演讲嘉宾介绍

Sagar Mehra 是印度德里科技大学土木工程系的一名研究学者。目前，研究方向为高层建筑，深基础和桩基础，现在课题为循环扭转荷载作下群桩承载力特性研究。对 ETABS，SAFE，SAP，STAAD-PRO，Abaqus / CAE 和 Mathematica 软件应用方面拥有丰富的专业知识。在维也纳举办的中欧岩土工程会议（2018 年）上撰写过一篇题为“扭矩作用下单桩和桩群试验研究”的论文。

Analysis and Simulation of Cyclic Torque Application on Pile Groups
循环扭矩作用下群桩基础有限元分析

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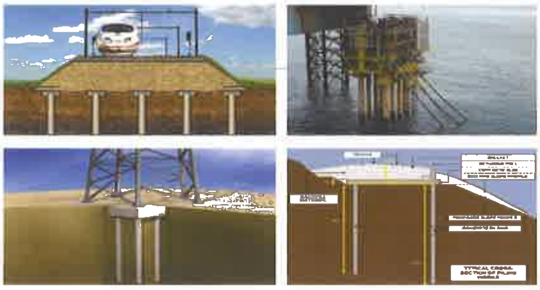

Large Structures on Pile Foundations

- The pile foundation groups (large structures) subjected to torque
- 承受扭矩作用大型结构的群桩基础实例
  - Offshore platforms海洋平台结构
  - Wind turbines风力涡轮机
  - Bridges桥梁
  - Railway embankment铁路路基
  - Traffic and signal pole structures 交通信号杆结构
  - High-rise buildings高层建筑

Abstract

- These structures experiences large cyclic loads in axial and lateral modes
- The lateral cyclic loads may in turn induce significant cyclic torsional moments to the pile foundations
- These cyclic torsional loads are induced due to the actions of wind and waves, ship impacts or moving trains etc.
- 这些结构由于风、波浪荷载和船撞、列车移动等，一般都会承受较大的轴向和水平向循环荷载，而水平循环荷载会导致桩基产生很大的循环扭矩。

Mechanism

- Mechanism of application of torque to a model single pile and model (m x n) pile groups ; m and n are the number of piles in the rows and columns of the group
- Experimental results of (1x2), (1x2) and (2x2) pile groups
  - In terms of torque-twist plots for the model single pile and model (m x n) pile groups
  - Simulate 3D models of (m x n) pile groups subjected to torque using finite element modelling, Abaqus/CAE
  - Analyse basis of pile-soil-pile interactions in the model (m x n) pile groups subjected to torque experimentally and using numerical model
- 单桩和群桩承受扭矩的力学机理
- (1x2), (1x2) and (2x2)的群桩试验结果分析：
  - 单桩和群桩的扭矩-扭转角曲线
  - 承受扭矩的群桩的三维数值模拟
  - 基于桩-土-桩相互作用分析基础上的承受扭矩的群桩试验和数值模拟

Overview

- During wind and wave actions torsional moments in addition to bending moments, shear and axial forces affect the load deformation behaviour of the pile foundations
- Transmission towers, traffic and signal pole structures are subjected to lateral loads of considerable magnitude
- Significant torsional forces can be transferred to the foundation of these structures due to the laterally loaded high tension wires
- Torsional moments can also be transferred to the foundations of offshore structures due to ship impacts, or high speed vehicles
- Inadequate consideration of torsional moments may results in failure of piles and ultimately into disastrous consequences
- 在风、浪的作用下，扭矩、弯矩、剪力和轴力都会影响桩基荷载作用下的形变。
- 输电塔、交通信号杆结构都承受了非常大的水平荷载。
- 由于高压线的水平荷载，巨大的扭矩会传递到这些结构的基础。
- 由于船舶撞击或者高速车辆，扭矩同样也会传递到海洋结构的基础上
- 对扭矩的考虑不足可能导致桩的破坏，最终导致灾难性的后果

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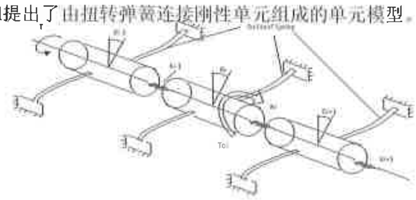
Overview

- Tall buildings (Mayer-Kaiser, Miami and Great Plains life, Lubbock, Texas) had suffered permanent damage due to wind action (Vickery, 1979)
- A support pier of the 6.82 km long Sunshine Skyway Bridge in Florida was eccentrically impacted by a bulk carrier and collapsed in 1980 (Barker and Puckett 1997)
- About 395m of the bridge fell into the sea, resulting in thirty five deaths (Barker and Puckett 1997)
- 由于风荷载作用，高层建筑受到了永久的破坏
- 佛罗里达长6.82公里的Sunshine Skyway 桥的一个支撑桥墩被一艘货船偏心撞击，并在1980年倒塌
- 桥梁大约有395米坠落到海中，并且造成了35人死亡

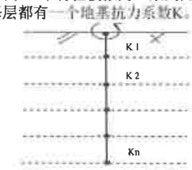
Review-Torque on Single Piles

- O'Neill (1964) presented the mechanical modal composed of rigid elements connected by torsional springs
- O'Neill提出了由扭转弹簧连接刚性单元组成的单元模型。

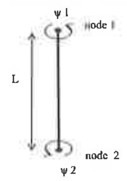


Discrete element mechanical modal
模型单元

- Chow (1985) presented a discrete element approach in which the pile was modelled as a series of elements
- Soil was treated as a series of independent layers, each with a modulus of subgrade reaction, K
- Chow提出了一个将桩模拟为一系列元素的离散元方法。土体被看作一系列独立的土层，且每层都有一个地基抗力系数K。



Discrete element modal for torsional response of Pile (Chow, 1985)
桩扭转响应的离散元模型



Typical torsional discrete element (Chow, 1985)
典型的扭转离散元

- The equilibrium equation for the torsional response of a pile embedded in a soil and modeled using the modulus of subgrade reaction approach (Yean K. Chow, 1985) is

$$- G_p J (\partial^2\psi/\partial Z^2) + K_{\psi} \psi = 0 \quad ...(1)$$

Where,
G_p = shear modulus of pile material
J = polar second moment of area of pile section
Ψ = angle of twist of pile
K_{ψ} = modulus of subgrade reaction of soil undergoing torsion
z = depth coordinate
T= Torque applied

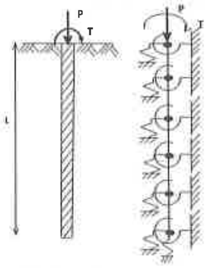
- For an element of length, L, the continuous variable, ψ is approximated (Yean K. Chow, 1985) in terms of its nodal values ψ_1 and ψ_2.

$$\Psi \cong \{n\}^T \{\psi\} \quad .... (2)$$

Where; $\{n\} = \{\frac{1-Z/L}{Z/L}\}$ and $\{\psi\} = \{\frac{\psi 1}{\psi 2}\}$

埋在土中桩的扭转响应的等式和利用地基抗力系数模量法来模拟

- Coupling between axial and torsional pile responses were investigated by Georgiadis (1987)
- Georgiadis (1987) 研究了桩在轴力和扭矩耦合作用下的响应



Numerical Pile Model (after Georgiadis 1987)

Assumptions
- A pile was considered as an elastic beam
- The soil was modelled with two series of elasto-plastic springs; one torsional and one axial
- Each pair of springs acts independently until at some depth the vectorial sum of the tangential and axial reaction becomes equal to the ultimate unit pile shaft resistance

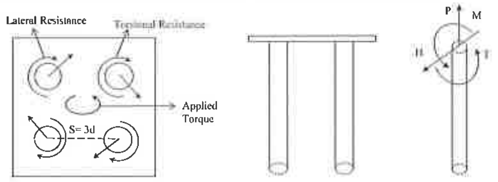
Findings
- Georgiadis and Saflekou (1990) modified the numerical model to account for non-linearity of the soil and to improve the interaction between the axial and torsional springs
- It was found that the application of an axial load reduced the ultimate torsional capacity and increases the pile rotation
- 假设：
- 桩被看作弹性梁
- 土体被模拟有两组弹塑性弹簧，一组是扭矩弹簧，一组是轴向弹簧
- 直到切向和轴向反力的矢量和与单位极限桩侧阻力相等的深度之前，每一个弹簧都是独立工作的。
- 成果：
- 考虑到土的非线性特征，并且为了改进轴向弹簧和扭矩弹簧的联系，Georgiadis and Saflekou改进了数值模型。
- 研究发现，轴向荷载的作用降低了桩的极限扭转承载力，增加了桩的旋转。

Review-Pile Groups

- Pile group behavior has been summarized by many researchers
很多研究者总结过群桩性能
  - O'Neill (1983)
  - Poulos (1989)
  - Reese and Van Impe (2001),
  - Basile (2003)
  - Kong(2006)

- Accordingly load sharing among piles in a group is influenced by
群桩钟每根桩的荷载分配的影响因素：
  - Pile-to-pile interaction桩间效应
  - Group stiffening effect群桩强化效应
  - Load deformation coupling载荷变形耦合
  - Soil non-linearity土的非线性

- The response of a pile group subjected to torsion is governed by the interaction between the torsional and lateral behavior of individual piles
- 群桩受扭时的响应由单根桩的扭转和水平横向性能的相互作用决定。



Movements in (2x2) pile group under torque and pile head forces in a torsional loaded pile group
扭转荷载作用下的群桩(2x2)的位移以及桩顶力

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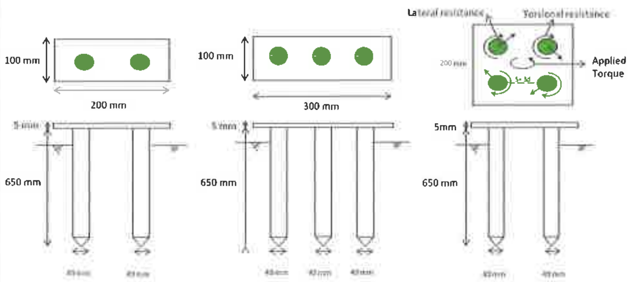
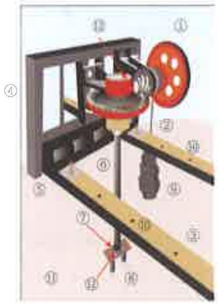
Model Test 模型试验

- The test models (1x2), (1x3) and (2x2) consist of mild steel pipe piles having 400 mm diameter cross-section and 650 mm length
- The thickness of the steel pipe pile is 2.5 mm
- The pile cap is also made up of mild steel plate having dimension (200mm x 100mm), (300mm x 100mm) and (200mm x 200mm) respectively
- The thickness of the pile cap plate is 5 mm
- The centre to centre distance between the steel pipe piles is maintained at three times the outer diameter of pipe pile
- The tip of the steel pipe pile is a cone maintained at 45° apex angle
- 试验模型(1x2)、(1x3)和(2x2)由直径为400毫米、长度为650毫米的低碳钢管桩组成
- 钢管桩的厚度为2.5 mm
- 承台亦由尺寸分别为(200mm x 100mm)、(300mm x 100mm)及(200mm x 200mm)的低碳钢板组成
- 承台厚度为5mm
- 钢管桩截面中心之间的距保持在管桩外径的三倍
- 钢管桩的尖部为圆锥，圆锥角保持在45度

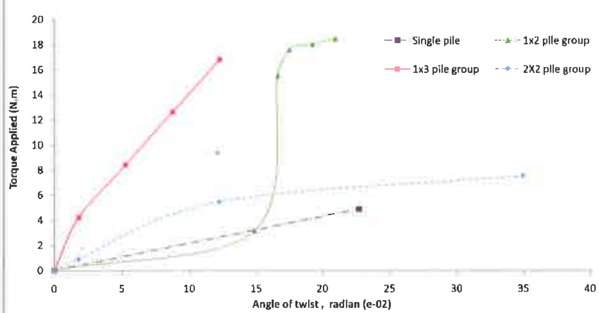


Diagrammatical representation of (1 x 2), (1x3) and (2x2) pile group
(1x2),(1 x3)和(2 x2)群桩的图像表示

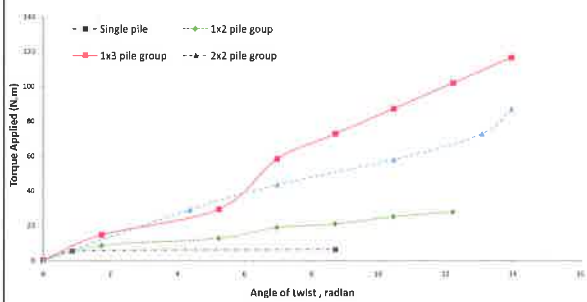


①	Pulley for hanging weights 吊重滑轮
②	High tensile wire 高强度钢丝
③	Girder ISMC 100 梁ISMC 100
④	Vertical suspension 垂直悬挂
⑤	Supporting frame 支撑结构
⑥	Connecting shaft 连接轴
⑦	Pile cap 承台
⑧	(1x2) pile group（1x2）群桩
⑨	Weights 重物
⑩	Holes for moving machine移动机孔
⑪	Loose/dense sand 松散/密致砂
⑫	Angle of twist 扭转角

Mechanism of applying torque on a model single pile and model (m x n) pile groups, where m and n are the number of piles in a group (Mehra, 2011)
当扭矩作用在模型单桩和模型(m x n)群桩上时的力学机制，m和n是群桩中桩的数量



Plot of applied torque and twist angle in dense sand
紧砂中施加扭矩与扭转角关系的图像



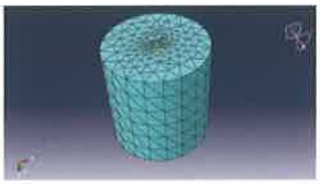
Plot of applied torque and twist angle in dense sand
紧砂中施加扭矩与扭转角关系的图像

Numerical Modelling 数值模拟

- Three dimensional (3D) plain-strain finite element analysis was carried out using Abaqus/CAE to investigate the nonlinear behaviour of (m x n) pile groups subjected to pure torsional loads
- 3D modelling was set up to represent the behaviour of soil-pile interface using interface elements
- In this the soil continuum was divided into number of (volume) elements
- Each element consists of nodes and each node has a number of degrees of freedom that corresponds to discrete values of unknowns. The boundary conditions were thus applied to solve the problem
- The pile cap and piles were modelled as an elastic perfectly plastic model in the Abaqus/CAE
- 采用Abaqus/CAE对(m x n)群桩在纯扭转荷载作用下的非线性特性进行了三维平面应变有限元分析
- 建立了三维模型，利用界面元表示桩土界面的特性。
- 在这种情况下，连续土体被分为单位元（体积）
- 每个单元都由节点组成，每个节点都有多个自由度，这些自由度对应于未知的离散值。应用边界条件求解这些问题。
- 在Abaqus/CAE软件中，承台和桩被模拟为理想的弹塑性模型

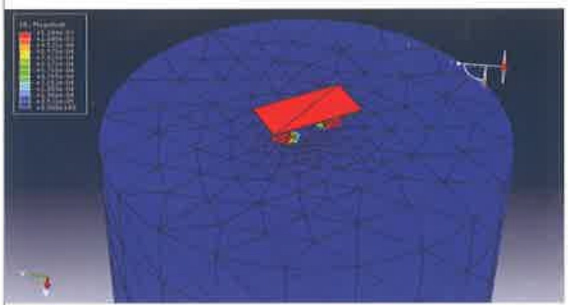
- A strain hardening model using Mohr-Coulomb failure criterion was adopted for the soil
- In the present FE analysis, the authors used 10-noded tetrahedron interface elements (nonlinear-C3D10) that could capture the interlocking effects to some extent in terms of strength parameters, effective friction angle, ϕ_{soil} and young modulus of soil, E_s of the soil
- A relatively fine mesh was adopted for the pile cap and piles and coarser mesh was adopted for the sand
- 采用莫尔-库仑破坏准则建立了土的应变强化模型
- 在目前的有限元分析中，作者用十节点四面体界面单元，这种方式可以在某种程度上就强度参数，有效摩擦角ϕ_{soil}和土体杨氏模量获得一些连锁效果。
- 承台和桩采用较细的网格，砂采用较粗的网格

Boundary conditions used in Abaqus/CAE with triad and compass;

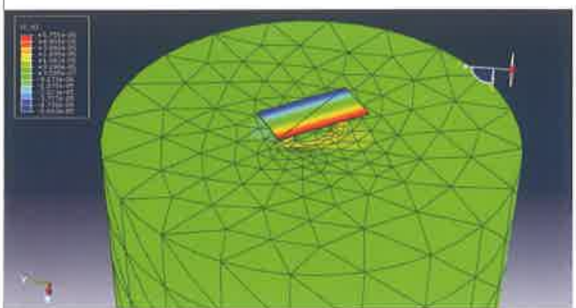


Three dimensional numerical model; Tet shape mesh
三维数值模型

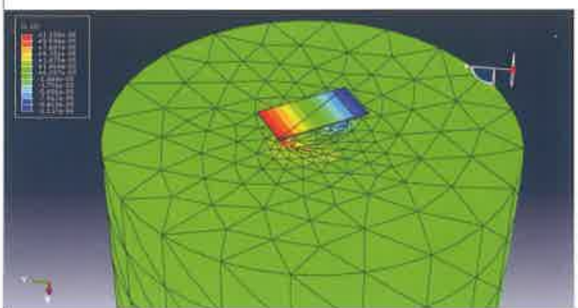
(m x n) pile group; m=1 n=2



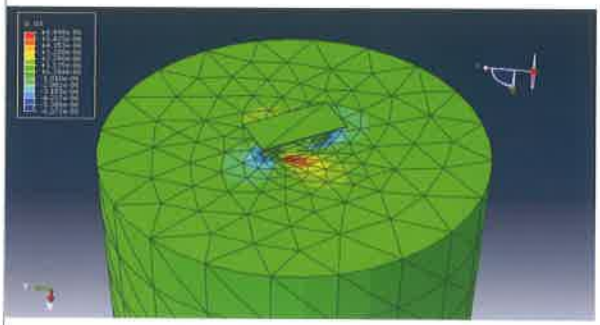
Rotational displacement (UR) of nodes;
(m x n) pile group; m=1, n=2
节点的旋转位移



Spacial displacement of nodes in x-direction(U1)
(m x n) pile group; m=1, n=2
x方向节点空间位移



Spacial displacement of nodes in y-direction(U2)
(m x n) pile group; m=1, n=2
y方向节点空间位移



Spacial displacement of nodes in z-direction(U3)
(m x n) pile group; m=1, n=2
z方向节点空间位移

Conclusion

Experimental Result

- Model (m x n) pile groups resistance to applied torque compared to the model single pile is at rate shown by the numerical model
- Resistance to application of torque is significantly greater in dense sand as compared to loose sand
- The behavior was accompanied by lateral and torsional movement of individual piles as shown by the NM
- The patterns in the shear zones around the pile in the dense and loose sand were dilative and densifying respectively

试验结果：

对于施加的扭转荷载，通过数值模型用模型群桩 (m x n)与单桩的抗力比值来表示。

与松砂相比，筋砂对施加的扭矩阻力要大得多。

在桩性行为研究中，通过NM来表现各单桩的水平位移和扭转位移表

在紧砂和松砂中的桩周剪切层的形态分别为膨胀型和紧缩型

Conclusion

Numerical Modelling- Abaqus/CAE

- Numerical results show consistent trend with the experimental results
- Torsional resistance of model single pile and model (m x n) pile groups increases with increase in modulus of elasticity
- The behavior was accompanied by lateral and torsional deformations of individual piles and soil
- Spacial displacement of nodes shows the soil mass compression in the direction of torque applied and dilate in opposite direction

数值模拟-Abaqus/CAE

数值结果与实验结果有一致性

模型单桩和模型(m x n)群桩的抗扭能力随弹性模量的增加而增加

在此过程中，单桩和土体均发生横向变形和扭转变形

节点的空间位移表示土体在施加扭矩方向上压缩，在相反方向膨胀

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