RE-USE AND REINFORCEMENT OF EXISTING PILED FOUNDATIONS A CASE STUDY

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PILING SYSTEMS
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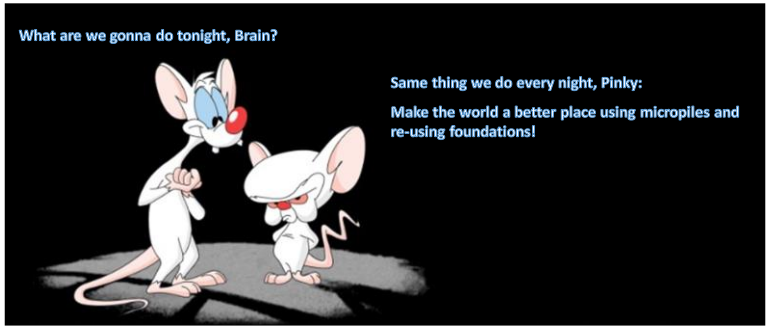
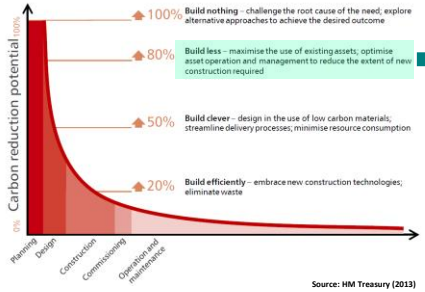
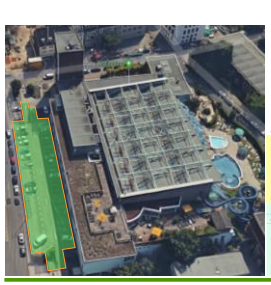


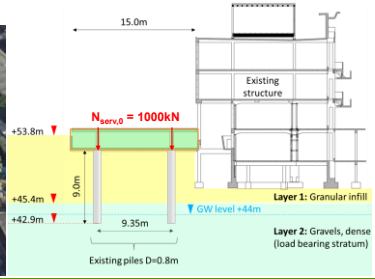
SUSTAINABILITY ASPECTS OF THE RE-USE OF EXISTING STRUCTURES AND THEIR FOUNDATIONS



FEASIBILITY STUDY: THE *AGGRIPABAD* IN COLOGNE, GERMANY

As a part of the feasibility study for the expansion of the existing facilities, different upgrading and extension measures were evaluated ➔ Re-use of a two-story parking deck to house an extension of the attached five-story building:





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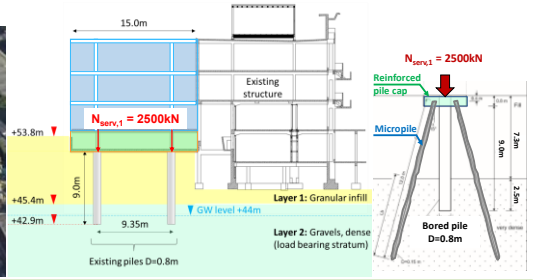
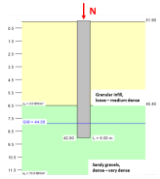


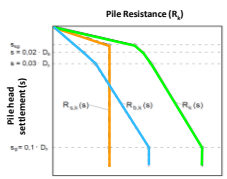
Analysis of the reinforced piled foundation

There is no analytical method to evaluate the interaction between the existing piles an the reinforcement, specially in terms of **settlement compatibility**.

The evaluation was carried out with a 3D-FEM model (PLAXIS) of the reinforced pile foundation system

Preliminary analysis were carried out to assess the behavior of the single piles, comparing the results of the numerical simulations with those of the analytical models acc. to the German practice (EAP2012 + DIN EN 1997-1-1):





$$R_{b,k(s)} = \frac{\pi}{4} * D * q_{b,k(s)}$$

$$R_{s,k(s)} = \pi * D * \sum q_{s,k,i} * L_i$$

$$R_{k(s)} = R_{b,k(s)} + R_{s,k(s)}$$

Layer	Description	Tip resistance CPT q_c (MN/m²)	Base resistance $q_{b,k}$ (kN/m²) s/D=0.02	s/D=0.03	s/D=0.10	Skin friciton $q_{s,k}$ (kN/m²)
1	Granular infill loose – med. dense	< 5	-	-	-	10
2	Sandy gravels, dense – very dense	15	1050	1350	3000	105

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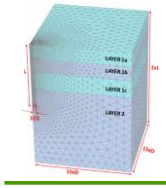


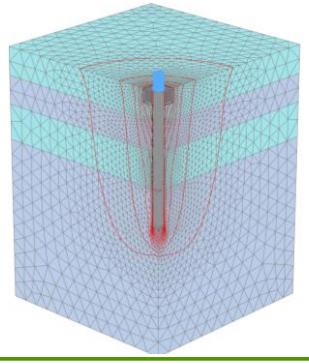
Layer	1a	1b	1c	2
Upper level (m)	0.0	-2.0	-4.0	-8.5
Description	Granular infill, loosen to medium dense			Gravels, dense to very dense
Unit weight (effective): γ' (kN/m³)	8.5	8.5	8.5	10.3
Void ratio: e (-)	0.85	0.85	0.85	0.60
Secant triaxial loading stiffness: E_{50}^{ref} (kN/m²)	1452	3497	5471	65014
Tangent oedometer loading stiffness: E_{oed}^{ref} (kN/m²)	1177	2835	4436	43174
Triaxial unloading/reloading stiffness: E_{ur}^{ref} (kN/m²)	4358	10490	16414	199041
Exponent: m (-)	0.8	0.8	0.8	0.5
Cohesion: c' (kN/m²)	0.0	0.0	0.0	0.0
Friction angle: φ' (°)	28	28	28	40
Dilatancy: ψ (°)	0	0	0	10
Reference shear strain: $\gamma_{0.7}$ (-)	$1x10^{-3}$	$1x10^{-3}$	$1x10^{-3}$	$1x10^{-3}$
Dynamic shear modulus: G_0^{ref} (kN/m²)	19650	34035	45023	109696
Poisson's ratio: ν (-)	0.3	0.3	0.3	0.2
Reference stress: p^{ref} (kN/m²)	6.05	18.14	31.74	68.57
At-rest earth pressure coefficient: k_0 (-)	0.531	0.531	0.531	0.357
Strength reduction factor for interfaces: R_{inter} (-)	0.6	0.6	0.6	0.8

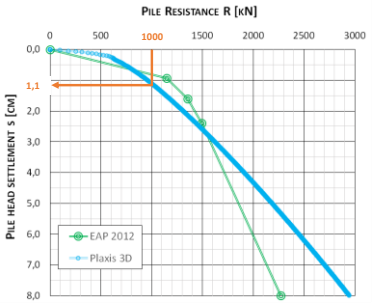
Structural element	Bored pile
Upper level (m)	0.0
Length (m)	9.0
Diameter: D (m)	0.8
Unit weight: γ (kN/m³)	25
Young modulus: E (kN/m²)	$30x10^6$
Poisson's ratio: μ (-)	0.3

Numerical model (PLAXIS3D)
(IGtH University of Hannover – Germany, 2019)

Geometry: 3D / axisymmetric
Pile: volume elements (concrete), lineal-elastic
Soil: HSsmall

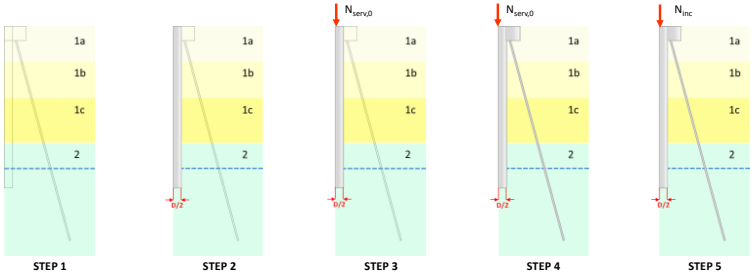
Analysis of the reinforced piled foundation





Analysis of the reinforced piled foundation

After calibrating the numerical models to simulate the behavior of the single piles, the interaction between the elements of the reinforced foundation (pile and micropiles) was evaluated:



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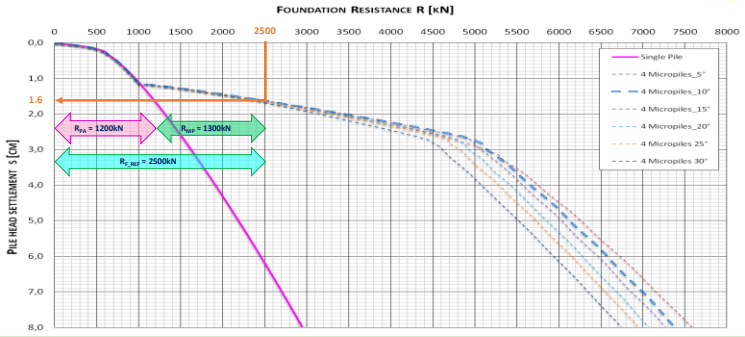

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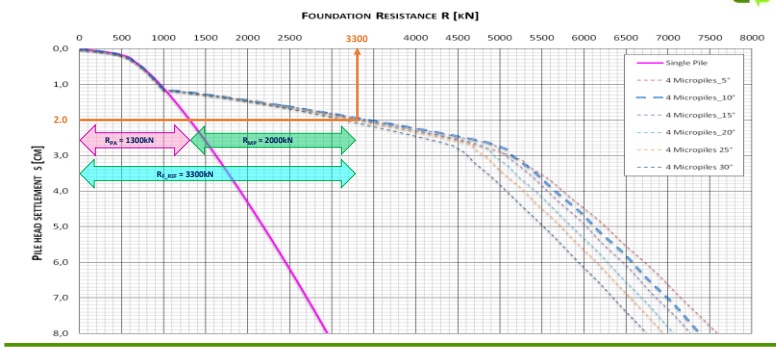
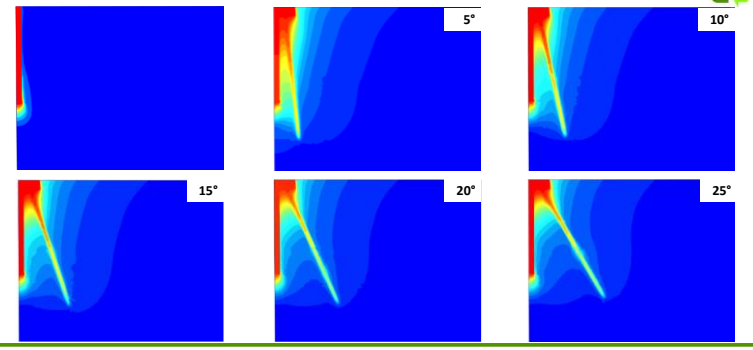
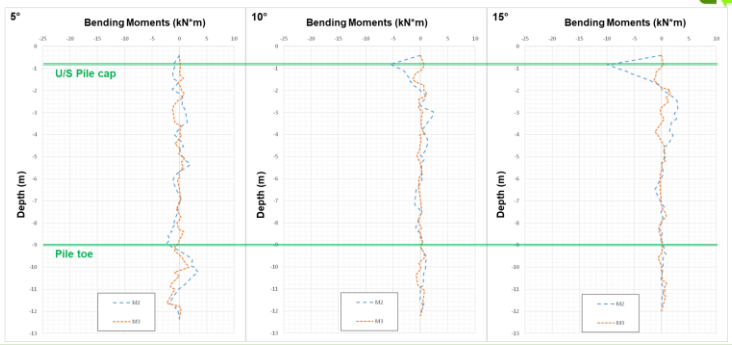


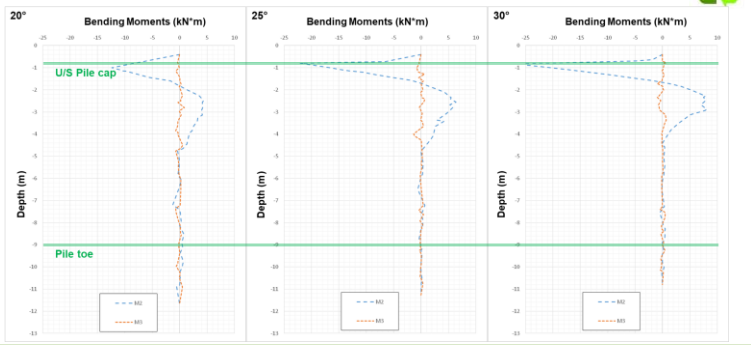
Reinforced piled foundation: Influence of the inclination of the micropiles



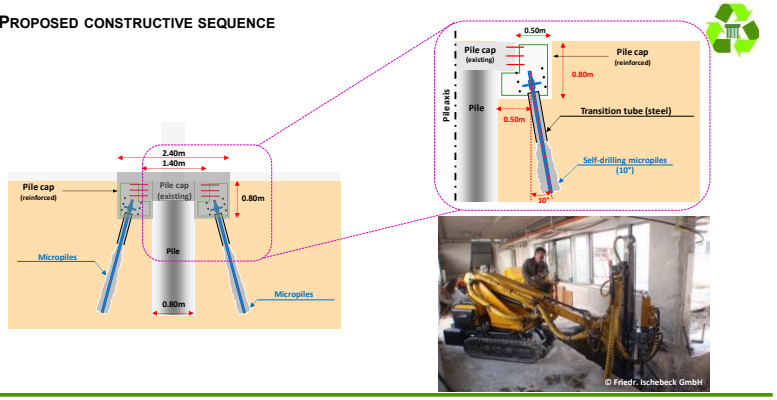
Reinforced piled foundation: Influence of the inclination of the micropiles



Reinforced piled foundation: Influence of the inclination of the micropiles



Proposed constructive sequence



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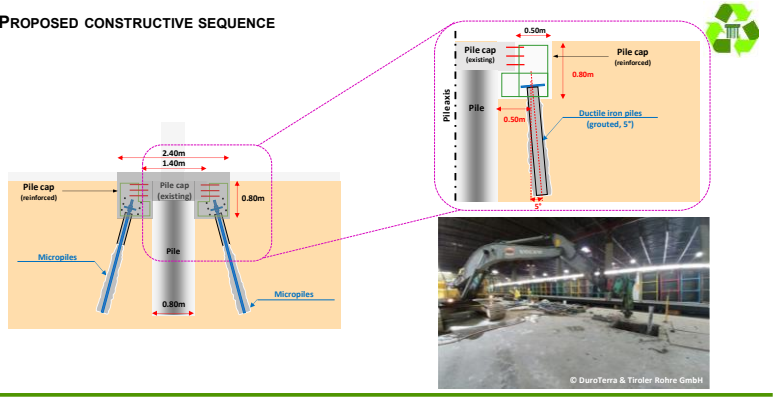

Summary and Conclusions

During the feasibility study of an intervention project in the city of Cologne, Germany, the re-use of a two-story parking deck (founded on piles) to house an extension of an attached five-story building (a public indoor swimming pool) was assessed. Due to the extension works and change of use of the structure, significant load increments were expected.

In order to re-use the existing piled foundations and to increase their load-bearing capacity, a reinforcement with a group of small diameter piles (self-drilling micropiles and ductile iron piles) was proposed.

A numerical model (PLAXIS 3D) was developed by the IGtH at the University of Hannover (Germany) to evaluate the interaction of the existing pile foundation and the reinforcement, considering different inclinations for the latter.

The results of numerical model show, that the load bearing capacity of the reinforced piled foundation is effectively increased, with very low additional settlements.

The reinforcement and re-use of the existing piled foundations comply with the core philosophy of embodied carbon reductions, in line with the principles of ***building less***, ***cleverly*** and ***more efficiently***; making an important contribution to a more sustainable deep foundations industry. In this context, ductile iron piles are a comparatively resource-saving and sustainable solution, falling into the category of low carbon materials, due to the use of 100 % recycled steel and iron scrap and the implementation of potential improvements in their manufacturing process to reduce the gray or embodied carbon footprint (reuse of waste heat, use of renewable energies, etc.)

Acknowledgments

- To Dennis Krämer (*Finck▪Billen Ingenieurgesellschaft GmbH & Co. KG*, Cologne) for the openness to a change and to explore more sustainable technical approaches.
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- To *Tiroler Rohre GmbH, Friedr. Ischebeck GmbH* and the *International Society for Micropiles (ISM)* for their continuous efforts to build a better world!
- To the Technical and Organizing Committee of the *3rd Annual Conference on Foundation Decarbonization and Re-use*
- To you for your kind attention!

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