Testing of Cores taken from Cement Stabilised Soil

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Part A - Introduction

Deep Mixing is a technique of mixing chemical binder (cement/lime) with soil to improve the engineering properties of the soil.

- Consistency
- Strength
- Deformation

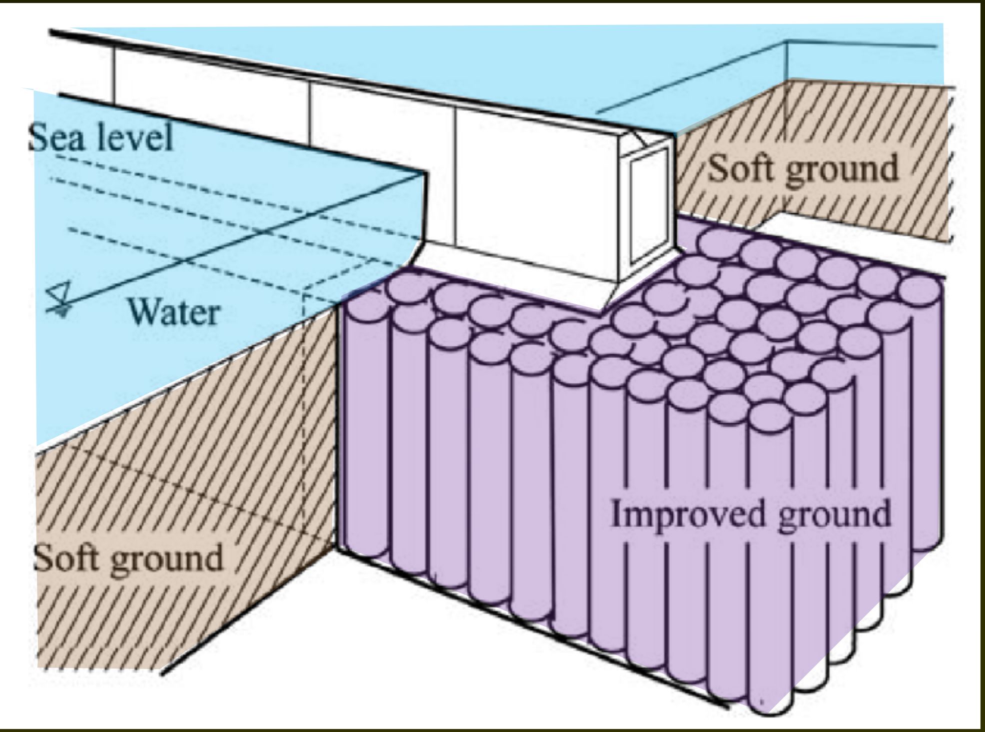
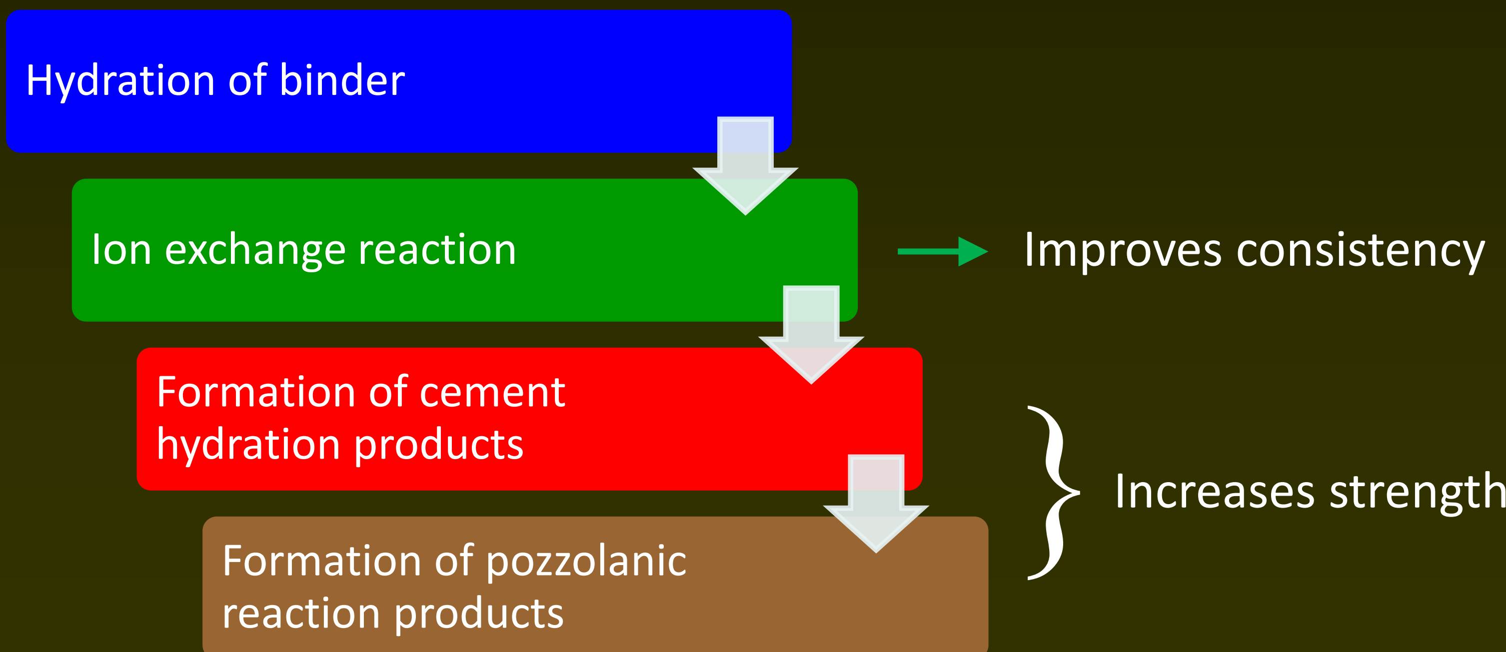


Figure ref: Kitazume and Terashi “The Deep Mixing Method”

Mechanism of deep cement mixing:

- Ion exchange at the surface of clay minerals
- bonding of soil particles
- filling of void spaces by chemical reaction products.



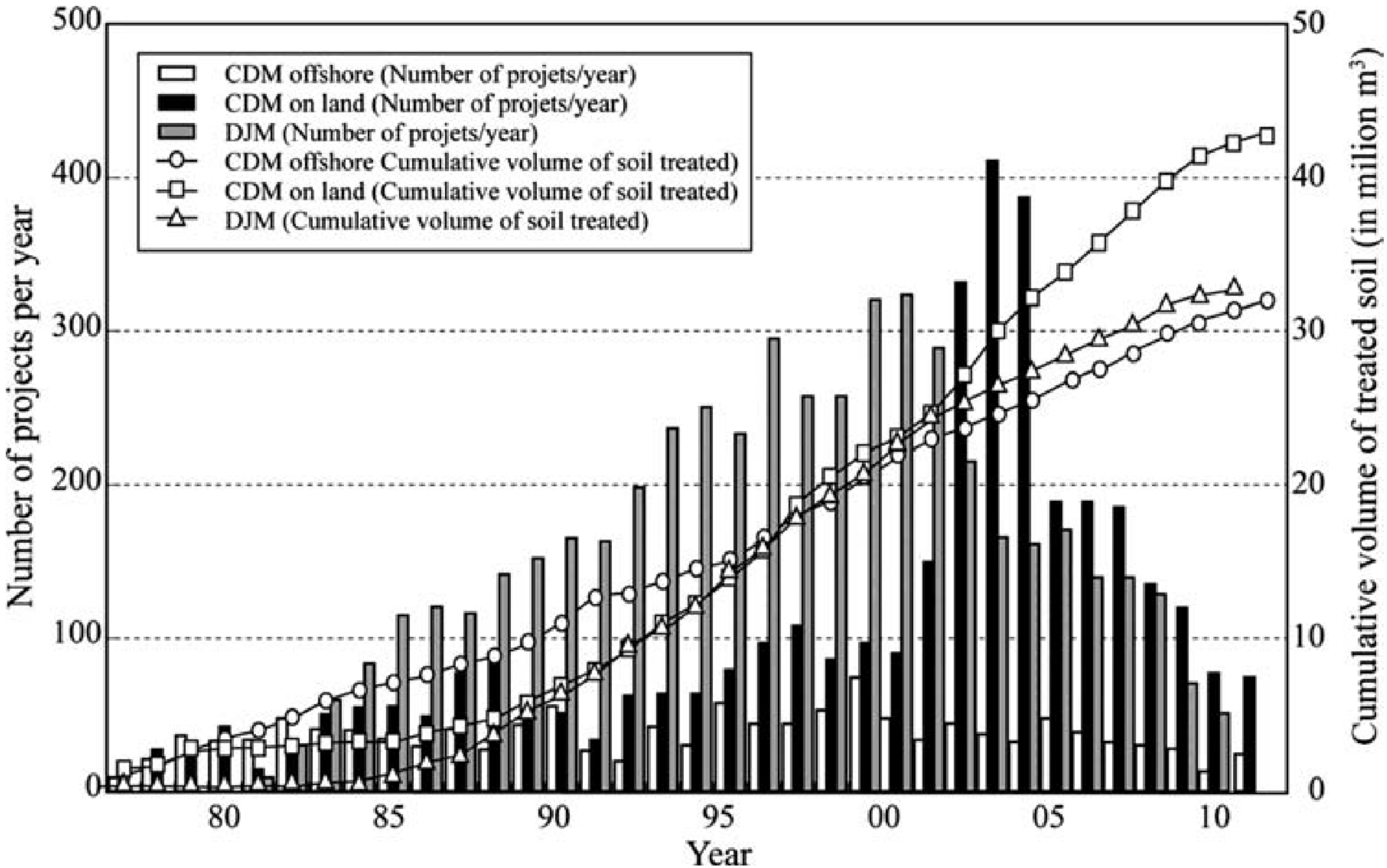
$$2(3CaO \cdot SiO_2) + 6H_2O = 3CaO \cdot 2SiO_2 \cdot 3H_2O + 3Ca(OH)_2$$

The deep mixing method utilizes mixing blades or augers to manufacture a stabilized soil column of predetermined size and shape in situ

Photo credit:
http://www.treviicos.com/Technologies/DeepMixingPiles

Barges for Deep Cement Mixing used in 3RS

Ref: 3RS



Statistics of deep mixing method works in Japan.

Ref: Kitazume and Terashi "The Deep Mixing Method"

What is the quantity of cement stabilized soils used/to be used in HK?

Tung Chung East reclamation
Mainly beneath the 4.95km long seawall. Vol. ≈ 3 million m^3

Boundary Crossing Facilities BCF
No published data, mainly for additional strengthening works. My rough estimate : Vol. ≈< 1 million m^3

Integrated Waste Management Facilities on an artificial island near Shek Kwu Chau
No published data, my rough estimate : Vol. ≈> 1 million m^3

Third Runway System 3RS
No published data, my rough estimate based on about 230,000 soil cement clusters and average length >20m: Vol. ≈> 20 million m^3

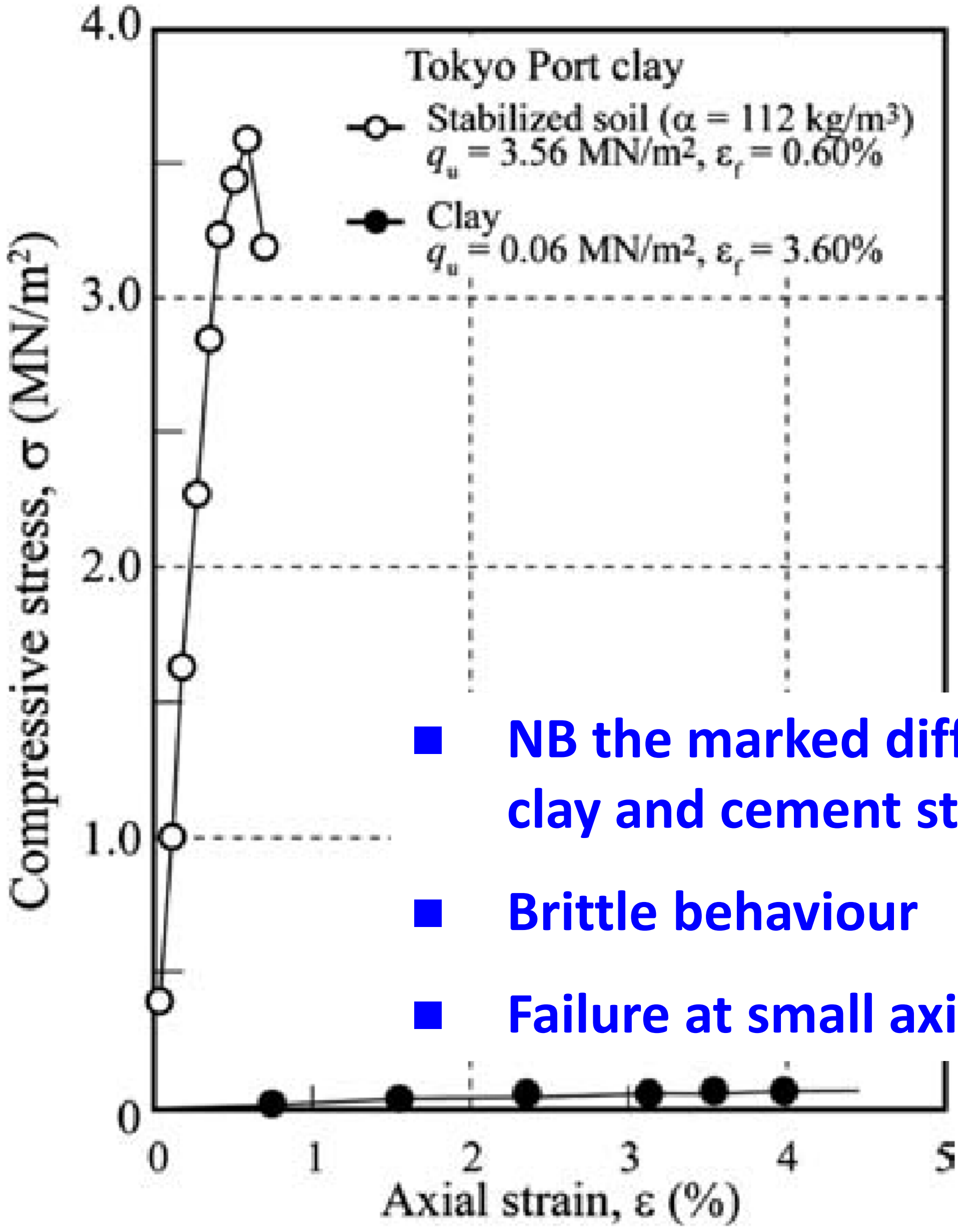
What is the quantity of cement stabilized soil cores tested / planned for testing in HK laboratories?

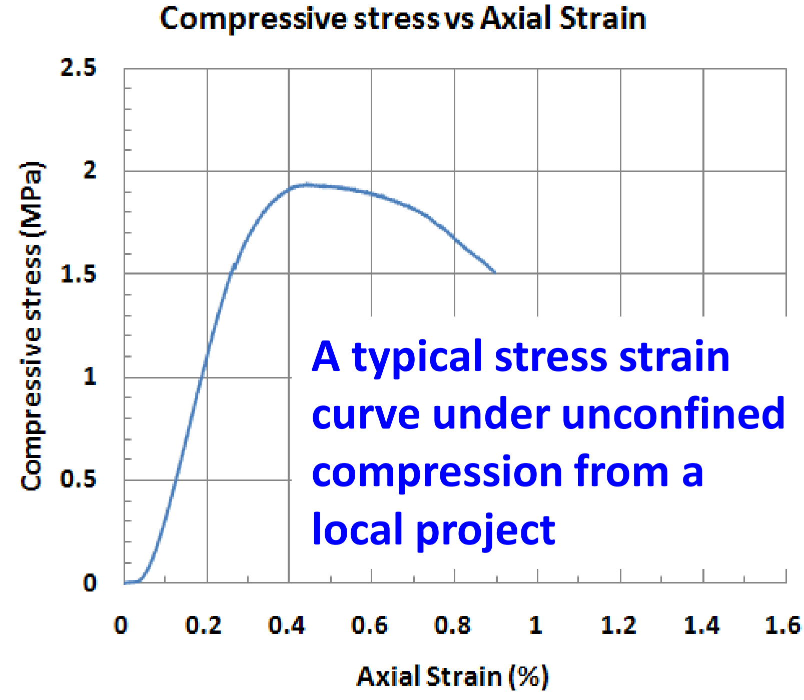
My rough estimate:
> 250,000 numbers within a few years !!

Table 6. Summary of evaluations, information, and testing considerations for highway applications of DMM.

Geotechnical Issues	Engineering Evaluations	Information for Assessment and Analysis	Field Testing	Laboratory Testing
• Deep mixing (for support of embankments, piers, abutments, retaining walls, and culverts)	• Settlement • Stability • Load transfer platform • Lateral movement of adjacent structures if they might be affected by the proposed construction • Compatibility of soil with stabilizers • Suitability of soil for deep mixing	• Subsurface profile • Soil characterization • Tolerable settlement of facility • Factor of safety and/or reliability against slope instability • Compressibility parameters • Shear strength parameters • Unit weights • Chemical and mineralogical composition of soil • Presence of buried obstructions/ utilities • Identification of on/offsite disposal location (for wet mixing)	• Standard penetration test (SPT) • Cone penetration test (CPT) • Field vane shear strength • Geophysical testing • Observation wells/ piezometers • Near-surface ground temperature	• In situ water content • Organic content • pH • Loss on ignition • Conductivity • Chloride and sulfide content • Atterberg (liquid and plastic) limits • Grain size distribution • Consolidation of existing site soils • Shear strength of existing site soils • Unconfined compressive strength of soil-binder mixtures

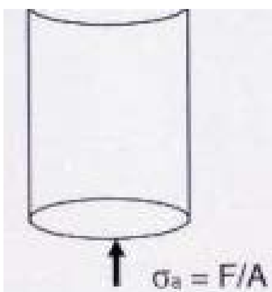
Ref: FHWA Design Manual: Deep Mixing for Embankment and Foundation Support





- **NB the marked difference between parent clay and cement stabilized clay**
- **Brittle behaviour**
- **Failure at small axial strain**

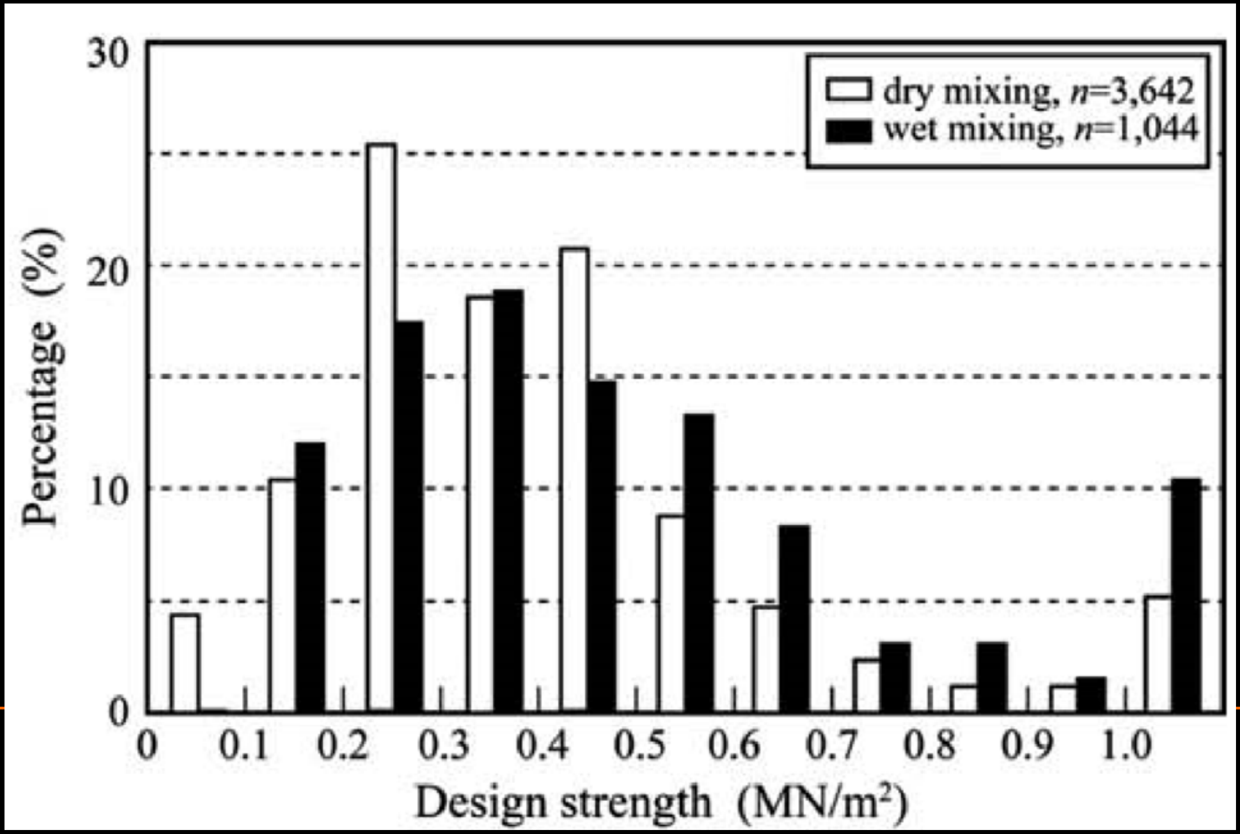
Stress–strain of in-situ cement stabilized soil (Sugiyama *et al.*, 1980).



Design UCS values

- In the United States, the 28 day to 56 day UCS for deep cement mixing projects ranged from about 0.7 to 2.1 MPa.

- Statistics of deep mixing improved grounds in Japan compiled by the Public Works Research Center in 2004 showed that most of the project specified 28 day UCS is < 1 MPa. (see figure)



Design UCS values

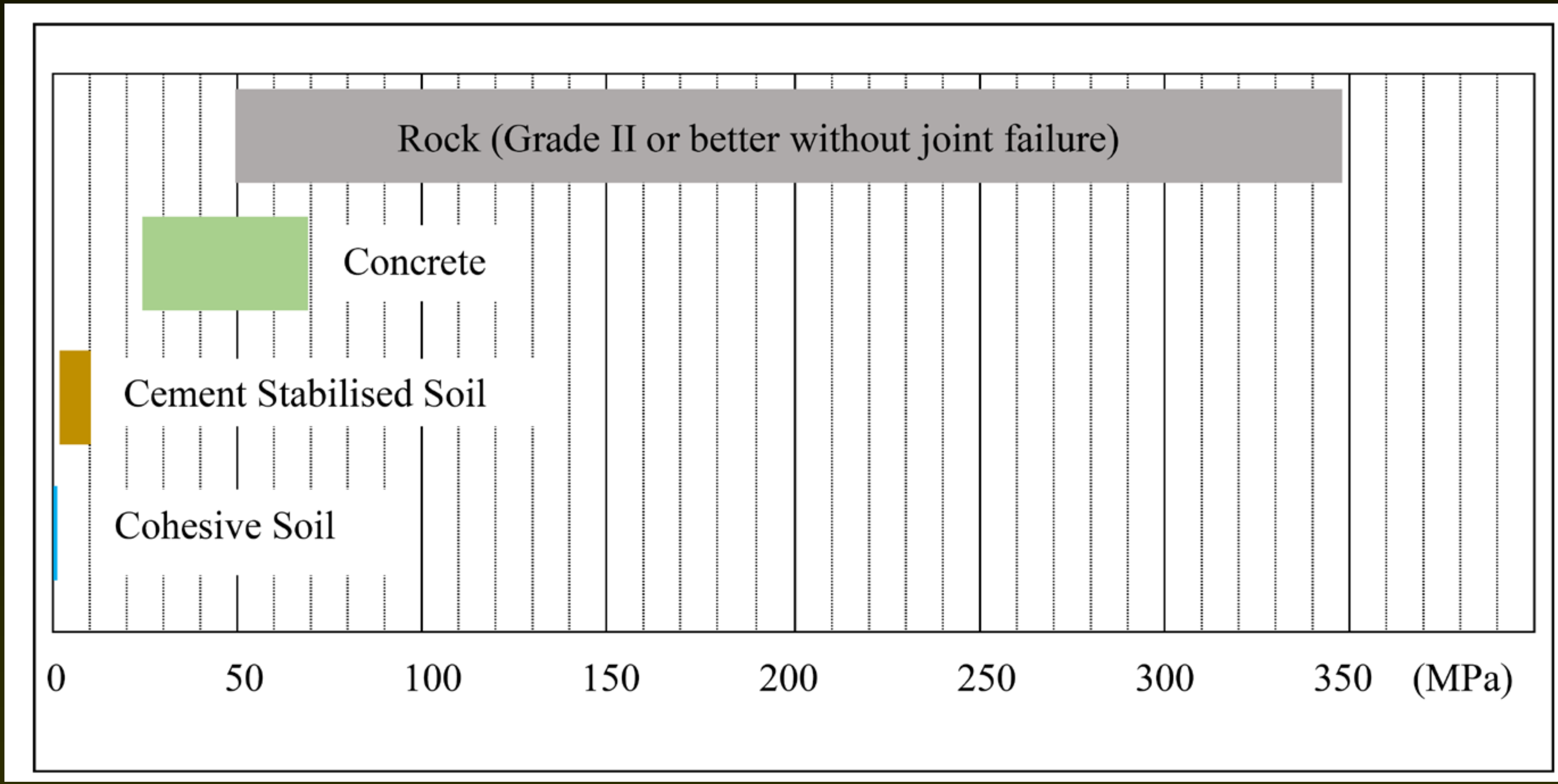
- How about the design UCS values for our local major projects using deep cement mixing?

  - BCF under the HKZM bridge and related project (??)

  - Third Runway project (≈ 0.8 – 1.4 MPa)

  - Tung Chung East reclamation project (≈ 1 MPa)

  - Artificial Island near Shek Kwu Chau (??)



Approximate values of UCS of different construction materials

Variability of Field Strength

- According to the Japanese accumulated data, the Coefficient of Variation (COV) is shown below: (Coastal Development Institute of Technology, 2008).

On land dry mixing	On land wet mixing	Marine wet mixing
50 -68 %	15 – 50 %	20 – 48 %

- According to 7,873 UCS results obtained from different projects carried out in the United States, the COV ranges from 34% to 79% with an average value of 56%

Differences between lab strength and field strength

Adv of lab specimen : better quality control (e.g. more thorough mixing)

Adv of field product : effects of confinement, potentially higher curing temp.

Coastal Dev. Institute of Technology (CDIT) :

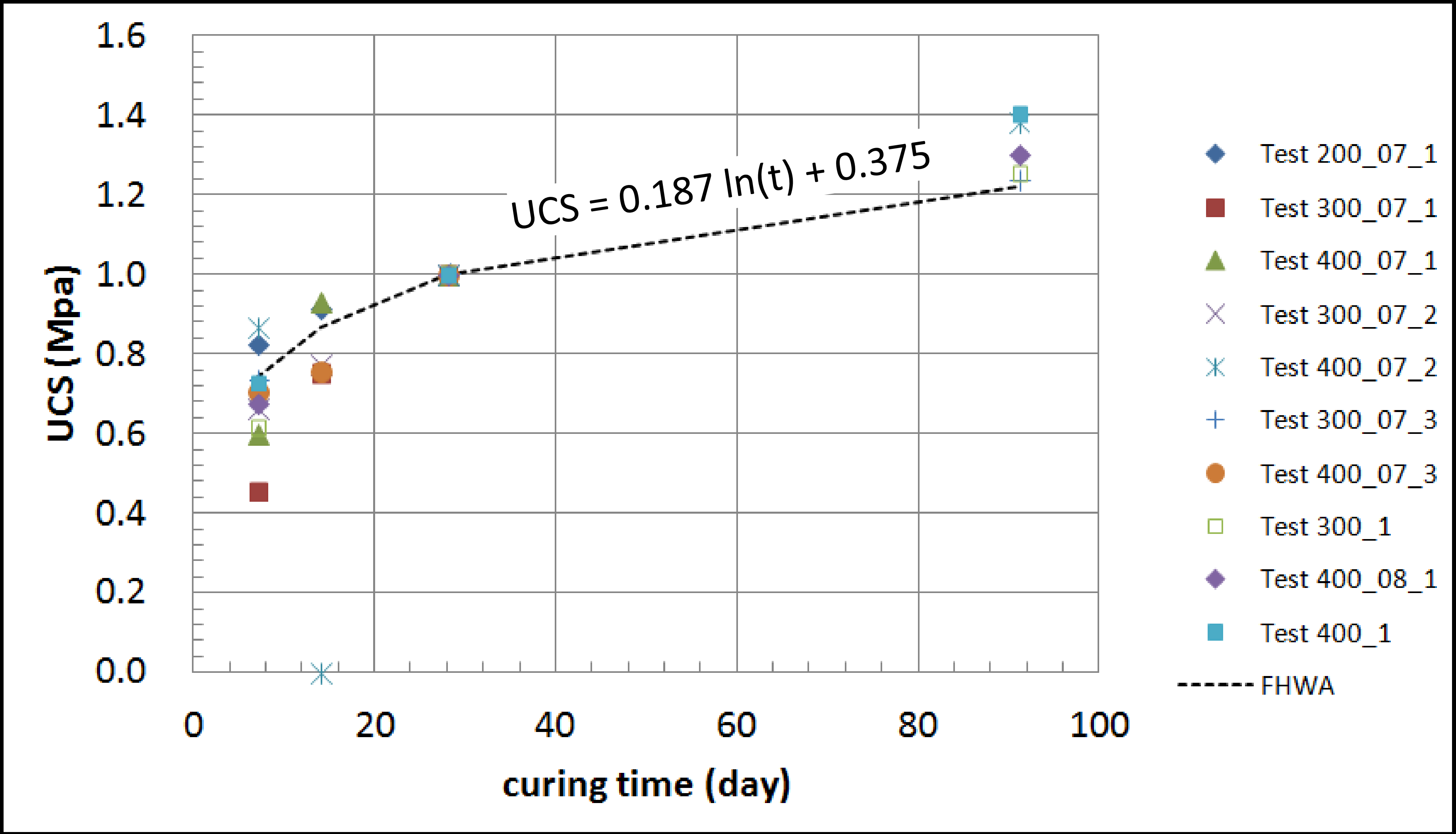
Field strength = 20 – 100 % of lab mixed specimens

EuroSoilStab :

Field strength = 20 - 50 % of lab mixed specimens

FHWA DM :

Field strength = at least 50 % of lab mixed specimens



UCS normalized with 28-day strength

Data from tests conducted in the Public Works Central Laboratory for a local project

Part B - TESTING

Any relevant National or International Testing Standards available?

References

Major References

1. BS 1377-7:1990 “Methods of Test for Soils for Civil Engineering Purposes – Part 7: Shear Strength Tests (Total Stress)”

2. BS 1924-2:1990 “Stabilized Materials for Civil Engineering Purposes – Part 2: Methods of Test for Cement-Stabilized and Lime-Stabilized Materials”

3. ASTM D2166/D2166M-16 “Standard Test Method for Unconfined Compressive Strength of Cohesive Soil”

4. CS1:2010 “Construction Standard CS 1:2010 Testing Concrete”

Other References

1. ASTM D2938-95 "Standard Test Method for Unconfined Compressive Strength of Intact Rock Core Specimen"
2. ASTM D7012-14 "Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures"
3. ASTM D4543-85 "Standard Practices for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances"
4. ASTM C42/C42M-03 "Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete"
5. Federal Highway Administration Design Manual: Deep Mixing for Embankment and Foundation Support. Publication no. FHWA-HRT-13-046. October 2013
6. Kitazume, M. & Terashi, M.: The Deep Mixing Method. 2013.

- There is no such standard specifically for cored soil cement specimens
- Most of the countries (e.g. Korean, Japan, Nodic countries, USA etc) adopted a testing standard designed for cohesive soils or rocks.
- In view of the need for a local testing standard on this material, a Task Force was set up under the Geotechnical Division of Hong Kong Institution of Engineers in mid 2017.
- An interim guideline was issued in late 2017 titled *"Interim Guidelines on Testing of Unconfined Compressive Strength (UCS) of Cement Stabilised Soil Cores in Hong Kong"*

Contents

- Background of developing guidelines on UCS test of cement soil
- Salient features of the Interim Guidelines
  - ✓ Scope
  - ✓ Apparatus
  - ✓ Curing
  - ✓ Sample preparation (L/D ratio, Cutting, Capping, dimensional checking)
  - ✓ Loading rate
  - ✓ Calculation, plotting, photo taking and reporting of results

Scope

- Test method is applicable to cement soil formed in field or in laboratories.
- Diameter of cores is preferably between 63 mm and 100 mm, with UCS values below 10 MPa.

1. L/D ratio
2. Cutting
3. Dimensional checking (parallelism, perpendicularity and flatness)
4. Capping

Loading rate

- Loading rates specified under various standards :

Testing Standards	Materials	Loading Rate	Remarks
BS 1377-7:1990	Cohesive soil	≦ 2 %/min	Strain rate control
ASTM D2166M-16	Cohesive soil	0.5 – 2 %/min [1]	Strain rate control
BS 1924-2:1990	Cement stabilised soil	1 mm/min [2]	Strain rate control
BS EN 12390-3:2009	Concrete core	0.6 ± 0.2 MPa/s	Stress rate control
ASTM C39/C39M-17a	Concrete core	0.25 ± 0.05 MPa/s	Stress rate control
CS1:2010	Concrete core	0.2 – 1.0 MPa/s [3]	Stress rate control
ASTM D2938-95	Rock core	Rate that can produce failure in a test time between 2 and 15 min [4]	Stress rate or strain rate control
ASTM D7012-14			

Note:
(1) Time to failure should not exceed about 15 minutes.
(2) For specimen height of 100 to 200 mm, strain rate is around 0.5-1%/min.
(3) For concrete cube and concrete cylinders, CS1:2010 specifies a stress rate of 0.6 ± 0.2 MPa/s in compressive strength test.
(4) Strain rate control is usually used in Hong Kong and a typical value is around 0.18 mm/min.

- A total of 6 specimens were prepared and subject to 3 different loading rates after specimens were cured for 7 days

- The results are shown below:

Loading Rate	1 mm/min				0.1 mm/min	10 mm/min
UCS (MPa)	1.05	0.99	0.83	1.06	**0.98**	**1.12**
	Average = **0.98**					

Note: Specimen height = 110 mm, hence 1 mm/min = 0.9%/min

- **Effect of loading rates** on measured UCS values was **not significant**.

- Rate of axial strain is recommended to be within 0.5 – 2% /min.

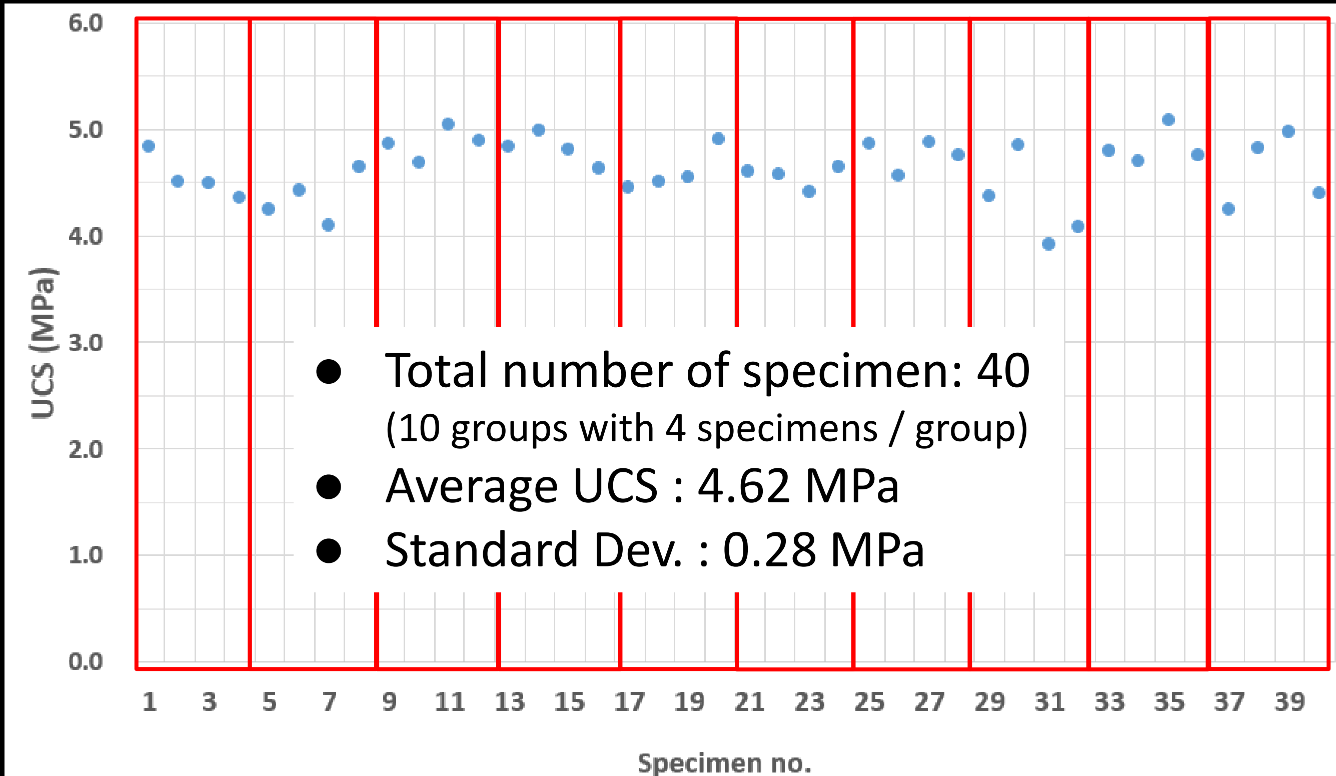
Proficiency Testing

According to clause 3.6 of HOKLAS SC-33:

An applicant laboratory shall have taken part in appropriate proficiency testing activity(ies), representative of each test area of the laboratory's scope of accreditation to demonstrate its competence in each test area, and obtain satisfactory result before initial accreditation or accreditation extended to a new test area will be granted.

Proficiency Testing

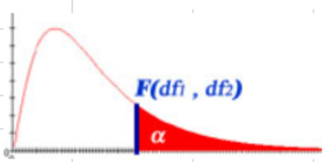
- To facilitate the interested laboratories to obtain the HOKLAS accreditation in accordance with the interim guidelines, a PT has been arranged with 11 participating laboratories.
- A challenging and time consuming process to prepare suitable and sufficient soil cement specimens for the PT
- It took us almost a month to prepare the specimens and one month for curing.
- The specimens passed the homogeneity check



- Total number of specimen: 40
  (10 groups with 4 specimens / group)
- Average UCS : 4.62 MPa
- Standard Dev. : 0.28 MPa

Levene Statistic 2.133	$W = \frac{(N-k)}{(k-1)} \frac{\sum_{i=1}^{k} N_i (\bar{Z}_{i.} - \bar{Z}_{..})^2}{\sum_{i=1}^{k} \sum_{j=1}^{N_i} (Z_{ij} - \bar{Z}_{i.})^2}$

$F_{0.05,9,30} = 2.211$



$F_{\alpha,\, k-1,\, N-k}$

The Levene test rejects the hypothesis that the variances are equal if W > F

Now W = 2.133 is smaller than F = 2.211

We accept the null hypothesis that the variances amongst the 10 groups are the same

Consistency Check for PT

The homogeneity check is carried out in accordance with ISO 13528:2005(E)

Future Works

- Endeavour to collect more test data and undertake a review for enhancing the guidelines
- Following issues are suggested to be further reviewed and studied:
  - ✓ Effect of loading rate
  - ✓ Effect of L/D and capping
  - ✓ Effect of curing (duration and temperature)
  - ✓ Stress strain behaviour
  - ✓ Measurement and interpretation of elastic modulus

Thank You…

Question and Answer…