Performance Evaluation of Design Methods for Geosynthetic -Reinforced Pile-Supported Embankments

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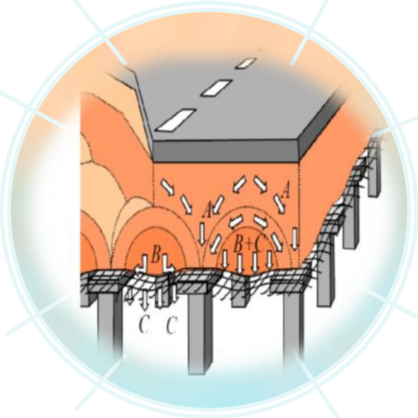


Introduction

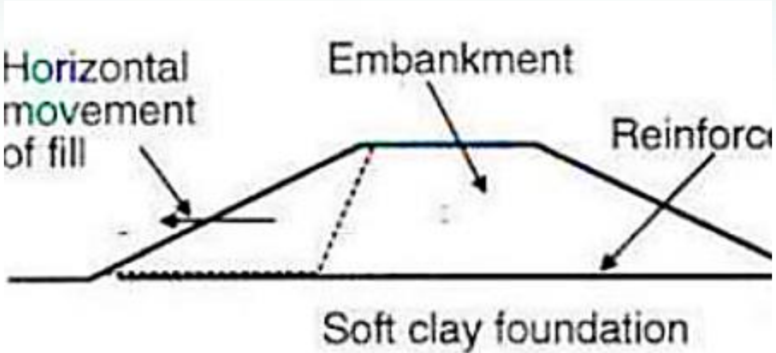
Introduction

Potential challenges of constructing road embankment on soft soils:

Excessive Differential Settlements

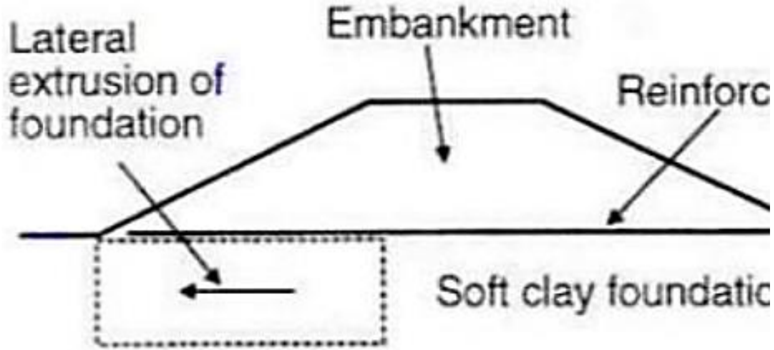
(Sloan, J. A., 2011)

Lateral Sliding



(https://www.slideserve.com/hadley-hodge/application-of-geosynthetics-in-embankment)

Bearing capacity failures



(https://www.slideserve.com/hadley-hodge/application-of-geosynthetics-in-embankment)

Slope failures

(Chai et al., 2015)

Introduction

Methods of Ground Improvement

- Soil Replacement
- Preloading
- Light Weight Fill
- Preloading with Vertical Drain
- Vacuum Preloading
- Stone Column-OSC.ESC
- Piled Raft
- Basal Reinforcement
- Piled Embankment
- **Geosynthetic Reinforced Pile Supported Embankment**

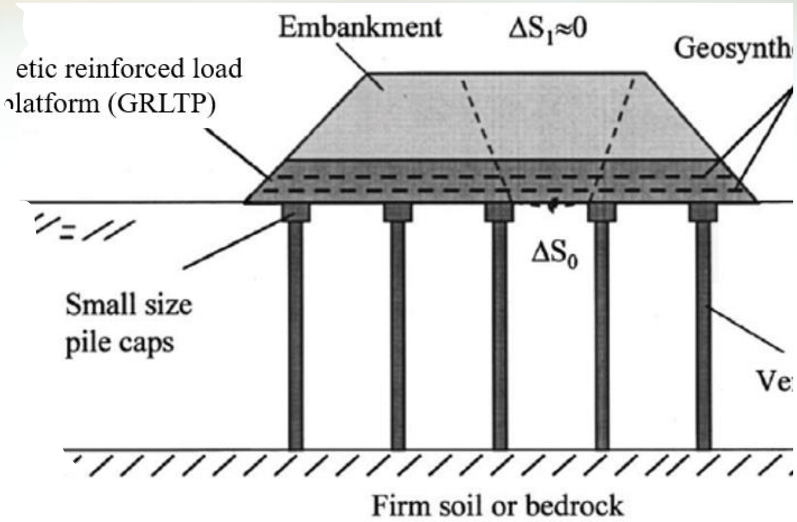
(https://reforcandoideias.com.br/materiadecapa)

Introduction

Geosynthetic-reinforced pile-supported (GRPS) embankments

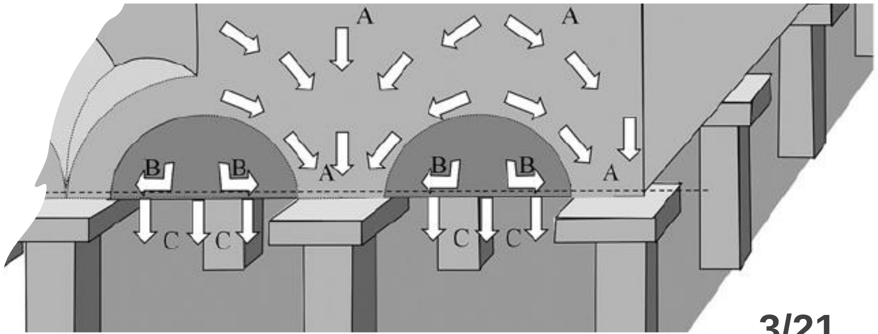
The vertical load transfer from embankment to pile caps takes place due to:

- Soil Arching
- Development of Geosynthetic Tension
- Soil-Geosynthetics Interaction.

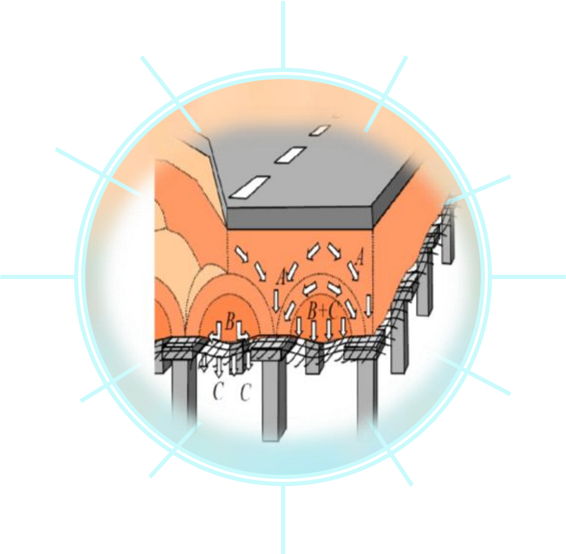


(Han and Gabr, 2002)

Dividing the load into three parts:
A)directly to the piles,
B)via the GR to the piles,
C)to the soft subsoil in between the piles



(Van Eekelen et al., 2011)

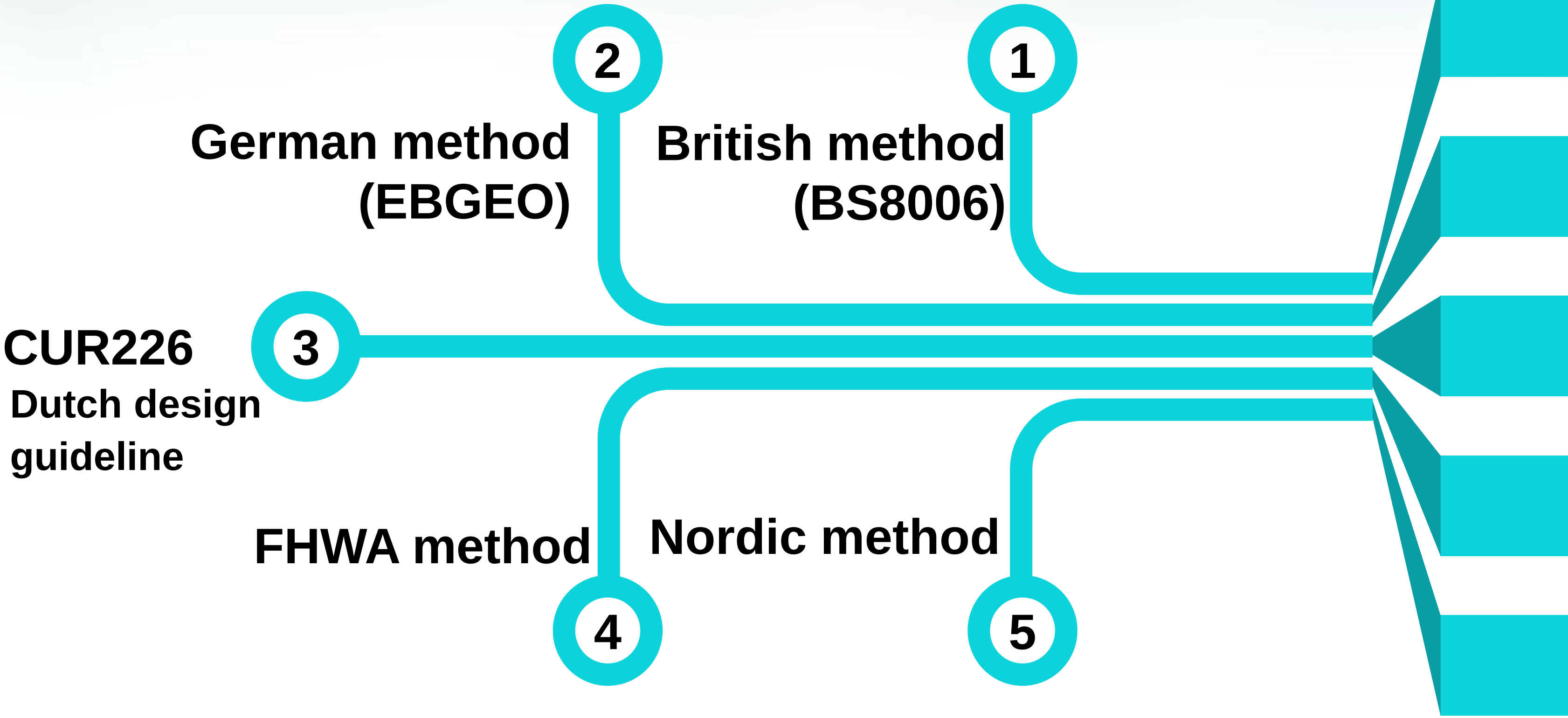


FEM model and Design methods

FEM MODEL

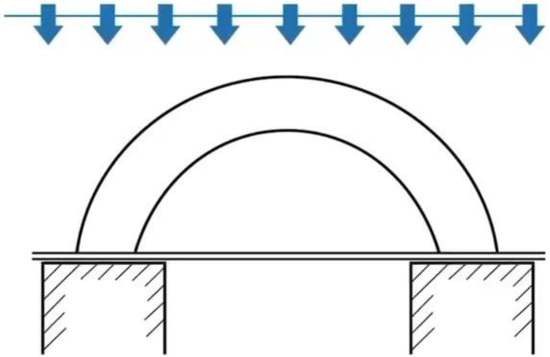
- **Cohesionless soil layers and embankment fill:**
  linear elastic perfectly plastic Mohr-Coulomb (MC)
- **Cohesive soils :**
  Modified Cam Clay (MCC)
- **Granular material in the load transfer platform (LTP)**
  Hardening Soil (HS)
- **Piles:**
  linear elastic(LE)model.
- **Permeability change index:**
  $c_k = 0.5e_0$
- **Reduction factors :**
  1: Geogrid-geomaterial interface
  0.8: Geotextile-geomaterial interface, and Pile-soil interface
- **Triangular 15-nodded elements**

DESIGN METHODS



DESIGN METHODS

British Standard BS8006 (2010)



- Adopted the Hewlett and Randolph method (1988).

$$\mathrm{E}_{\mathrm{min}} = (\mathrm{E}_{\mathrm{a}}^{\mathrm{cap}}, \mathrm{E}_{\mathrm{Crown}}).$$

- Vertical load acting on <u>top of geosynthetic layers</u>:

$$W_T = \frac{s^3(\gamma H + q)}{s^2 - a^2}(1 - E_{min})$$

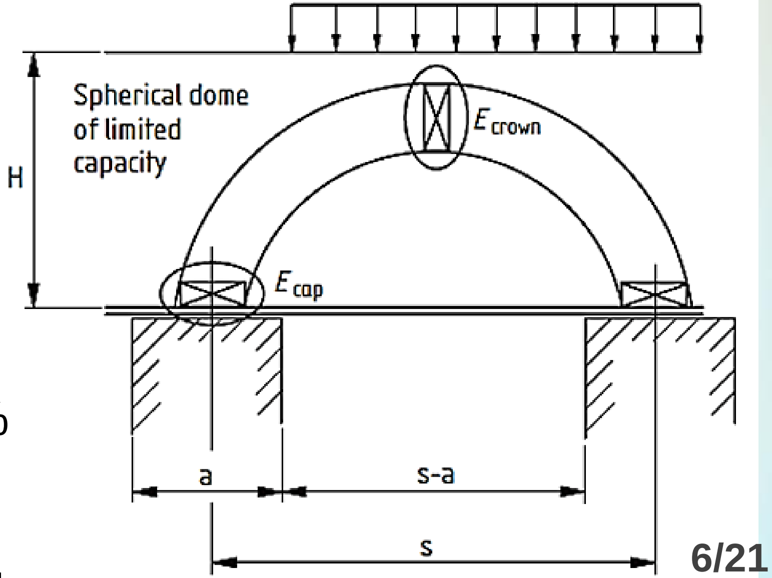
- Maximum tension in geosynthetics:

$$T = \frac{W_T(s-a)}{2a}\sqrt{1 + \frac{1}{6\varepsilon}}$$

- Maximum differential settlement:

$$y = (s-a)\sqrt{\frac{3\varepsilon}{8}}$$

ε : 6%



- Subsoil support is not considered in this method.

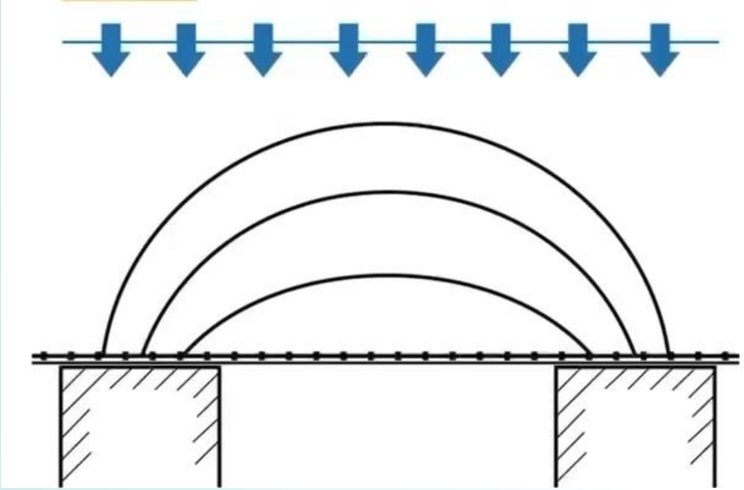
DESIGN METHODS

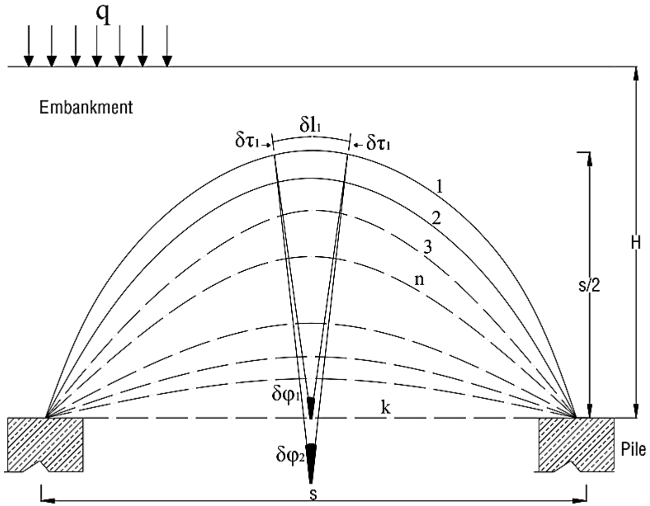
German Standard EBGEO (2011)

- Multi-arching theory
- Analytical model is based on

  Lower bound theorem of the plasticity and Experimental observations
- The membrane theory is used to calculate the tensile force in geosynthetic reinforcement.

- Subsoil support can be considered Reaction modulus of the subgrade (k_s)





$$k_s = \frac{E_s}{t}$$

DESIGN METHODS

Dutch Standard CUR226 (2016)

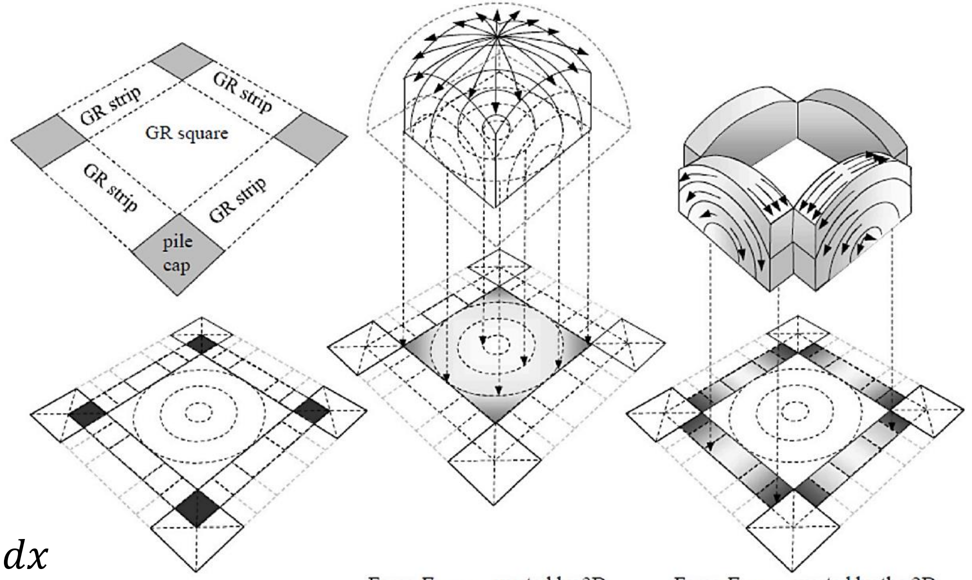
Van Eekelen et al. (2013) developed a concentric arches model for GRPS embankments. Concentric-arch model solved by a limit equilibrium approach

Based on close <u>observations of stress formation and distribution in laboratory testing</u> and is a <u>modification of the Hewlett and Randolph</u> (1988) model

$$\mathbf{P_c^a} = (\boldsymbol{\gamma}\mathbf{H} + \mathbf{q})\mathbf{s_x}\,\mathbf{s_y} - \mathbf{F_{GR_{square}}} - \mathbf{F_{GR_{strips}}}$$

$$\boldsymbol{T(x) = T_H\sqrt{1+\left(y'(x)\right)^2}}$$

$$\int_0^{L/2}\sqrt{1+y'(x)^2}dx - L/2 = \left(\frac{1}{J_{GR}}\right)\int_0^{L/2}T(x)dx$$



Force on piles A

Force $F_{GRsquare}$ exerted by 3D hemispheres on the GR square

Force $F_{GRstrips}$ exerted by the 2D arches on the GR strips

DESIGN METHODS

FHWA Design Manual (Filz and Smith method)

To estimate vertical load on top of pile cap as well as geosynthetic reinforcement, the load-displacement compatibility method proposed by Filz and Smith

$$H + q = a_s\sigma_{col,geotop} + (1 - a_s)\sigma_{soil,geotop} = a_s\sigma_{col,geobot} + (1 - a_s)\sigma_{soil,geobot}$$

$$H_{crit} = \max\begin{cases}1.5\,(s - a)\\ 1.15s' + 1.44d_p\end{cases}$$

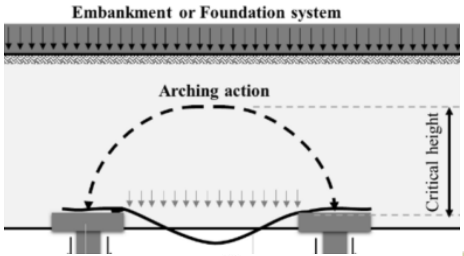
$$H_{crit}\ ?\ H$$

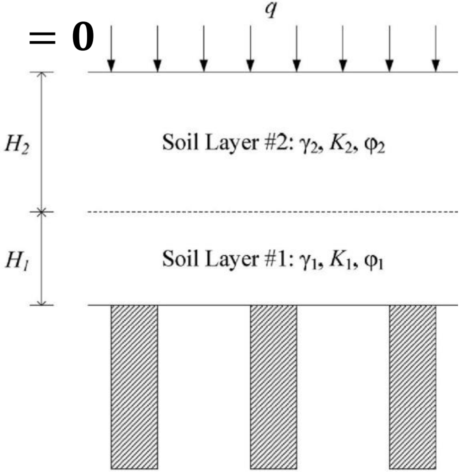
→

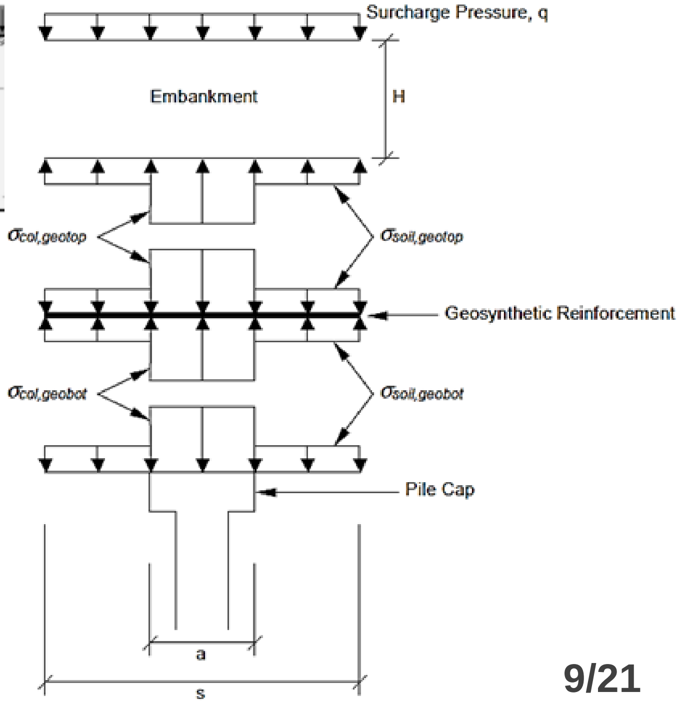
$$6T^3_{soil,geotop} - 6T\left(\frac{\sigma_{net}A_{soil}}{p}\right)^2 - J\left(\frac{\sigma_{net}A_{soil}}{p}\right)^2 = 0$$

$$\sigma_{net} = \sigma_{soil,geotop} - \sigma_{soil,geobot}$$

$$y = (s - a)\sqrt{\frac{3T}{8J_{GR}}}$$







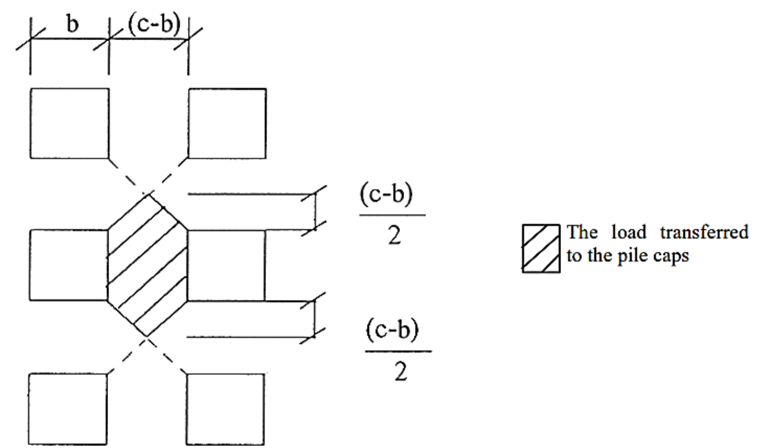
DESIGN METHODS

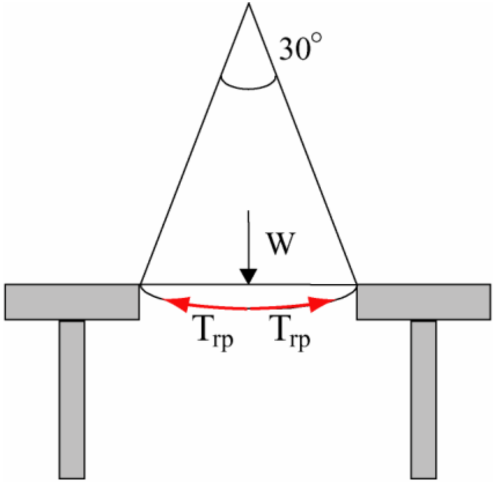
Nordic Design Guideline

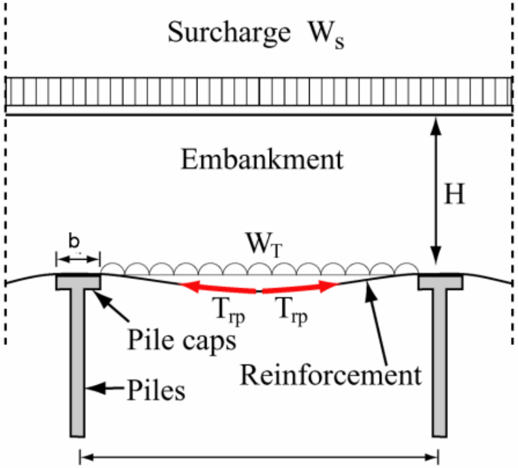
$$W_{2Dd} = \frac{(s-a)^2}{4\tan 15^\circ}\gamma = 0.93\,(s-a)^2\gamma$$

$$W_{3Dd} = \frac{1 + {}^{s}/_{a}}{2} W_{2Dd}$$

$$T = \frac{W_{3Dd}}{2}\sqrt{1 + \frac{1}{6\varepsilon}}$$







Comparison criteria:

- Efficacy (E%)

$$\mathbf{E} = \frac{\mathbf{P}}{(\boldsymbol{\gamma}\mathbf{H}+\mathbf{q})\mathbf{A}_{\mathbf{unitcell}}} \times \mathbf{100}$$

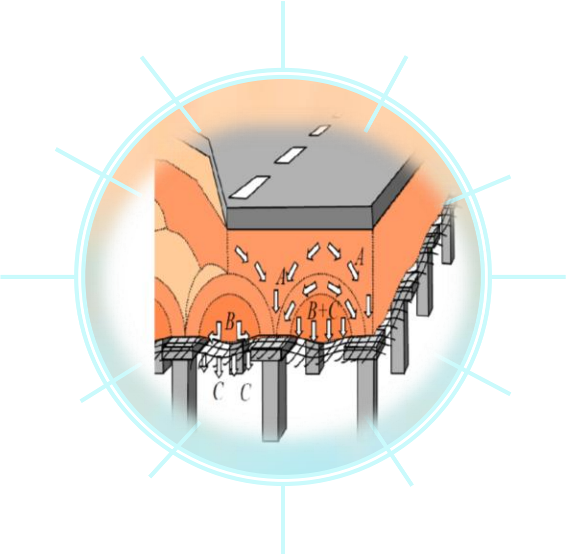
- Stress Concentration Ration (SCR)

$$\mathbf{SCR} = \frac{\boldsymbol{\sigma}_{\boldsymbol{C}}}{\boldsymbol{\sigma}_{\boldsymbol{S}}}$$

- Maximum differential settlement

- Maximum Reinforcement Tension (T)

$$\mathbf{T} = \mathbf{J}_{\mathbf{GR}}\,\boldsymbol{\varepsilon}$$

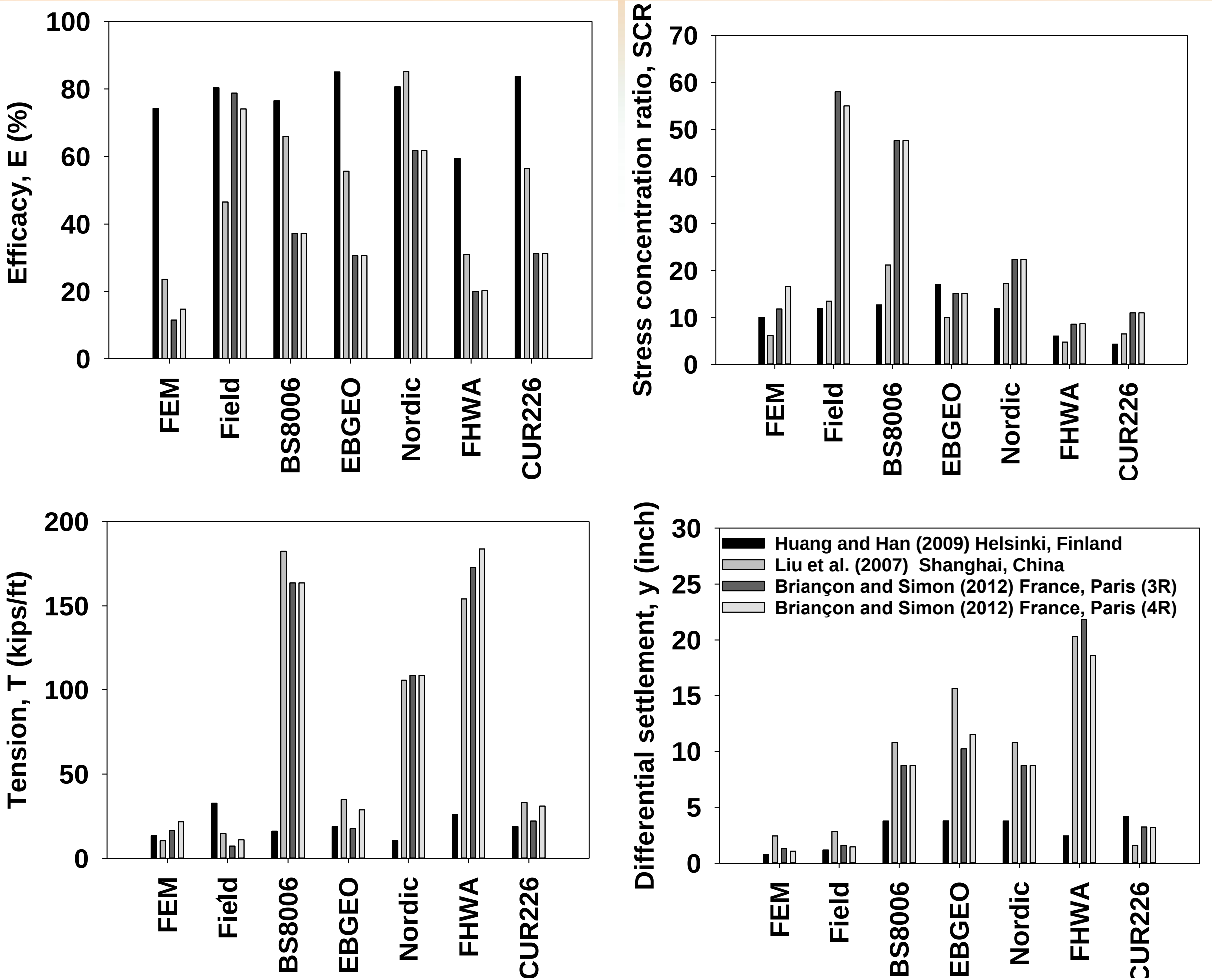


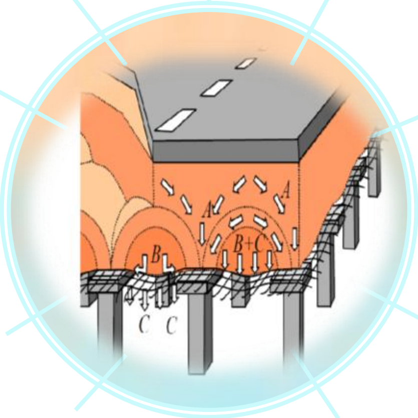
Evaluation of GRPS embankment design methods using case studies

Comparison between Field Measurements, FEM Results, and Design Methods

Sections	Parameters	Liu et al. (2007) (Shanghai)	Briançon and Simon (2012) (Paris)		Huang and Han (2009) (Finland)
			3R	4R	
LTP properties	Number of GR layers	1	1	2	1
	Thickness of LTP (ft)	1.64	1.8	2.13	1.97
	J_{GR} (Kips/ft)	80.86	39.74	54.13	116.49
Embankment properties	H (ft)	18.37	16.40		5.91
	γ (lb/ft^3)	118.4	118.4		128
	ϕ (◦)	30	36		38
	C (kips/ft2)	0.21	0.36		0.10
	ϕ equiv (◦)	34	42.5		42.62
	surcharge q (kips/ft^2)	0.00	0.00		0.25
Pile	Pile Pattern	Square	Square		Square
	Sx (ft)	9.84	6.56		4.59
	Sy (ft)	9.84	6.56		4.59
	a (ft)	3.28	1.25		2.30
Sub-Soil	K_s (kips/ft)	0.33	0.22		0.03

Comparison between Field Measurements, FEM Results, and Design Methods

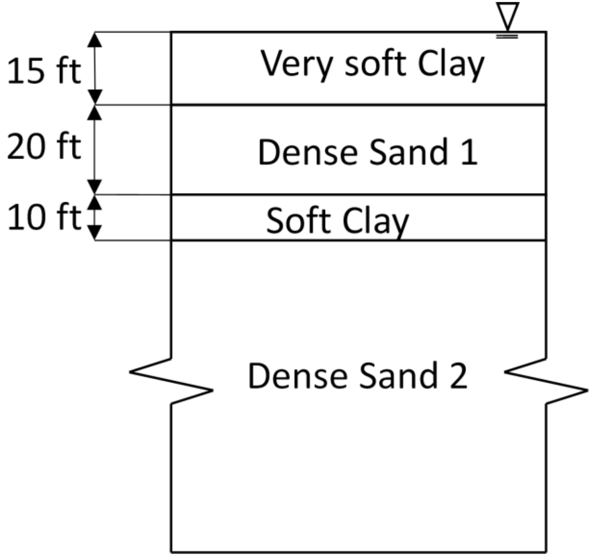




Evaluation of GRPS embankment design methods using 2D FEM

Evaluation of GRPS Embankment Design Methods Using 2D FEM Results

- Typical Louisiana soil conditions and recent LA DOTD project experience
- Three different embankment heights: 10 ft, 20 ft, and 30 ft.
- Timber piles' diameter: 1 ft
- Piles Square pattern Spacing: 3 ft, 4 ft, 5 ft, and 6 ft.
- All piles are end-bearing piles that are tip on the dense sand layer.

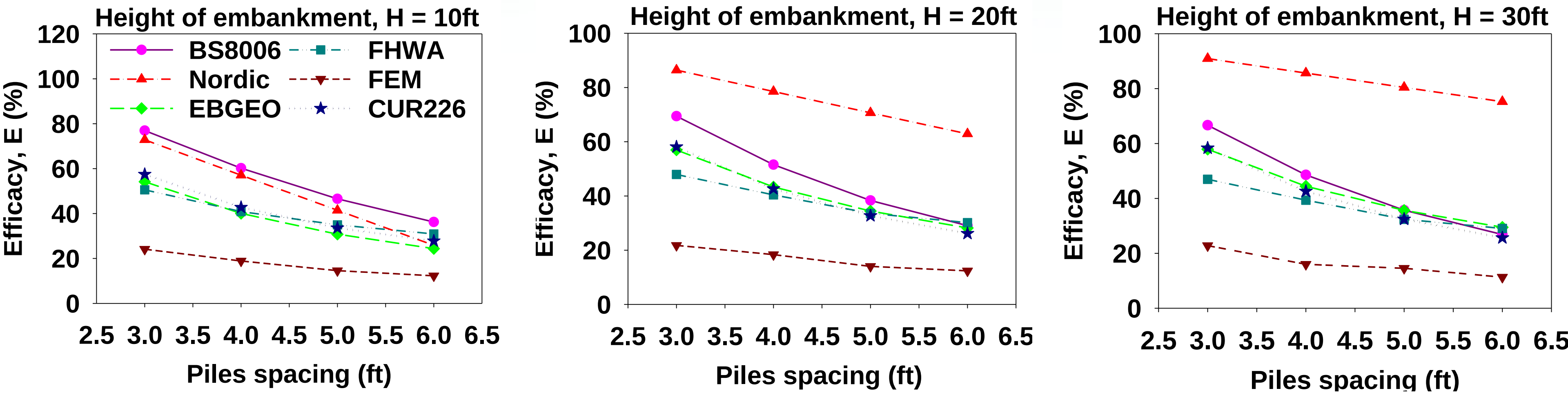


Evaluation of GRPS Embankment Design Methods Using 2D FEM Results

Soil Layer	γ lb/ft^3	e_0 (ψ °)	λ (ϕ'°)	κ (c' lb/ft^2)	M (E' kips/ft^2)	v	K_0	k_v $\times 10^{-4}$ (ft/day)	E_{50}^{ref} (kips/ft^2)	E_{oed}^{ref} (kips/ft^2)	E_{ur}^{ref} (kips/ft^2)	m power
Very soft clay	110.7	1.2	0.174	0.026	0.77	0.35	0.66	14.17	-	-	-	-
Soft clay	113.5	1.08	0.15	0.023	0.9	0.35	0.61	14.17	-	-	-	-
Medium dense sand	121.5	0.74	(33)	0	(731)	0.25	0.45	32808	-	-	-	-
Dense sand 1	129.8	0.53	(38)	0	(1148)	0.25	0.38	32808	-	-	-	-
Dense sand 2	131.1	0.5	(38)	0	(1148)	0.25	0.38	32808	-	-	-	-
Embankment	117.7	-	(30)	(208.8)	(418)	0.3	-	-	-	-	-	-
LTP gravel properties	117.7	(15)	(45)	(417.7)	-	0.2	-	-	710.1	551.3	2155	0.5

Evaluation of GRPS Embankment Design Methods Using 2D FEM Results

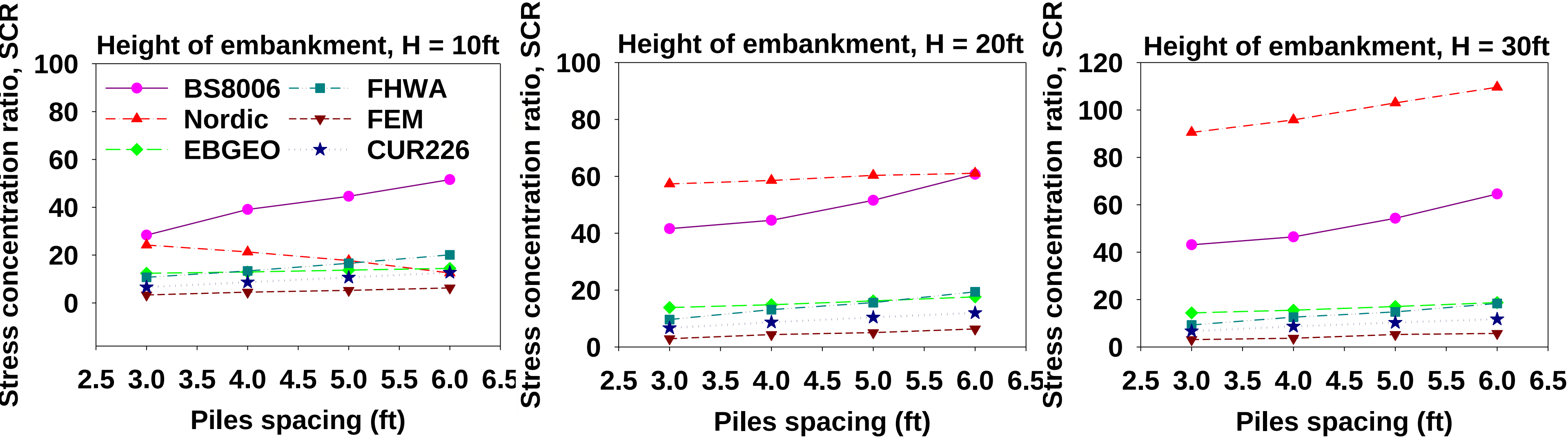
- **<u>Efficacy (E%)</u>**



- Efficacy decreases as pile spacing increases
- The FEM simulation results produce the lowest efficacy
- CUR226, EBGEO, and FHWA method gives the closest estimations to the FEM results

Evaluation of GRPS Embankment Design Methods Using 2D FEM Results

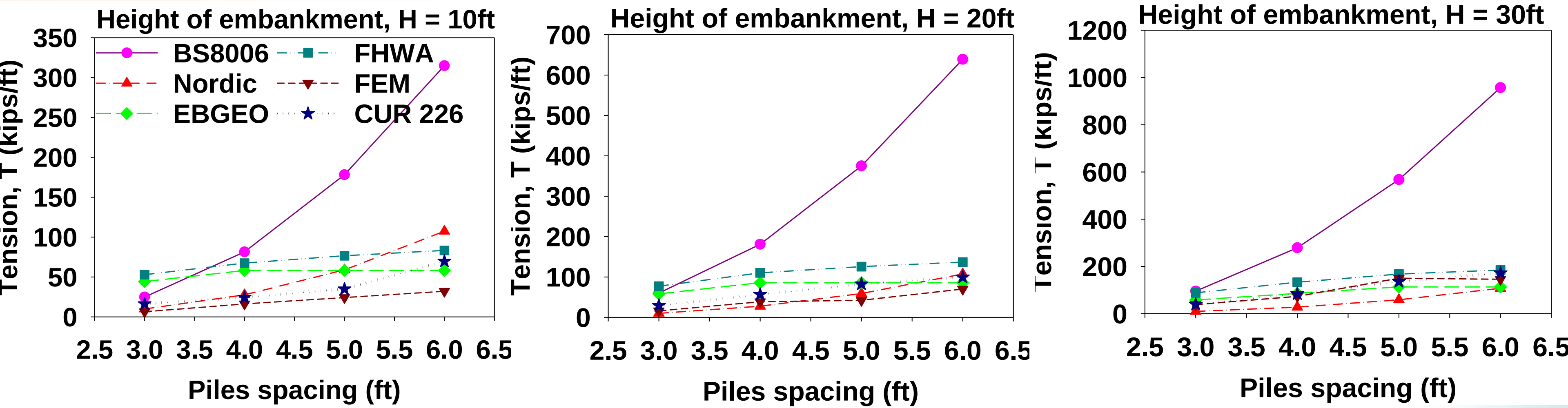
- **Stress Concentration Ration (SCR)**



- In most scenarios SCR index increases with increasing the pile spacing
- CUR226 method outperforms the other GRPS design methods
- Nordic and BS8006 methods overestimate the SCR index significantly

Evaluation of GRPS Embankment Design Methods Using 2D FEM Results

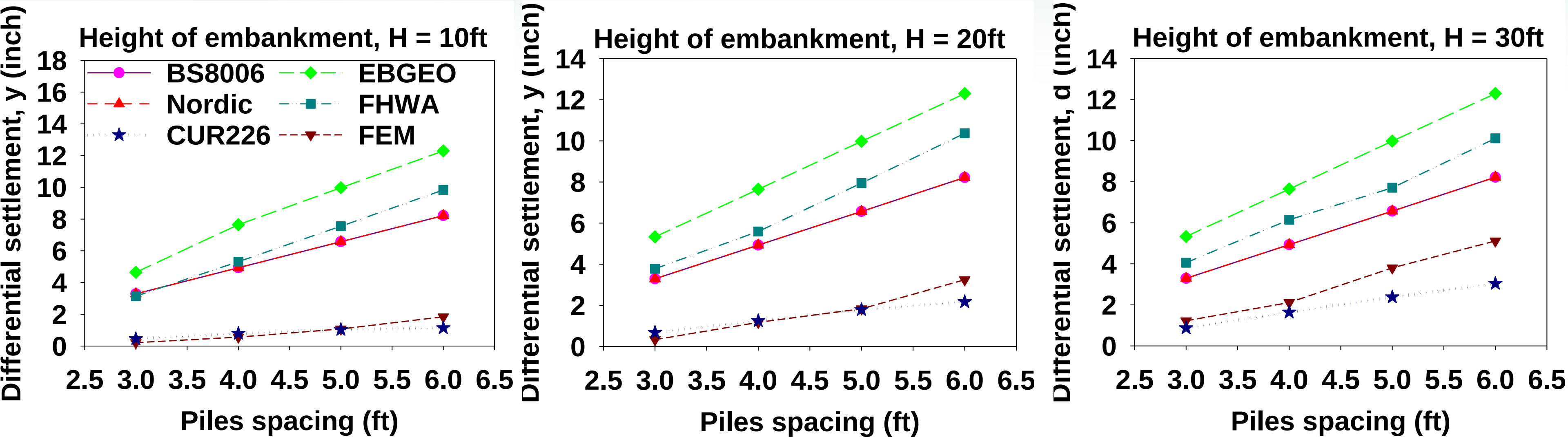
- **Maximum Reinforcement Tension(T)**



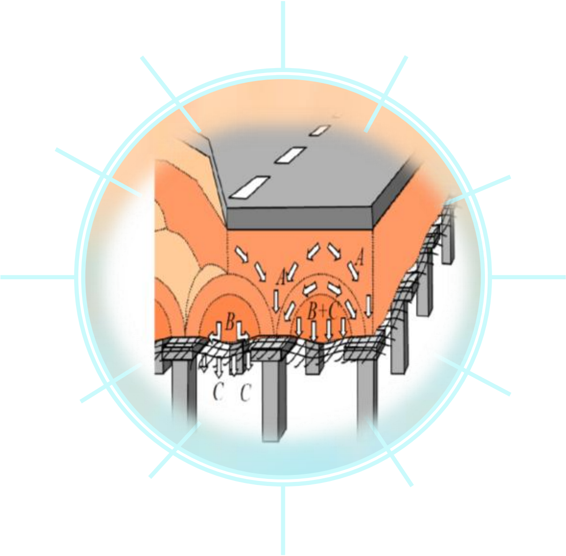
- BS8006 method, highly overestimate due to the assumption that there is no subsoil support under geosynthetic reinforcements.
- CUR226 and EBGEO prediction is the closest, which consider the subsoil support.

Evaluation of GRPS Embankment Design Methods Using 2D FEM Results

- **Maximum differential settlement**



- BS8006, FHWA, EGBEO, and Nordic methods overestimate the maximum differential settlement
- CUR226 produces results that agree well with the FEM results
- BS8006 and Nordic methods adopt the same equation.



Conclusions

Conclusions

- Assessment of the GRPS design methods using the three case studies shows that the performance of these methods varies from case to case and depends on the criterion considered.

- CUR226 method demonstrated the most reliable predictions of the case studies with good accuracy in all design criteria, except the efficacy in which the CUR226 gave higher predictions.

- The FHWA and EGBEO methods provide good estimations for efficacy, stress concentration ratio, and maximum reinforcement tension, but overestimate the differential settlement.

Conclusions

- The BS8006 and Nordic design methods give too conservative values of the four design criteria.

- The BS8006 method poorly estimated the maximum reinforcement tension for large pile spacing (> 4 ft), which is mainly due to its assumption that there is no vertical subsoil support to the geosynthetics.

- Contrary to other design methods, the Nordic method is found to be not applicable to small embankment heights due to its assumption that the soil wedge angle is fixed at 30 degrees, which is related to pile spacing only, regardless of the embankment height.

Thank you

Link of Paper