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Feasibility Study for Converting IBA and Marine Clay to Useful Construction Materials

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Outline

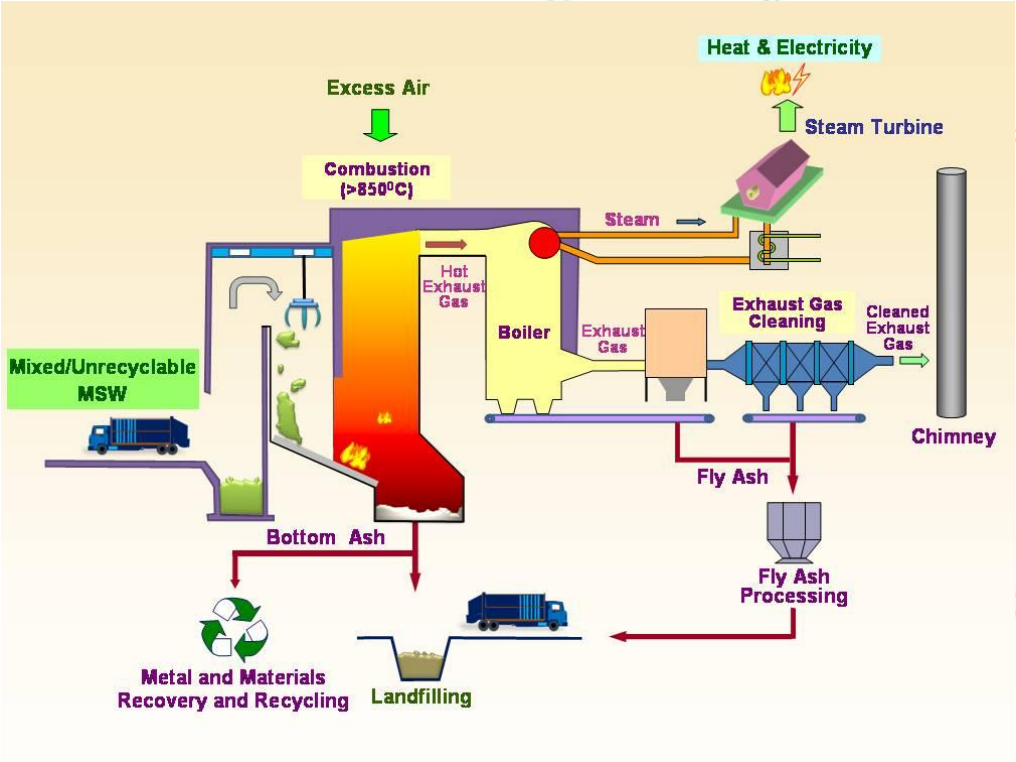
- Classification of IBA
- Introduction on IBA's reuse and application over the world
- Treatment technologies for IBA
- Feasibility study of IBA for land reclamation in Singapore
- Conclusions

Incinerator Bottom Ash - IBA

IBA is a form of **ash** produced in **MSW** (Municipal Solid Waste) incineration facilities.

General Properties of Raw IBA:

- Heterogeneous material
- Quality and composition varies in a wide range
- Still chemically active
- High salt content
- Significant metal contents for recovery (Fe, Al, Cu)
- Heavy metals are not evenly distributed and have different mobility under different conditions and different kinds of pre-treatment
- High residual organics



Typical incineration flow chart

IBA – hazardous/non hazardous waste

- The European Waste Catalogue and Hazardous Waste List (2002) classifies IBA as non-hazardous (19 01 12) or hazardous (19 01 11) dependent on whether it contains **"dangerous substances".**

- Regulatory criteria for classification – Total and Leachable

- As a result of this non-hazardous classification, IBA can be disposed of at a non-hazardous waste landfill or used for an alternative beneficial use.

- **REGULATION (EC) No 1272/2008 - the Classification, Labelling and Packaging of substances and mixtures (CLP Regulation)**

- **Council Decision 2003/33/EC - Acceptance Criteria for Landfill**

Comments: Based on the criteria for classification and test results, Singapore IBA should be classified as non-hazardous waste

Total Threshold Limit for Hazardous Toxic Waste

Element	Danish Ministry of Environment and Energy [mg/kg]	US (California Department of Toxic Substance Control), ppm	Singapore IBA test Results (ppm)
Zn	50,000	5000	3200
Pb	5,000	1000	300
As	1,000	500	40
Cd	1,000	100	< 10
Hg	500	20	14
Cu	250,000	2500	800
Ni	1,000	2000	90
Se	/	100	
Silver	/	500	

Eco toxic evaluation for IBA: 0.1% (1000 ppm according to the CLP regulations)

Comments: Based on these the concentrations for classification, Singapore IBA should be classified as non-hazardous waste.

Leaching Criteria in EU Landfill Directive

Compound	Inert material			Non-hazardous waste			Dangerous waste		
	LS=2	LS=10	LS=0.1	LS=2	LS=10	LS=0.1	LS=2	LS=10	LS=0.1
	Batch test	Batch test	(percolation test)	Batch test	Batch test	(percolation test)	Batch test	Batch test	(percolation test)
	mg/kgds	mg/kgds	mg/l	mg/kgds	mg/kgds	mg/l	mg/kgds	mg/kgds	mg/l
As	0.1	0.5	0.06	0.4	2	0.3	6	25	3
Ba	7	20	4	30	100	20	100	300	60
Cd	0.03	0.04	0.02	0.6	1	0.3	3	5	1.7
Cr	0.2	0.5	0.1	4	10	2.5	25	70	15
Cu	0.9	2	0.6	25	50	30	50	100	60
Hg	0.003	0.01	0.002	0.05	0.2	0.03	0.5	2	0.3
Mo	0.3	0.5	0.2	5	10	3.5	20	30	10
Ni	0.2	0.4	0.12	5	10	3	20	40	12
Pb	0.2	0.5	0.15	5	10	3	25	50	15
Sb	0.02	0.06	0.1	0.2	0.7	0.15	2	5	1
Se	0.06	0.1	0.04	0.3	0.5	0.2	4	7	3
Zn	2	4	1.2	25	50	15	90	200	60
Cl	550	800	460	10000	15000	85000	17000	25000	15000
F	4	10	2.5	60	150	40	200	500	120
SO4	560	1000	1500	10000	20000	7000	25000	50000	17000
Phenolindex	0.5	1	0.3				Phenolindex		
DOC	240	500	160	380	800	250	480	1000	320
TDS	2500	4000		40000	60000		70000	100000	

Leaching Criteria in US/Canada for Hazardous waste

Element	Singapore Landfill limit	USA , Federal hazardous waste TCLP	Canada. BC hazardous waste TCLP	Singapore IBA 10 years data TCLP, 98% confidence
Cd	1	1	0.5	0.48
Ag	5	5	5	0.17
As	5	5	2.5	0.003
Cr	5	5	5	0.38
Cu	100		100	3.56
Pb	5	5	5	3.55
Zn	100		500	77
Ni	5			3.7
Se	1	1	1	0.009
Mn	50			12.3
Ba	100	100	100	21.3
Fe	100			40

Comments: Based on the USA/Canada leaching criteria for Hazardous waste, Singapore IBA should be classified as non-hazardous waste, so it can be landfilled directly without any further treatment.

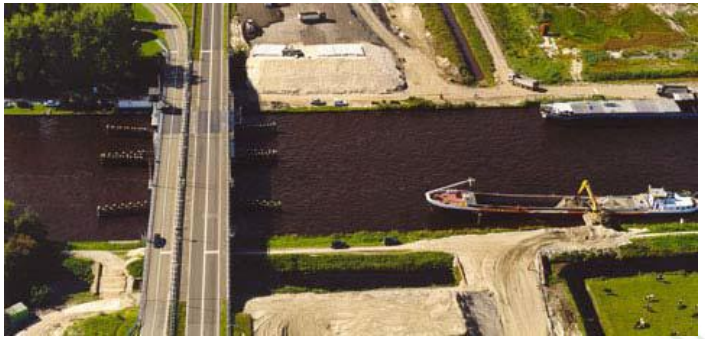
Different leaching tests and Landfill leaching Criteria are used in EU, so some Side-by side tests are conducting in Chemilink Lab using local IBA.

Utilization of IBA

IBA is a secondary raw material. Using IBA to replace natural aggregates is more sustainable and environmentally friendly (avoids the use of natural resources).

Main Applications of IBA in Civil Engineering

- as granular sub-base in road construction
- as a foundation material in noise barriers
- as a capping layer on landfill sites
- as filler material for land reclamation
- as an aggregate in asphalt and concrete (still in the early stages)



Utilization of IBA in European countries and USA

Country	Primary Type of Utilization	Utilisation, %
Belgium	Construction Material	100
Czech Republic	Landfill construction	0
Denmark	Primarily used as granular sub-base for car parking, bicycle paths and paved and un-paved roads, embankments and filler material for land reclamation	98
France	Road construction, civil engineering	30
Germany	Civil works, Sub-paving applications	86
Italy	Civil works, based material for landfill	20
Netherlands	Road construction and embankments	75
Norway	Landfill construction	52
Switzerland	Landfill	0
Spain	Road construction	/
Sweden	Civil works and landfill construction	/
UK	Road construction, concrete aggregate	40
USA	Road construction and landfill	10

Pretreatment of IBA for reuse

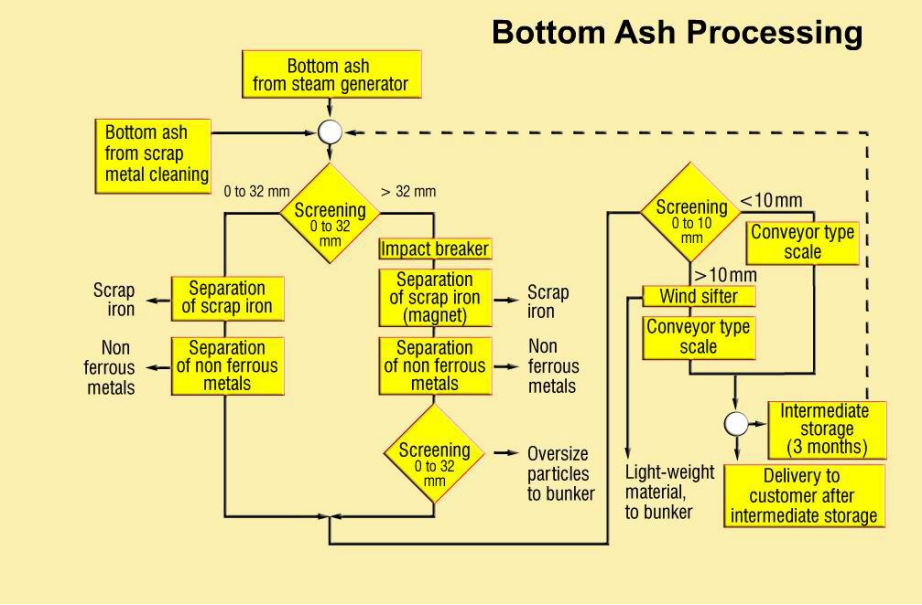
The IBA must be treated and upgraded for the purpose of utilization

General Properties of raw IBA:

- Heterogeneous material
- Quality and composition varies in a wide range
- Still chemically active
- High salt content
- Significant metal contents for recovery
- High heavy metals
- High residual organics

General quality criteria for IBA to be used for construction

- Environmental:
  - Low content of TOC (Total Organic Carbon < 3%);
  - Low content of heavy metals (total and leachable);
  - Low content of trace elements, easily soluble salts and potentially toxic organic matter
- Engineering:
  - Well-graded;
  - Low content of the loss on ignition (< 5%);
  - Low content of fine particles;
  - Good compressive strength



Treatment Options for IBA

Treatment Methods	Treatment process	Remark
Separation	Wash and extraction	soluble salts, fine fraction, chlorides
	Screening and crushing	Density and particle size based separation
	Magnetic separation	Ferrous metals, 6 - 10%
	Eddy-current separation	non-magnetic metals, 1 - 2%
Thermal Treatment (to reduce toxic organic compounds and heavy metal leaching)	Sintering	400 - 600 °C, reducing metal mobility
	Melting/vitrification	1100 - 1500 °C, high reduction of metals and salts
Stabilization and/or Solidification (to reduce heavy metal leaching)	Addition of hydraulic binders	Cement: 5-10 % (physical encapsulation and maintaining high pH)
	Addition of pore-filling additives	Asphalt
	Weathering/aging	> 3 months, reducing pH
	Chemical stabilization	Wes-Phix®-Process, FESI-BOND® dry power (FESI), CO2-stabilisation

Barriers for utilization and Market Trend

Barriers

- Environmental problems and Health impact
- General worry and public concern for IBA (because it is from waste)
- Better access to low cost natural aggregates
- Competition from other recyclables
- Cheap prices for landfill disposal in some countries
- Reduction in property value (if IBA was used)
- Uncertain future spending on environmental measures (future treatment or removal of IBA used)
- Being classified as hazardous waste sometimes due to its high concentration of some heavy metals
- The pollutants will be set free after the constructions is demolished.

Market Trend:

Utilization in larger projects and Registration of the locations where IBA may be reused.

- bottom ash is accumulated at one spot and well controlled
- the environmental impact well investigated,
- the building or project owner are mostly authorities which excludes the question of reduction in property value
- better delivery security for the supplier of bottom ash

Engineering properties of Singapore Marine Clay

Typical characteristics of Marine Clays:

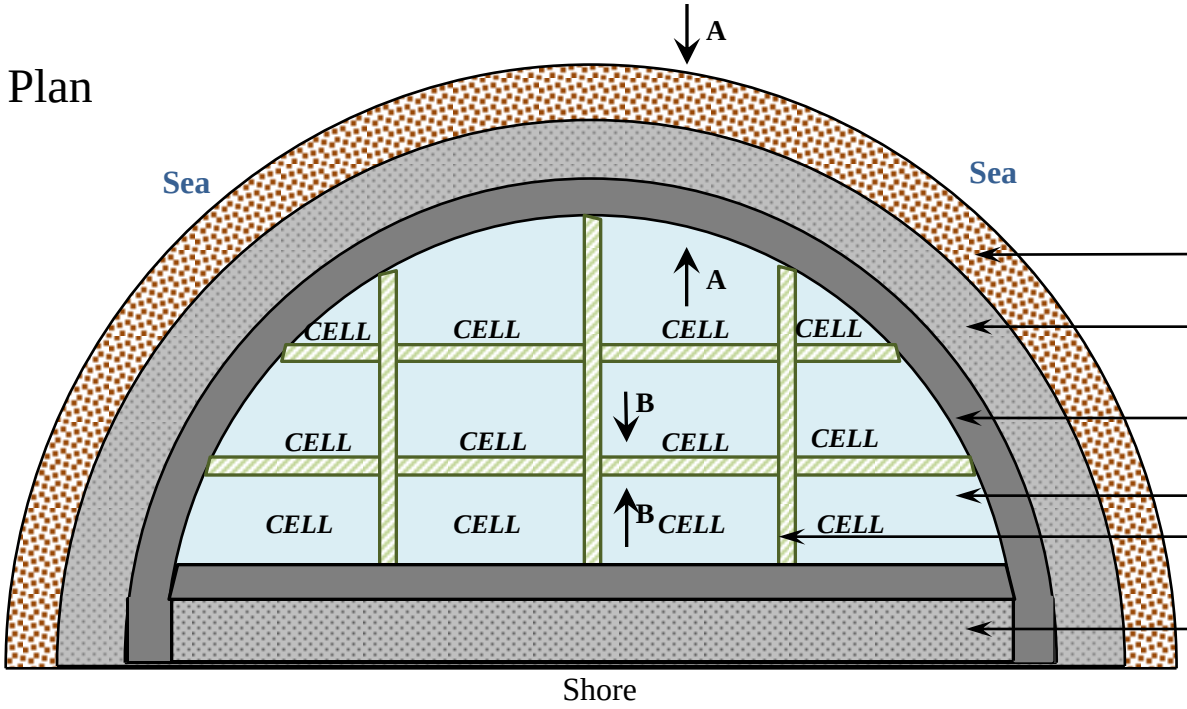
- **Low soil strength**: Undrained Shear Strength: 10-20 kpa at low water content; < 5 kpa when Water content is high than 1 LL;
- **Highly deformable**
- **Low permeability**: Coefficient of permeability: 10^{-8} - 10^{-10} m/s
- Low residual strength
- Creep behaviour

No	Properties	Value
1	Specific Gravity, G_s	2.66
2	Natural Water Content, w	60%
3	Liquid Limit, LL	79%
4	Plastic Limit, PL	34%
5	Plasticity Index, PI	45%
6	Organic Content	3.8%
7	Grain Size Distribution	
	a) Sand	3%
	b) Silt	48%
	c) Clay	49%

Feasibility study of IBA and marine clay for land reclamation in Singapore

- **Features for this application**
- **Features for IBA utilization**
- **Risk control and Ecotoxic evaluation**

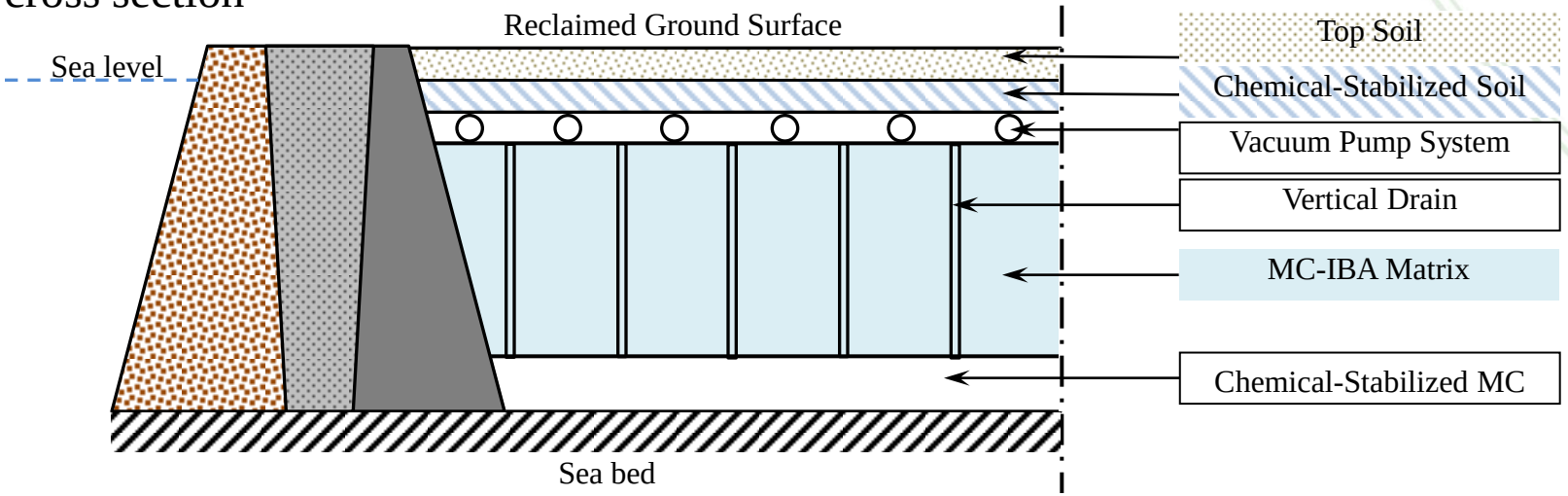
Plan



Not to scale

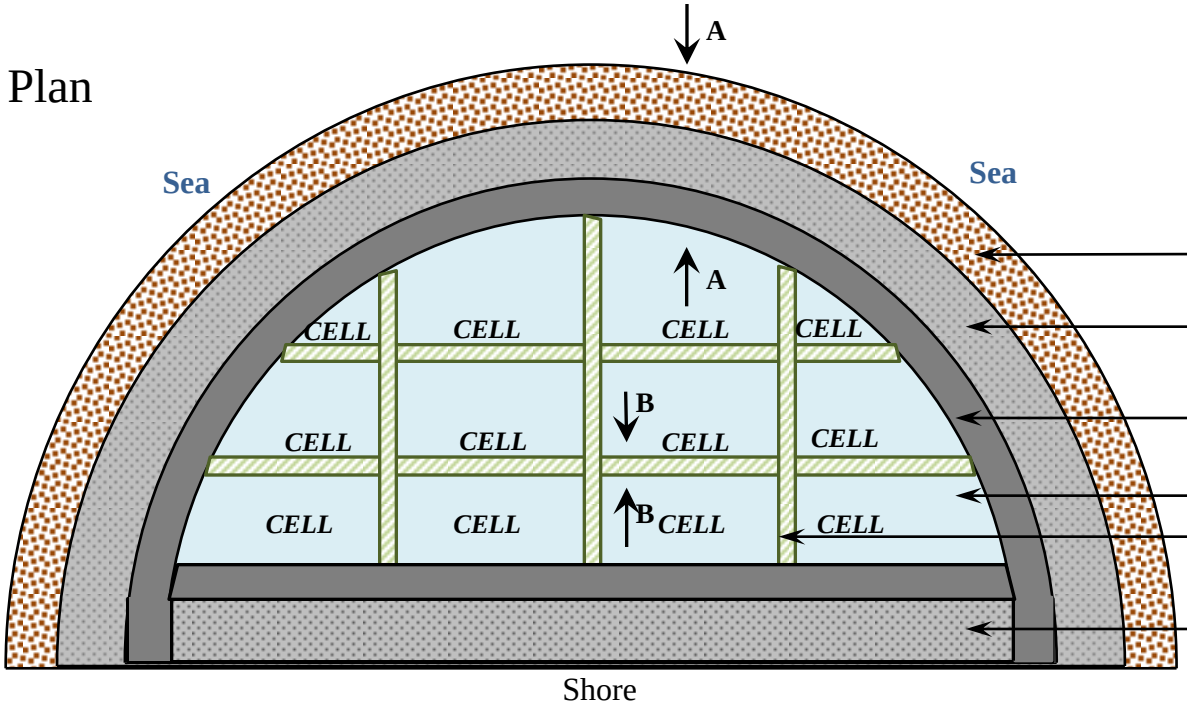
- Outer Dyke (stone & sand)
- Chemical-Stabilized MC
- Inner Dyke
- MC-IBA Matrix
- Separation Dyke
- Chemical-Stabilized MC

A-A cross section



- Top Soil
- Chemical-Stabilized Soil
- Vacuum Pump System
- Vertical Drain
- MC-IBA Matrix
- Chemical-Stabilized MC

Plan



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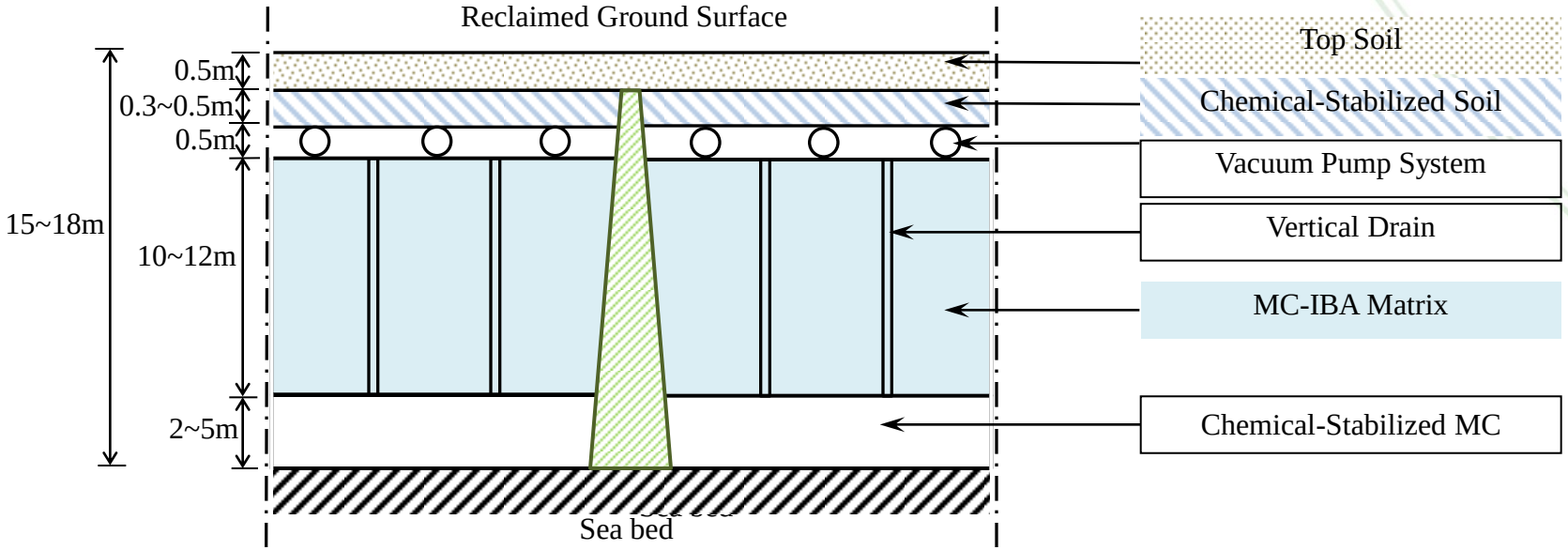
Not to scale

- Outer Dyke (stone & sand)
- Chemical-Stabilized MC
- Inner Dyke
- MC-IBA Matrix
- Separation Dyke
- Chemical-Stabilized MC

B-B cross section



- Top Soil
- Chemical-Stabilized Soil
- Vacuum Pump System
- Vertical Drain
- MC-IBA Matrix
- Chemical-Stabilized MC

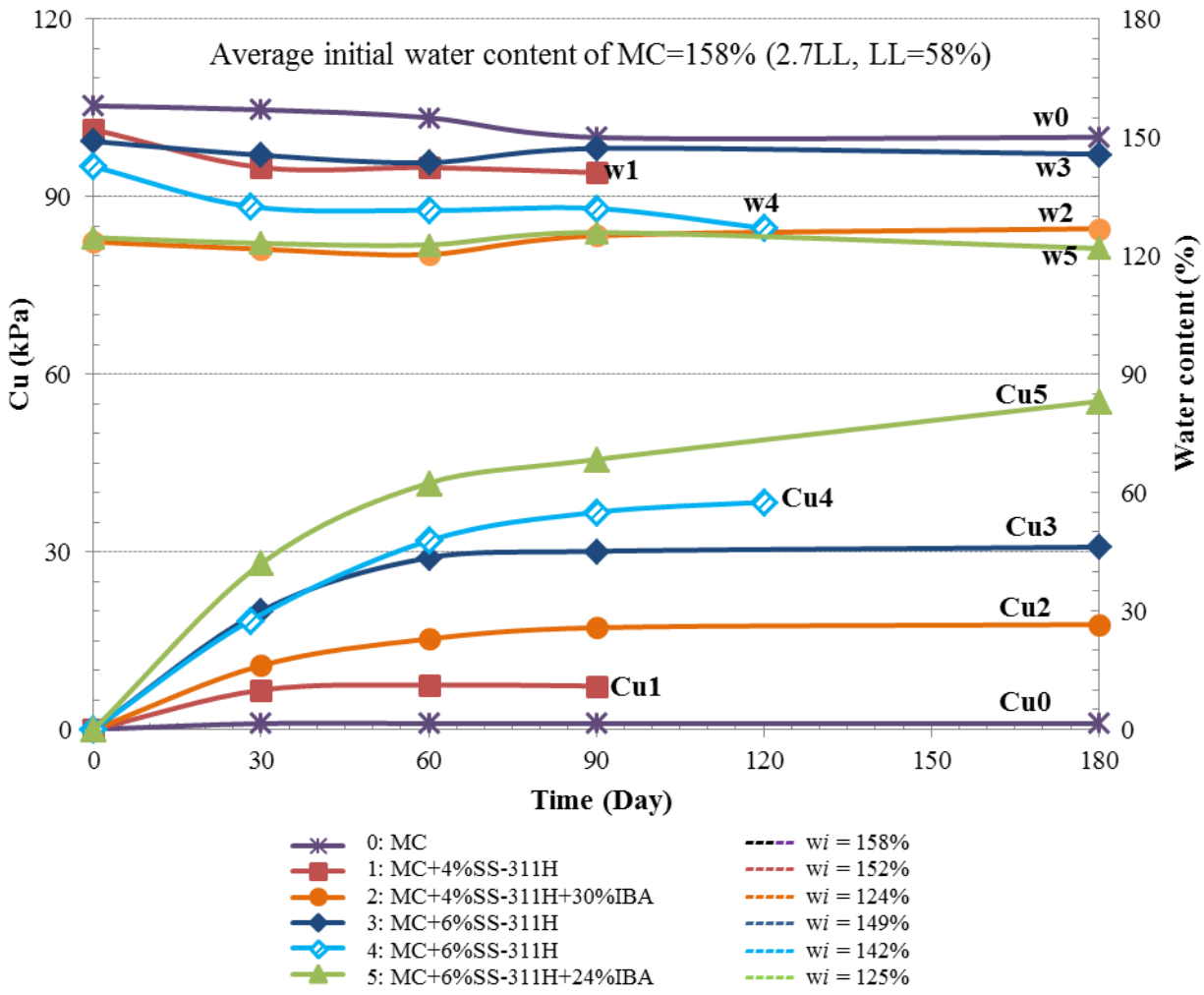
Chemical-Stabilized MC

1. The shear strength Cu0 of the pure MC has no improvement even at 180 days, without any treatment.

2. The Cu3 & Cu4 of the pure MC with lower initial water content (averagely 2.7LL) can be improved by Chemical Stabilization Method from 0 to about 30~40kPa at 120 days, which is equivalent to the allowable bearing capacity of 6-10t/m^{2,} (conventionally 3t/m^2).

3. The Cu5 of the MC-IBA matrix has constantly increased even at 180days when Cu5 achieving about 60kPa which is equivalent to about 15t/m2 of allowable bearing capacity.

4. Cu value is sensitive to both the chemical dosage and the initial wi.



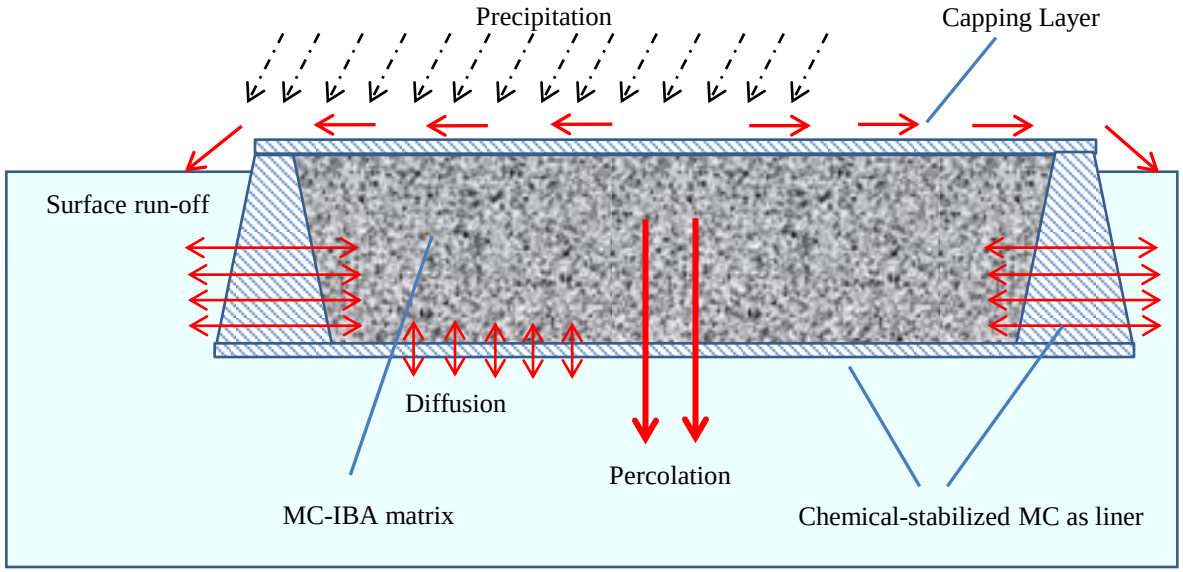
Feasibility study of IBA and marine clay for land reclamation in Singapore

- **Features for this application (MC-IBA Matrix):**
  - Physically encapsulated by marine clay – the leaching of heavy metals from IBA would be significantly reduced by the encapsulation of low permeability marine clay
  - Chemical-stabilized by specially designed chemical additives – to improve the engineering properties and reduce the leachable heavy metals by the specially designed chemical additives
  - Mechanical strengthened by vacuum preloading or other physical means – to further improve the overall performances
  - The second robust barriers – Chemical-stabilized MC dyke, liner and capping layer
- **Features for IBA utilization**
  - Fit market trends
    - Large project / well controlled / reduction in property value
  - Eliminate the barriers encountered in existing applications
    - Cost effective solution / Easy for future treatment
  - Increase land capacity
  - Improve the sustainability of solid waste management system
  - Reduce the dependence on imported sand

HM Release Scenarios for MC-IBA Matrix

1. Before or during construction stage – percolation control scenario
    1. Granular IBA placed on soil (during storage)
    2. IBA + MC + chemical additives : Surface water
    3. IBA + MC + chemical additives : outgoing pore water during vacuum preloading

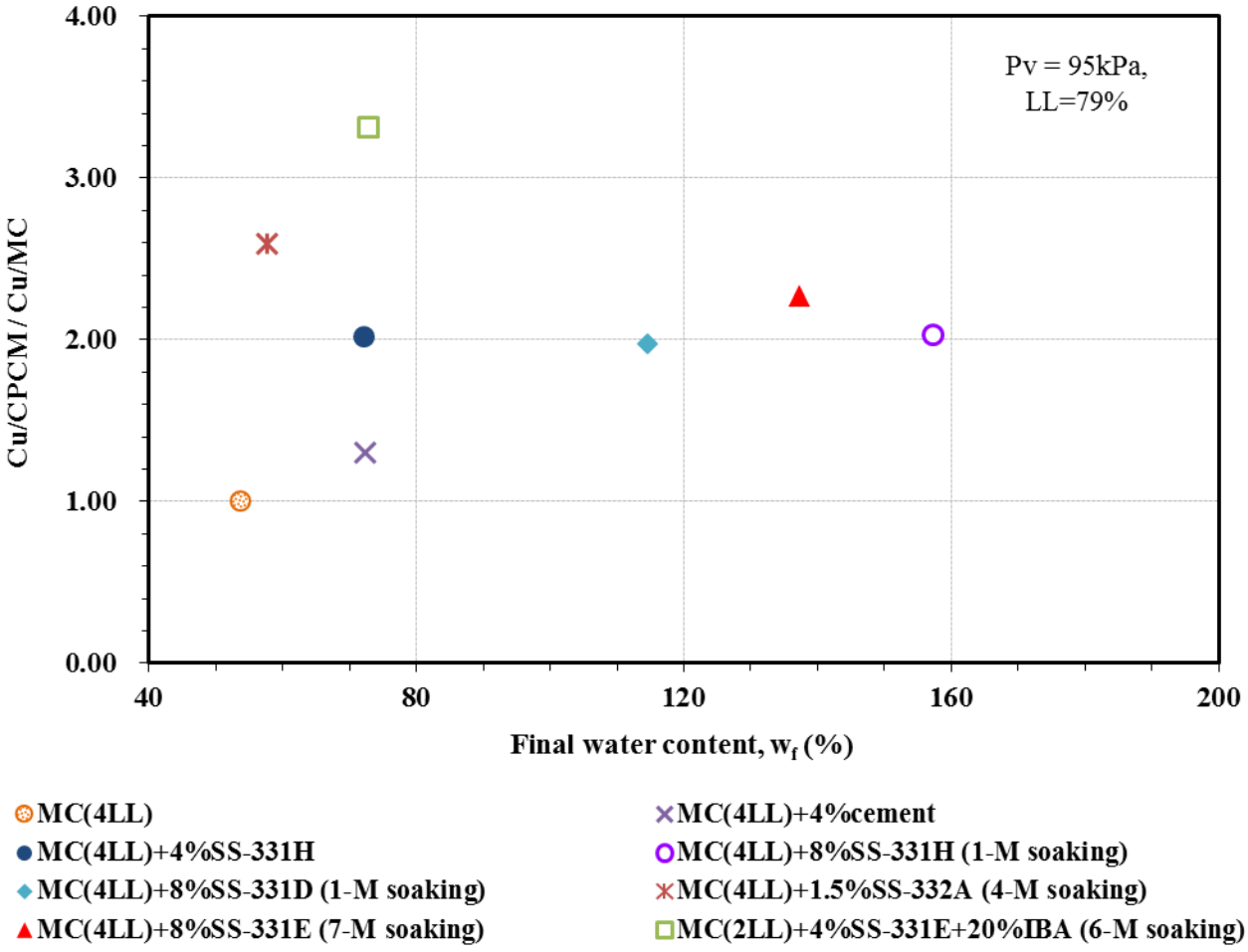
2. During service – diffusion control scenario
    1. MC-IBA matrix (monolith) contact with surrounding water/soil
    2. Runoff from surface (Monolithic diffusion test)
    3. MC-IBA matrix with high permeability (percolation test)



Strength improvement through CPCM

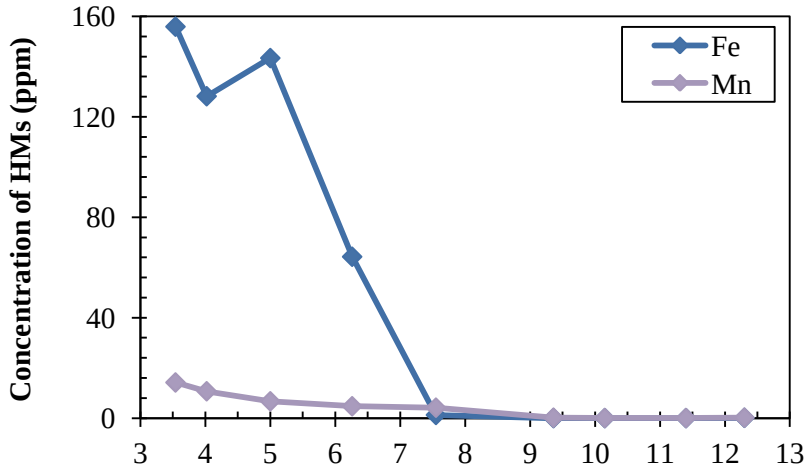
The strength of marine clays (MC) and MC-IBA matrix can be improved 2-3 times of pure marine clay by Chemical-Physical Combined Method (CPCM).

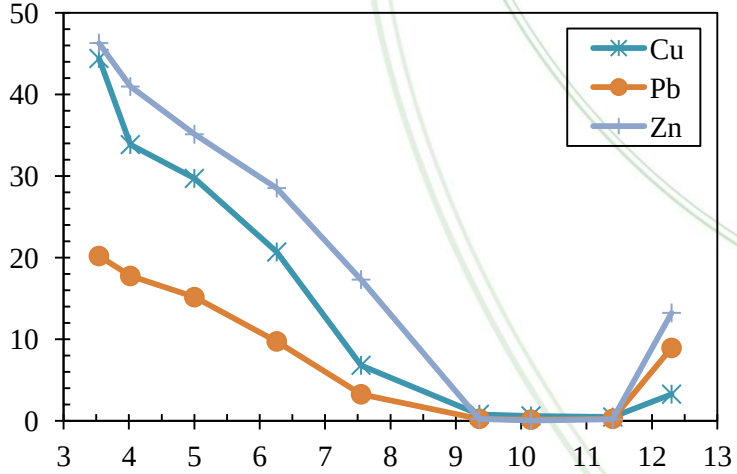
The achieved allowable bearing capacity could be up to 15t/m^2 (conventionally 3t/m^2).

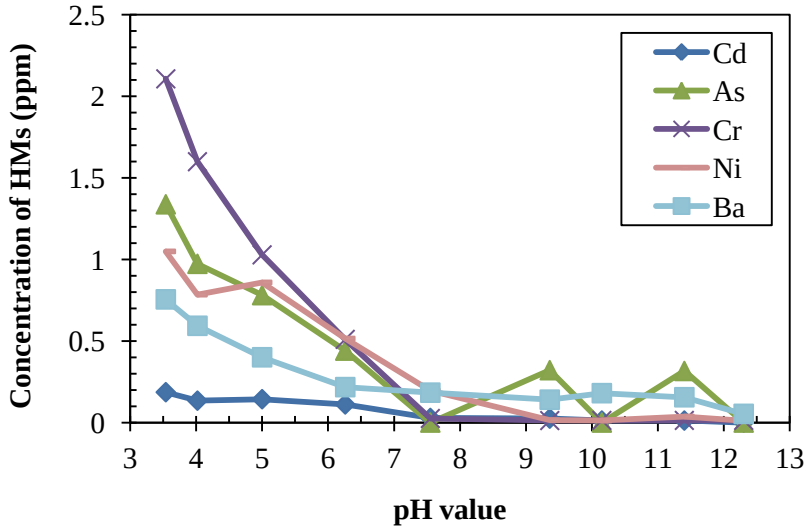


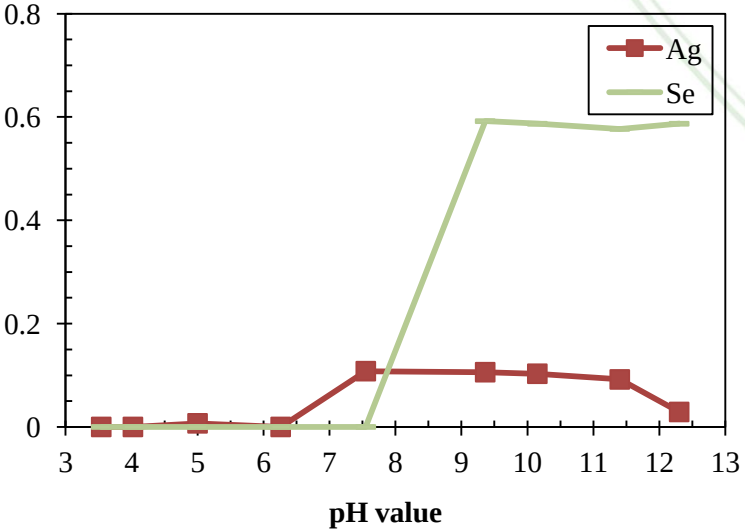
Leaching as a function of pH

MC-IBA matrix can maintain a constant pH (8.0-8.5) and reduce the risk of HM leaching due to the changes of conditions.









Conclusions

- IBA in Singapore should be classified as Non-hazardous waste material
- Using MC to encapsulate IBA and then improved by CPCM for land reclamation should be an innovative and sustainable solution for solid waste management in Singapore. Further studies are required to explore the details of this utilization.

- The quality criteria and pre-treatment cost of IBA for land reclamation should be competitive compared to other utilizations in Civil Engineering.

- The risk caused by the movable heavy metals should be well controlled and future treatment (in case) should be easily applied.
  - Robust barriers (dykes) and low permeability of MC-IBA matrix – target to no leaching
  - Maintain constant pH
  - Easily to apply further protection measures

- A specialized laboratory is necessary for this utilization of IBA involving Quality control and improvement as well as long-term risk assessment.

Acknowledgement

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