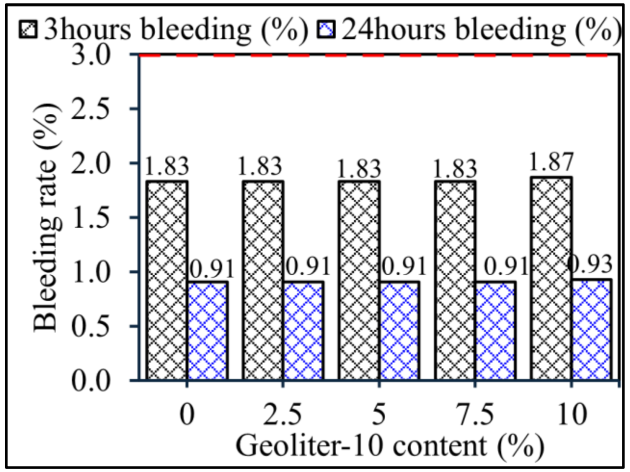

Fig. 14 Effects of geoliter-10 content on bleeding

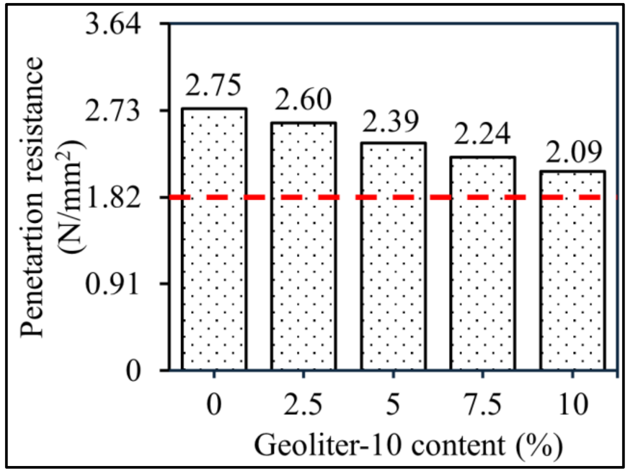

Fig. 15 Effects of geoliter-10 content on hardening time

[1] Blanco, A., Pujadas, P., Cavalaro, S. H. P., & Aguado, A. (2014). Methodology for the design of controlled low-strength materials. Application to the backfill of narrow trenches. *Construction and Building Materials*, *72*, 23-30

WET-DRY CYCLES

- Effect of wetting and drying cycles on **mass** and **strength loss**.
- The 28-day mass loss at each cycle ranged from **0.65%-11.77%.**
- Compared to the **initial, the residual UCS** is reduced by **26.75%.**
- After **12 wet-dry cycles**, the eco-friendly CLSM still meets the minimum strength for buried pipe backfilling **(206.49 kN/m²).**

Fig. 16 Wetting-drying cycles [Specimens-wetting in water tank-drying in oven]

HEXAVALENT CHROMIUM

- A key environmental concern in **concrete recycling** is **Cr(VI)**
- A leaching test was conducted on an **optimal binder.**
- Leaching of **Cr(VI) minimization** is needed for **on-site.**
- Utilization of GGBFS minimizes the leaching of **Cr(VI).**

Table 5: Leaching of hexavalent chromium detection

Heavy metal element	Detected value with different binders (mg / L)				Environmental quality standards for soil (mg / L)
	CLSM with GGBFS (This study)	CLSM with OPC [2]	CLSM with BFS cement Type B [2]	CLSM with BFS cement Type B [3]	
Cr(VI)	**0.007**	0.13	0.02	0.05	≤ 0.05

❖ The study found that **leaching of hexavalent chromium (Cr(VI))** can be controlled to less than the environmental quality standards for soil when GGBFS binder is used.

[1] Achtemichuk, S., et al., The utilization of recycled concrete aggregate to produce controlled low-strength materials without using Portland cement. Cement and Concrete Composites, 2009. 31(8): p. 564-569.
[1] Horiguchi, T., Fujita, R., & Shimura, K. (2011). Applicability of controlled low-strength materials with incinerated sewage sludge ash and crushed-stone powder. *Journal of Materials in Civil Engineering*, *23*(6), 767-771.
[2] Funayama, M., et al.,. Investigation on Physical Properties of Liquefied Stabilized Soil Using Aggregate Made from Returned Concrete, in The 45th JCI Technical Conference. 2023, Japan Concrete Institute, Kyushu, Japan

GOAL AND SCOPE DEFINITION (ISO 14041)

Purpose of the study:

- To **assess** and **compare the potential environmental impacts of three backfill materials.**
- To **identify key phases and processes** contributing the most.

System boundaries: **Extraction, transportation, production, and installation**

Functional Unit (FU): FU in this study is **1 linear meter of trench**

LIFE CYCLE INVENTORY (LCI) (ISO 14041)

- Preparation of **Inventory Data** for Environmental Performance Evaluation of Concrete and Concrete Structures **(Kawai et al., 2005)** and **(Kawai et al., 2010)**
- **Realtà Mapei International and Taiheiyo Cement Corporation**
- The **Construction Technology Institute of Catalonia (ITeC) database**

LIFE CYCLE IMPACT ASSESSMENT (LCIA) (ISO 14042)

LCA Software → openLCA 2.4.1 – **Free and open-source**

LCIA Methods → ReCiPe 2016 Midpoint (H) – **Widely used**

TOTAL COST (TC) → **DIRECT COST (DC)**

TOTAL COST (TC) → **INDIRECT COST (IC)**

DIRECT COST (DC) → **Material Cost (MC)**, **Labor Cost (LC)**, **Equipment Cost (EC)** → Current Price Assessment [**List of Cost Break Down**] → **RATE ANALYSIS** [Fixing cost per unit of measurement] → **UNIT PRICE**

LCA ACROSS SIX IMPACT CATEGORIES

- **Eco-friendly CLSM** is the **most sustainable alternative** across all six impact categories, whereas **granular compacted fill** is the **least efficient option**.
- The **installation phase** significantly contributes to the overall impact categories, except for **mineral resources scarcity.**
- **Life cycle assessment (LCA)** confirms that eco-friendly CLSM improves **resource efficiency, minimizes waste**, and aligns with **circular economy** principles.

Table 6: Contribution of each stage in the environmental impact category

Type of Material	Stages	Global warming (kg CO_2 eq)	Fossil resource scarcity (kg oil eq)	Ozone formation (kg NO_x eq)	Fine particulate matter formation (kg PM2.5 eq)	Terrestrial acidification (kg SO_2 eq)	Mineral resource scarcity (kg Cu eq)
Conventional CLSM	Extraction	42.32%	19.46%	9.60%	16.68%	20.10%	100%
	Transportation	13.87%	20.44%	15.49%	15.97%	14.41%	-
	Production	1.11%	-	0.07%	0.15%	0.15%	-
	Installation	42.69%	60.10%	74.84%	67.20%	65.33%	-
Eco-Friendly CLSM	Extraction	-226.48%	9.32%	6.79%	7.54%	7.17%	-
	Transportation	5.63%	1.66%	1.06%	1.20%	1.13%	-
	Production	8.14%	-	0.09%	0.21%	0.22%	-
	Installation	312.72%	89.02%	92.06%	91.05%	91.48%	-
Granular Compacted Fill	Extraction	20.67%	7.51%	4.22%	52.96%	9.82%	100%
	Transportation	21.18%	23.90%	16.35%	9.22%	16.45%	-
	Production	-	-	-	-	-	-
	Installation	58.15%	68.59%	79.43%	37.81%	73.73%	-

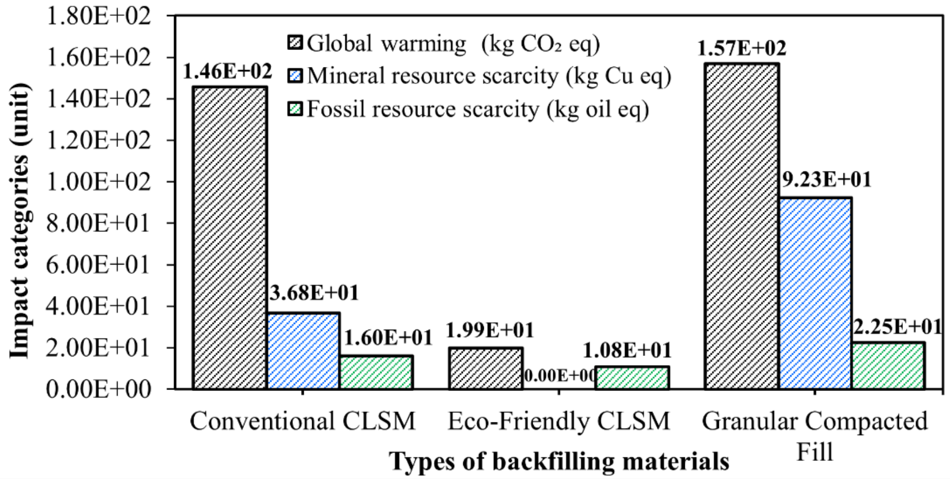

Fig. 17 Global warming, mineral, and fossil resource scarcity

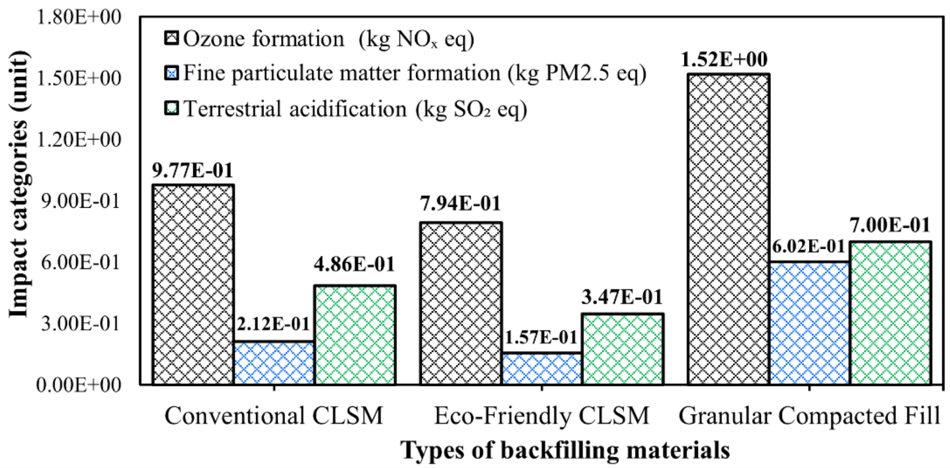

Fig. 18 Ozone formation, fine PM2.5, and terrestrial acidification

[1] Josa, I., Petit-Boix, A., Casanovas-Rubio, M. M., Pujadas, P., & de la Fuente, A. (2023). Environmental and economic impacts of combining backfill materials for novel circular narrow trenches. J Environ Manage, 341, 118020.

LCC UNIT PRICE RATE ANALYSIS

- The **LCC analysis** reveals that the **filling stage dominates total costs**.
- **Compaction cost** is negligible for **eco-friendly and conventional CLSM**.
- **Eco-friendly CLSM** cuts LCC per meter by **53% and 22.6%** compared to **granular fill** and **conventional CLSM**, respectively
- **Eco-friendly CLSM** achieves a **36.5 % reduction** in the filling stage cost relative to the **conventional CLSM**.
- **Eco-friendly CLSM** is the most **cost-effective backfill solution.**

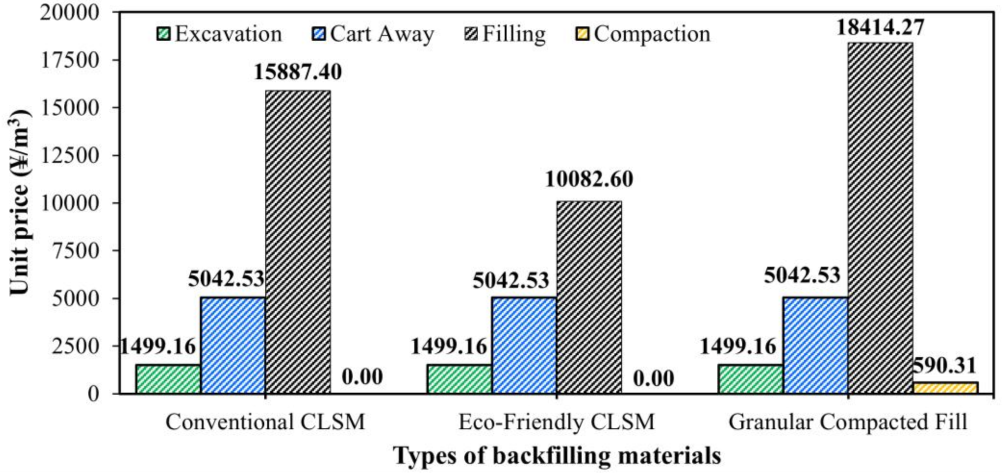

Fig. 19 Unit price comparison for each stage of the LCC

Table 7: Contribution of each LCC phase to the unit and total price per linear trench

List of stages	Types of backfilling materials		
	Conventional CLSM	Eco-Friendly CLSM	Granular compacted fill
Contribution of each LCC phases to the total price per cubic meter (%)			
Excavation	6.68%	9.02%	5.87%
Cart away	22.48%	30.33%	19.74%
Filling	70.83%	60.65%	72.08%
Compaction	0.00%	0.00%	2.31%
Contribution of each LCC phases to the total price per linear trench (%)			
Excavation	7.33%	9.47%	6.24%
Cart away	30.82%	39.82%	26.22%
Filling	61.85%	50.71%	65.45%
Compaction	0.00%	0.00%	2.10%

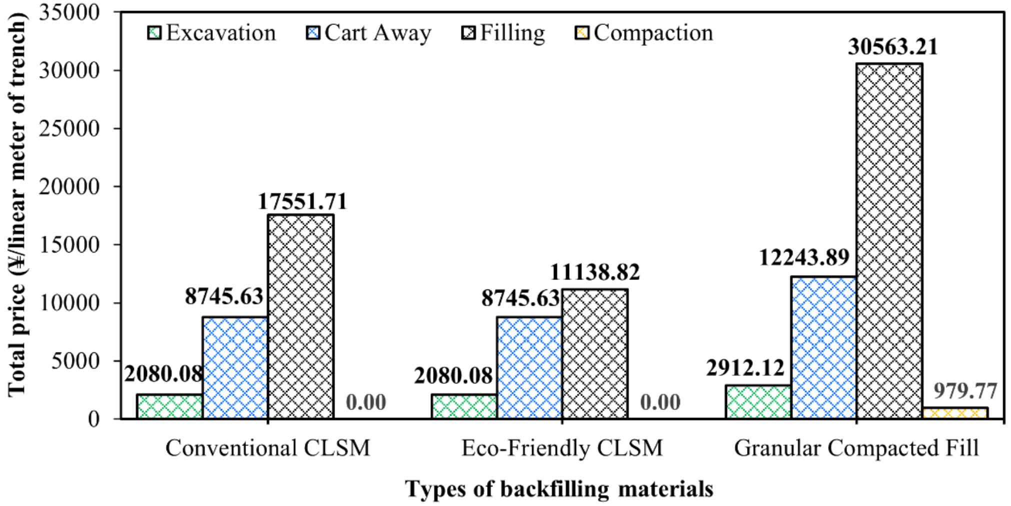

Fig. 20 Total price comparison for each stage of the LCC

[1] Josa, I., Petit-Boix, A., Casanovas-Rubio, M. M., Pujadas, P., & de la Fuente, A. (2023). Environmental and economic impacts of combining backfill materials for novel circular narrow trenches. J Environ Manage, 341, 118020.

CONCLUSION

1. Utilization of **returned concrete** waste and **by-products** promotes **resource efficiency** and the **circular economy**.
2. An **optimal binder content of 40 kg/m³** was selected based on **re-excavation criteria** for eco-friendly CLSM.
3. **Hexavalent Chromium** leaching value of **0.007 mg/L** confirms GGBFS's effectiveness in **minimizing leaching**.
4. Eco-friendly CLSM subjected to **twelve wet-dry cycles** demonstrated **resistance to degradation**.
5. **Eco-friendly CLSM** represents a promising alternative for achieving **sustainability** and offers a **cost-effective solution**.

RECOMMENDATIONS

1. Future research should conduct **comprehensive on-site field studies** to evaluate the **long-term excavatability.**
2. Future research should utilize **commercial databases** such as **ecoinvent** or **IDEA**, employing various **LCIA methods.**
3. A more thorough study is needed to establish **industry standards** for the broader adoption of CLSM in construction.
4. Future research should use advanced techniques to better understand the **mechanisms** of **eco-friendly CLSM**.

THANK YOU VERY MUCH

FOR YOUR KIND ATTENTION!

ご清聴ありがとうございます

Peer-Reviewed Conference Paper:

Hateu, E., Hosoda, A., Ngoc, P., & Mitsuya, M. (2025, July 16–18). ***Development of eco-friendly controlled low-strength material utilizing fresh concrete waste and by-products.*** In the 47th JCI Annual Proceedings 2025 (pp. 306–311). Japan Concrete Institute. https://confit.atlas.jp/guide/event/jci2025/subject/1048/tables?cryptoId=

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- I am also sincerely grateful to **FUJIYAMA SENSEI** for her kind support and valuable guidance in helping me complete this research study.

08 REFERENCES

[1] Ferrari, G., M. Miyamoto, and A. Ferrari, New sustainable technology for recycling returned concrete. Construction and Building Materials, 2014. 67: p. 353-359.

[2] Lachemi, M., et al., Properties of controlled low-strength materials incorporating cement kiln dust and slag. Cement and Concrete Composites, 2010. 32(8): p. 623-629.

[3] Achtemichuk, S., et al., The utilization of recycled concrete aggregate to produce controlled low-strength materials without using Portland cement. Cement and Concrete Composites, 2009. 31(8): p. 564-569.

[4] Xuan, D., C.S. Poon, and W. Zheng, Management and sustainable utilization of processing wastes from ready-mixed concrete plants in construction: A review. Resources, Conservation and Recycling, 2018. 136: p. 238-247.

[5] ACI Committee 229, ACI 229R-13; Report on Controlled Low-Strength Materials, . 2013: American Concrete Institute (ACI): Farmington Hills, MI, USA, 2013.

[6] Folliard, K.J., Development of a recommended practice for use of controlled low-strength material in highway construction. Vol. 597. 2008: Transportation Research Board.

[7] Public Works Research Institute, Technical manual for fluidized soils (in Japanese). 2007/2nd ed. 2008, Japan: Gihodo Publishing.

[8] Parhi, S.K., et al., A comprehensive study on Controlled Low Strength Material. Journal of Building Engineering, 2023. 76.

[9] Abd Rahman, N., et al., Production of Controlled Low Strength Material Utilizing Waste Paper Sludge Ash and Recycled Aggregate Concrete. MATEC Web of Conferences, 2016. 47.

[10] Funayama, M., et al., Investigation on Physical Properties of Liquefied Stabilized Soil Using Aggregate Made from Returned Concrete, in The 45th JCI Technical Conference. 2023, Japan Concrete Institute Kyushu, Japan.

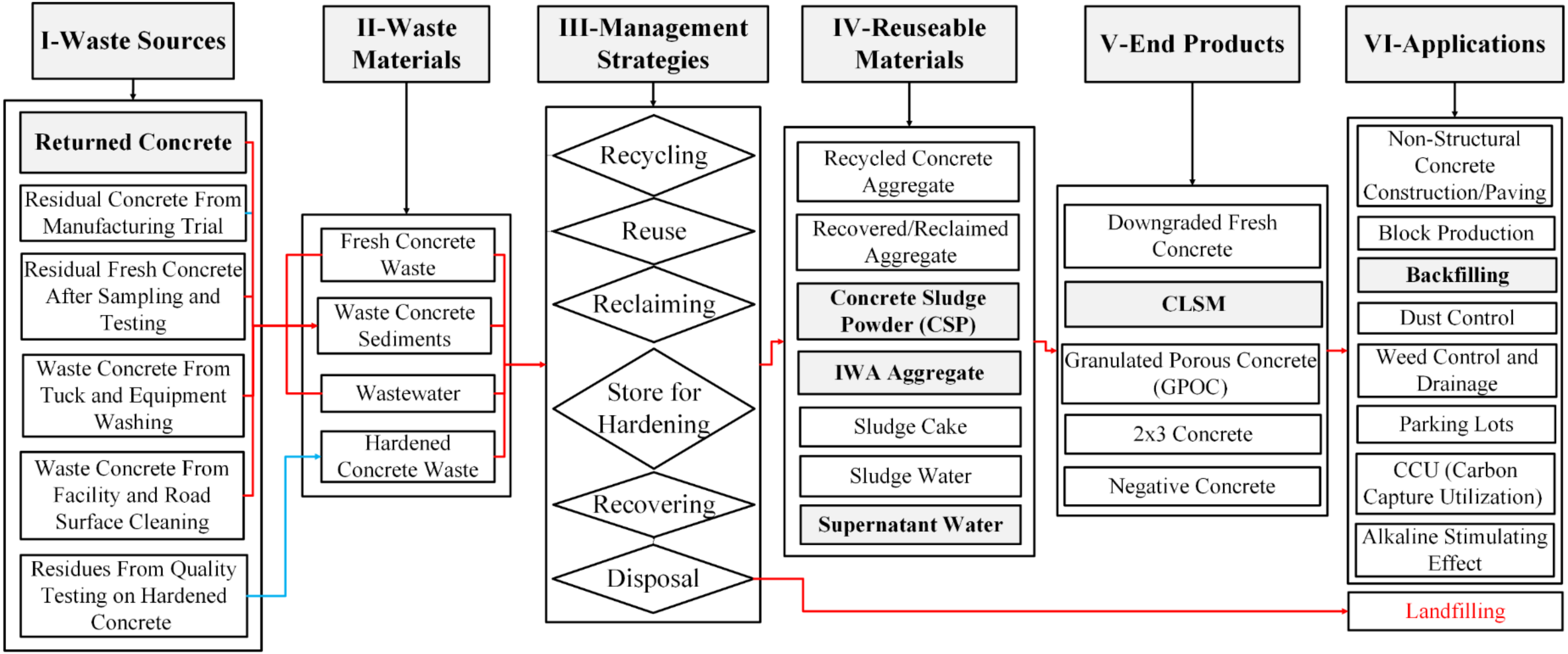
[11] Shigematsu, Y., et al., Experimental study on properties of liquefied stabilized soil produced with different types of solidifiers and thickeners. Case Studies in Construction Materials, 2023. 19.

[12] Blanco, A., et al., Methodology for the design of controlled low-strength materials. Application to the backfill of narrow trenches. Construction and Building Materials, 2014. 72: p. 23-30.

[13] Kawai, K., Fujiki, A., Aoki, Y., & Iwatani, Y. (2010). Preparation of Inventory Data for Environmental Performance Evaluation of Concrete and Concrete Structures. Proceedings of Second International Conference on Sustainable Construction Materials and Technologies, Ancona, Italy

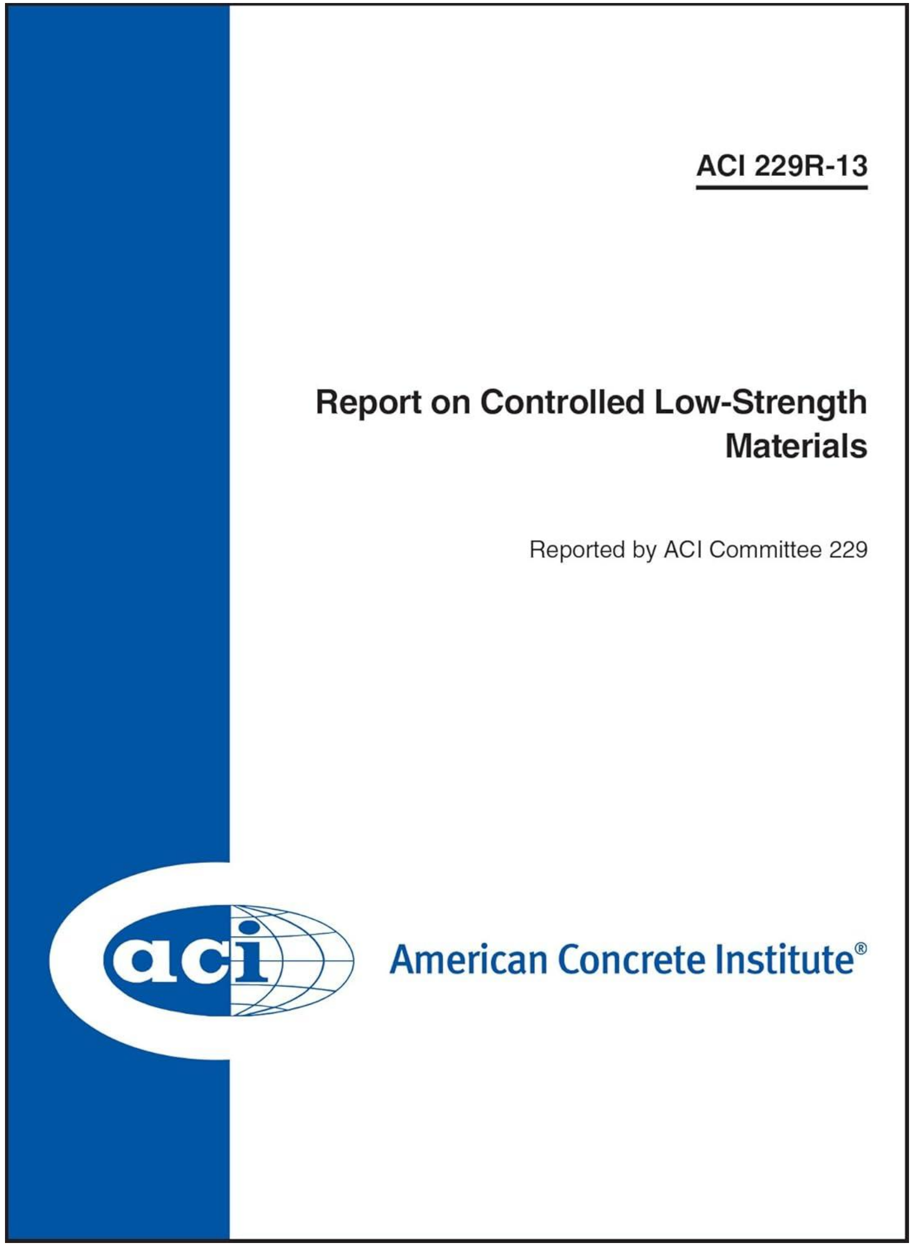
[14] Kawai, K., Sugiyama, T., Kobayashi, K., & Sano, S. (2005). Inventory data and case studies for environmental performance evaluation of concrete structure construction. *Journal of Advanced Concrete Technology*, *3*(3), 435-456.

Current management of processing wastes in RMC plants [1]

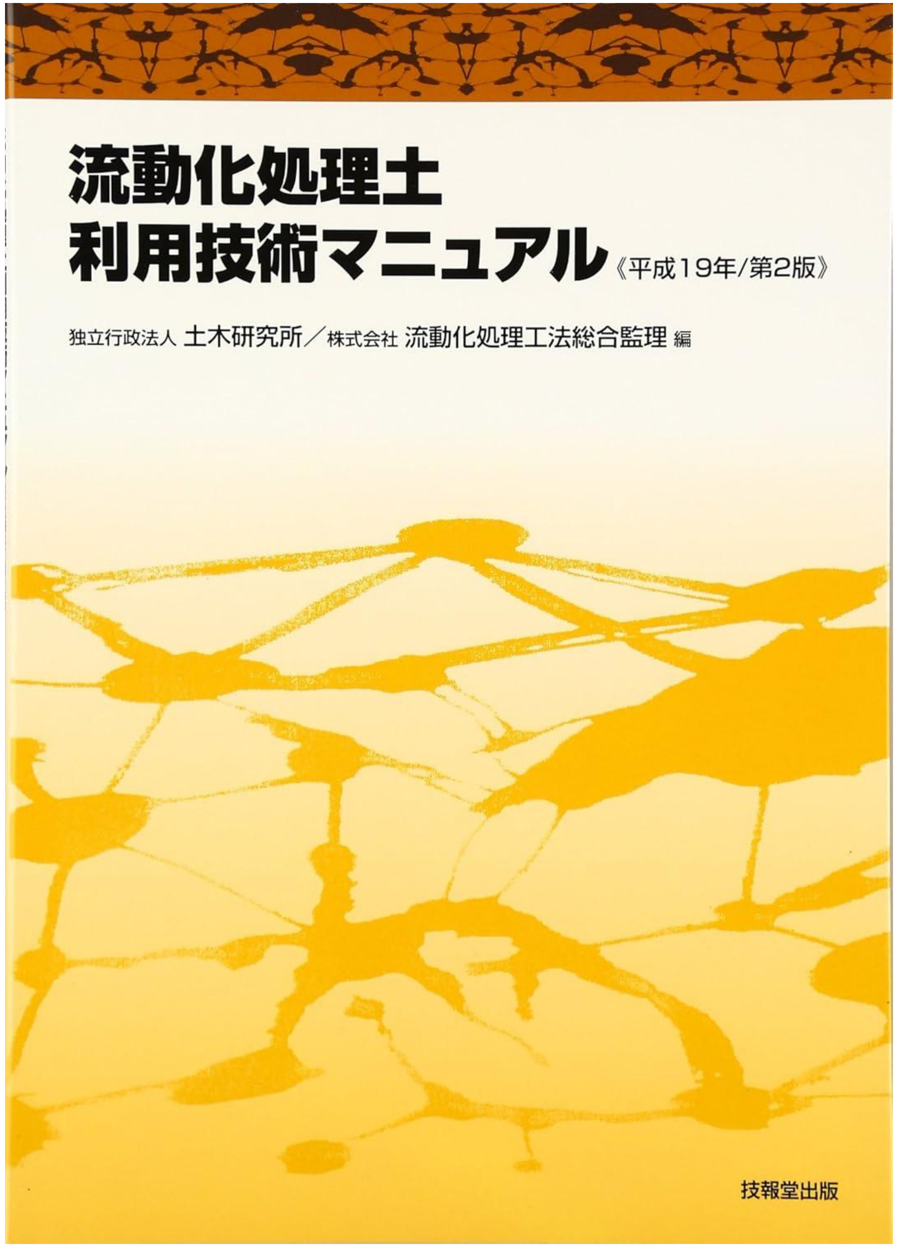


[1] Xuan, D., Poon, C. S., & Zheng, W. (2018). Management and sustainable utilization of processing wastes from ready-mixed concrete plants in construction: A review. *Resources, Conservation and Recycling*, *136*, 238-247.

GUIDELINES AND SPECIFICATIONS



American Concrete Institute (ACI) 229R-13



Technical Manual for Fluidized Soils

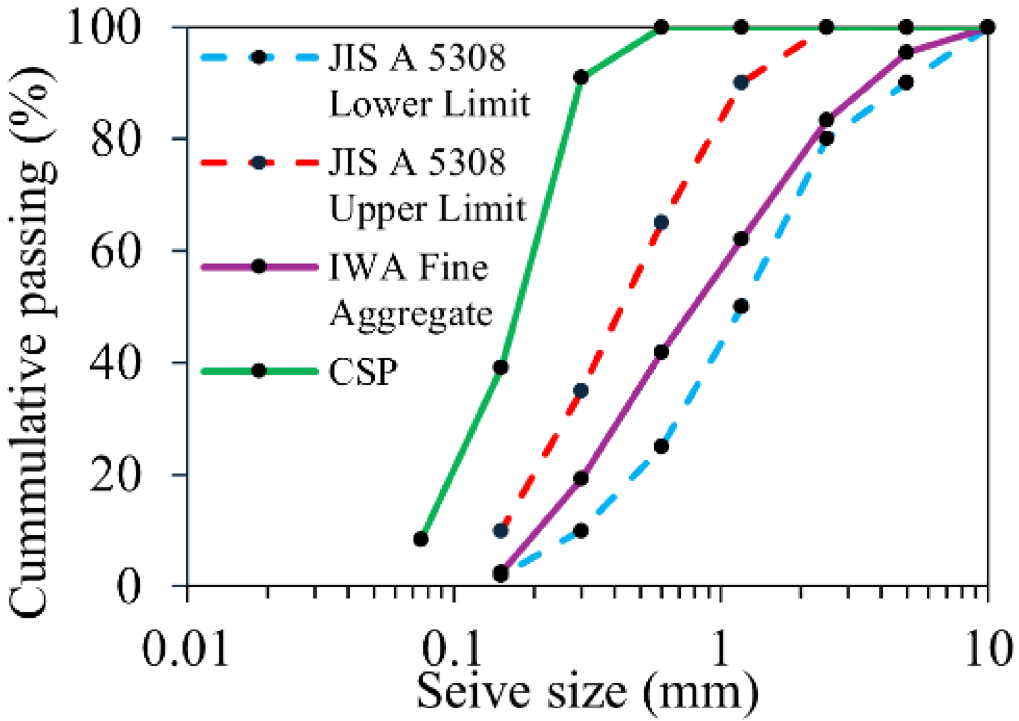


Fig. 1 Particle size distribution of materials

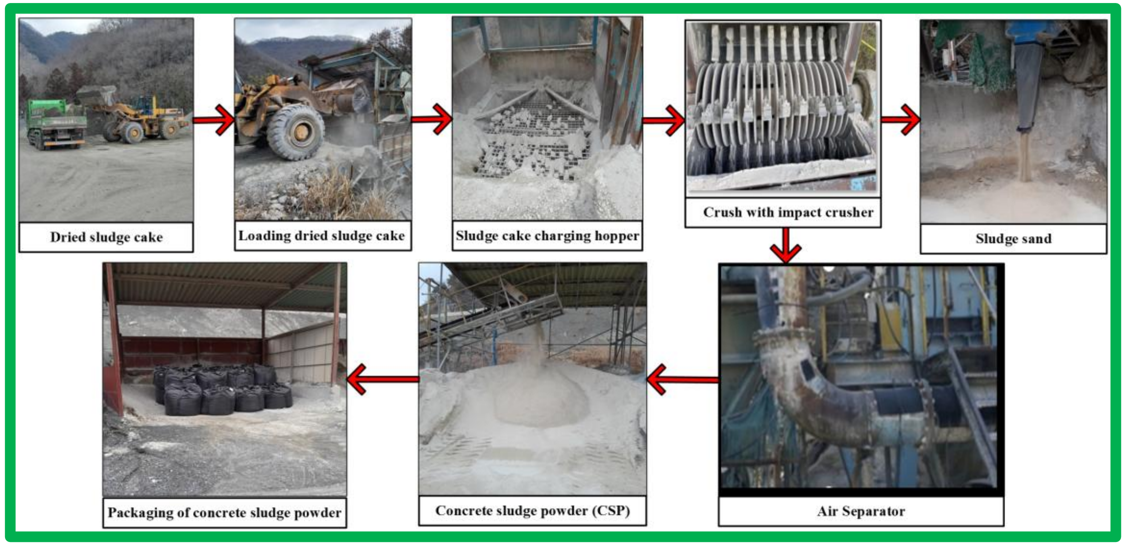


Fig. 2 Concrete sludge powder production (CSP)

Table 1: Chemical Properties of Materials

Materials	Chemical Composition (%)									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	TiO_2	MnO	ZnO	K_2O
GGBFS 4000	33.02	14.44	0.79	42.03	5.80	2.00	0.41	-	-	0.65
CSP	16.61	2.89	8.73	67.99	-	1.47	0.74	0.18	0.12	0.88
IWA Fine Aggregate	18.47	3.58	9.81	64.52	-	2.13	0.84	0.22	0.14	-

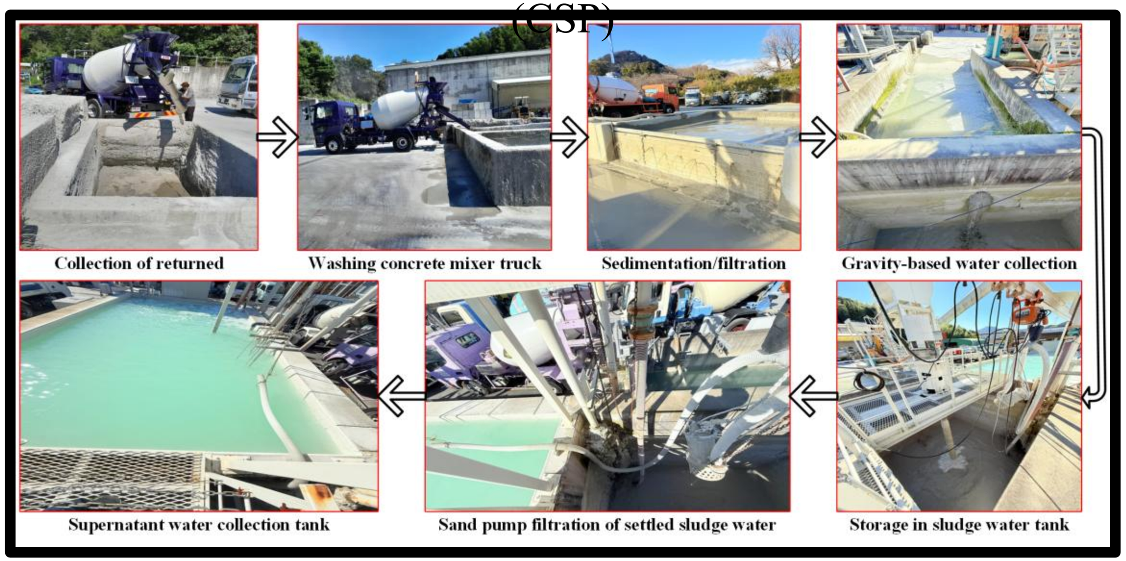


Fig. 3 Treatment stages of supernatant water

[1] Ferrari, G., M. Miyamoto, and A. Ferrari, New sustainable technology for recycling returned concrete. Construction and Building Materials, 2014. 67: p. 353-359.

Table 2: Test methods for fresh, hardened, and Durability CLSM properties

Categories	Property	Test Methods	Description
Fresh CLSM Test Methods	Sampling	ASTM D 5971	Standard Practice for Sampling Freshly Mixed CLSM
	Flowability	JHS A 313-1992	Test Methods for Air Mortar and Air Milk
	Bleeding	JSCE F 522	Test Method for Bleeding Rate and Expansion Rate of Injection Mortar of Prepacked Concrete (Polyethylene Bag Method)
	Wet Density	Constant Volume Method	Measure the mass of the CLSM sample filled in a container of known volume and divide it by the volume of the container
	Air Content	JIS A 1128	Method of test for air content of fresh concrete by the pressure method
	Hardening time	JIS A 1147	Method of test for the time of setting of concrete mixtures by penetration resistance
Hardened CLSM Test Methods	UCS	JIS A 1216	Unconfined Compression Test Method for Soil
	Excavatability	Technical Manual and ACI-229R-13	28-day UCS, Removability Modulus, and Long-term UCS (91-day)
	Permeability	JIS A 1218	Soil Permeability Test Method
Durability Test Methods	Wet-dry cycles	ASTM D559	Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures
	Leaching Test	JIS K 0102 65.2	Inductively coupled plasma (ICP) mass spectrophotometry

[1] ACI 229R-13; Report on Controlled Low-Strength Materials, ACI Committee 229. American Concrete Institute (ACI): Farmington Hills, MI, USA, 2013.
[2] Public Works Research Institute; Technical Manual for Liquefied Stabilized Soil (in Japanese), 2nd ed.; Gihodo Publishing Co., Ltd.: Tokyo, Japan, 2007
[3] Folliard, K. J. (2008). Development of a recommended practice for use of controlled low-strength material in highway construction (Vol. 597). Transportation Research Board.

General criteria and requirements for Buried Pipe Backfilling [2]

埋設管の埋戻し	ガス管，上下水道管など	最大粒径	管周り 13 mm 以下
		フロー値(流動性)	140 mm 以上(打設時)
		ブリーディング率(材料分離性)	3%未満
		処理土の湿潤密度	1.40 g/cm^3 以上
		(後日復旧) 一軸圧縮強さ	(車道下) 交通開放時 130 kN/m^2 以上 28 日後　200～600 kN/m^2 (歩道下) 交通開放時 50 kN/m^2 以上 28 日後　200～600 kN/m^2

[1] ACI 229R-13; Report on Controlled Low-Strength Materials, ACI Committee 229. American Concrete Institute (ACI): Farmington Hills, MI, USA, 2013.
[2] Public Works Research Institute; Technical Manual for Liquefied Stabilized Soil (in Japanese), 2nd ed.; Gihodo Publishing Co., Ltd.: Tokyo, Japan, 2007

Fig. 4 Flowability, wet density, bleeding, and air content tests in Stage-I

Fig. 5 Flowability, wet density, bleeding, air content, and UCS tests in Stage-II

STAGE-I: OPTIMIZATION OF AGGREGATE

- **Maximized flow** was a primary focus to ensure adequate water content in **Stage-II**.
- Higher *w/s* ratios **increase the average flowability**, due to **higher water content.**
- As the *w/s* ratio increased, the **wet density decreased**, due to **higher water content.**
- Higher *w/s* ratios resulted in an **increased bleeding rate**.
- The **bleeding rate** surpassed the target of **3%** at a ***w/s* ratio of 24 %.**
- A ***w/s* ratio of 22%** was determined to be the **optimal *w/s* ratio** for **Stage-II.**

Table 3: Mixture proportions of Stage-I

w/s (%)	Eco-Friendly CLSM Mixtures: GGBFS (kg/m³)	IWA Fine Aggregate (kg/m³)	Supernatant Water (kg/m³)	Air (%)
18	50	1378	264	3.9
21	50	1345	286	3.4
22	**50**	**1315**	**307**	**2.8**
24	50	1282	326	2.5

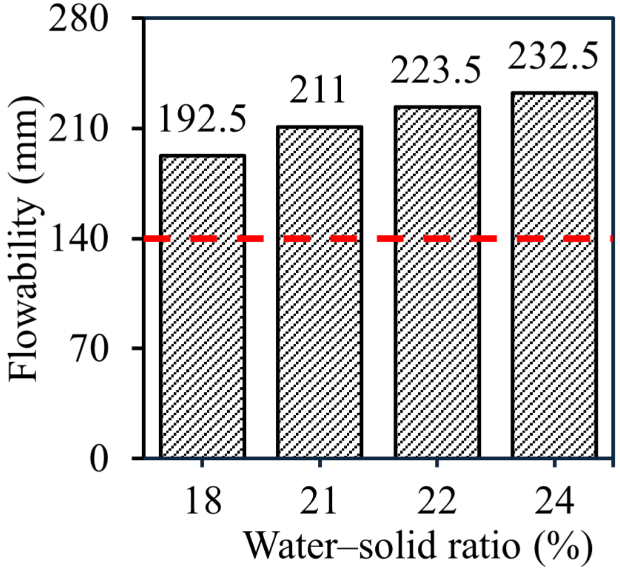


Fig. 6 Effects of *w/s* on flowability

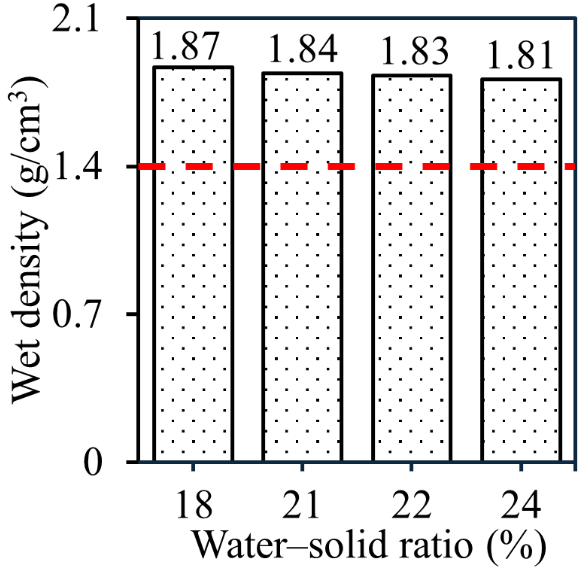


Fig. 7 Effects of *w/s* on wet density

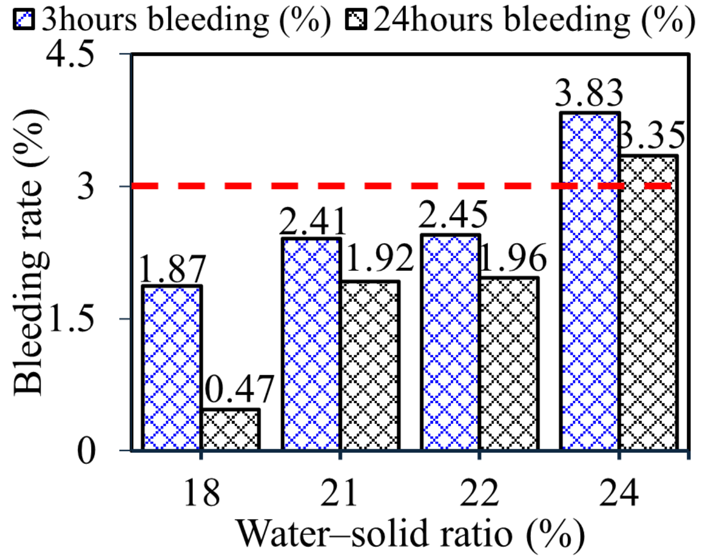


Fig-8 Effects of *w/s* on bleeding

1. Applicability of Controlled Low-Strength Materials with Incinerated Sewage Sludge Ash and Crushed-Stone Powder
2. Investigation on Physical Properties of Liquefied Stabilized Soil Using Aggregate Made from Returned Concrete

STAGE-II PARTIAL REPLACEMENT BY CSP

- **The optimal *w/s* ratio of 22% from Stage-I** was used as a control mix.
- Targeted to **maximize CSP utilization** for improved **stability** and **strength.**
- **Stage-II** focused on the **plastic** and **hardened** properties of CLSM.
- Higher *f/a* ratios **reduced flowability**, requiring additional water for workability.
- As the *f/a* ratio increased, **fresh density decreased**, from 1.83 to 1.73 g/cm³.
- **Bleeding rate decreased** with higher *f/a* ratios, remaining below the target.
- **Strength** falls within the **200–1000 kN/m²** excavatability range across all *f/a* ratios.
- Stage-II showed that up to **20% CSP filler** effectively produced eco-friendly CLSM.

Table 4: Mixture proportions of Stage-II

f/a (%)	Eco-Friendly CLSM Mixtures (kg/m³)				Air (%)
	GGBFS	CSP	IWA Fine Aggregate	Supernatant Water	
0	**50**	**-**	**1315**	**307**	**2.8**
10	50	131	1175	307	2.6
15	50	195	1105	307	2.5
20	**50**	**259**	**1036**	**307**	**2.4**
25	50	323	968	307	1.9

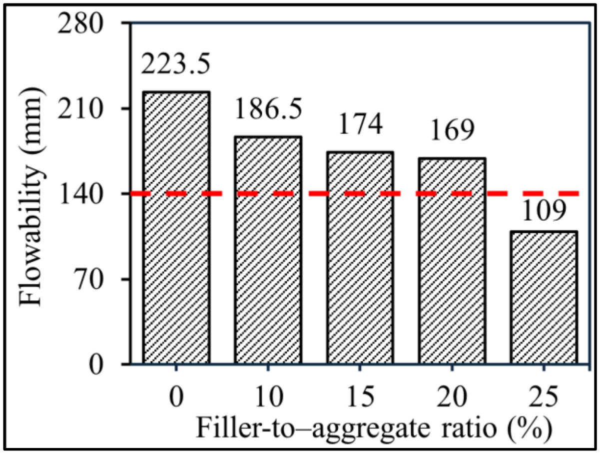


Fig. 9 Effects of *f/a* on flowability

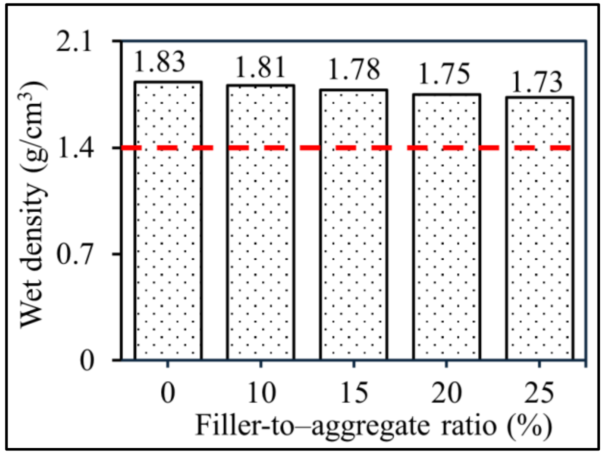


Fig. 10 Effects of *f/a* on wet density

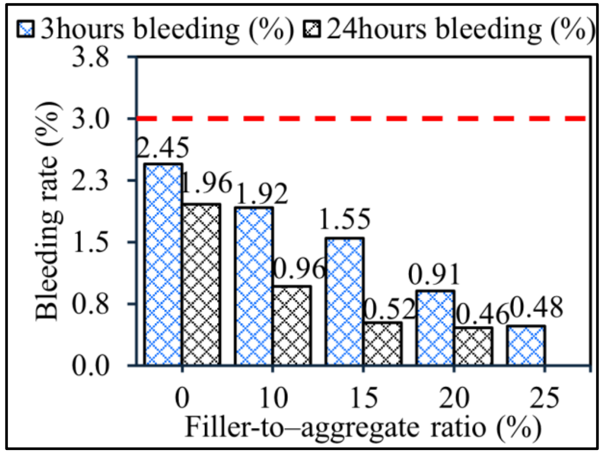


Fig. 11 Effects of *f/a* on bleeding

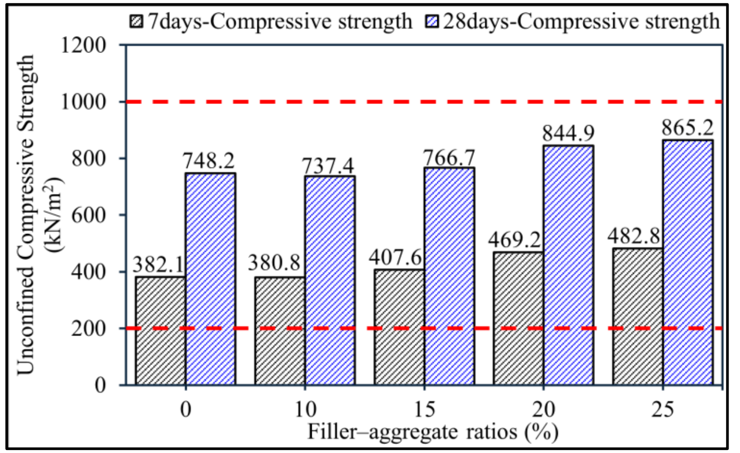


Fig. 12 Effects of *f/a* on strength (UCS)

1. Applicability of Controlled Low-Strength Materials with Incinerated Sewage Sludge Ash and Crushed-Stone Powder
2. Investigation on Physical Properties of Liquefied Stabilized Soil Using Aggregate Made from Returned Concrete

Fig. 9 Flowability, wet density, bleeding, air content, penetration, permeability and UCS tests in Stage-III

Fig. 10 Flowability, wet density, bleeding, air content, penetration, tests in Stage-IV

- The water demand of the control mix was adjusted based on findings from Stage-II
- GGBFS's **water affinity** and **flow-reducing effect** require water adjustment.
- **The optimal *f/a* ratio of 20% from Stage-II** was used in the mix proportions.
- This stage determines the **minimum binder** for strength and **easy excavation**.
- As binder content increased, a consistent **decrease in flowability** was observed.
- The **wet density slightly increased** with the increment of binder content.
- Higher binder content resulted in a **decrease in bleeding rate**.
- CLSM with optimum **binder content 40 kg/m^3** had a **hardening time of 2 hours.**

Table 5: Mixture proportions of Stage-III

Binder content	Eco-Friendly CLSM Mixtures					
	GGBFS	CSP	IWA Fine Aggregate	Supernatant Water	Extra Water	Air
	(kg/m^3)					(%)
30	30	247	990	307	40	2.9
40	**40**	**246**	**984**	**307**	**40**	**2.5**
50	50	245	979	307	40	2.4
60	60	243	973	307	40	2.1

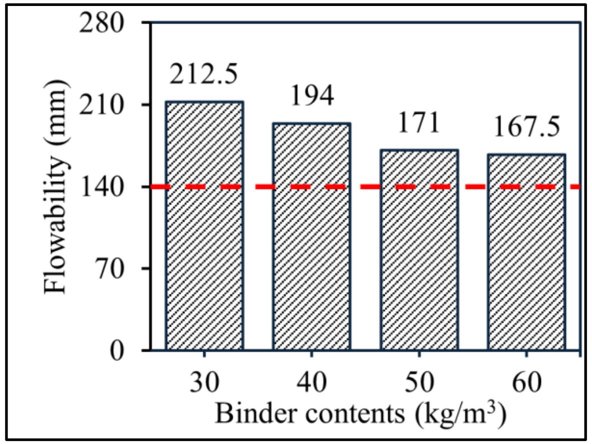


Fig. 11 Effects on the flowability

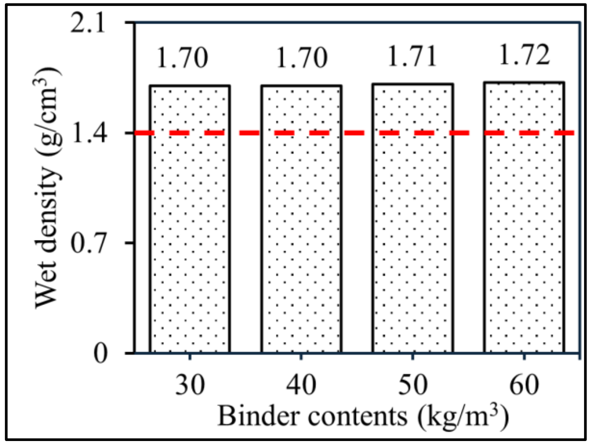


Fig. 12 Effects on wet density

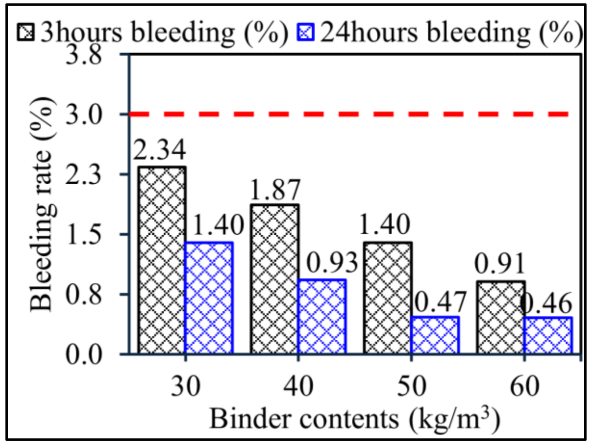


Fig. 13 Effects on bleeding

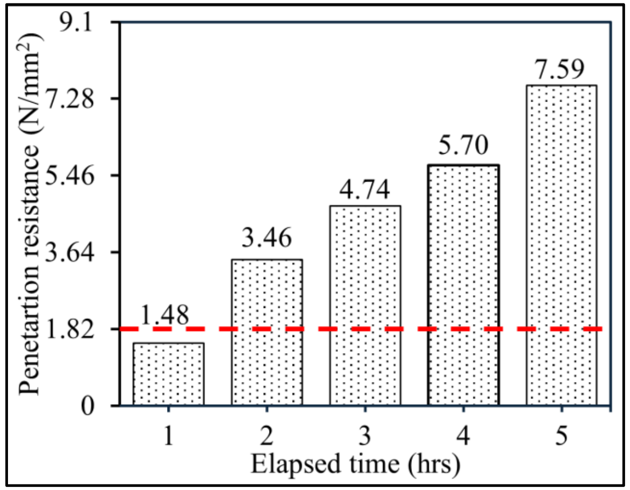


Fig. 14 Effects of w/s on hardening

[1] ACI 229R-13; Report on Controlled Low-Strength Materials, ACI Committee 229. American Concrete Institute (ACI): Farmington Hills, MI, USA, 2013.

[2] Folliard, K. J. (2008). Development of a recommended practice for use of controlled low-strength material in highway construction (Vol. 597). Transportation Research Board.

STAGE-IV: COLOR INTENSITY OF ECO-FRIENDLY CLSM

The **American Public Works Association (APWA)** utility color code is a standardized system of colors used to mark underground utilities.

Table 6: The American Public Works Association utility color code

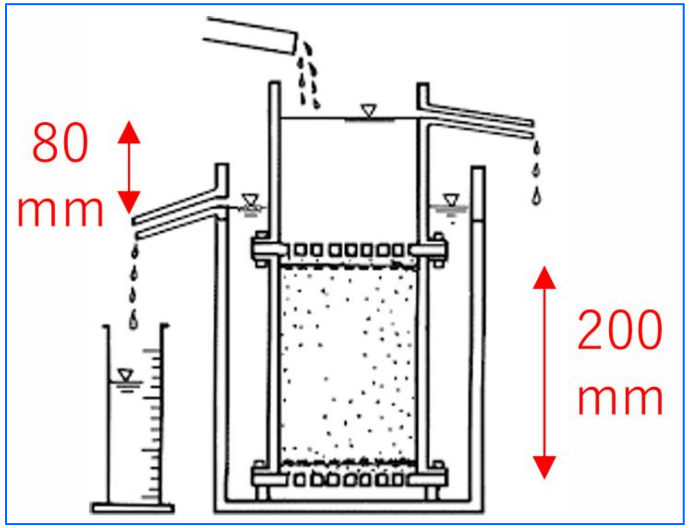
Color Type	Underground Utilities Line
White	Proposed excavation
Pink	Temporary survey markings
Red	**Electric power lines, cables, conduit, and lighting cables**
Yellow	**Gas, oil, steam, petroleum, or gaseous materials**
Orange	**Communication, alarm, or signal lines, cables, or conduit**
Blue	Potable water
Purple	Reclaimed water, irrigation, and slurry lines
Green	Sewers and drain lines

ASTM C 979 Standard Specification for Pigments for Integrally Colored Concrete

Source: Frank A. Kozeliski

Fig. 15 Utility Color Intensity

WATER PERMEABILITY OF ECO-FRIENDLY CLSM



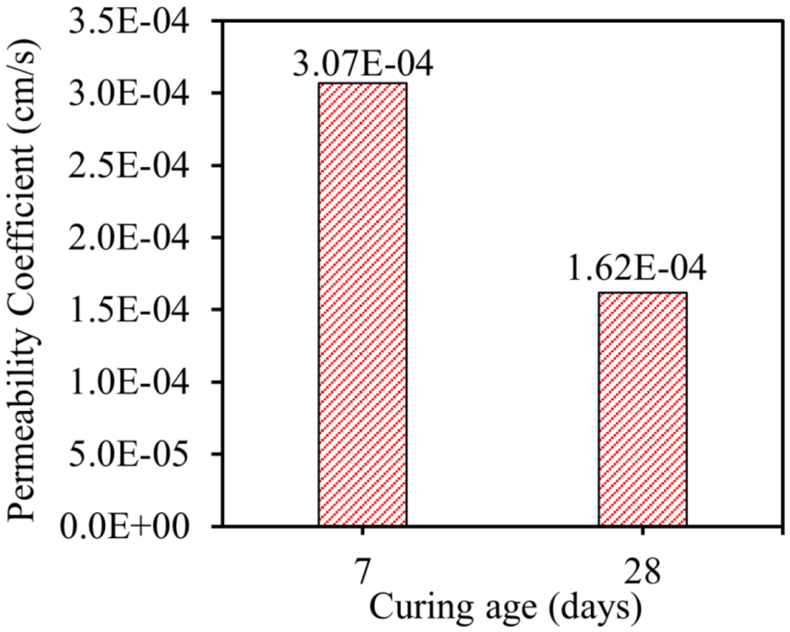


Fig. 16 Water Permeability

IWA FINE AGGREGATE GRADATION ZONE

- To investigate the **effects of gradation** on **eco-friendly CLSM** properties.
- **Eight gradation zones** encompass the range from **JIS A 5308 UL to the LL.**
- The gradation zone has a significant influence on **mixture proportions**, **affecting flow**, **wet density**, **bleeding**, and the development of **UCS [1].**
- Gradation zone ranges of ② **and** ④ are **recommended** for eco-friendly CLSM.
- ***Funayama et al.*** [2] **recommended** ranges of ④ **and** ⑤ to produce fluidized soil.

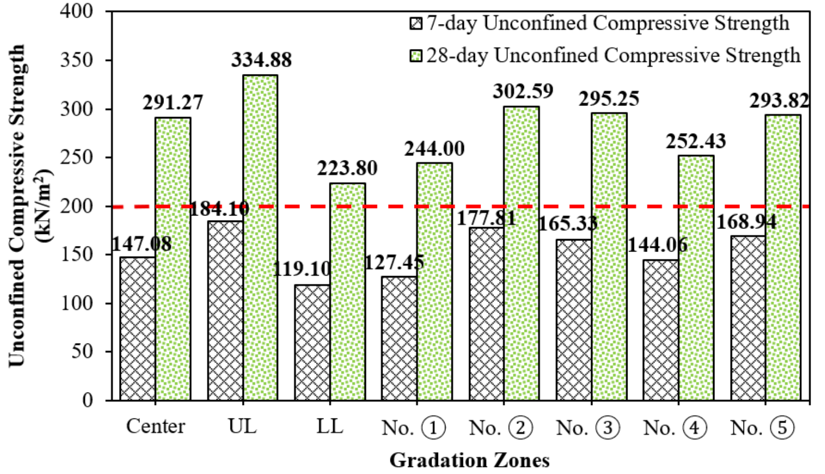


Fig. 17 Effects of gradation zone on UCS

Table 7: Gradation zone

Nominal Opening of Sieve (mm)	Target the gradation curve zones							
	JIS A 5308 Center	JIS A 5308 LL	JIS A 5308 UL	① Average of LL and Center	② Average of Center and UL	③ ① and 1/2 of Center	④ LL and 1/3 of ①	⑤ Center and 1/3 of ②
10.00	100	100	100	100	100	100	100	100
5.00	95	90	100	92.50	97.50	93.75	90.83	95.83
2.50	90	80	100	85	95.	87.50	81.67	91.67
1.20	70	50	90	60	80	65.00	53.33	73.33
0.60	45	25	65	35	55	40.00	28.33	48.33
0.30	22.50	10	35	16.25	28.75	19.38	12.08	24.58
0.15	6	2	10	4	8	5	2.67	6.67

Table 8: Effects of gradation zone

Target gradation limit	Properties					Freshness Properties
	Wet density (g/cm^3)	Average flow (mm)	Bleeding(%)		Fineness modulus (FM)	
			3 hours	24 hours		
Lower Limit	1.63	266.00	3.57	3.20	3.43	Material Separation
No.④	1.62	246.00	2.45	1.96	3.31	Good
No.①	1.62	223.50	1.92	0.96	3.07	Good
No.③	1.59	218.00	1.55	0.52	2.89	Good
Center	1.58	202.50	1.40	0.47	2.72	Good
No.⑤	1.58	192.00	1.37	0.46	2.60	Good
No.②	1.55	181.00	1.44	0.48	2.36	Good
Upper Limit	1.52	138.00	0.89	0.45	2.00	Excessive Viscosity

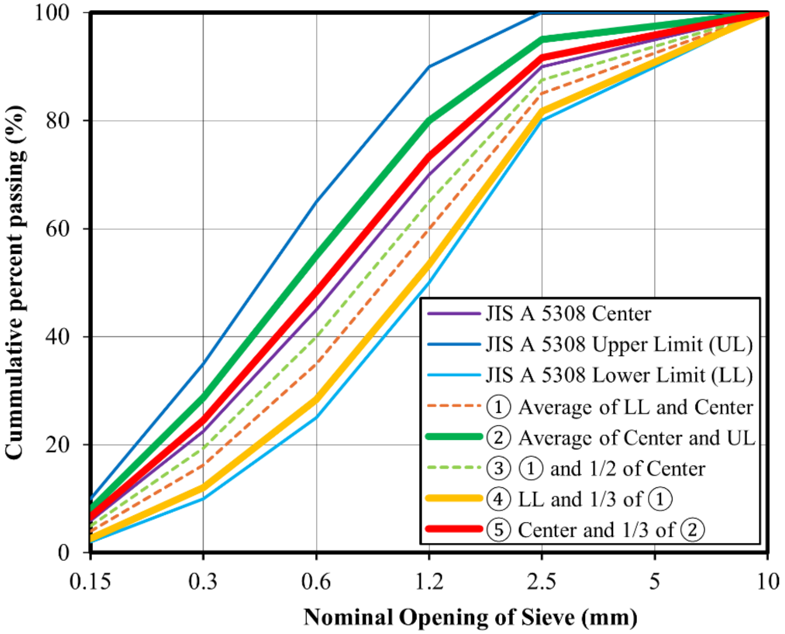


Fig. 18 Recommended gradation zone

[1] Crouch, L. K., Dotson Jr, V. J., Clouse, L., & Hall, S. M. (2003). Effect of Fine Aggregate Type on CLSM Properties. In the International Center for Aggregates Research 11th Annual Symposium: University of Texas at Austin
[2] Funayama, M., et al.,. Investigation on Physical Properties of Liquefied Stabilized Soil Using Aggregate Made from Returned Concrete, in The 45th JCI Technical Conference. 2023, Japan Concrete Institute Kyushu, Japan

DURABILITY: WETTING-DRYING CYCLES

Table 9: Mass losses in wet-dry cycles

Measurement at each cycle	Average mass loss at each curing days			
	7 days	**28 days**	56 days	91 days
Original mass (g)	317.33	**312.20**	303.03	296.40
1st cycle (g)	315.57	**310.17**	300.40	294.77
2nd cycle (g)	312.17	**309.33**	298.13	293.40
3rd cycle (g)	309.23	**308.37**	297.30	293.03
4th cycle (g)	307.27	**306.60**	295.77	290.87
5th cycle (g)	304.13	**302.83**	293.83	288.50
6th cycle (g)	302.00	**299.50**	290.87	285.47
7th cycle (g)	295.43	**295.56**	287.80	280.40
8th cycle (g)	291.30	**290.13**	283.73	276.63
9th cycle (g)	278.37	**283.30**	278.87	272.23
10th cycle (g)	266.93	**279.87**	274.03	269.43
11th cycle (g)	256.77	**277.27**	271.23	266.43
12th cycle (g)	247.40	**275.47**	269.07	263.90
Dry mass loss (%)	22.04%	**11.77%**	11.21%	10.96%

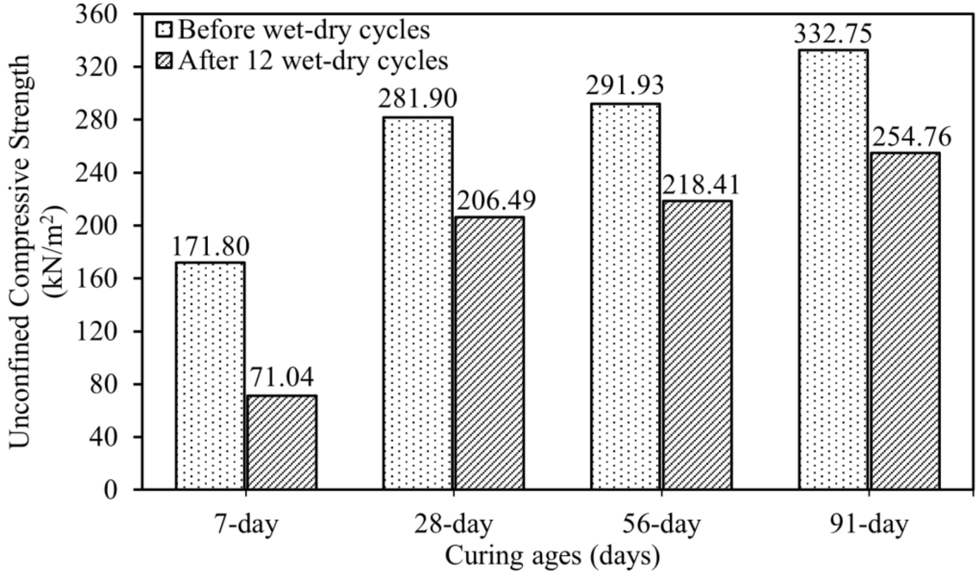
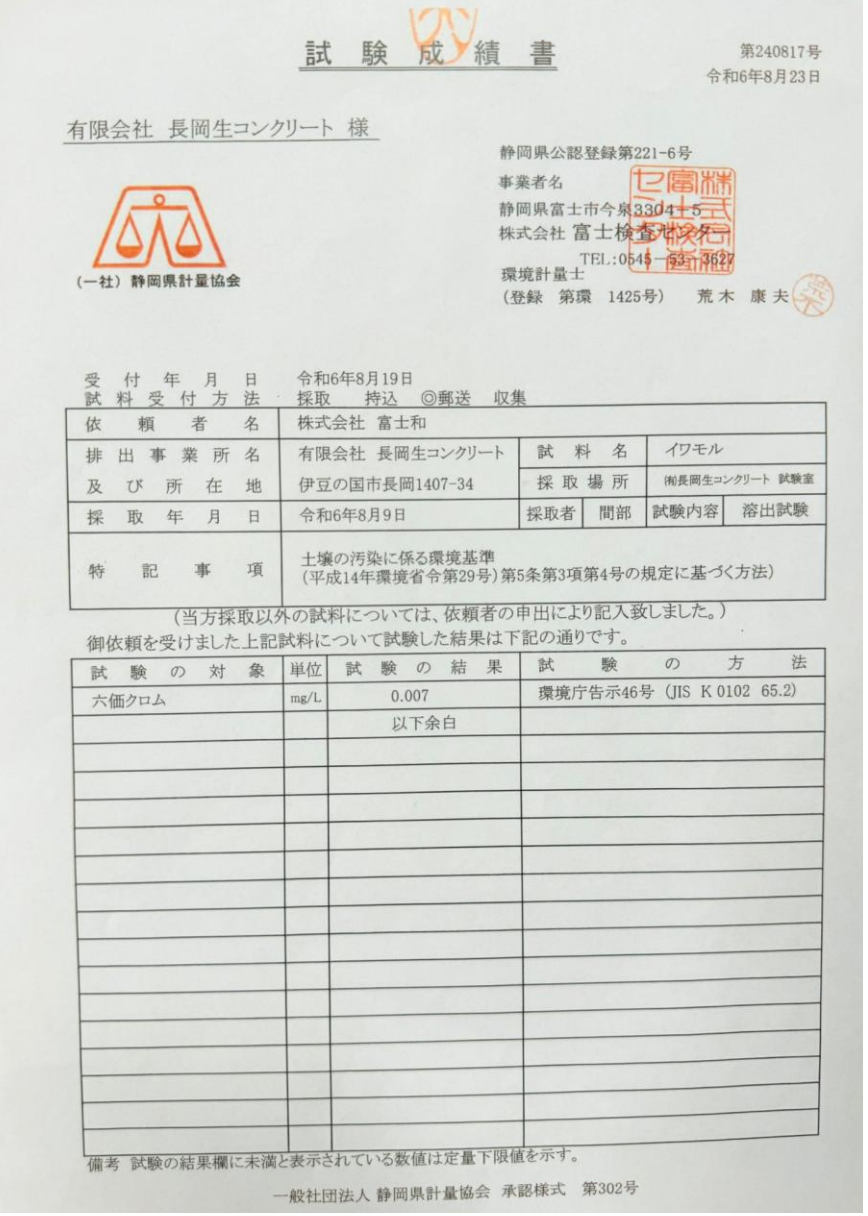


Fig. 19 Variation of initial and residual UCS

Fig. 20 Mass losses in wet-dry cycles

[1] Achtemichuk, S., et al., The utilization of recycled concrete aggregate to produce controlled low-strength materials without using Portland cement. Cement and Concrete Composites, 2009. 31(8): p. 564-569.

DURABILITY: HEXAVALENT CHROMIUM



試験成績書

第240817号
令和6年8月23日

有限会社 長岡生コンクリート 様

静岡県公認登録第221-6号
事業者名
静岡県富士市今泉3304-5
株式会社 富士検査センター
TEL:0545-53-3627
環境計量士
(登録 第環 1425号) 荒木 康夫

(一社) 静岡県計量協会

受付年月日 令和6年8月19日
試料受付方法 採取 持込 ◎郵送 収集

依頼者名	株式会社 富士和				
排出事業所名及び所在地	有限会社 長岡生コンクリート 伊豆の国市長岡1407-34	試料名		イワモル	
		採取場所		(有)長岡生コンクリート 試験室	
採取年月日	令和6年8月9日	採取者	間部	試験内容	溶出試験
特記事項	土壌の汚染に係る環境基準 (平成14年環境省令第29号)第5条第3項第4号の規定に基づく方法)				

(当方採取以外の試料については、依頼者の申出により記入致しました。)
御依頼を受けました上記試料について試験した結果は下記の通りです。

試験の対象	単位	試験の結果	試験の方法
六価クロム	mg/L	0.007	環境庁告示46号 (JIS K 0102 65.2)
		以下余白	

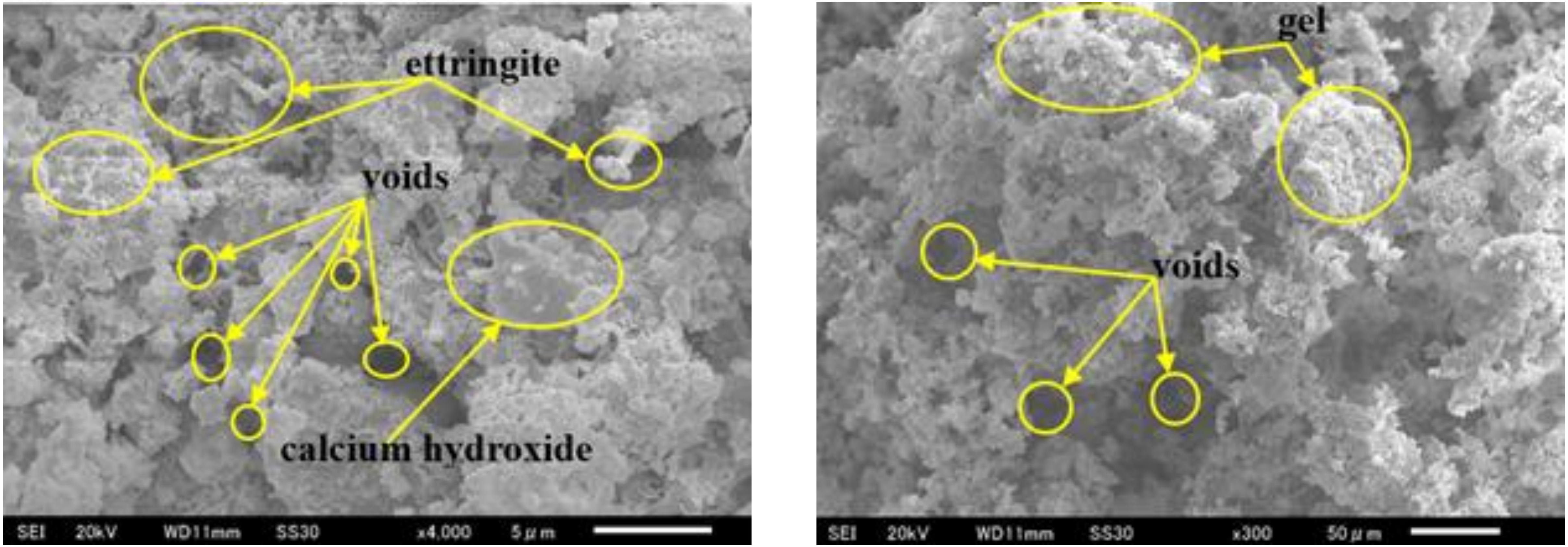
備考 試験の結果欄に未満と表示されている数値は定量下限値を示す。

一般社団法人 静岡県計量協会 承認様式 第302号

Fig. 21 **Hexavalent Chromium** leaching result

Table 10: Limit of heavy metals

Designated hazardous substances	
Heavy metals	**Soil Leachate Standard**
Cadmium	≤0.01mg / L
Hexavalent Chromium	**≤0.05mg / L**
Mercury	≤0.0005mg / L
Selenium	≤0.01mg / L
Lead	≤0.01mg / L
Arsenic	≤0.01mg / L
Fluorine	≤0.8mg / L
Boron	≤1mg / L



a) 7-day eco-friendly SEM

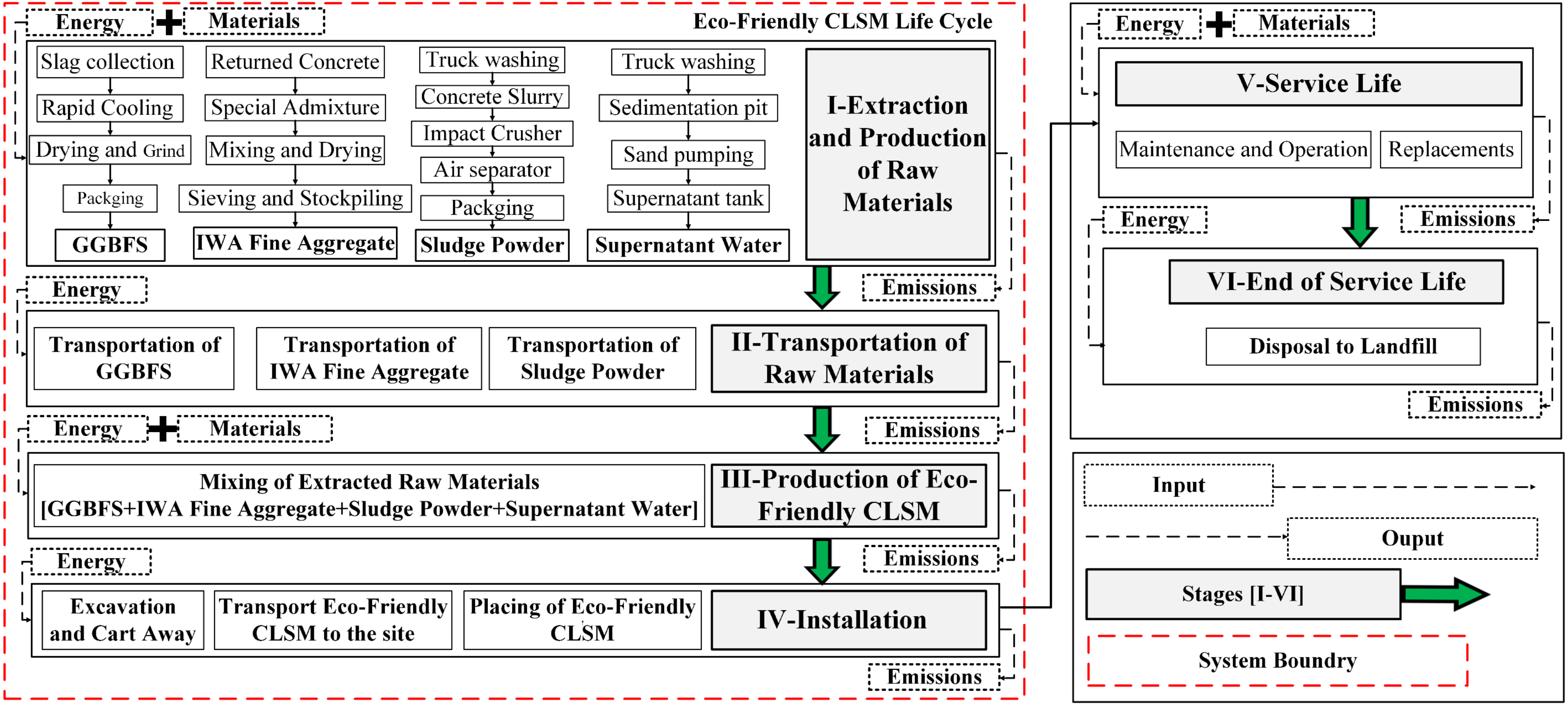
b) 28-day eco-friendly SEM

Fig. 22 SEM of eco-friendly CLSM

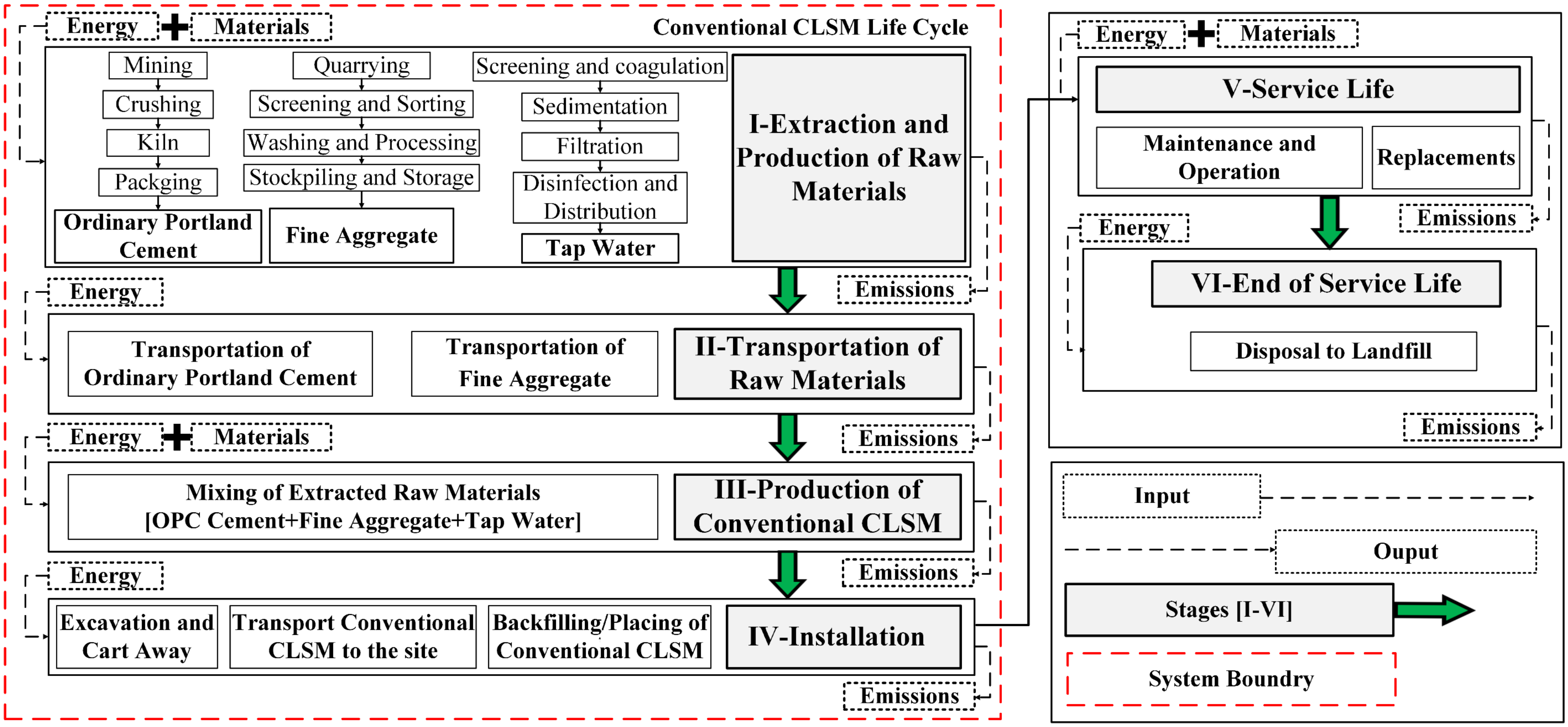
PRACTICAL APPLICATION AND TRIAL EXPERIMENTS

Fig. 23 Practical Application and Trials

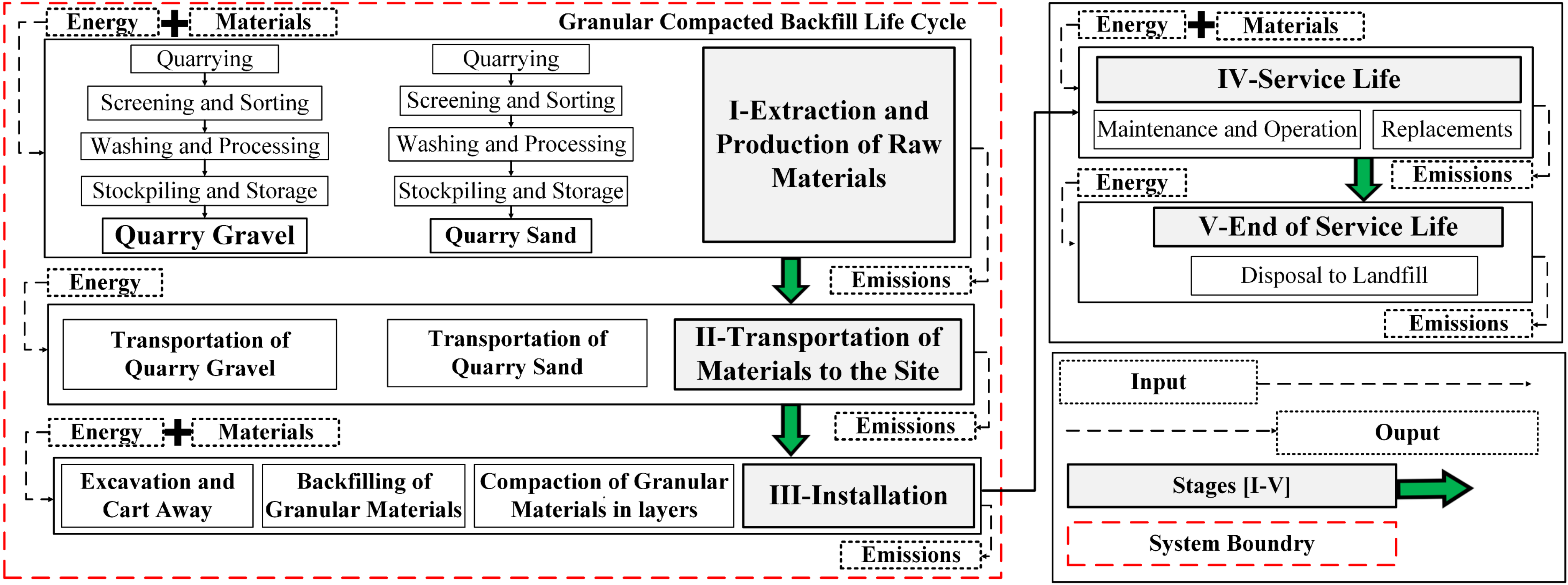
Eco-friendly CLSM System Boundaries Considered in this Study:



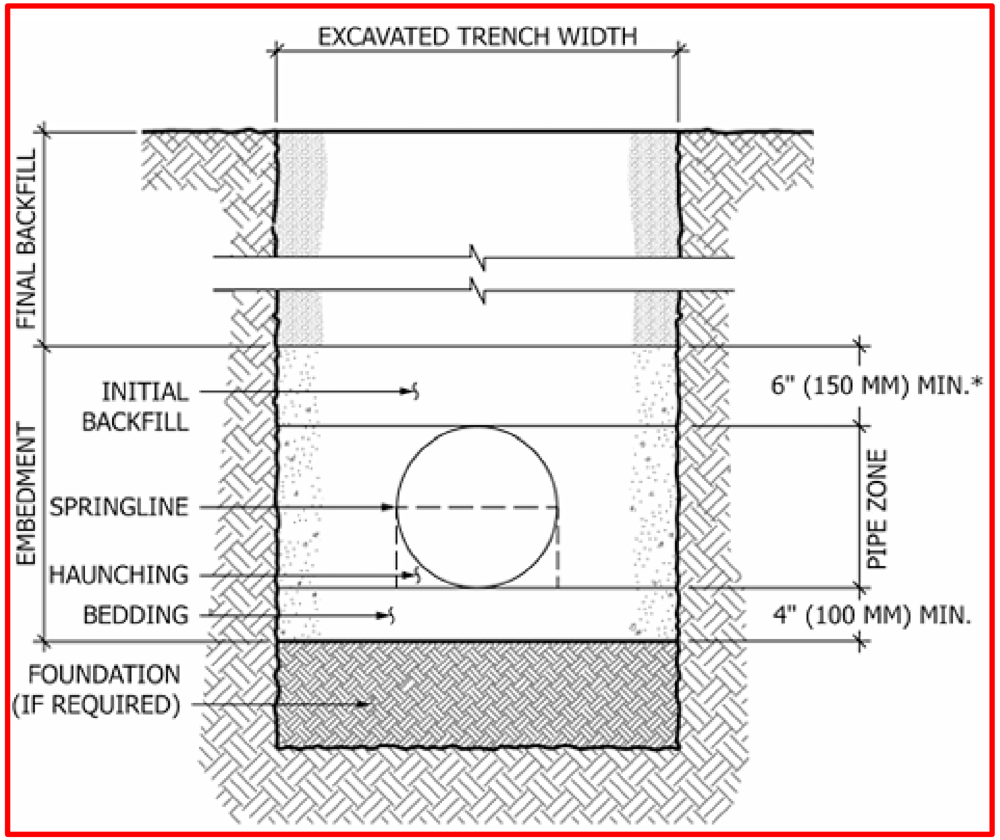
Conventional CLSM System Boundaries Considered in this Study:



Granular Compacted Fill System Boundaries Considered in this Study:



TRENCH CROSS-SECTION DETAILS



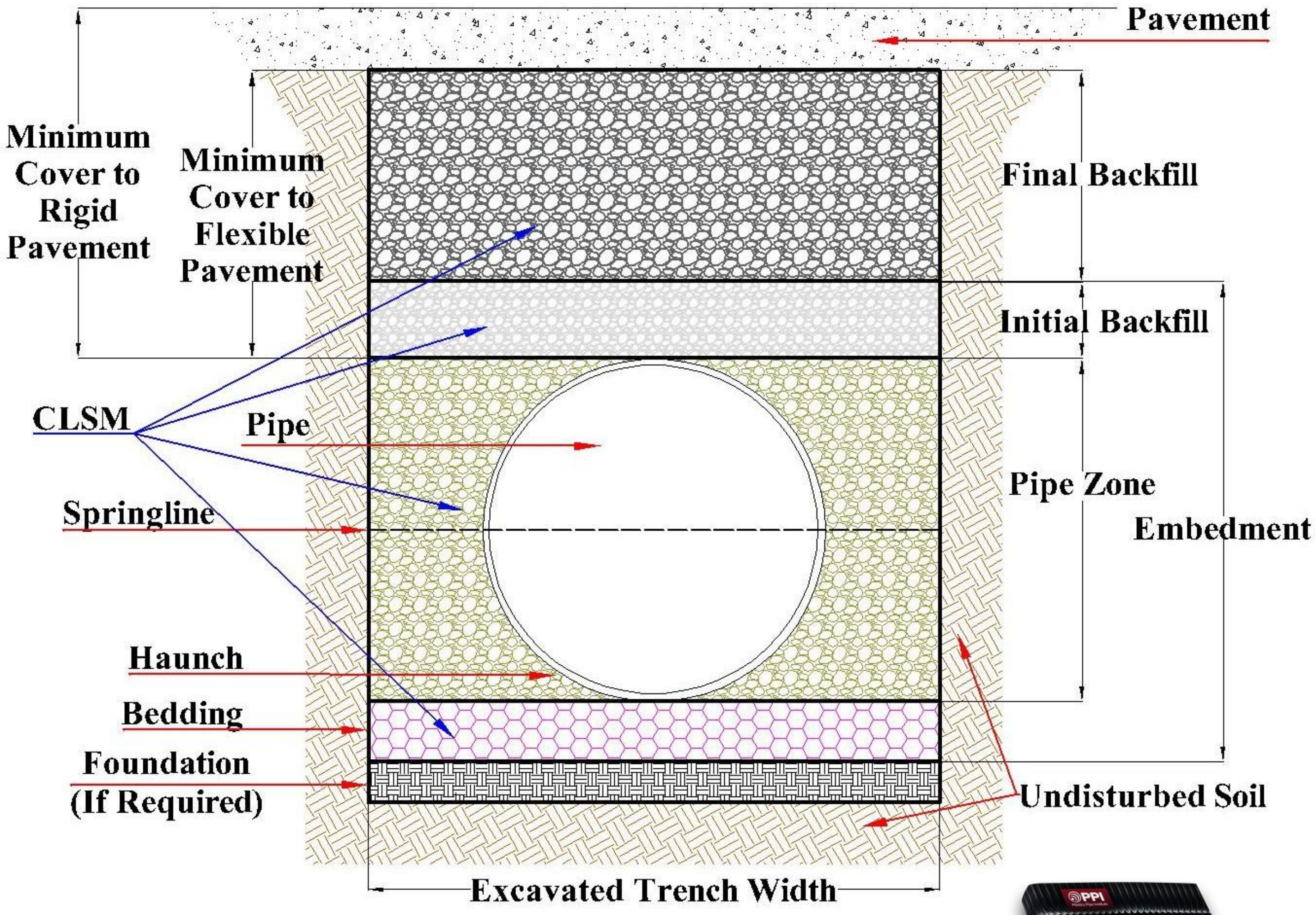
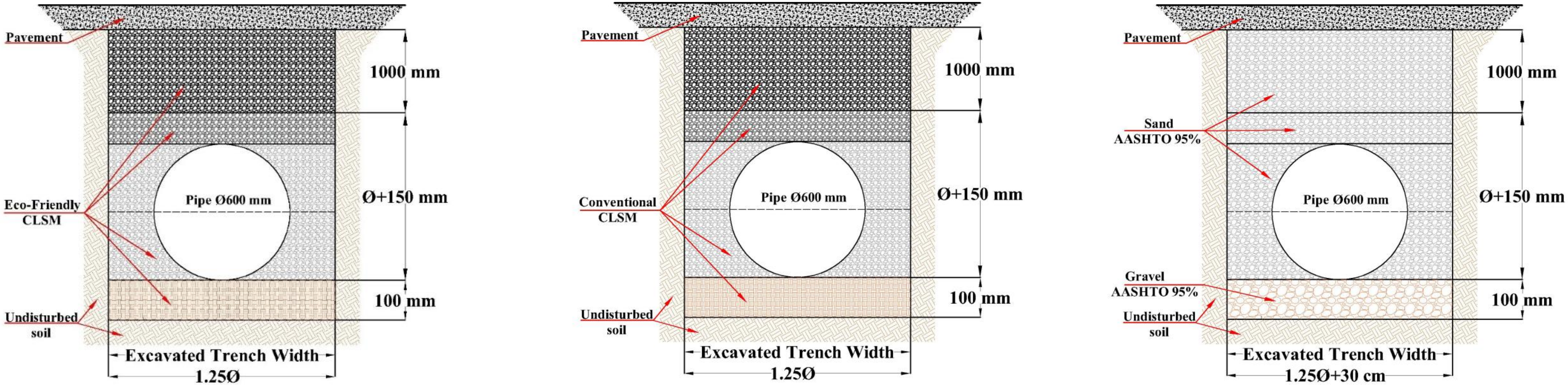


Fig. 24 Utility Trench Cross Section Details: ASTM D2321-20 Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications



a) Eco-friendly CLSM **b) Conventional CLSM** **c) Granular Compacted fill**

Fig. 25 Utility trench cross-section details

Table 11: Mixture proportions

Mix ID	Mix proportion by weight			
Eco-Friendly CLSM	**GGBFS**	**IWA Fine Aggregate**	**CSP**	**Supernatant Water**
	1m³ of Eco-friendly CLSM (kg/m³)			
	40	984	246	347
Conventional CLSM (ACI)	**OPC**	**Fine Aggregate**		**Tap Water**
	1m³ of Conventional CLSM (kg/m³)			
	40	1604		347
Granular Compacted Backfill	**Quarry Sand**		**Quarry Gravel**	
	1m³ of Granular Compacted Backfill (kg/m³)			
	2577		95	

GRANULAR COMPACTED FILL

- 📌 Minimum Trench Width: **1.25Ø+300 mm**
- 📌 Minimum Bedding: **100 mm**
- 📌 Minimum Initial Backfill:**150 mm**
- 📌 Final Backfill: **1000 mm**

CONVENTIONAL/ECO-FRIENDLY CLSM

- 📌 Minimum Trench Width: **1.25Ø**
- 📌 Minimum Bedding: **100 mm**
- 📌 Minimum Initial Backfill:**150 mm**
- 📌 Final Backfill: **1000 mm**

LOCATION AND ACTUAL TRANSPORT DISTANCE

Items	Entity	Origin	Destination	Distance (km)
Ordinary Portland Cement	Taiheiyo Cement Fujiwara Plant	Inabe City, Mie	Izunokuni City, Shizuoka	284
GGBFS	Nippon Steel Kimitsu Area	Kimitsu City, Chiba	Izunokuni City, Shizuoka	178
Fine Aggregate	Ishimori Industry Co., Ltd.	Nanbu Town, Yamanashi	Izunokuni City, Shizuoka	73
IWA Fine Aggregate	Nagaoka Ready-Mixed Concrete	Izunokuni City, Shizuoka	Izunokuni City, Shizuoka	Recycled in situ*
CSP	Nagaoka Ready-Mixed Concrete	Izunokuni City, Shizuoka	Izunokuni City, Shizuoka	Recycled in situ*
Quarry Gravel	Ishimori Industry Co., Ltd.	Nanbu Town, Yamanashi	Numazu City, Shizuoka	51
Quarry Sand	Ishimori Industry Co., Ltd.	Nanbu Town, Yamanashi	Numazu City, Shizuoka	51
Landfill site	Kimura Doboku Co., Ltd.	Izunokuni City, Shizuoka	Izunokuni City, Shizuoka	5.4
Project site	Nagaoka Ready-Mixed Concrete	Numazu City, Shizuoka	Numazu City, Shizuoka	9.7

**Material recycled at the concrete plant is considered 0 km.*

LOCATION AND ACTUAL TRANSPORT DISTANCE

Inventory Data and Case Studies for Environmental Performance Evaluation of Concrete Structure Construction (Kawai et al., 2005)

- Petroleum Energy Center, Japan [PEC 2002]
- Plastic Waste Management Institute, Japan [PWMI 2001]
- Federation of Electric Power Companies of Japan [FEPC 2004a]
- Japan Construction Mechanization Association [JCMA 2001, 2008]
- Japan Cement Association (JCA)
- Assessment for Environmental Impact of Concrete [JSCE 2002, 2004]
- Calculation Methodology of the Emissions of GHG [MOE 2000, 2003]
- 3EID for Japan Using Input-Output Tables (3EID)
- Hokkaido University report [HOK 1998]
- Construction Research Institute. [CRI,1998]

Preparation of Inventory Data for Environmental Performance Evaluation of Concrete and Concrete Structures (Kawai et al., 2010)

- **Emission Inventory Data for Energy Used for Operation**
  - Light oil , Gasoline, Coal, Oil Coke, Heavy oil (Type A and C) and Electricity
- **Emission Inventory Data for Transportation**
  - Truck, Dump truck, and Agitator Truck
- **Emission Inventory Data for Constituent Materials**
  - OPC, Sand, Crushed Gravel, and GGBFS
- **Emission Inventory Data for Construction**
  - Concrete mixer, Agitator truck, Tamper and Excavator
- **Emission Inventory Data for Demolition**
- **Emission Inventory Data for Disposal and Recycling**
  - Landfill site for wastes: Leachate-controlled type

ITeC database of construction elements

Scope and contents

The ITeC database supplies technical, environmental and economic information regarding all kind of elements used in every situation in the construction market.

Materials	Building	Cost
Tools and machinery	Civil engineering	Specifications
Health and safety elements	Renovation and restoration	Environmental impact
Quality control elements		Waste generation

G228AH0F P
P2255-DPIC

51,39 € / m3

Filling and compaction of trenches with a width of more than 0.6 and up to 1.5 m, with gravels for drainage from 5 to 12 mm, in thicknesses of up to 25 cm, using a vibrating fuel tamper, with compaction of 95% PM

PRICE JUSTIFICATION

ON	T	Code	Description	Price	Quantity	Amount
P	MO	A0150000 A0E-000A	Specialist Laborer	20,34 € / h x	0.08 h =	€1.62720
P	MAT	B0330A00 B03J-0K8T	Quarried gravel, 5 to 12 mm	24,45 € / t x	1.7 t =	€41.56500
P	MAQ	C1313330 C13C-00LP	Backhoe loader on tires from 8 to 10 t	€54.34 / h x	0.1389 h =	€7.54783
P	MAQ	C133A030 C13A-00FR	700 kg manual duplex fuel compactor	€7.77 / h x	0.08 h =	€0.62160
	AUX	A%AUX001 A%AUX001	Auxiliary labour costs	€1.62720 x	0,015 =	€0.02441
Total €1.63 €	41.57	€8.17 €	0.02	Direct cost		51,38603 € / m3

ENVIRONMENTAL INFORMATION

F228AM00
P2255-DPIO P 42,56 € / m3

Filling and compaction of trenches with a width of more than 0.6 and up to 1.5 m, with sand, in layers of thickness of more than 25 and up to 50 cm, using a vibrating fuel tamper

PRICE JUSTIFICATION

ON	T	Code	Description	Price		Quantity		Amount
P	MO	A0150000 A0E-000A	Specialist Laborer	20,34 € / h	x	0.08 h	=	€1.62720
P	MAT	B0310500 B03L-05N5	Quarry sand from 0 to 3.5 mm	20,57 € / t	x	1.8 t	=	€37.02600
P	MAQ	C1313330 C13C-00LP	Backhoe loader on tires from 8 to 10 t	€54.34 / h	x	0.06 h	=	€3.26040
P	MAQ	C133A030 C13A-00FR	700 kg manual duplex fuel compactor	€7.77 / h	x	0.08 h	=	€0.62160
	AUX	A%AUX001 A%AUX001	Auxiliary labour costs	€1.62720	x	0,015	=	€0.02441
Total	€1.63 €	37.03	€3.88 €	0.02		Direct cost		42,55961 € / m3

ENVIRONMENTAL INFORMATION

❖ReCiPe 2016

❖ **ReCiPe 2016** offers both **midpoint** and **endpoint** indicators.

❖ This dual-level approach allows users to choose between a detailed analysis (midpoints) or a more simplified, overarching view of environmental impacts (endpoints).

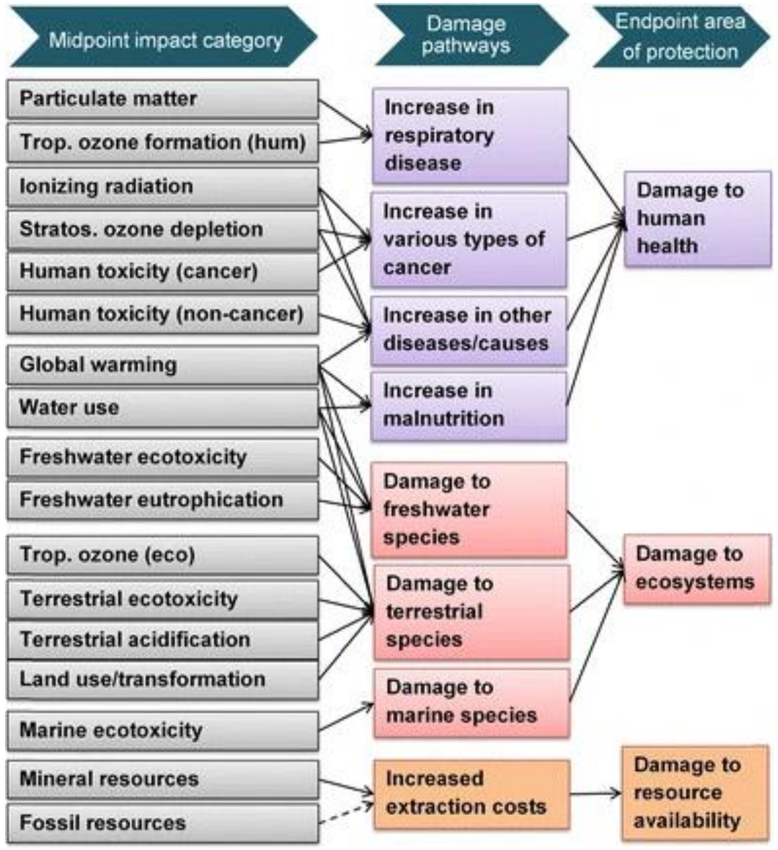
❖ It targets **LCA practitioners**, **researchers**, **policymakers**, **industry professionals,** and **consultants** who need a versatile and reliable tool for environmental impact assessment.

❖ The ReCiPe 2016 midpoint method, **Hierarchist** version, is the default **ReCiPe midpoint method**.

❖ **Region: Global**

❖ **Source or author:** Created by RIVM, Radboud University, Norwegian University of Science and Technology, and PRé Consultants.

❖ **Standard**: ReCiPe 2016 follows Recipe 2008.



Items	Unit (*)	CO_2 emission ($kg\text{-}CO_2$/*)	SO_x emission ($kg\text{-}SO_x$/*)	NO_x emission ($kg\text{-}NO_x$/*)	Particulate matter emission (kg-PM/*)
i. Emission Inventory Data for Energy Used for Operation					
Electricity	kWh	0.407	0.00013	0.00016	0.00003
Light oil for truck	L	2.64	0.00204	0.01977	0.00166
Light oil for equipment	L	2.64	0.00204	0.03961	0.00201
Coal (imported)	kg	2.36	-	-	-
Heavy oil (Type A)	L	2.77	0.013	0.00238	0.003
Heavy oil (Type C)	L	2.97	0.0564	-	-
Petroleum coke	kg	3.31	-	-	-
Gasoline	L	2.31	0.00059	-	-
ii. Emission Inventory Data for Transportation					
Truck Diesel (20t)	km.t	0.0714	0.0000549	0.000534	0.0000448
Dump truck Diesel (10t)	km.t	0.106	0.0000836	0.000811	0.0000681
Agitator truck (0.8-0.9m^3)	km.t	0.378	0.000297	0.00288	0.000242

Items	Unit (*)	CO_2 emission ($kg\text{-}CO_2$/*)	SO_x emission ($kg\text{-}SO_x$/*)	NO_x emission ($kg\text{-}NO_x$/*)	Particulate matter emission (kg-PM/*)
iii. Emission Inventory Data for Constituent Materials					
Ordinary Portland Cement	t	766.6	0.122	1.55	0.0358
Fine aggregate	t	3.7	0.00860	0.00586	0.00199
Tap water	m^3	0.59	-	-	-
Blast furnace slag	t	26.5	0.00836	0.0102	0.00169
IWA fine aggregate	t	2.81	0.00120	0.0164	0.00119
Concrete sludge powder	t	-208	-	-	-
Supernatant water	m^3	0.0576	-	-	-
Crushed gravel	t	2.9	0.00607	0.00415	0.00141
Manufactured sand	t	3.7	0.00860	0.00586	0.00199
iv. Emission Inventory Data for Construction					
Backhoe Excavator (0.6m^3)	h	51.7	0.0398	0.774	0.0393
Concrete mixer (1.5m^3)	m^3	0.73	0.000235	0.000289	0.0000542
Agitator truck (0.8-0.9m^3)	h	10.0	0.00769	0.0747	0.00628
Vibrating tamper	h	2.1	0.000000451	0.0000132	0.000000489
v. Emission Inventory Data for Disposal and Recycling					
Leachate-controlled type landfill	t	3.3	0.00447	0.0255	0.00198

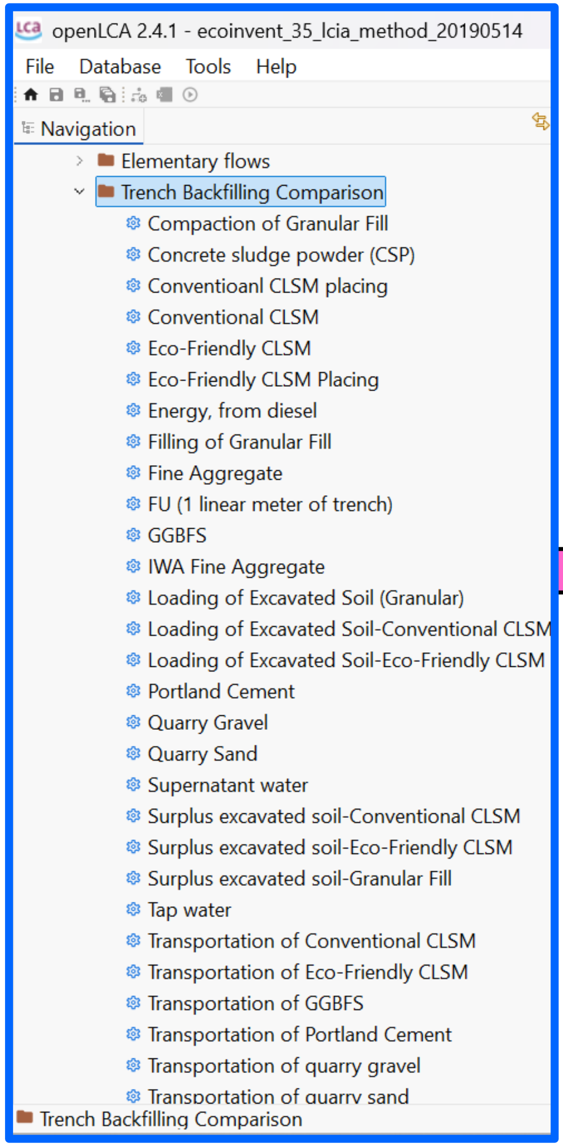
GGBFS EMISSION INVENTORY DATA CALCULATION

CLSM per linear trench=0.75mx1.85mx1m-(πx0.3^2)m^{2}x1m=1.10m^3/m

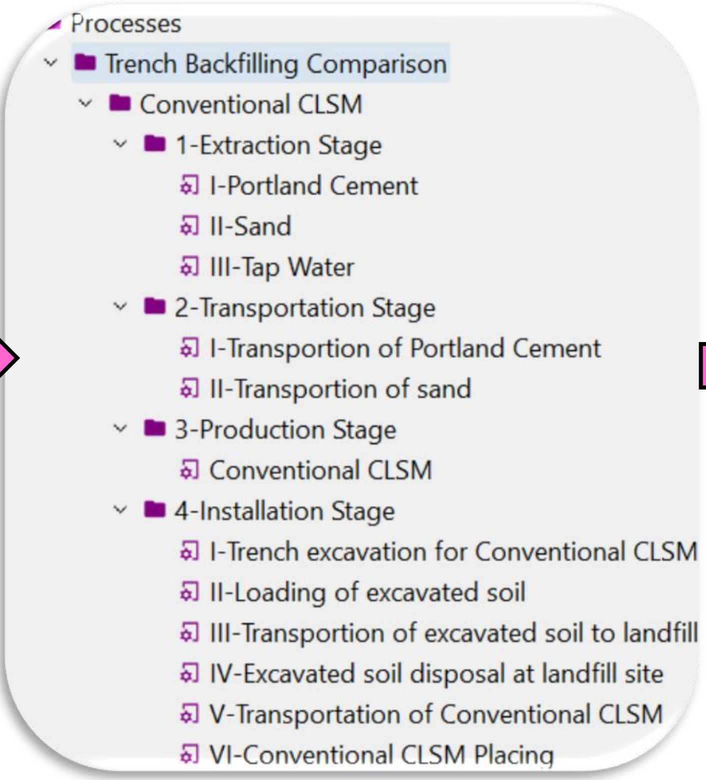
GGBFS=40kg/m^3=0.04t/m^3 → GGBFS=0.04t/m^{3}x1.10m^3/m=0.044t/m

CO_2 emission (kg-CO_2/m)	=(26.5kg-CO_2/t)*0.044t/m= 1.166
SOx emission (kg-SOx/m)	=(0.00836kg-SOx/t)*0.044t/m= 0.000368
NOx emission (kg-NOx/m)	=(0.0102kg-NOx/t)*0.044t/m= 0.000449
Particulate matter emission (kg-PM/m)	=(0.00169kg-PM/t)*0.044t/m= 7.44E-05

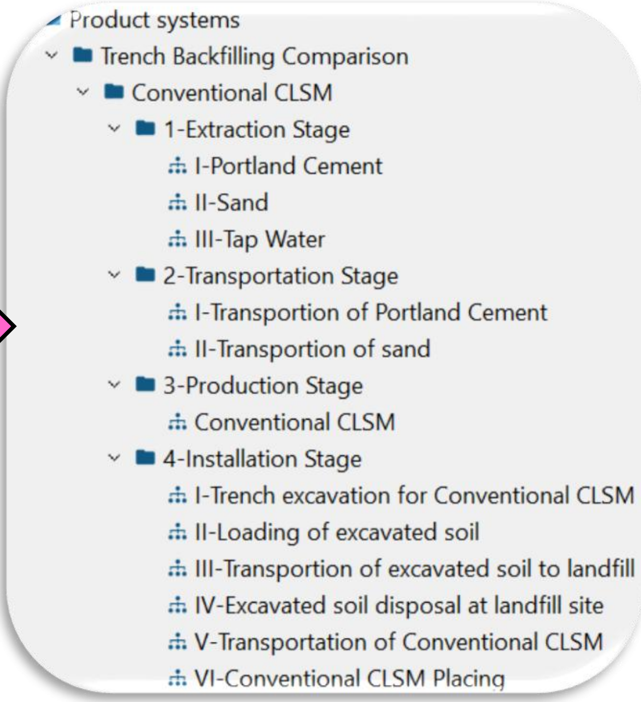
FLOWS



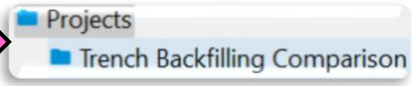
PROCESSES



PRODUCT SYSTEMS



PROJECTS



THE MODEL GRAPH ECO-FRIENDLY CLSM

I-Trench excavation for Eco-Friendly CL...

Input flows		
Oil, crude, in ground	3.51	kg
Output flows		
FU (1 linear meter of trench)	1.00	m
Surplus excavated soil-Eco-Frie...	2.78	t
Carbon dioxide, fossil	1.85E1	kg
Nitrogen oxides	0.32	kg
Particulates, < 2.5 um	1.65E-2	kg
Sulfur oxides	1.67E-2	kg

II-Loading of excavated Soil

Input flows		
Surplus excavated soil-Eco-Friendly CLSM	2.78	t
Oil, crude, in ground	0.20	kg
Output flows		
FU (1 linear meter of trench)	1.00	m
Loading of Excavated Soil-Eco-Friendly...	1.00E-2	h
Carbon dioxide, fossil	1.06	kg
Nitrogen oxides	1.85E-2	kg
Particulates, < 2.5 um	9.00E-4	kg
Sulfur oxides	1.00E-3	kg

III-Transportion of excavated soil to land...

Input flows		
Loading of Excavated Soil-Eco-Fri...	1.00E-2	h
Oil, crude, in ground	0.57	kg
Output flows		
FU (1 linear meter of trench)	1.00	m
Transportation of surplus soil-E...	1.50E1	t*km
Carbon dioxide, fossil	3.34	kg
Nitrogen oxides	2.53E-2	kg
Particulates, < 2.5 um	2.10E-3	kg
Sulfur oxides	2.60E-3	kg

IV-Excavated soil disposal at landfill site

Input flows		
Transportation of surplus soil-E...	1.50E1	t*km
Energy, from hydro power	7.55	kWh
Oil, crude, 42 MJ per kg	2.00	kg
Oil, crude, in ground	2.00	kg
Output flows		
FU (1 linear meter of trench)	1.00	m
Carbon dioxide, fossil	2.73E1	kg
Nitrogen oxides	0.24	kg
Particulates, < 2.5 um	1.85E-2	kg
Sulfur oxides	4.14E-2	kg

I-GGBFS

II-Concrete Sludge P...

III-IWA Fine Aggregate

IV-Supernatant Water

Transportion of GGBFS

Eco-Friendly CLSM

Input flows		
Concrete sludge powder (CSP)	0.27	t
IWA Fine Aggregate	2.00	t
Supernatant water	0.38	m3
Transportation of GGBFS	7.87	t*km
Energy, from hydro power	2.00	kWh
Output flows		
Eco-Friendly CLSM	1.10	m3
FU (1 linear meter of trench)	1.00	m
Carbon dioxide, fossil	1.62	kg
Chromium VI	7.00E-3	mg
Nitrogen oxides	7.00E-4	kg
Particulates, < 2.5 um	1.00E-4	kg
Sulfur oxides	5.00E-4	kg

V-Transportation of Eco-Friendly CLSM

Input flows		
Eco-Friendly CLSM	1.10	m3
Oil, crude, in ground	1.36	kg
Output flows		
FU (1 linear meter of trench)	1.00	m
Transportation of Eco-Friendl...	1.07E1	m3*km
Carbon dioxide, fossil	7.64	kg
Nitrogen oxides	5.78E-2	kg
Particulates, < 2.5 um	4.90E-3	kg
Sulfur oxides	6.00E-3	kg

VI-Eco-Friendly CLSM Placing

Input flows		
Transportation of Eco-Friendly ...	1.07E1	m3*km
Oil, crude, in ground	6.00E-2	kg
Output flows		
Eco-Friendly CLSM Placing	0.40	h
FU (1 linear meter of trench)	1.00	m
Carbon dioxide, fossil	4.43	kg
Nitrogen oxides	6.63E-2	kg
Particulates, < 2.5 um	3.40E-3	kg
Sulfur oxides	3.50E-3	kg

THE MODEL GRAPH FOR CONVENTIONAL CLSM

I-Trench excavation for Conventional CLSM

Input flows		
Oil, crude, in ground	3.51	kg
Output flows		
FU (1 linear meter of trench)	1.00	m
Surplus excavated soil-Conventional...	2.78	t
Carbon dioxide, fossil	1.85E1	kg
Nitrogen oxides	0.32	kg
Particulates, < 2.5 um	1.65E-2	kg
Sulfur oxides	1.67E-2	kg

II-Loading of excavated soil

Input flows		
Surplus excavated soil-Convention...	2.78	t
Oil, crude, in ground	0.20	kg
Output flows		
FU (1 linear meter of trench)	1.00	m
Loading of Excavated Soil-Con...	1.00E-2	h
Carbon dioxide, fossil	1.06	kg
Nitrogen oxides	1.85E-2	kg
Particulates, < 2.5 um	9.00E-4	kg
Sulfur oxides	1.00E-3	kg

III-Transportion of excavated soil to landfill

Input flows		
Loading of Excavated Soil-Conventio...	1.00E-2	h
Oil, crude, in ground	0.57	kg
Output flows		
FU (1 linear meter of trench)	1.00	m
Transportation of surplus soil-Conv...	1.50E1	t*km
Carbon dioxide, fossil	3.34	kg
Nitrogen oxides	2.53E-2	kg
Particulates, < 2.5 um	2.10E-3	kg
Sulfur oxides	2.60E-3	kg

IV-Excavated soil disposal at landfill site

Input flows		
Transportation of surplus soil-...	1.50E1	t*km
Energy, from hydro power	7.55	kWh
Oil, crude, 42 MJ per kg	2.00	kg
Oil, crude, in ground	2.00	kg
Output flows		
FU (1 linear meter of trench)	1.00	m
Carbon dioxide, fossil	2.73E1	kg
Nitrogen oxides	0.24	kg
Particulates, < 2.5 um	1.85E-2	kg
Sulfur oxides	4.14E-2	kg

III-Tap Water

I-Portland Cement

I-Transportion of Portland Cement

II-Sand

II-Transportion of sand

Conventional CLSM

Input flows		
Tap water	0.38	m3
Transportation of Portland Ce...	1.26E1	t*km
Transportation of sand	1.29E2	t*km
Energy, from hydro power	2.00	kWh
Output flows		
Conventional CLSM	1.10	m3
FU (1 linear meter of trench)	1.00	m
Carbon dioxide, fossil	1.62	kg
Chromium VI	0.13	mg
Nitrogen oxides	7.00E-4	kg
Particulates, < 2.5 um	1.00E-4	kg
Sulfur oxides	5.00E-4	kg

V-Transportation of Conventional CLSM

Input flows		
Conventional CLSM	1.10	m3
Oil, crude, in ground	1.36	kg
Output flows		
FU (1 linear meter of trench)	1.00	m
Transportation of Conventiona...	1.07E1	m3*km
Carbon dioxide, fossil	7.64	kg
Nitrogen oxides	5.78E-2	kg
Particulates, < 2.5 um	4.90E-3	kg
Sulfur oxides	6.00E-3	kg

VI-Conventional CLSM Placing

Input flows		
Transportation of Conventi...	1.07E1	m3*km
Oil, crude, in ground	6.00E-2	kg
Output flows		
Conventioanl CLSM placing	0.44	h
FU (1 linear meter of trench)	1.00	m
Carbon dioxide, fossil	4.43	kg
Nitrogen oxides	6.63E-2	kg
Particulates, < 2.5 um	3.40E-3	kg
Sulfur oxides	3.50E-3	kg

THE MODEL GRAPH FOR GRANULAR COMPACTED FILL

I-Trench excavation for Granular fill

Input flows		
Oil, crude, in ground	4.91	kg
Output flows		
FU (1 linear meter of trench)	1.00	m
Surplus excavated soil-Granul...	3.89	t
Carbon dioxide, fossil	2.59E1	kg
Nitrogen oxides	0.45	kg
Particulates, < 2.5 um	2.31E-2	kg
Sulfur oxides	2.34E-2	kg

II-Loading of excavated Soil

Input flows		
Surplus excavated soil-Granular Fill	3.89	t
Oil, crude, in ground	0.28	kg
Output flows		
FU (1 linear meter of trench)	1.00	m
Loading of Excavated Soil (Gran...	2.00E-2	h
Carbon dioxide, fossil	1.48	kg
Nitrogen oxides	2.59E-2	kg
Particulates, < 2.5 um	1.30E-3	kg
Sulfur oxides	1.30E-3	kg

III-Transportion of excavated soil to landfill

Input flows		
Loading of Excavated Soil (Granular)	2.00E-2	h
Oil, crude, in ground	0.80	kg
Output flows		
FU (1 linear meter of trench)	1.00	m
Transportation of surplus soil-Gra...	2.10E1	t*km
Carbon dioxide, fossil	4.67	kg
Nitrogen oxides	3.54E-2	kg
Particulates, < 2.5 um	3.00E-3	kg
Sulfur oxides	3.60E-3	kg

IV-Excavated soil disposal at landfill site

Input flows		
Transportation of surplus soil-Gran...	2.10E1	t*km
Energy, from hydro power	1.06E1	kWh
Oil, crude, 42 MJ per kg	2.80	kg
Oil, crude, in ground	2.80	kg
Output flows		
FU (1 linear meter of trench)	1.00	m
Carbon dioxide, fossil	3.82E1	kg
Nitrogen oxides	0.33	kg
Particulates, < 2.5 um	2.59E-2	kg
Sulfur oxides	5.79E-2	kg

I-Quarry Gravel → I-Transportion of quarry gravel

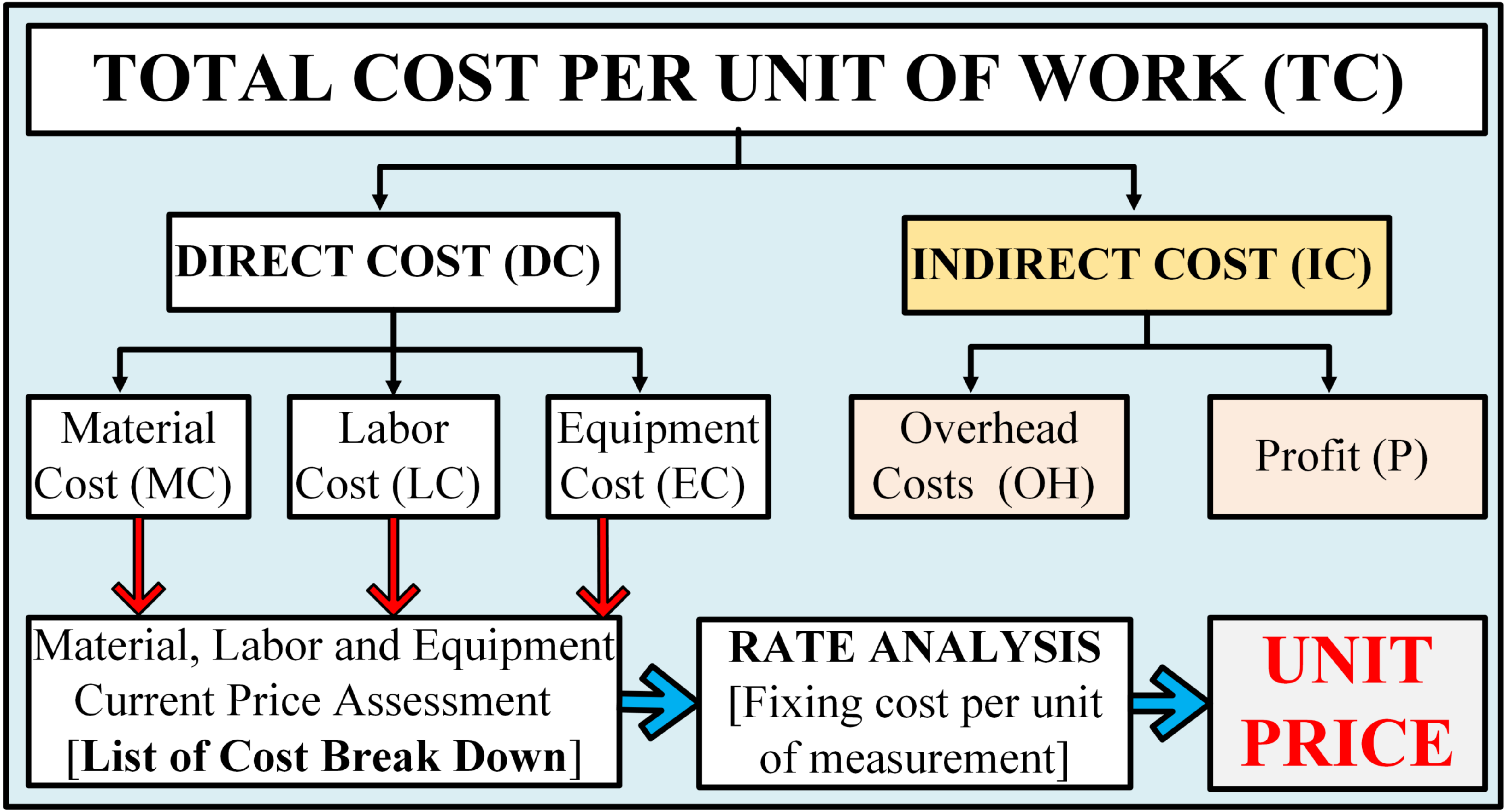
II-Quarry Sand → II-Transportion of quarry sand

V-Filling of Granular Fill

Input flows		
Transportation of quarry gra...	1.48E1	t*km
Transportation of quarry sand	2.18E2	t*km
Oil, crude, in ground	3.86	kg
Output flows		
Filling of Granular Fill	0.23	h
FU (1 linear meter of trench)	1.00	m
Carbon dioxide, fossil	2.04E1	kg
Nitrogen oxides	0.36	kg
Particulates, < 2.5 um	1.81E-2	kg
Sulfur oxides	1.84E-2	kg

VI-Compaction of Granular Fill

Input flows		
Filling of Granular Fill	0.23	h
Oil, crude, in ground	7.00E-2	kg
Output flows		
Compaction of Granular Fill	0.10	h
FU (1 linear meter of tren...	1.00	m
Carbon dioxide, fossil	0.61	kg
Nitrogen oxides	1.30E-6	kg
Particulates, < 2.5 um	4.87E-8	kg
Sulfur oxides	4.23E-5	kg


TOTAL COST PER UNIT OF WORK (TC)
DIRECT COST (DC)
INDIRECT COST (IC)
Material Cost (MC)
Labor Cost (LC)
Equipment Cost (EC)
Overhead Costs (OH)
Profit (P)
Material, Labor and Equipment Current Price Assessment [List of Cost Break Down]
RATE ANALYSIS [Fixing cost per unit of measurement]
UNIT PRICE

1.0 EXCAVATION

ANALYSIS SHEET FOR DIRECT & INDIRECT COSTS

Project: Trench Backfilling Materials Life Cycle Cost (LCC)

Work Item: (1.1) Trench excavation up to 2 m deep, in soft soil, with a backhoe loader and mechanical loading of the excavated material.

Targeted Output Quantity: 1 m^3 Result: 1499.16 ¥/m^3

Material Cost (1:01)					Labor Cost (1:02)						Equipment Cost (1:03)				
Type of Material	Unit	Qty*	Rate	Cost per Unit	Labor by Trade	No.	UF	Labour Output (hr/m^3)	Indexed hourly cost**	Hourly cost	Type of Equipment	No.	Equipment Output (hr/m^3)	Hourly Rental	Hourly Cost
					Equipment Operator	1	1	0.08	3638	291.04	Backhoe Excavator with fuel	1	0.1208	7000	845.6
					Site Supervisor	1	0.5	0.08	5813	232.52					
					Daily Laborer	1	1	0.04	3250	130					
Total (1:01)					Total (1:02)					653.56	Total (1:03)				845.6

A= Materials Unit Cost 0 ¥/m^3 B= Manpower Unit Cost 654 ¥/m^3 C= Equipment Unit Cost 845.60 ¥/m^3

Direct Cost of Work Item = A+B+C =		1499.16	¥/m^3
Overhead Cost:	0%	0.00	¥/m^3
Profit Cost:	0%	0.00	¥/m^3
Total :		1499.16	¥/m^3
VAT	0%	0	¥/m^3
Total unit cost:		1499.16	¥/m^3

Notes:

UF: Utilization Factor (UF) = 1/ the # of crew or people under supervision

* Inclusive of transporting, loading and unloading, handling, etc.

** Inclusive of benefits, travel subsides, and cost of overtime related to targeted output.

2.0 CART AWAY

ANALYSIS SHEET FOR DIRECT & INDIRECT COSTS

Project: Trench Backfilling Materials Life Cycle Cost (LCC)

Work Item: (2.1) Hauling surplus excavated material 5.4 km away

Targeted Output Quantity: 1 m³

Result: 5042.53 ¥/m³

Material Cost (1:01)					Labor Cost (1:02)						Equipment Cost (1:03)				
Type of Material	Unit	Qty*	Rate	Cost per Unit	Labor by Trade	No.	UF	Labour Output (hr/m³)	Indexed hourly cost**	Hourly cost	Type of Equipment	No.	Equipment Output (hr/m³)	Hourly Rental	Hourly Cost
Surplus Soil Disposal	m³	1	4500	4500	Equipment Operator	1	1	0.0069	3638	25.10	Backhoe Loader with fuel	1	0.0069	7000	48.3
					Truck Driver	1	1	0.015	3275	49.13	Dump truck (10t) with fuel	1	0.056	7500	420
Total (1:01)				4500	Total (1:02)					74.23	Total (1:03)				468.3

A= Materials Unit Cost 4500 ¥/m³

B= Manpower Unit Cost 74.23 ¥/m³

C= Equipment Unit Cost 468.3 ¥/m³

Direct Cost of Work Item = A+B+C =		5042.53	¥/m³
Overhead Cost:	0%	0.00	¥/m³
Profit Cost:	0%	0.00	¥/m³
Total :		5042.53	¥/m³
VAT	0%	0	¥/m³
Total unit cost:		5042.53	¥/m³

Notes:

UF: Utilization Factor (UF) = 1/ the # of crew or people under supervision

* Inclusive of transporting, loading and unloading, handling, etc.

** Inclusive of benefits, travel subsides, and cost of overtime related to targeted output.

CONVENTIONAL CLSM FILLING RATE ANALYSIS

3.0 FILLING

ANALYSIS SHEET FOR DIRECT & INDIRECT COSTS

Project: Trench Backfilling Materials Life Cycle Cost (LCC)

Work Item: (3.1) Conventional CLSM

Targeted Output Quantity: 1 m^3

Result: 15887.40 ¥/m^3

Material Cost (1:01)					Labor Cost (1:02)						Equipment Cost (1:03)				
Type of Material	Unit	Qty*	Rate	Cost per Unit	Labor by Trade	No.	UF	Labour Output (hr/m^3)	Indexed hourly cost**	Hourly cost	Type of Equipment	No.	Equipment Output (hr/m^3)	Hourly Rental	Hourly Cost
OPC Cement	kg	40	19	740	Site Supervisor	1	0.5	0.0672	5813	195.3168	Concrete mixer (1.5m^3)	1	0.336	4688.00	1575.17
Sand	kg	1604	6.50	10426	Daily Laborer	1	1	0.025	3250	81.25	Agitator truck (0.8-0.9m^3) with fuel	1	0.14	7500.00	1050
Tap Water	m^3	0.347	400	139	Mixer Operator	1	1	0.336	3638	1222.368					
					Agitator truck driver	1	1	0.14	3275	458.5					
Total (1:01)				11304.80	Total (1:02)					1957.43	Total (1:03)				2625.17

A= Materials Unit Cost	11304.80	¥/m^3	B= Manpower Unit Cost	1957.43	¥/m^3	C= Equipment Unit Cost	2625.17	¥/m^3

Direct Cost of Work Item = A+B+C =		15887.40	¥/m^3
Overhead Cost:	0%	0.00	¥/m^3
Profit Cost:	0%	0.00	¥/m^3
Total :		15887.40	¥/m^3
VAT	0%	0	¥/m^3
Total unit cost:		15887.40	¥/m^3

Notes:

UF: Utilization Factor (UF) = 1/ the # of crew or people under supervision

* Inclusive of transporting, loading and unloading, handling, etc.

** Inclusive of benefits, travel subsides, and cost of overtime related to targeted output.

3.0 FILLING

ANALYSIS SHEET FOR DIRECT & INDIRECT COSTS

Project: Trench Backfilling Materials Life Cycle Cost (LCC)

Work Item: (3.2) Eco-Friendly CLSM

Targeted Output Quantity: 1 m^3

Result: 10082.60 ¥/m^3

Material Cost (1:01)					Labor Cost (1:02)						Equipment Cost (1:03)				
Type of Material	Unit	Qty*	Rate	Cost per Unit	Labor by Trade	No.	UF	Labour Output (hr/m^3)	Indexed hourly cost**	Hourly cost	Type of Equipment	No.	Equipment Output (hr/m^3)	Hourly Rental	Hourly Cost
GGBFS	kg	40	15	580	Site Supervisor	1	0.5	0.0672	5813	195.3168	Concrete mixer (1.5m^3)	1	0.336	4688.00	1575.17
IWA Fine Aggregate	kg	984	4	3936	Daily Laborer	1	1	0.025	3250	81.25	Agitator truck (0.8-0.9m^3) with fuel	1	0.14	7500.00	1050
Sludge Powder	kg	246	4	984	Mixer Operator	1	1	0.336	3638	1222.368					
Supernatant Water	m^3	0.347	0	0	Agitator truck driver	1	1	0.14	3275	458.5					
Total (1:01)				5500	Total (1:02)					1957.43	Total (1:03)				2625.17

A= Materials Unit Cost 5500 ¥/m^3

B= Manpower Unit Cost 1957.43 ¥/m^3

C= Equipment Unit Cost 2625.17 ¥/m^3

Direct Cost of Work Item = A+B+C =		10082.60	¥/m^3
Overhead Cost:	0%	0.00	¥/m^3
Profit Cost:	0%	0.00	¥/m^3
Total :		10082.60	¥/m^3
VAT	0%	0	¥/m^3
Total unit cost:		10082.60	¥/m^3

Notes:

UF: Utilization Factor (UF) = 1/ the # of crew or people under supervision

* Inclusive of transporting, loading and unloading, handling, etc.

** Inclusive of benefits, travel subsides, and cost of overtime related to targeted output.

3.0 FILLING

ANALYSIS SHEET FOR DIRECT & INDIRECT COSTS

Project: Trench Backfilling Materials Life Cycle Cost (LCC)

Work Item: (3.3) Granular Compacted fill

Targeted Output Quantity: 1 m^3

Result: 18414.27 ¥/m^3

Material Cost (1:01)					Labor Cost (1:02)						Equipment Cost (1:03)				
Type of Material	Unit	Qty*	Rate	Cost per Unit	Labor by Trade	No.	UF	Labour Output (hr/m^3)	Indexed hourly cost**	Hourly cost	Type of Equipment	No.	Equipment Output (hr/m^3)	Hourly Rental	Hourly Cost
Quarry gravel	kg	175	5.50	962.50	Site Supervisor	1	0.5	0.08	5813	232.52	Backhoe Loader with fuel	1	0.06	7000	420
Quarry sand	kg	2577	6.50	16750.50	Daily Laborer	1	1	0.015	3250	48.75					
Total (1:01)				5500	Total (1:02)					1957.43	Total (1:03)				2625.17

A= Materials Unit Cost 17713.00 ¥/m^3

B= Manpower Unit Cost 281.27 ¥/m^3

C= Equipment Unit Cost 420 ¥/m^3

Direct Cost of Work Item = A+B+C =		18414.27	¥/m^3
Overhead Cost:	0%	0.00	¥/m^3
Profit Cost:	0%	0.00	¥/m^3
Total :		18414.27	¥/m^3
VAT	0%	0	¥/m^3
Total unit cost:		18414.27	¥/m^3

Notes:

UF: Utilization Factor (UF) = 1/ the # of crew or people under supervision

* Inclusive of transporting, loading and unloading, handling, etc.

** Inclusive of benefits, travel subsides, and cost of overtime related to targeted output.

4.0 COMPACTION

ANALYSIS SHEET FOR DIRECT & INDIRECT COSTS

Project: Trench Backfilling Materials Life Cycle Cost (LCC)

Work Item: (4.1) Granular Compacted fill

Targeted Output Quantity: 1 m^3

Result: 590.31 ¥/m^3

Material Cost (1:01)					Labor Cost (1:02)						Equipment Cost (1:03)				
Type of Material	Unit	Qty*	Rate	Cost per Unit	Labor by Trade	No.	UF	Labour Output (hr/m^3)	Indexed hourly cost**	Hourly cost	Type of Equipment	No.	Equipment Output (hr/m^3)	Hourly Rental	Hourly Cost
					Site Supervisor	1	0.5	0.08	5813	232.52	Vibrating Tamper with fuel	1	0.08	400	32
					Daily Laborer	1	1	0.015	3250	48.75					
					Compactor Operator	1	1	0.08	3463	277.04					
Total (1:01)				0.00	Total (1:02)					558.31	Total (1:03)				32

A= Materials Unit Cost 0.00 ¥/m^3

B= Manpower Unit Cost 558.31 ¥/m^3

C= Equipment Unit Cost 32 ¥/m^3

Direct Cost of Work Item = A+B+C =		590.31	¥/m^3
Overhead Cost:	0%	0.00	¥/m^3
Profit Cost:	0%	0.00	¥/m^3
Total :		590.31	¥/m^3
VAT	0%	0	¥/m^3
Total unit cost:		590.31	¥/m^3

Notes:

UF: Utilization Factor (UF) = 1/ the # of crew or people under supervision

* Inclusive of transporting, loading and unloading, handling, etc.

** Inclusive of benefits, travel subsides, and cost of overtime related to targeted output.