Process design & Geotechnical design of deep mixing

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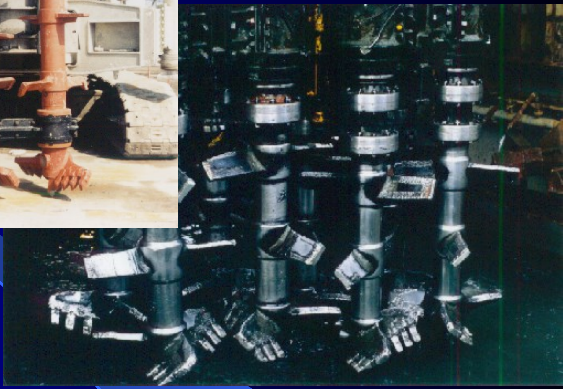
Key issues in the current presentation

- For the successful application of deep mixing , both process design and geotechnical design are equally important, which inevitably results in the iterative approach. The relevant issues were reviewed in the written version of the keynote.
- As the property of deep mixed soil differs very much from that of native soils, improved ground should be regarded as a composite system. No unique mode of deformation/failure applies to a specific application. The modes depends upon geometry, relative stiffness of constituting geo-materials, loading conditions, position of improved soil relative to the superstructure, and perhaps time. Geotechnical design should base on the full understanding of various modes of deformation /failure.

Japan



A variety of machines and mixing tools and much more

Europe

US

Classification of deep mixing process

- **Dry method**
  - Mechanical
    - End of shaft
      - DJM (Japan)
      - Nordic Dry (Sweden, Finland)
      - TREVIMIX (Italy)
- **Wet method**
  - Mechanical mixing
    - End of shaft
      - CDM (Japan)
      - SCC (Japan)
      - SSM (USA)
      - Keller system (USA, Europe)
      - MECTOOL (USA)
    - All along shaft
      - SMW (Japan、US)
      - DSM (USA)
      - MULTIMIX (Italy, USA)
      - COLMIX (France)
      - Bauer Triple Auger (Germany)
      - FMI (Germany)
  - Hybrid Mechanical + Jet
    - End of shaft
      - SWING (Japan)
      - JACSMAN (Japan)
      - GEOJET (USA)
      - HYDRAMECH (USA)
      - TURBOJET (Italy)
  - Jet grout
    - End of shaft
      - Super jet
      - Cross Jet
      - Other Jet grouting techniques

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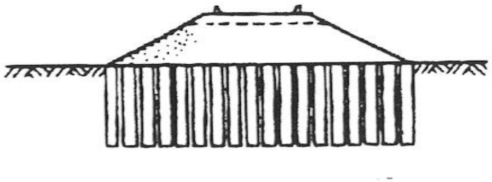
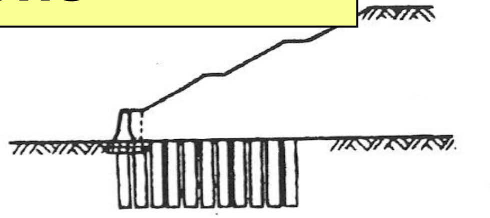
After Bruce

- The quality of improved soil depends upon the equipment, construction control values and characteristics of native soil, and hence, the quality of improved soil differs from one country to another and one site to another.
- It is important to develop appropriate construction process and QC/QA procedure appropriate for local conditions. Field trial installation to confirm the applicability of a new process is always recommended.
- To achieve the above mentioned, the researchers and the designers should not stay in their air-conditioned office but should step out to the actual construction sites to see the real life problem.

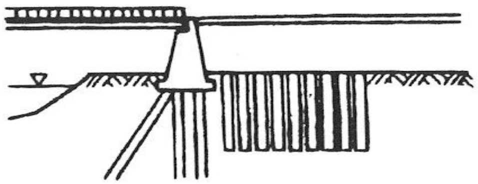
A variety of applications



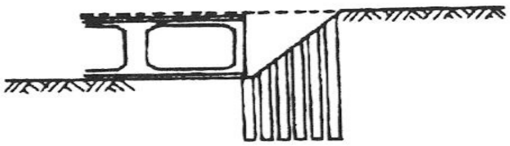
Road Embankment
stability / settlement



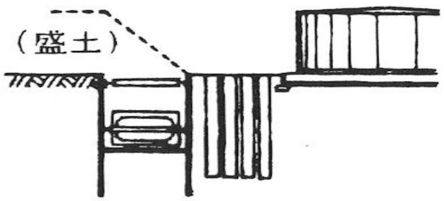
High embankment
stability



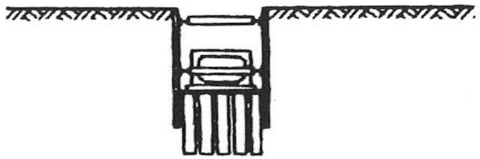
Bridge Abutment
uneven settlement



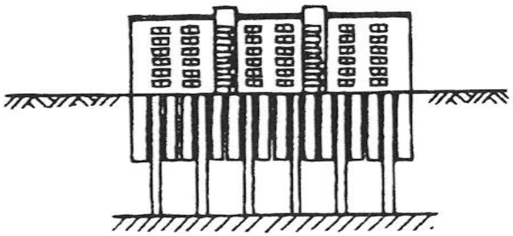
Stability of Cut Slope



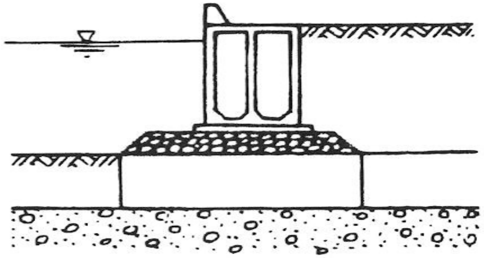
Reducing the influence
from nearby construction



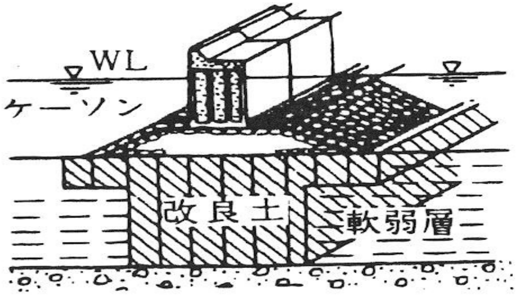
Braced Excavation
earth pressure/ heave



Pile foundation
lateral resistance



Sea wall
bearing capacity

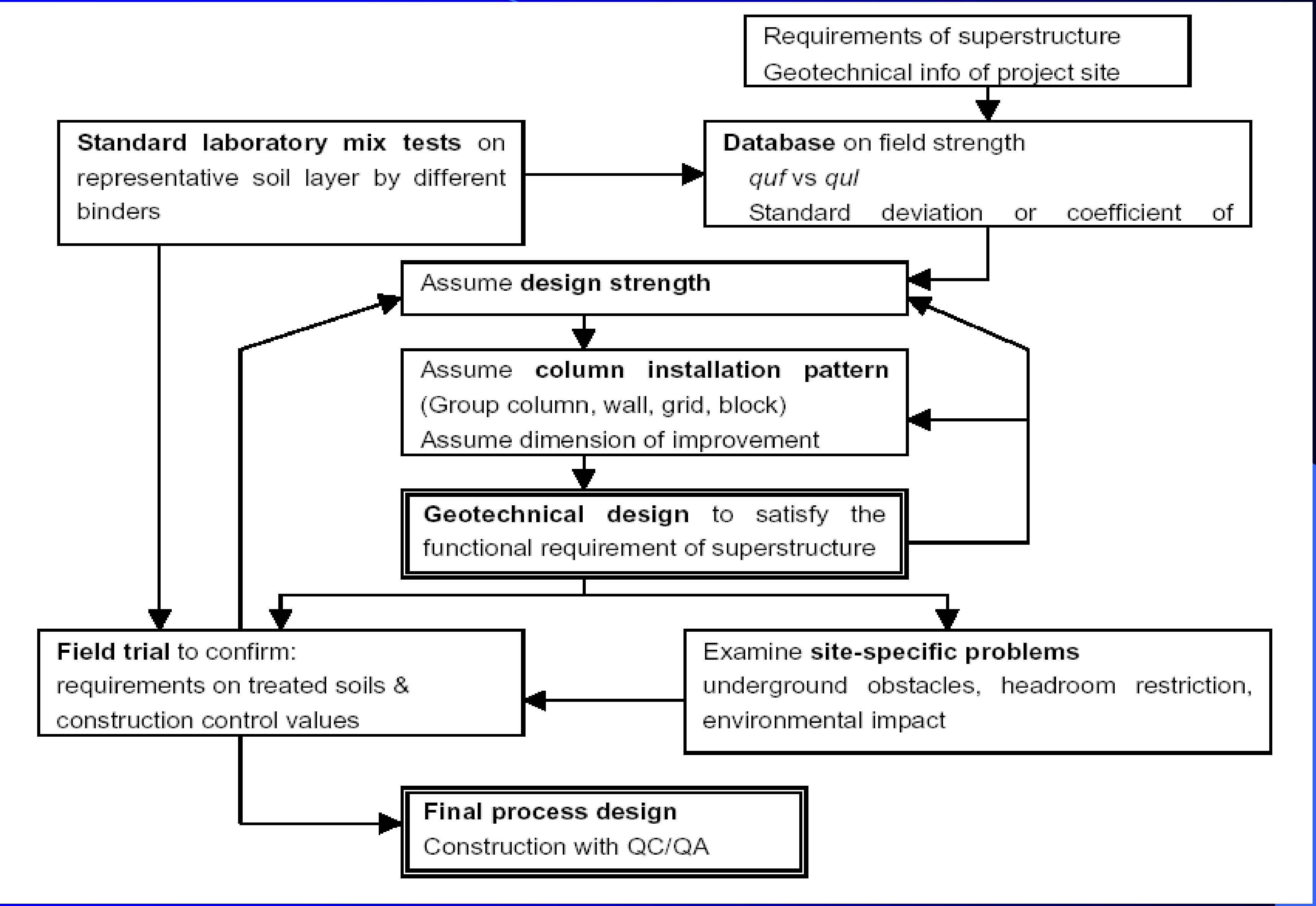


Break-water
bearing capacity

- The details of these applications may be found in the proceedings of the major past conferences in Tokyo 1996, Stockholm 1999, Helsinki 2000, Tokyo 2002, New Orleans 2003 and now again in Stockholm 2005.
- Obvious difference found in case records is the strength often in terms of unconfined compressive strength: 1 Mpa or more in the Japanese wet method, about 500 kPa in the Japanese dry method, and less than 150 kPa in Nordic dry method.
- The difference is not only in the strength of treated soil, much more important difference may be in the purpose of improvement and associated column installation patterns. Due to these differences, various design and construction manuals/standards are available today but the time does not permit to touch upon all these into detail.
- However, when we look at the concept we may arrive in the work flow common to all these applications.

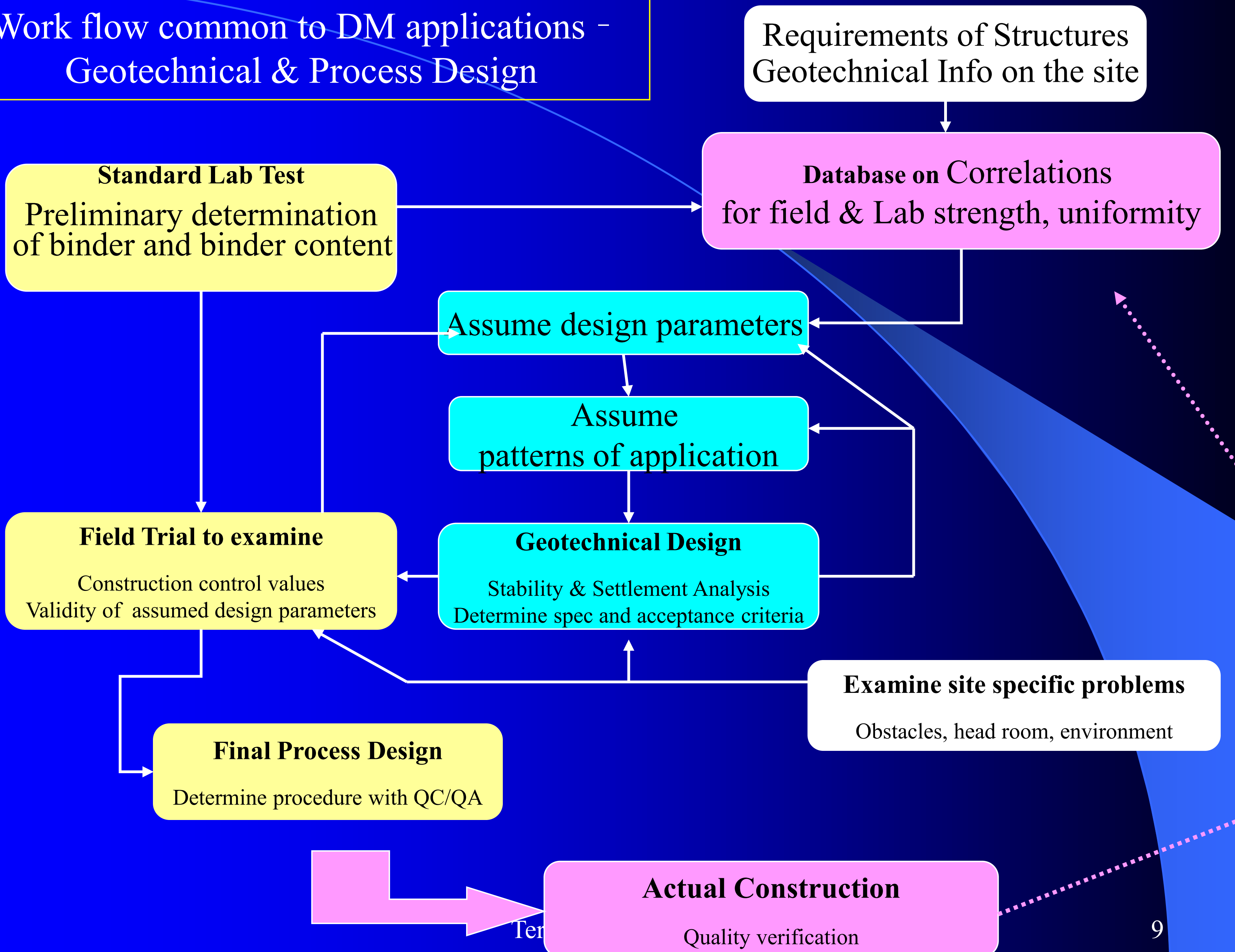
Work flow common to all the applications of deep mixing

Process design and Geotechnical design



Design should be followed by careful construction with appropriate QC/QA

Work flow common to DM applications – Geotechnical & Process Design



- The process design is to predict and realize the required strength and uniformity of the in-situ treated soil, and thereby determines the design parameters.
- The role of the geotechnical design is to determine, based on the design parameters, the size of improved area, installation depth and installation pattern so that the improved ground may satisfy the performance criteria of the superstructure.
- Only when both the process & geotechnical design are accomplished in harmony with the similar level of credibility, the best economy and the best performance will be guaranteed.
- Knowledge and experience of the former belong to the contractors and those for the latter belong to the geotechnical consultants. If one side feels distrust on the capability of the other, he/she will tend to take an extra margin of safety for his/her side of design.

process design

- Determination of design parameters or determination of the range of parameters.
- Determination of construction control values to realize required strength and required uniformity.
- Validity of process design may be justified by relevant database and/or field trial.

Process design is not an easy task

Various Factors affect both the strength and uniformity of in-situ treated soil

Factors affecting strength of treated soil

I Characteristics of binder

type & quality of binder/ mixing water/ secondary additives

II Characteristics and conditions of Soil

physical, chemical and mineralogical properties of Soil/ organic content/ pH of pore water/ water content

III Mixing conditions

degree of mixing/ timing of mixing & re-mixing/ quantity of binder

IV Curing conditions

temperature/ curing time/ humidity/ wetting and drying/ freezing and thawing

In-situ improved soils differ from laboratory in many ways.

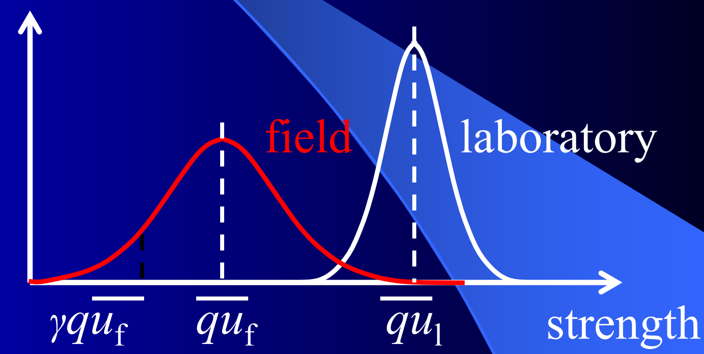
Average strength and uniformity differs between lab and field.

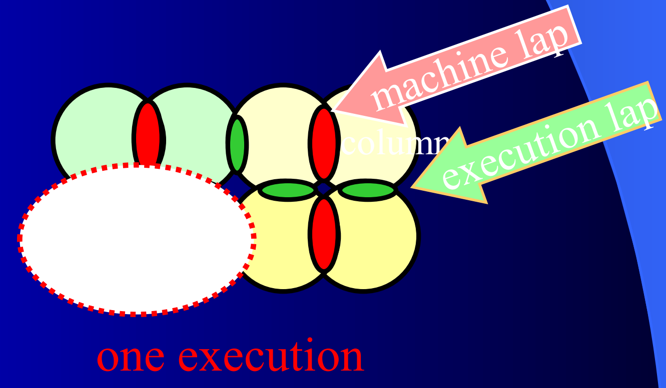
Inhomogeneity inevitably caused by execution process.

Overlapped portion may be weaker than the intact soil.

Long term strength may be influenced by environment.

Careful QC/QA and verification necessary.





Lab test: Basis for process design

- Laboratory mix test is standardized by the Japanese Geotechnical Society. The English translation of the standard will be included in the Proceedings volume 2 of the current conference .

Standardize the mixing energy, sample preparation and curing conditions.

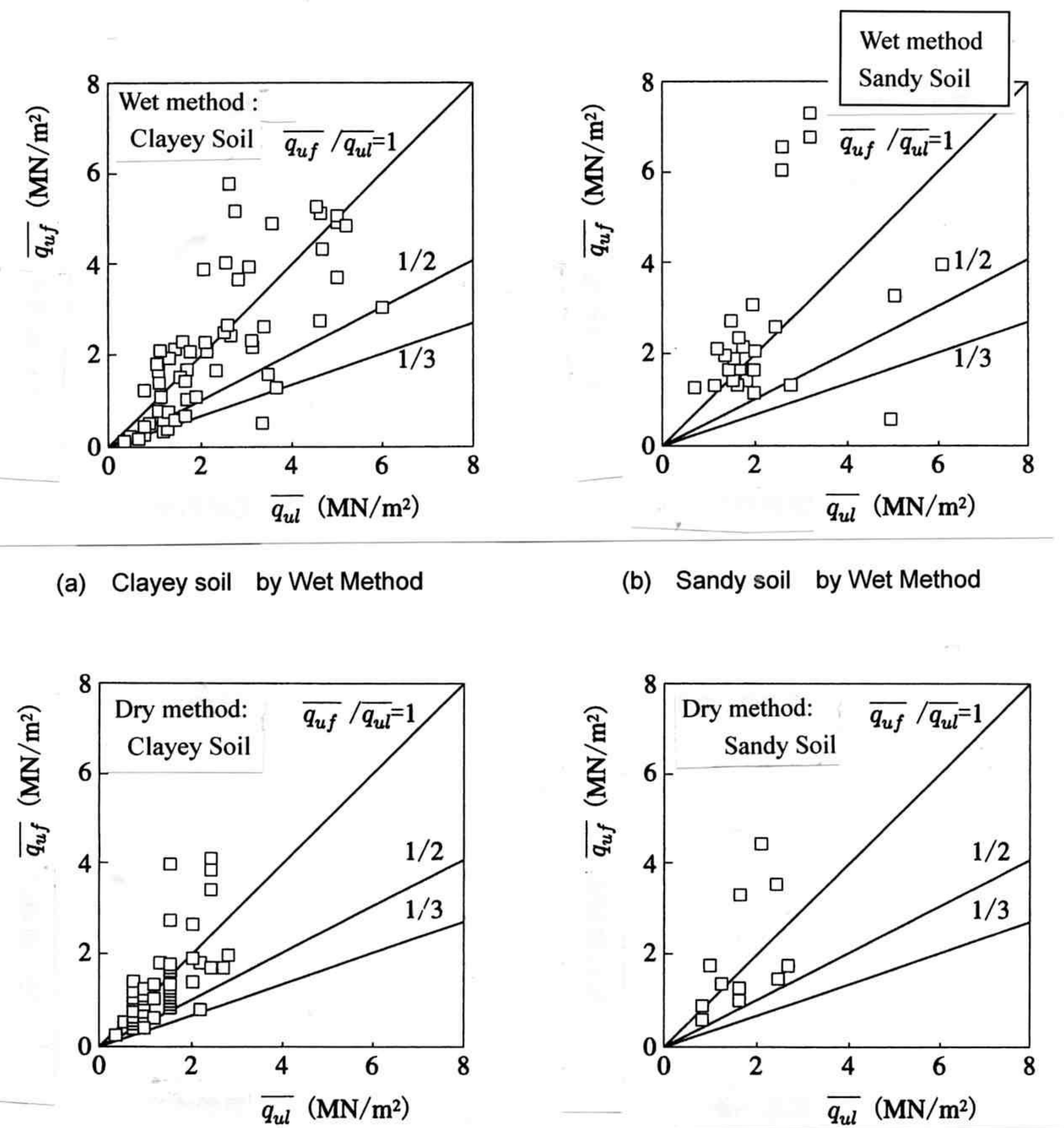
Lab test results is regarded as an index .

Field trial and/or verification through production columns are recommended.

Field strength quf differs from Lab strength qul

quf/qul depends upon various factors such as difference in the mixing process, soil type, and etc.

Database is only applicable for a specific process and specific soil type.



(a) Clayey soil by Wet Method

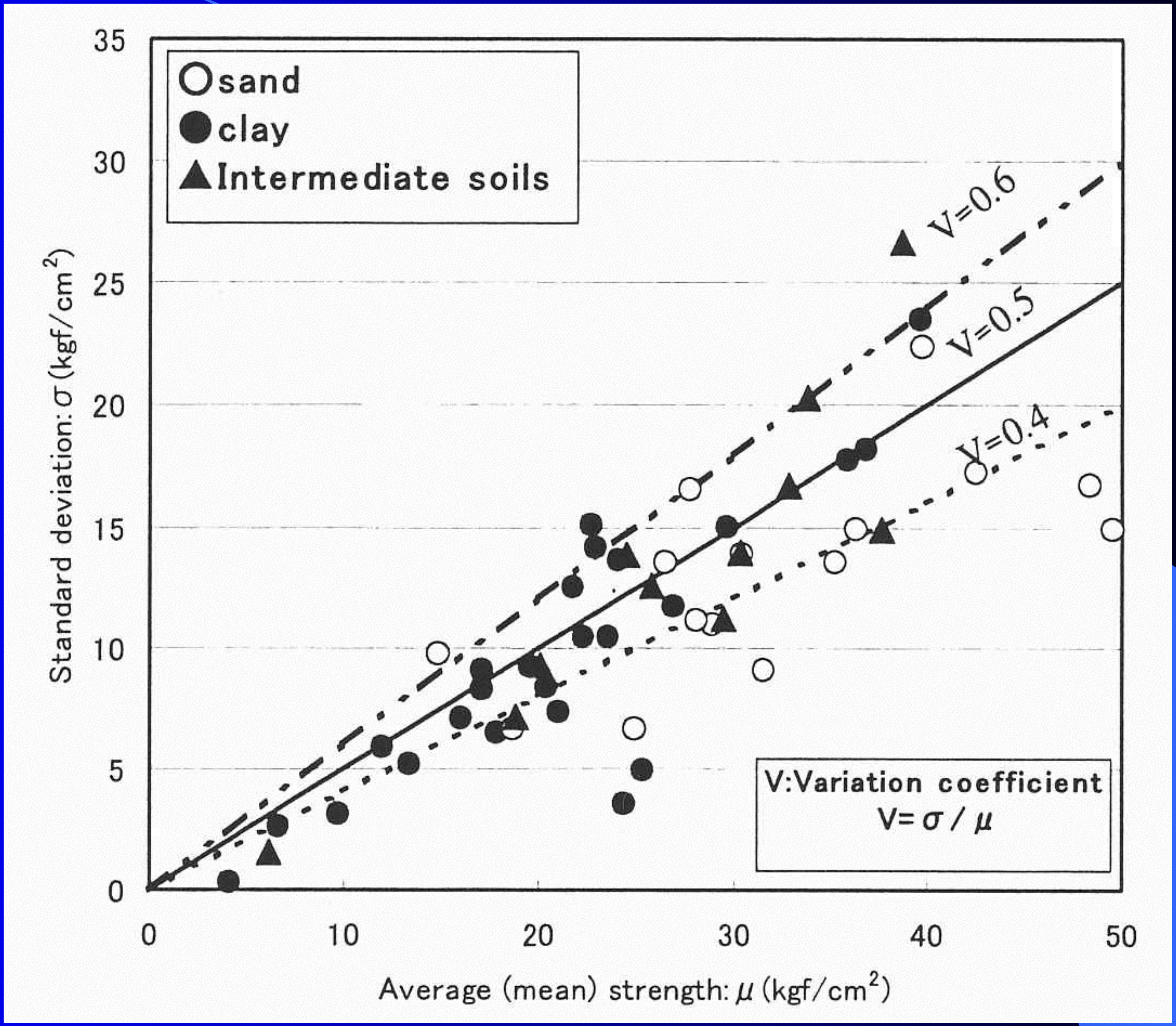
(b) Sandy soil by Wet Method

(c) Clayey soil by Dry Method

(d) Sandy soil by Dry Method

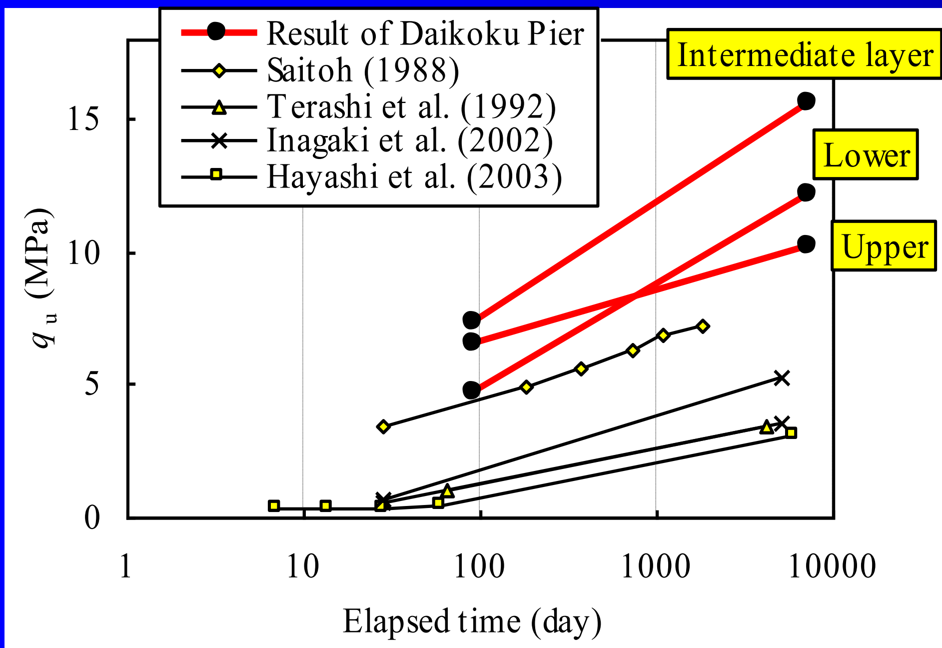
Uniformity of the treated soil

Coefficient of variation depends upon mixing process and soil type among others

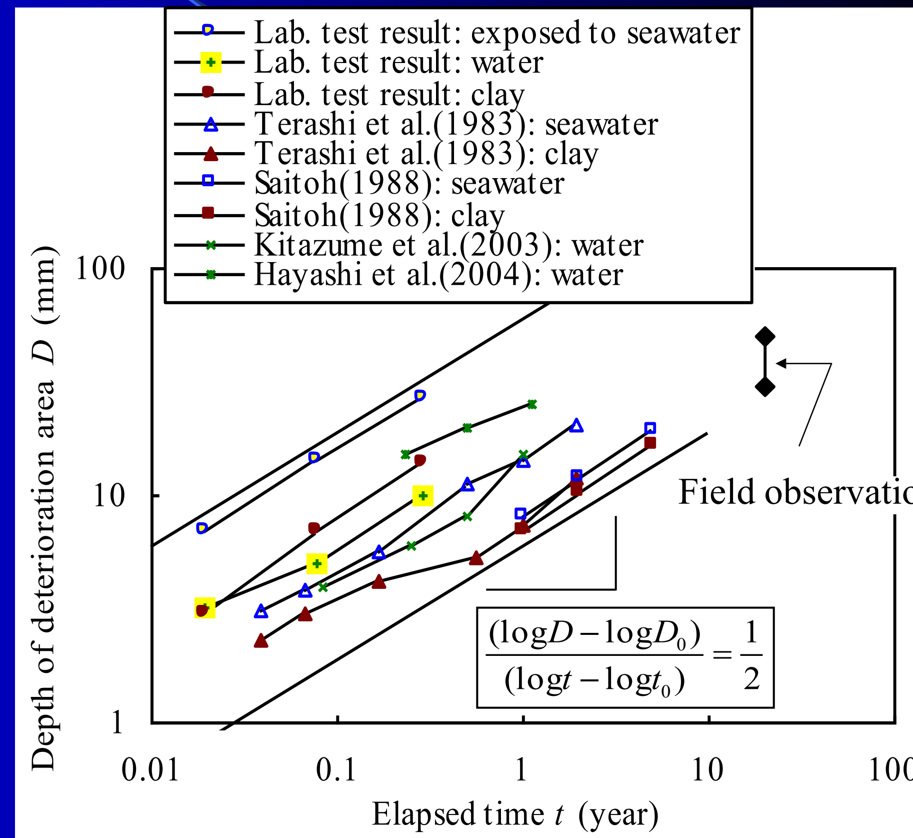


Why 28-day strength for design

Strength Increase



- Deterioration



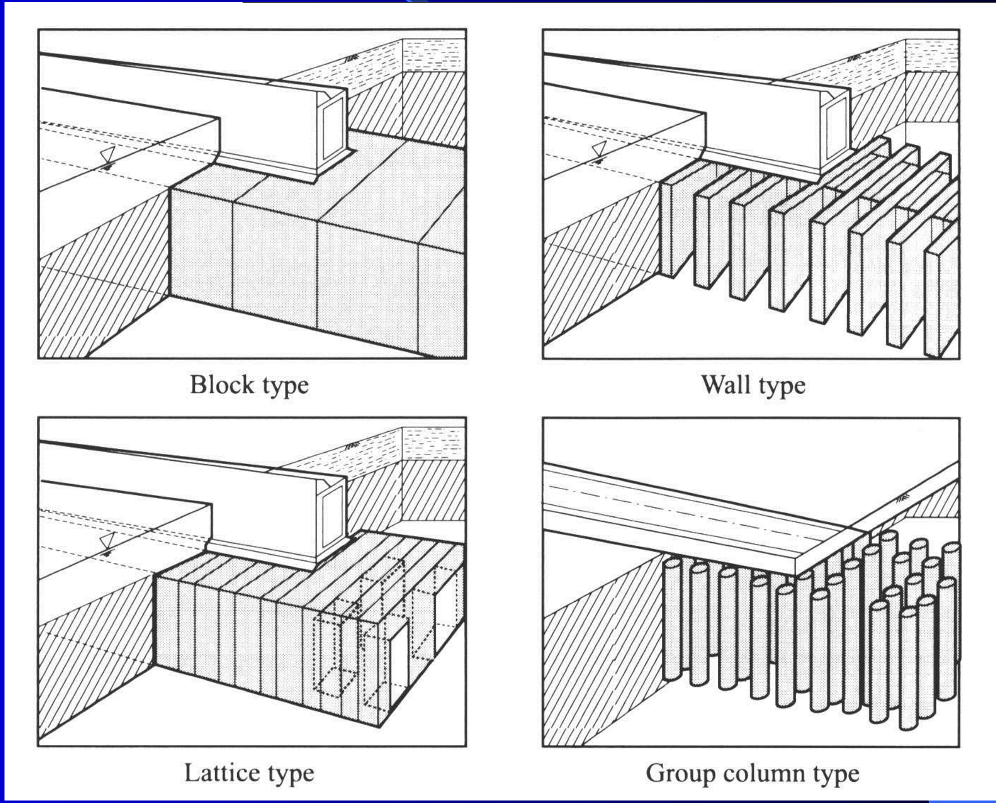
Influence of deterioration on group column type improvement will be discussed **later this morning by Mr. Ohishi**

Geotechnical Design

- Geotechnical design is an art of predicting the behavior of the improved ground: mode of deformation and mode of failure.
- The role of the geotechnical design is to determine, based on the design parameters, the size of improved area, installation depth and installation pattern so that the improved ground may satisfy the performance criteria of the superstructure.

Geotechnical Design start with the selection of column installation pattern appropriate for the purpose of improvement.

Block type
Wall type
Lattice type
and
Group Column type



- Current design procedures for different applications are described in the technical manuals issued by respective authorities.

CDIT (1999) Technical Manual of Deep Mixing for Marine Works
PWRC(1999) Technical Manual of Deep Mixing for On-land Works
BCJ (1997) The Guide for Design and QC/QA for Buildings

These manuals provide perhaps conservative design. For the new application, centrifuge modeling, field trial, and numerical analyses are often conducted to supplement engineering judgment.

Design flow for block and wall type improvements _ Iterative approach

determination of design conditions for superstructure

↓

assumption of size of super- and buried structures

↓

earthquake response analysis

↓

calculation of mass forces and external forces on superstructure

↓

examination of external stability of superstructure

↓

calculation mass forces and external forces on buried structure

→

examination of external stability of the buried structure; sliding, over-turning, bearing capacity

↓

examination of internal stability of buried structure; stress analysis, extrusion failure

↓

examination of immediate and long term settlements

↓

detailed design

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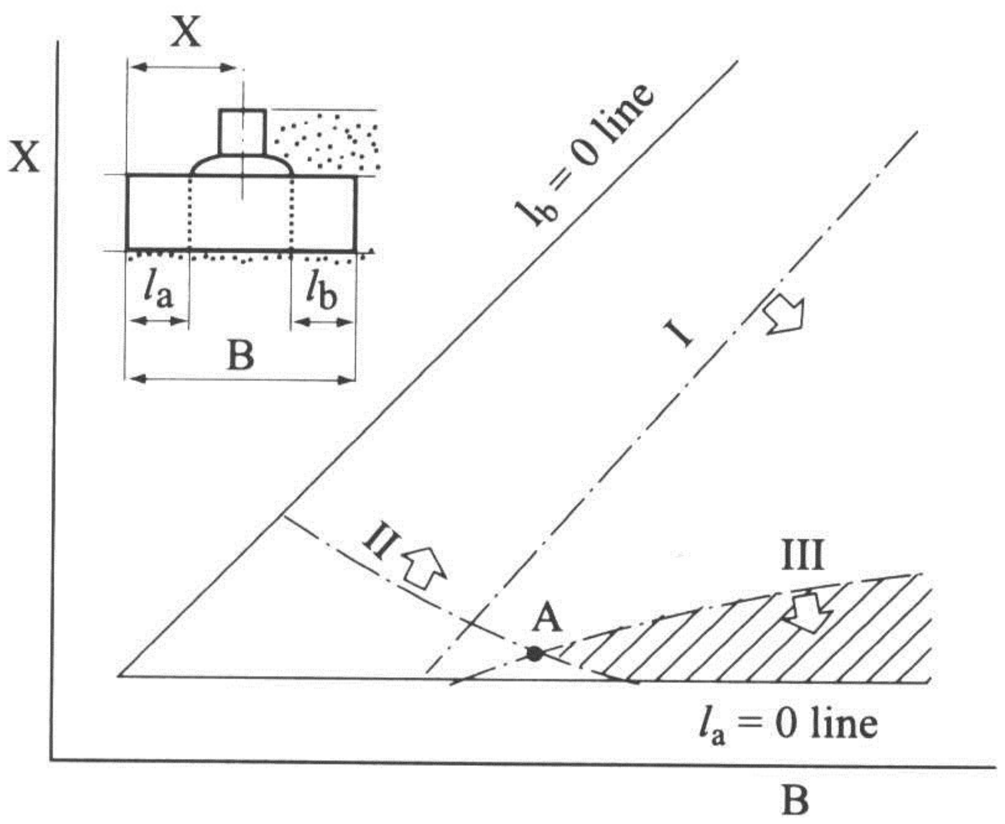
(Ministry of Transport, 1999)

Iterative design to get optimum solution considering various modes of failure



External Stability

I. Sliding failure of treated soil

Internal Stability

II. Shear stress at front edge of treated soil

III. Shear stress in vertical plane in front of super-structure

modes of deformation and failure

- In order to understand the background of the current design practice comprising external and internal stability,

  and in order to improve the accuracy of the current design procedure,

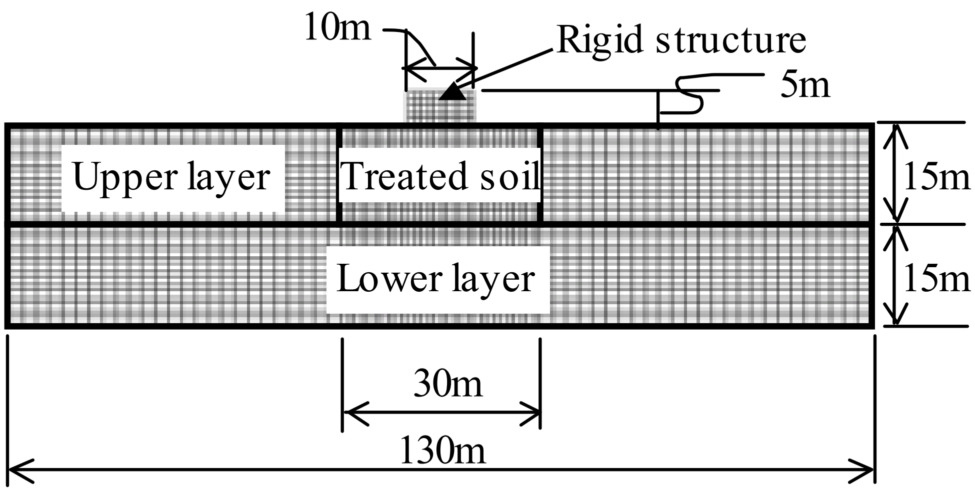
  it is important to understand the global picture of the behavior of the improved ground by means of reliable numerical modeling.

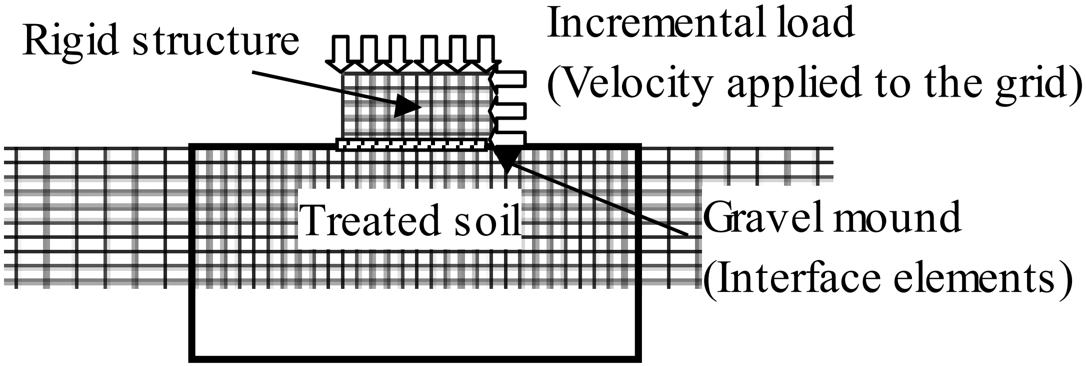
- The validity of numerical modeling should be verified through field observation or by reliable physical modeling. Such example is the paper by Kurisaki et al. and Ohishi et al. to this conference.

Simple example of block type Improvement

to understand the complicated response of composite system comprising superstructure, stiff deep mixed foundation, soft upper clay layer and lower layer with varying characteristics.

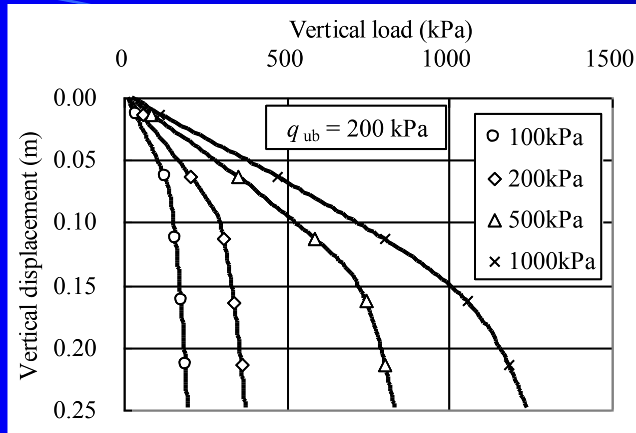
Dimension is set similar to that of the landmark project in 70s at Daikoku Pier

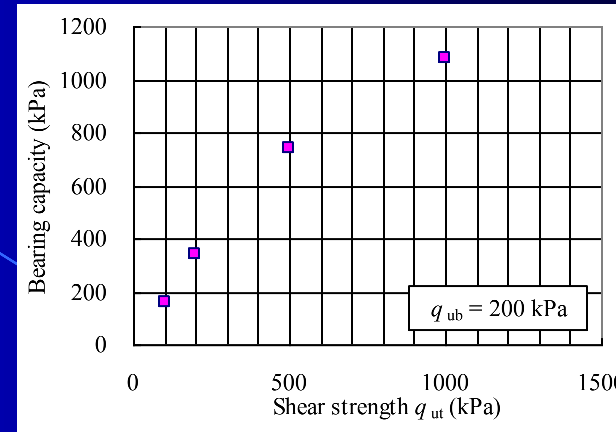




qu,b kept constant

200 kPa

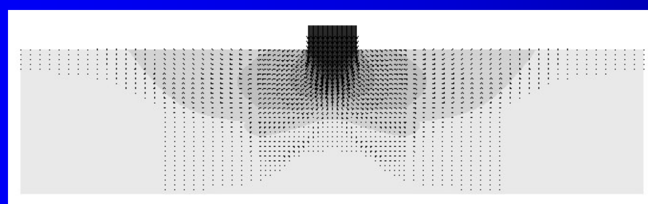


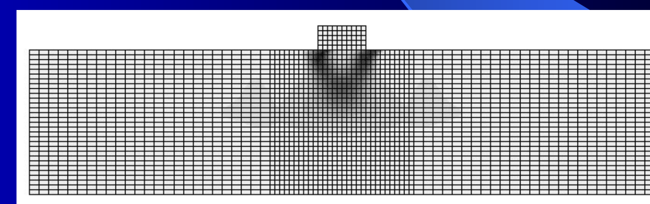


Increase of qu,t results in the increase of bearing capacity

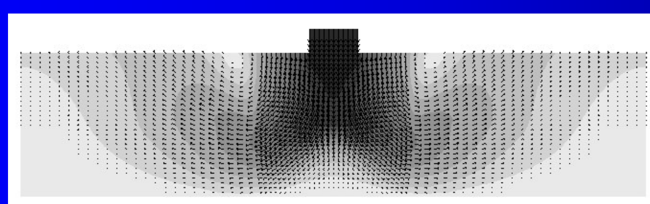
qu,t

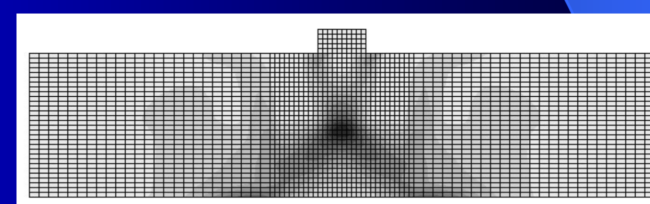
100 kPa





1,000 kPa



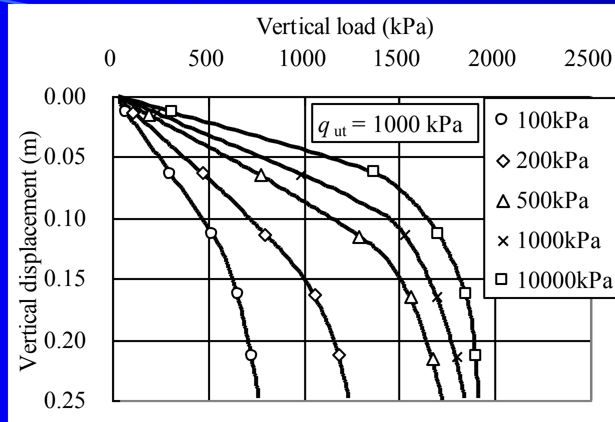


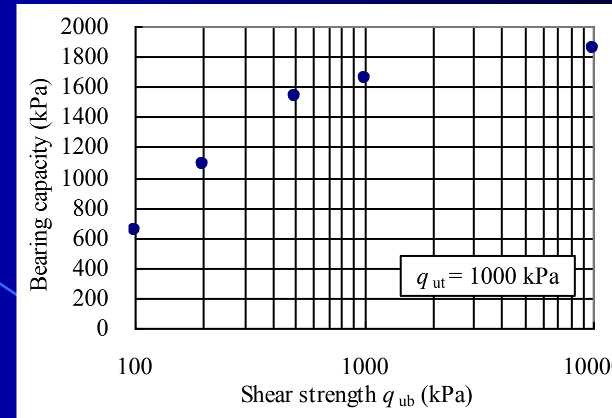
Displacement vector

Shear strain distribution

Mode of deformation & failure changes from internal to external with the increase of qu, t (strength of treated soil) qu,t kept constant

1000 kPa





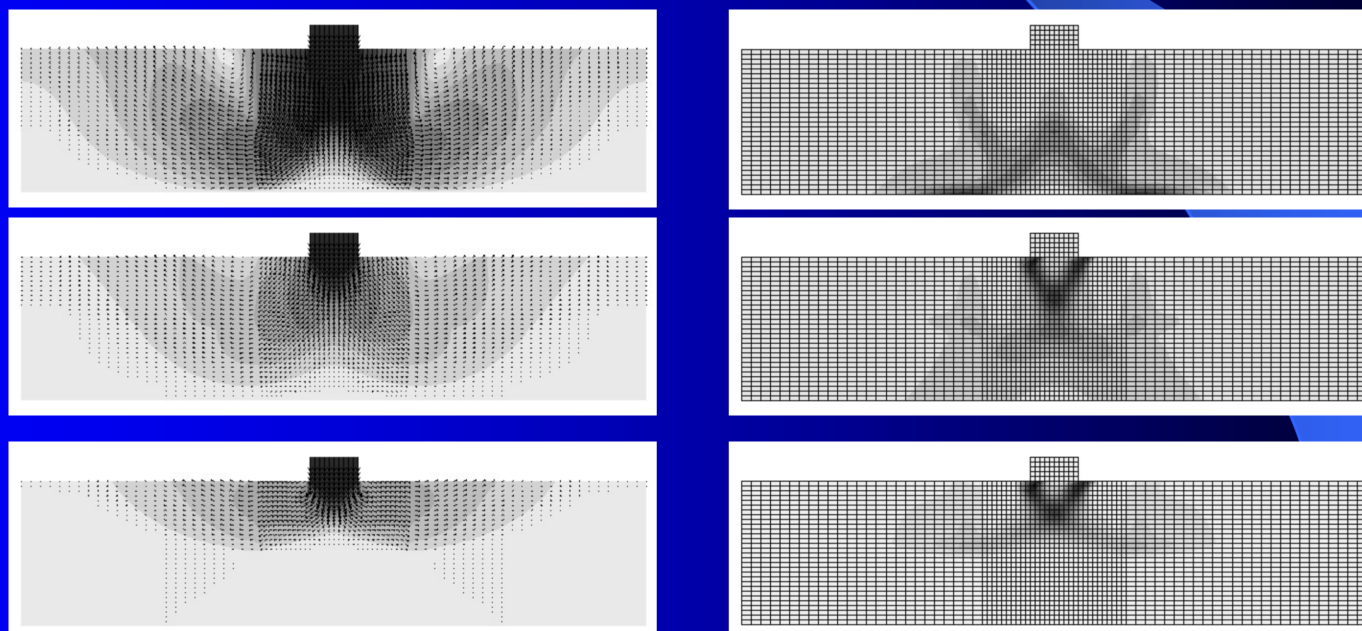
Increase of qu,b results in the increase of bearing capacity

qu,b

100 kPa

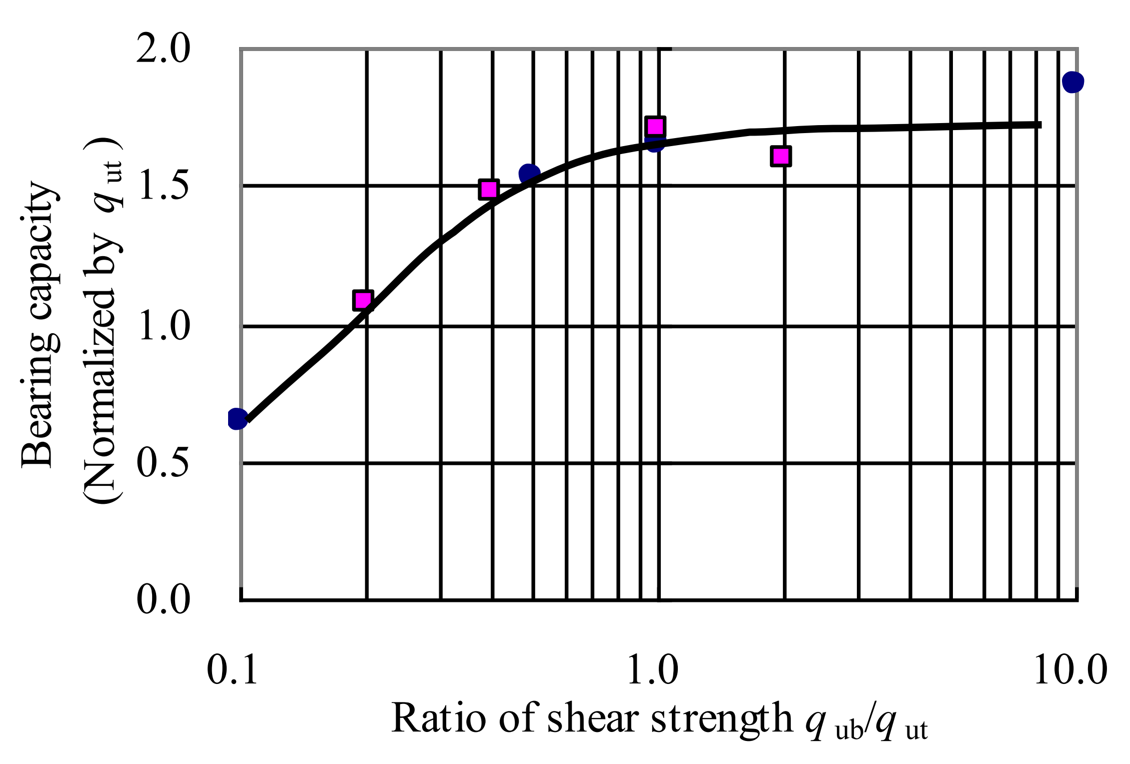
500 kPa

10,000 kPa



Mode of deformation & failure changes from external to internal with the increase of qu, b (strength of bearing layer)

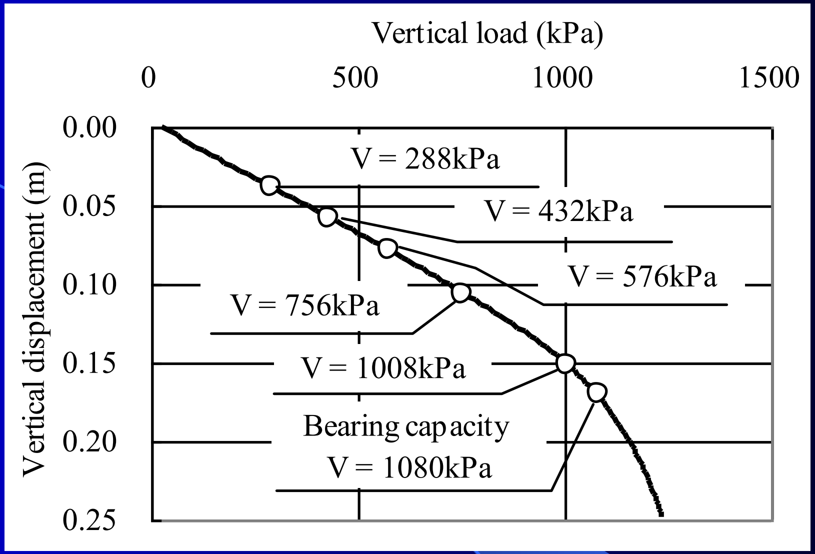
- Bearing capacity of superstructure resting on deep mixed foundation is not an unique function of qu,t but influenced by relative strength of treated soil and bearing layer.
- Under the given geometric condition, normalized bearing capacity can be determined by relative strength qu,b/qu,t and the change of bearing capacity is associated with the change of the mode of failure from external to internal stability.

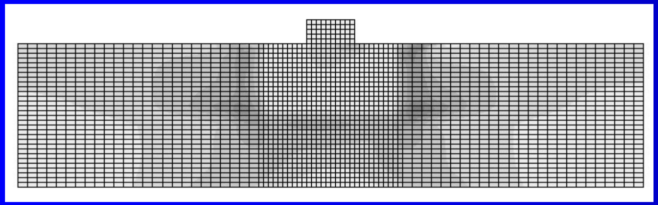


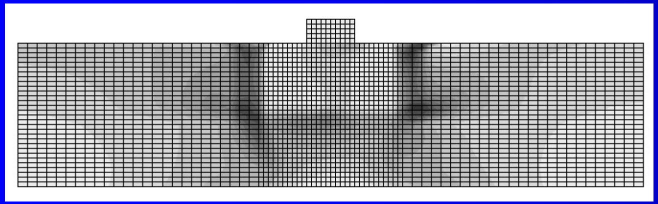
Influence of load inclination

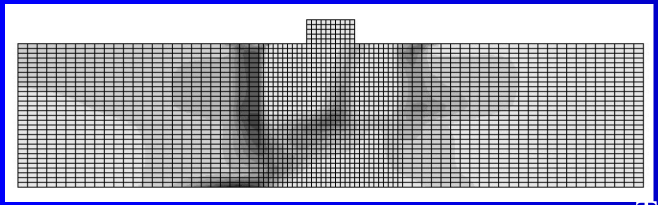
Horizontal load component is applied to the superstructure at different vertical stress level.

Load inclination invites the change in the mode of failure.







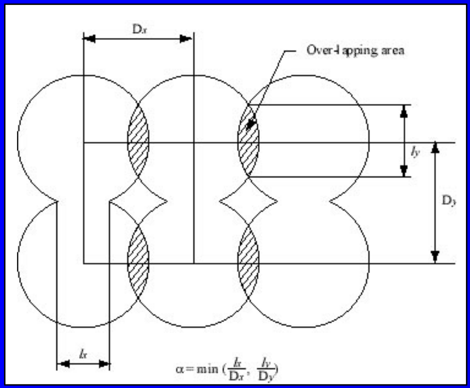


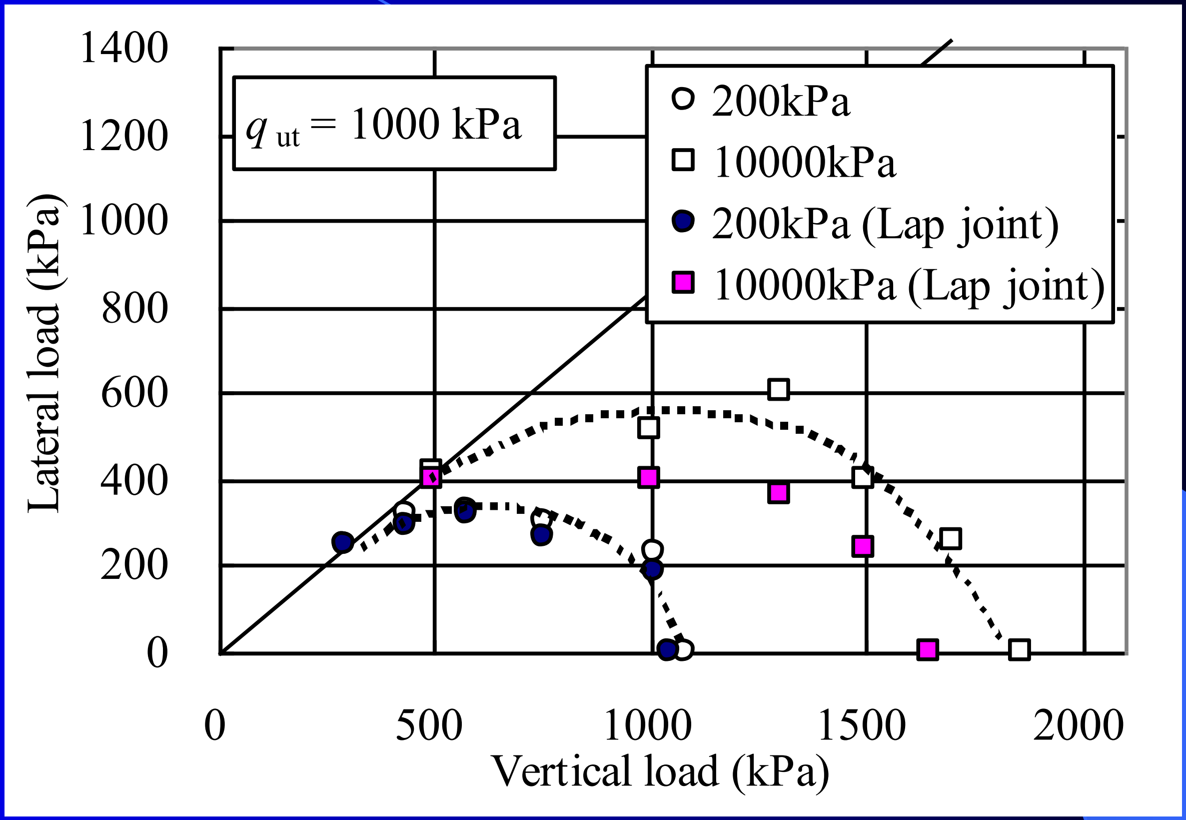
At the smaller vertical stress level, superstructure slides on the deep mixed foundation,

At the intermediate stress level deep mixed foundation fails by external stability in sliding mode

At the higher stress level deep mixed foundation fails internally.

Bearing capacity in the V-H load plane and the Influence of construction lap joint face



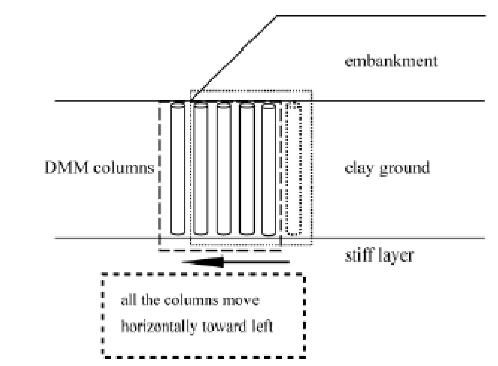


When internal stability dominates, the influence of lap joint face become large. Further study needed.

Geotechnical design should incorporate various modes of failure

- A qualitative picture of the behaviour of a deep mixed foundation is exemplified for a simple geometric condition. The results are not new but the picture is important for the designers or for the code writers.
- While the strengths of treated soil and the underlying layer were changed, the mode of failure shifted from one extreme of external stability to the other extreme of internal stability. In between these extremes there was a transition phase.
- The strength of treated soil alone does not govern the behaviour, relative stiffness among geo-materials constituting the composite system is found much more important.
- Goup of columns was not touched upon in the current keynote but may exhibit more complicated behavior. Some of the papers to this conference deal with the problem.

Physical modeling by Kitazume et al revealed various modes in the external and internal stability



(a) external stability (sliding failure)

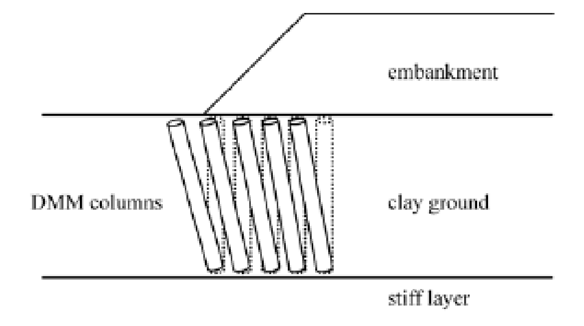
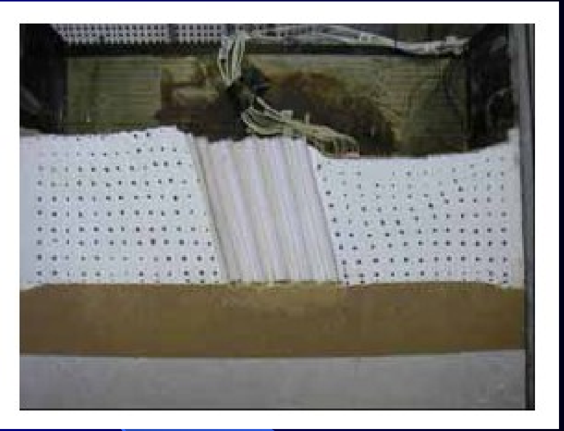
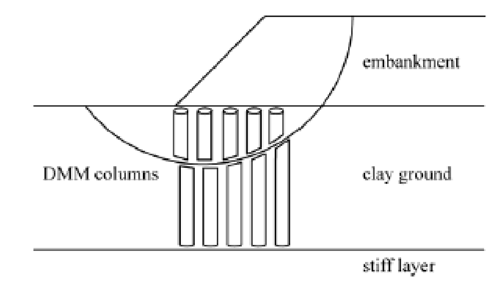


Figure 2. Collapse failure pattern of DMM improved ground.





(b) internal stability (rupture breaking failure)

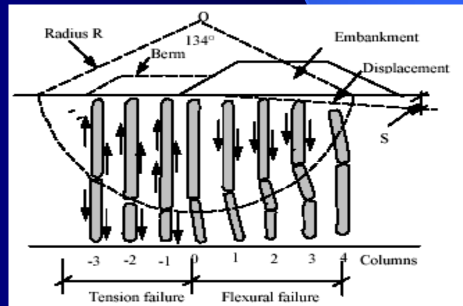


Figure 1. Possible Failure Modes of Columns (Broms, 1999)

Conceptual model for internal stability by Kivelo and Broms

Numerical modeling by Han, et al to the current conference also confirms the changing modes by parametric study

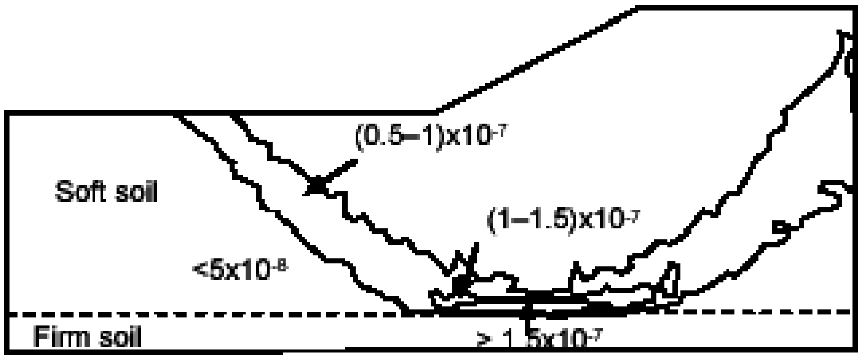


Figure 3. Contours of Shear Strain Rate for the Embankment over Soft Soil without DM Walls

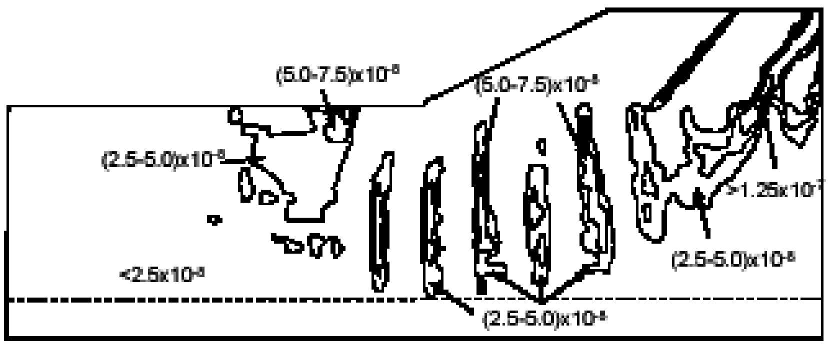


Figure 4. Contours of Shear Strain Rate for the Embankment over Soft Soil with DM Walls Having Cohesion of 100kPa

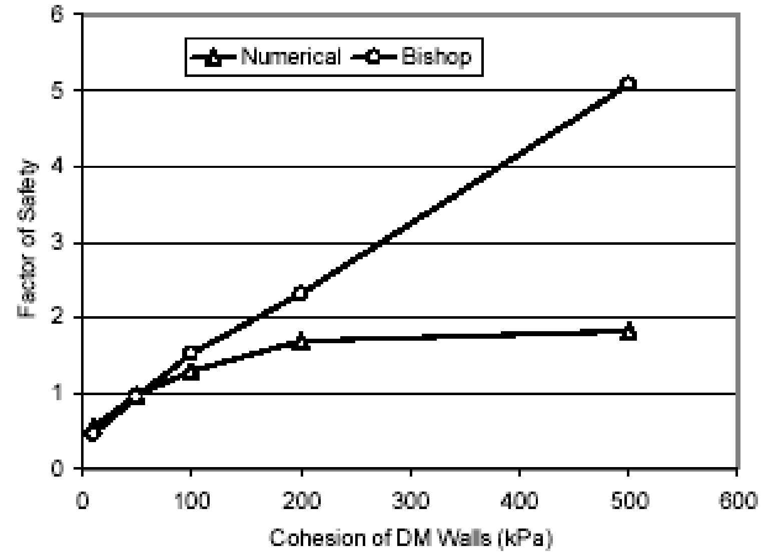


Figure 5. Influence of Strength of DM Columns

Design procedure for group of columns has to be refined as well.

Conclusion

- *1. General conclusion*
- The design of deep mixing should involve both the process design & the geotechnical design. The role of the former is to predict and realize the required strength and uniformity of the in-situ treated soil. The role of the latter is to determine the dimension of improved area, installation depth and installation pattern of the treated soil columns so that the improved ground may satisfy the performance criteria of the superstructure. Only when both the process design and the geotechnical design are accomplished in harmony each other with the similar level of credibility, the best economy and the best performance will be guaranteed. It should be noted that the design is an iterative process.

- *2. Aspect of Process design*
- The design of deep mixing work starts with the determination or initial assumption of design strength. Assumption becomes the requirement for construction. Laboratory mix test may become important source of information but …
- In-situ treated soils differ from lab specimen in many ways. quf/qul relation, uniformity, reliability of overlap joint, long-term strength should be taken into account in the determination of design parameters.
- The soils are local and execution machines and type of binders are different from one project (or one country) to another, there is a need to accumulate the laboratory and field data to establish the relation between laboratory strength and field strength, taking these differences into account.

- *3. Aspect of Geotechnical design*
- The behaviour of improved ground depends upon complicated time-dependent interaction between treated and untreated soils in the geo-composite system. Modes of deformation leading to failure are governed by such factors as geometry of improvement, relative stiffness of treated and untreated soils, loading condition typical for specific application, interface properties between structure and treated soil/ between treated and untreated soils.
- *4. Importance of field trial*
- If the in-situ treated soil does not satisfy the design requirements when soil improvement work finished, there would be no measure for further improving the already improved (unsatisfactorily hardened) soils. Field trial is important. Another important role for the field trial is establishing construction control values.

Thank you for your attention.

Please feel free to ask any question during the rest of the conference.

After the conference, advice is a fee business!






Quality of Core Samples