Embarkment construction by means of a membrane foundation

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Motivation

- Extension of infrastructural facilities in challenging areas
- Foundation for stockpiles, dikes etc.

Introduction
Introduction

Challenges

- Soft soils
  - Low stiffness
  - Low permeability
  - Low shear strength
  - High degree of saturation

Consequences

- Inacceptable deformations and/or horizontal thrust on adjacent constructions
- Insufficient stability
Introduction

Solutions

Construction methodology adopted to soil conditions

Soil improvement

Load transfer

Soil confinement
Soil confinement

Temporary to
- secure stability during earthquake/liquefaction

Permanent to
- Secure stability
- Prevents soil extrusion
- Reduce lateral thrust
- Reduce lateral deformation
- Cut-off depression curve

Poungchompu, 2009

Harata et al., 2009
Self-regulating membrane foundation

System

Tensile stiff membrane
Wall element
Soft soil
Competent layer
Self-regulating membrane foundation

System behavior

- Increase of horizontal pressure in subsoil due to embankment load → outward movement of vertical walls

- Activation of tensile forces in the membrane → restricting outward movement

- Further activation due to settlement depression of embankment
Self-regulating membrane foundation

Investigation

Centrifuge model set-up

Numerical model
Self-regulating membrane foundation

Investigation

In-flight refillable sand hopper

In-flight constructed embankment
Results of physical analysis

- **Total vertical stress over time**
  - $\Delta \sigma_{c1} = 46 \text{ kPa}$
  - $\Delta \sigma_{c2} = 40 \text{ kPa}$
  - $\Delta \sigma_{c3} = 25 \text{ kPa}$

- **Stress reduction over embankment height**
  - Reduction over time
    - $\Delta \sigma_{c1-2} = 4 \text{ kPa}$
    - $\Delta \sigma_{c2-3} = 13 \text{ kPa}$
    - $\Delta \sigma_{c3-end} = 15 \text{ kPa}$
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Results of physical analysis

Wall deformation over time
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Results of numerical analysis

Arching in embankment and rotational failure mechanism in subsoil

Wall deformation before and after consolidation
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Numerical simulation

- Input parameters:
  - Soft soil
  - $E_{s, WS}$
  - $\varphi_{WS}$
  - $c$
  - Embankment
  - $E_{s, Embankment}$
  - $\varphi_{Embankment}$
  - Sheet pile wall
  - $E_I$
  - Membrane
  - $J$
  - Geometry
  - $H_{Cantilever}$
  - $H_{Embankment}$

- Tool:
  - Numerical model
  - Metamodel

- Output:
  - $u_{x,Wall}$
  - $u_{y,Symmetry}$
  - $\Delta \sigma_v$
  - $M_{max}$
  - $F_{max}$

- Dominating parameters:
  - Soft soil
  - $E_{s, WS}$
  - Sheet pile wall
  - $E_I$
  - Membrane
  - $J$
  - Geometry
  - $H_{Cantilever}$
  - $H_{Embankment}$

- Validation
- Creating metamodel
- Generating parameter sets

- Parametric study
- Design approach

Global sensitivity analysis
Self-regulating membrane foundation

Numerical simulation – global sensitivity analysis

A. Casagrande (1936)
Self-regulating membrane foundation

Semi-analytical design approach

- System separation in two coupled sub-systems
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Semi-analytical design approach

- Determination of the system loadings and membrane forces

\[ F_i = F_{0.25,i} \cdot A_{geo,i} \cdot A_{Y,i} \cdot A_{E_{oed},i} \cdot A_{J,i} \]

- Loading/force
- Influence of geometry
- Influence of soft soil stiffness
- Influence of bulk density embankment
- Influence of membrane tensile stiffness

Loading of base system
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Semi-analytical design approach
Comparison numerical simulation and design approach
Self-regulating membrane foundation

System properties

- Easy to construct
- Can be loaded directly after construction
- Reduction of lateral thrust
- Cuts the depression curve off
- Reduced footprint, if walls are extending above the ground level
- Can be completely rebuilt
- Control of lateral deformation
Questions