演讲嘉宾介绍

Paulus Pramono Rahardjo 教授本科就读于 Universitas Katolik Parahyangan (UNPAR)，此后在该校任教。他曾在万隆理工学院（ITB）攻读公路工程研究生，然后获得了弗吉尼亚理工大学（美国）的硕士和博士学位。他积极从事教学、研究以及数百项岩土工程咨询工作。他在许多岩土工程问题上为客户提供设计和咨询服务，包括建筑地基、公路、隧道、桥梁、码头、水坝、采煤以及边坡保护措施。他撰写了超过 200 篇文章、论文、研究报告和手册。曾任大学系主任、工程学院副院长、研究生院院长和学术事务副校长。目前，他是岩土工程部协调员和基础设施和城市发展研究中心主任。他加入了印度尼西亚岩土学会（HATTI）、美国地质研究所土木工程师协会、印度尼西亚灾害专家（IABI）和国际滑坡联合会（ICL）董事会代表，目前担任印度尼西亚万隆 Universitas Katolik Parahyangan 深基础研究所的负责人。

MonitoringTheBehaviorofBoredPilesin LandslidesandSlopeProtectioninIndonesia

印尼滑坡与边坡防护中钻孔桩行为监测

PROF PAULUS P. RAHARDJO, PH.D

UNIVERSITAS KATOLIK PARAHYANGAN

BEHAVIOROFPILESINLANDSLIDES
ANDSLOPEPROTECTION 滑坡与护坡中钻孔桩的行为

Content：内容：

- Back Ground - 背景
- Instrumentation : Inclinometers -仪器仪表：测斜仪
- Formula used for slope and forces calculation 边坡及力计算公式
- CASE HISTORIES 历史使用情况
- CONCLUSIONS 结论

BACKGROUND 背景

Bored Piles in Landslides Area 滑坡区钻孔灌注桩

- Commonly Used 常用
- Failures of NATURAL SLOPE & MAN-MADE SLOPES
天然斜坡及人造斜坡的破坏
- For Protection of Excavation 为保护开挖

Seldom Measured for Their Actual Performance
很少衡量他们的实际表现

FiveCASEHISTORIES
五种历史使用情况

Piles in Landslides Area 滑坡区的桩

- (1) piles used for protection of excavation 基坑支护用桩
- (2) piles used for foundation of bridge abutment 桥梁桥台基础用桩
- (3) piles used to increase slope stability in landslides area,
用于提高滑坡地区边坡稳定性的桩
- (4) piles used for protection of embankment near failure due to reactivaed landslides 桩在复动滑坡路堤失稳防护中的应用
- (5) piles used for protection and substitute of bridge foundation in landslides area 桩基在滑坡区桥梁基础防护与置换中的应用

PILESINSTRUMENTATION
桩测仪器

MAINLY USE INCLINOMETERS
主要用测斜仪

Inclinometer 测斜仪

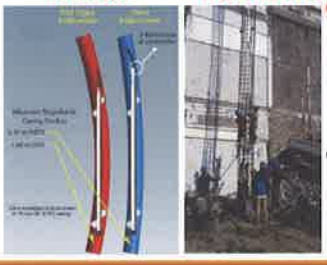
Inclinometer System 测斜仪系统

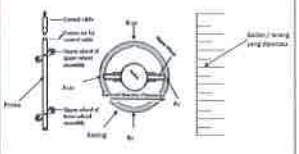
An inclinometer system includes :
一个测斜仪系统包括

- inclinometer casing 测斜管
- an inclinometer probe 测斜仪探头
- control cable and 控制电缆
- an inclinometer readout unit.
测斜仪读出装置

Inclinometer 测斜仪

Inclinometer Probe INSTALLATION IN BORED PILES
钻孔灌注桩中测斜仪的安装

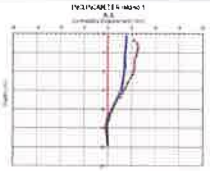




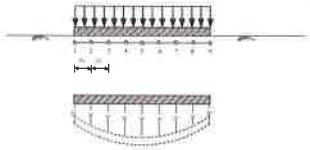
Example where Inclinometers needed
需要测斜仪的实例

1. Movement is ussually relatively slow 运动通常比较缓慢
2. Sliding plane not known (might need more than one)
   滑动平面未知（可能需要不止一个）
3. Embeded in piles (or other structures) to measure behavior of the piles
   嵌入桩(或其它构筑物)中以测量桩的行为
4. On going operation of highway, railways etc 公路、铁路等的运营
5. Excavation in Urban areas 城市开挖

FORMULAS USED for INTERPRETATION



Slope : dy/ dx
Momen : -EI d^2y/dx^2
Geser : -EI d^3y/dx^3



$dy/dx = (y_{i+1} - y_{i-1})/ 2\delta x$

$d^2y/dx^2 = (y_{i+1} - 2y_i + y_{i-1})/ (\delta x)^2$

$d^3y/dx^3 = (y_{i+2} - 2y_{i+1} + 2y_{i-1} - y_{i-2})/ (2\ \delta x)^3$

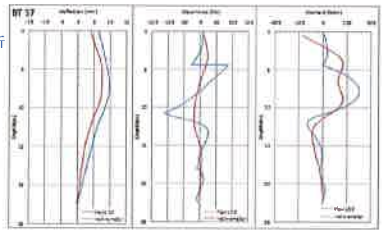
CASE 1 : PILES USED FOR PROTECTION OF EXCAVATION (SOLDIER PILES)

SOUVEREIGN TOWER andGKMTOWER
SouthJakarta 南雅加达
Excavation 12 m, 800mm dia bored pile, c/c 1.6 m
开挖12m，直径800mm的钻孔灌注桩，c/c 1.6m

CASE 1 : PILES USED FOR PROTECTION OF EXCAVATION (SOLDIER PILES)

Interpretation of slopes and internal forces of boredpiles
钻孔灌注桩的边坡和内力解释

Measured 测量值
Back analysis 反向分析



GKMTOWER
SouthJakarta 南雅加达
Excavation 11 m, 800mm dia bored pile, c/c 1.6 m
开挖12m，直径800 mm钻孔灌注桩，c/c 1.6m
Soil Nailing at 4 m below Ground 地下4米处的土钉

CASE 1 : PILES USED FOR PROTECTION OF EXCAVATION (SOLDIER PILES)

CiputraTOWER Jakarta 雅加达
Excavation 12.5 m, 800mm dia bored pile, c/c 1.2m
挖孔12.5米、直径800毫米钻孔灌注桩，c/c 1.2m
FreeStanding 独立式

CASE 1 : PILES USED FOR PROTECTION OF EXCAVATION (SOLDIER PILES)

CiputraTOWER
Jakarta 雅加达

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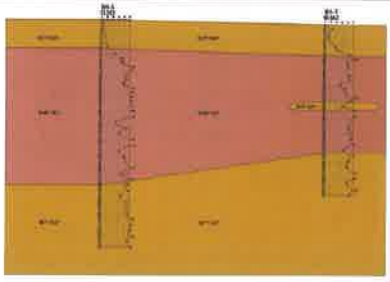

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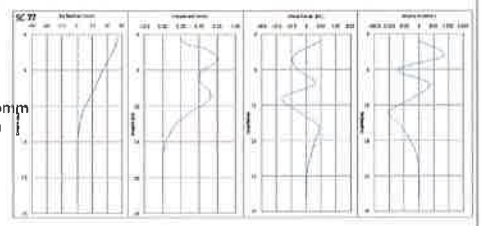

CASE 1 : PILES USED FOR PROTECTION OF EXCAVATION (SOLDIER PILES)

Interpretation of slopes and internal forces of boredpiles

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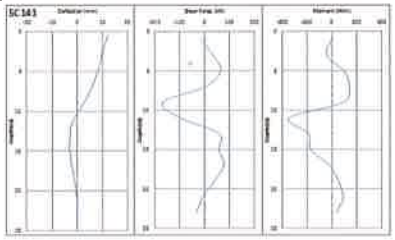
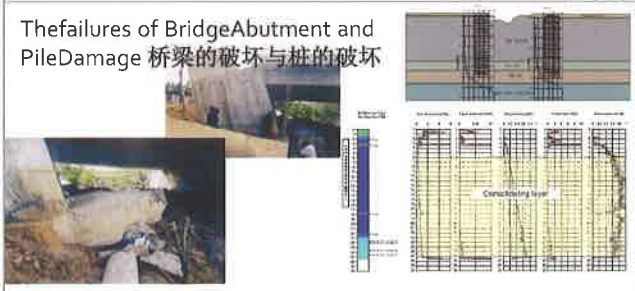
FreeStanding 独立式



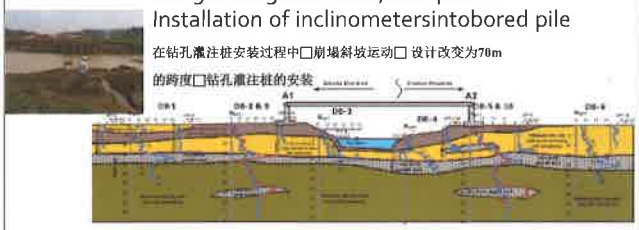
CASE 2: PILES UNDER BRIDGE ABUTMENT

Thefailures of BridgeAbutment and PileDamage 桥梁的破坏与桩的破坏



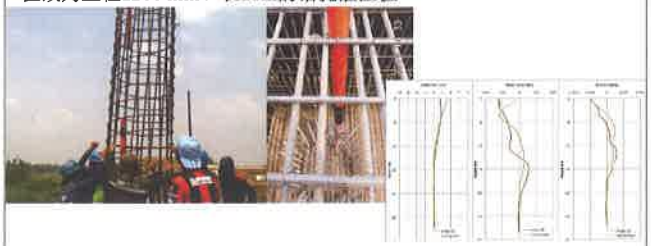
CASE 2: PILES UNDER BRIDGE ABUTMENT

During installation of driven piles → failuredueto slope movement → designchangedto have70m span → Installation of inclinometersintobored pile
在钻孔灌注桩安装过程中□崩塌斜坡运动□ 设计改变为70m的跨度□钻孔灌注桩的安装



CASE 2: PILES UNDER BRIDGE ABUTMENT

Pileswerealsochangedinto bored pile 1200 mm length28m
桩改为直径1200 mm、长28m的钻孔灌注桩



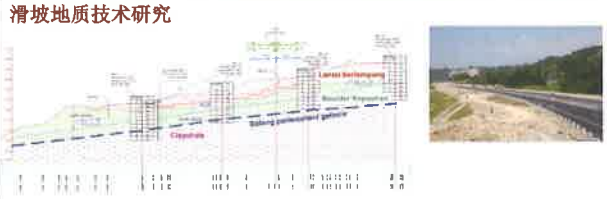
CASE 3: PILES TO SUPPORT LANDSLIDES

Crackswеredeveloped 裂纹形成

CASE 3: PILES TO SUPPORT HIGHWAY EMBANKMENT ON OLD LANDSLIDES

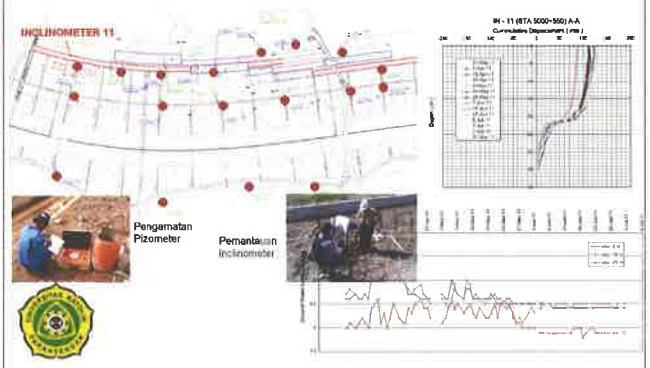
GeotechnicalStudy for landslides at Sta 5+500 –Sta 5+750 Semarang-Solo HighwaySection - Paket II

在Sta 5+500 –Sta 5+750 Semarang-Solo HighwaySection - Paket II 的滑坡地质技术研究



Geologi Lembar Semarang -Magelang

Peta Geologi Daerah Semarang dan sekitarnya (disederhanakan oleh S. Pandjaprajitno, [illegible] dan A. Cita, 2008 dari Peta Geologi Lembar Magelang dan Semarang, Thanden dkk, 1996)



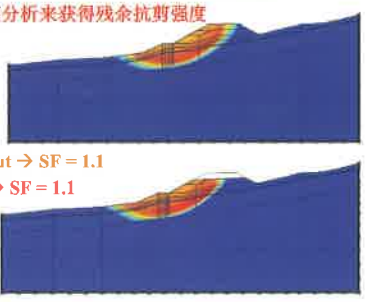
Reactivated Old Landslides where plane of failure is bondary between clayshale and breccia

Failure Plane deeper than whatwas expected

比预期更深的滑裂面

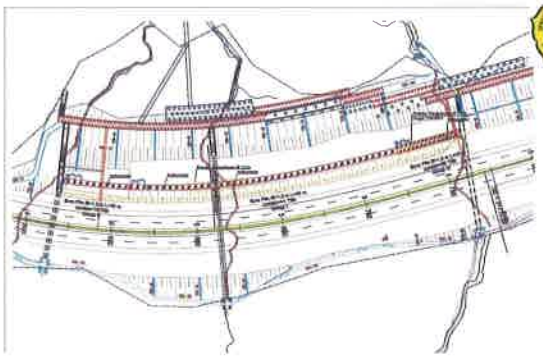
Back Analysis to give residual shear strength

通过反演分析来获得残余抗剪强度



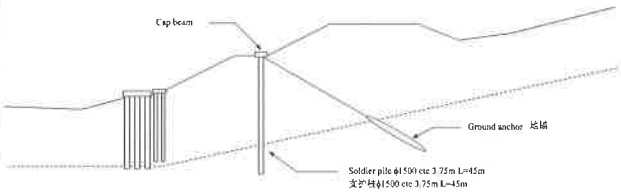
After 7 m cut → SF = 1.1

7m切割后→ SF = 1.1



Proposed method by soldier piles and ground anchor, FS = 1.52

支护桩与地锚法支护方案的提出，$FS = 1.52$

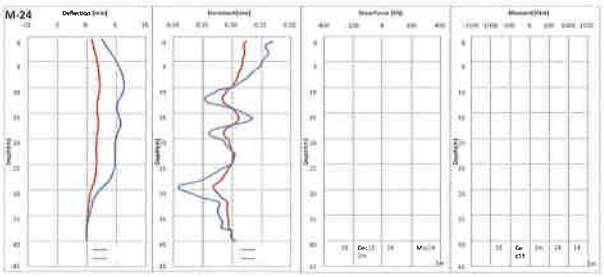


Construction progress

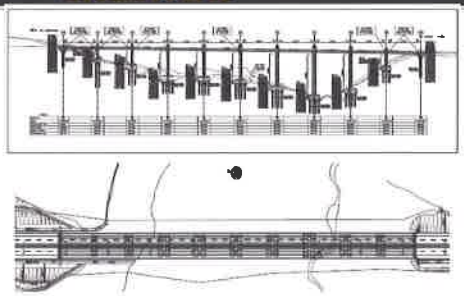
progress 50%

Fotograph during construction

Results of Pile Movement after 1 year



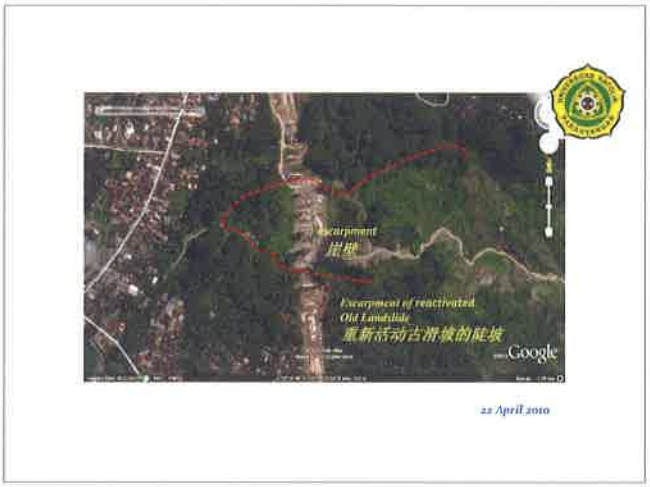
Case 4 : Piles Used to support briges in landslides area

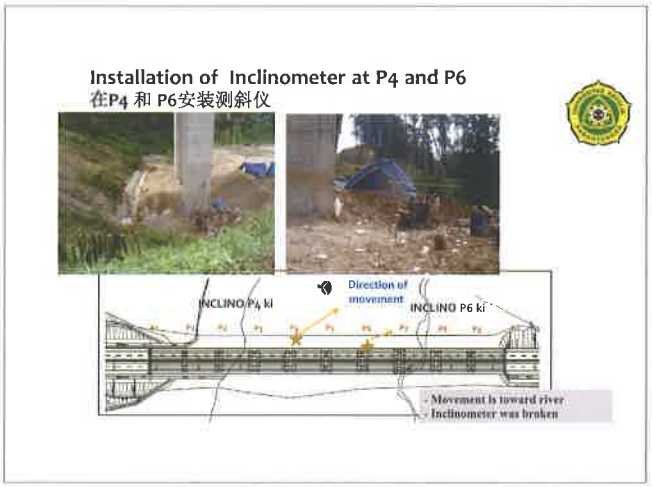


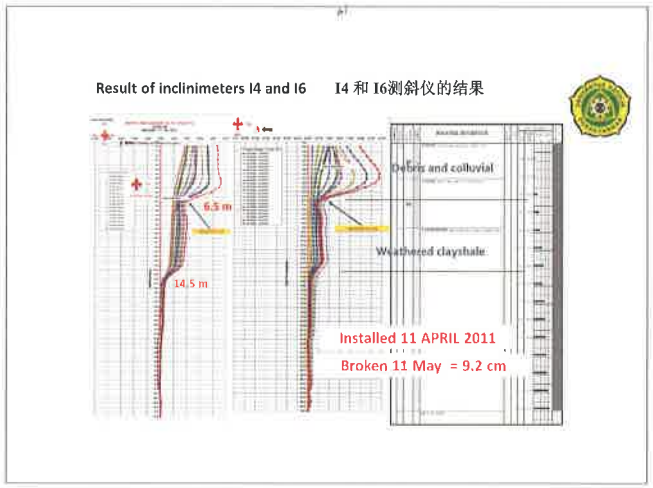
Geotechnical Problems with Clay-shale

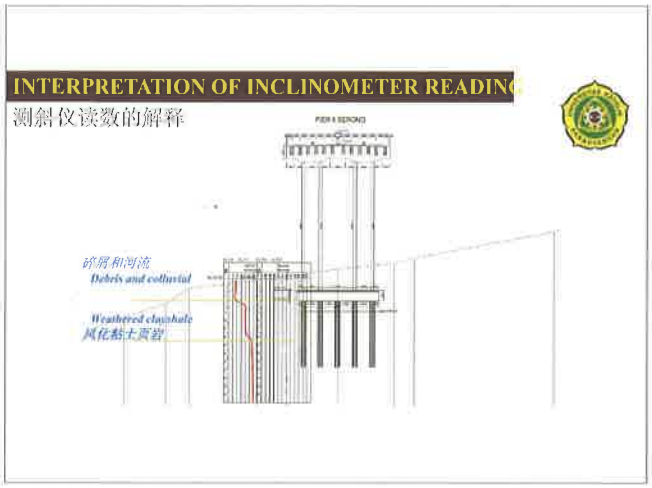
- Slope stability problems边坡稳定问题
- Unsuitable fill material 不合适的充填材料
- Soften when contact withwater →
  Reduce Bearing Capacity of boredpile
  接触水时软化□降低钻孔灌注桩承载力

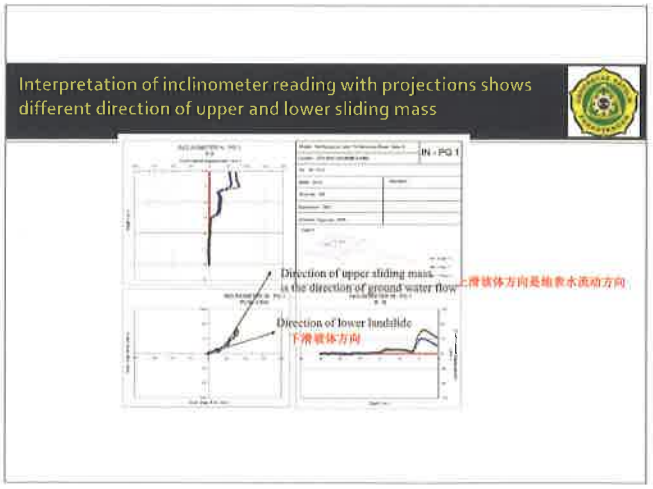

IDENTIFICATION OF OLD LANDSLIDES 历史滑坡识别
22 April 2010


Escarpment
崖壁
Escarpment of reactivated Old Landslide
重新活动古滑坡的崖坡
22 April 2010

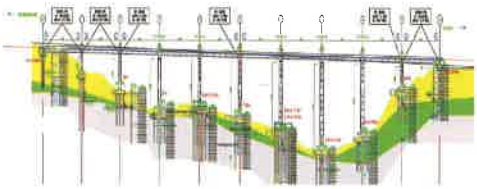

Installation of Inclinometer at P4 and P6
在P4 和 P6安装测斜仪
INCLINO P4 ki
Direction of movement
INCLINO P6 ki
Movement is toward river
Inclinometer was broken


Result of inclinimeters I4 and I6 I4 和 I6测斜仪的结果
6.5 m
14.5 m
Debris and colluvial
Weathered claystone
Installed 11 APRIL 2011
Broken 11 May = 9.2 cm


INTERPRETATION OF INCLINOMETER READING
测斜仪读数的解释
Debris and colluvial
Weathered claystone

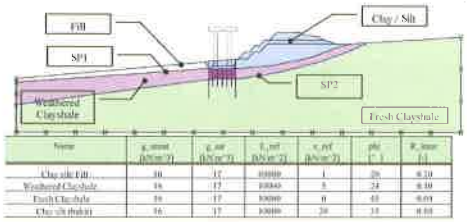

Interpretation of inclinometer reading with projections shows different direction of upper and lower sliding mass
Direction of upper sliding mass is the direction of ground water flow
Direction of lower landslide

桥梁地基稳定性的有限元分析
ASSESSMENTOF BRIDGE FOUNDATION STABILITY BY FINITE ELEMENTANALYSIS



Additional Geotechnical Drillings

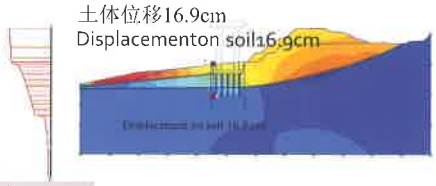
Assessment of Bridge Foundation stability by finite element analysis



Use Predetermined sliding plane, back analysis to obtain the residual friction angle

利用预定的滑动面，反演分析得到残余摩擦角。

2D FE Analysis at pier 4



桩位移模式
Mode ofpiledisplacement

Use Predetermined sliding plane, back analysis to obtain the residual friction angle

Result of 2D Analysis

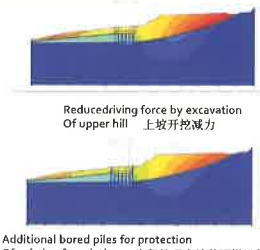
Maximumbendingmomentonpiles 史上最大弯矩

No.Pier	Deformasi Horizontal (cm)	Momen Maksimum (tonm)
P-04	15,8	135
P-05	12.7	142
P-06	17.6	153

Theseforces shall be comparedto pile Capacity
这些力应与桩的承载力相比较

Addition of bored pile increase safety factor by +0.1
钻孔灌注桩的加入使安全系数增加0.1
(assumption water teble 4 m below groundsurface) 假定地下水在地面以下4m

Result of analysis



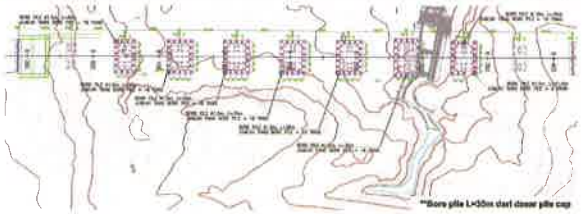
Reducedriving force by excavation Of upper hill 上坡开挖减力

Additional bored piles for protection Of existing foundation 为保护现有地基而增设的钻孔灌注桩

No.Pier	FaktorKeamanan	
	Pengupasan Bukit	Pengupasan Bukitdan Borpile
P-04	1.43	1.53
P-05	1.43	1.63
P-06	1.43	1.64

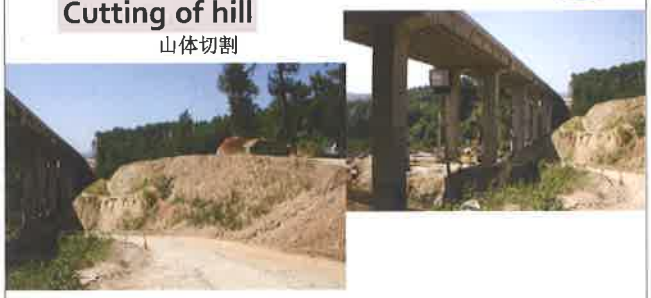
DESIGN FOR PROTECTION OF THE BRIDGE

- Keepwatertableaslowaspossible.保持尽可能低的水位
- Reducedrivingforce(byhillexcavation)减少驱动力(通过山坡挖掘)
- Installationof protectionboredpilessurrounding theexistingpiles保护桩的建立-对现有桩的围护



CONSTRUCTIONAND MONITORING 结构监测

Cutting of hill
山体切割

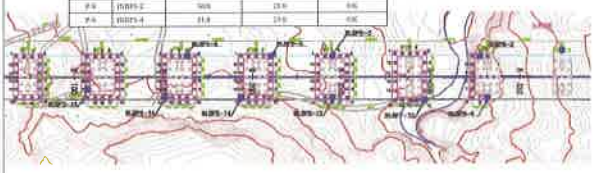


Bored Pile for protection of existing piles

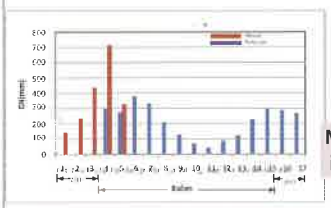
Installation oif inclinometers

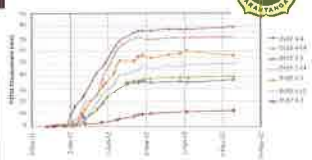
Monitoring Inklinometer

10 inclinometers were installed
安装了10个测斜仪
Only 8 inclinometers give valid data
只有8个有效



Monitoring Inklinometer

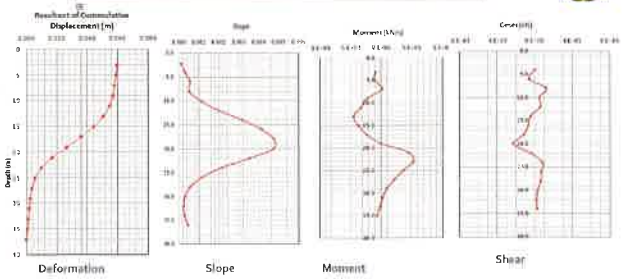




Movementof pile head from inclinometers
根据测斜仪得到的桩头位移

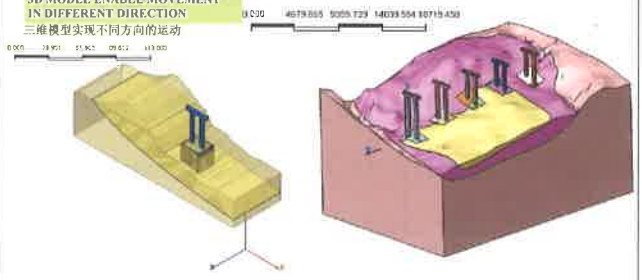
Rain intensity in the area
该地区的降雨强度

Estimasi Gaya Dalam pada Borpile Perkuatan

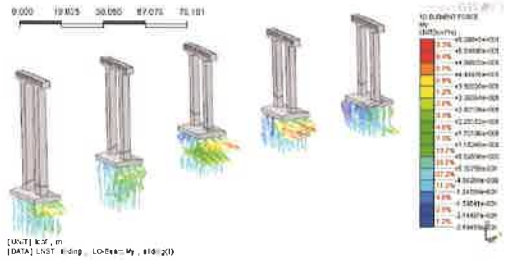


DEVELOPMENT IN 3DANALYSIS

3D MODEL ENABLE MOVEMENT IN DIFFERENT DIRECTION
三维模型实现不同方向的运动



Results of 3D Analysis



Conclusions

- The used of bored piles to control slope movement is effective, however there should be sufficient depth where the piles are fixed
钻孔灌注桩用于控制边坡滑移是有效的，然而桩应有足够的持力层深度。
- Based on inclinometers and other data, the failure plane can be detected, furthermore if the inclinometers are embedded into the boredpile, valuable information can be obtained, not only the safety and the plane of failure, but also the estimated forces acting in the boredpiles. This information has been used to assess the safety and performance of the bored piles and condition for further stabilization work.根据测斜仪等资料，可以检测出钻孔灌注桩的破坏面，将测斜仪埋入钻孔灌注桩内，不仅可以得到有价值的信息，而且还可以分析得到钻孔灌注桩的安全和破坏平面，以及钻孔灌注桩中的内力估计值。这些资料已用于评估钻孔灌注桩的安全性，可为进一步稳定工作的提供条件。

Conclusions

- During construction or following the remedial action, inclinometers can be installed inside the bored-piles to be monitored for long term. This will help the understanding of further movement and to ascertain the stability and safety of the slope and embankment.

在施工期或在补救措施之后，测斜仪可被安装在钻孔桩内，进行长期监测，这将有助于了解桩基的位移发展趋势，并确定边坡和路堤的稳定性和安全性。

Conclusions

- The finite element analysis is capable of simulating back analysis of the landslides mechanism and shows the additional (primarily lateral) load on the piles were still within the safe range of pile lateral capacity. However, further movement might cause subsequent damages and hence additional action shall be proposed At present many new piles have been constructed with inclinometers embedded in the piles to monitor possible further movement.

有限元能够为滑坡机理的提供反演分析，结果表明桩上附加（主要是侧向）荷载仍在桩基水平承载力的安全范围内。然而，进一步的移动可能会导致桩基的破坏。因此，应该提出更多的边坡防护措施。目前，许多安装有测斜装置的桩基已被应用至工程实际中，可对桩基的位移进行监测。

Thank you for your kind attention !