Reuse Testing & Inspection: Change Uncertainties to Opportunities

Marcel Bielefeld MSc MScBA
Allnamics Geotechnical & Pile Testing Experts

Topics

- Reuse of foundations comes with uncertainties
  - Uncertainties can lead to hesitation in the reuse of existing foundations
- Inspection and testing reduce these uncertainties
  - Activate the hidden safety in an existing foundation
  - Assess the remaining lifetime of an existing foundation
- Testing and Evaluation Reuse based on the present situation “As-Is”
  - Fit for Purpose:
    - Bearing Capacity & Durability

Reuse: change uncertainties to opportunities

- Reuse:
  - Is a crucial strategy in sustainable development and resource management
  - A significant reduction of waste, conservation of resources, and mitigation of environmental impacts

Reuse: change uncertainties to opportunities

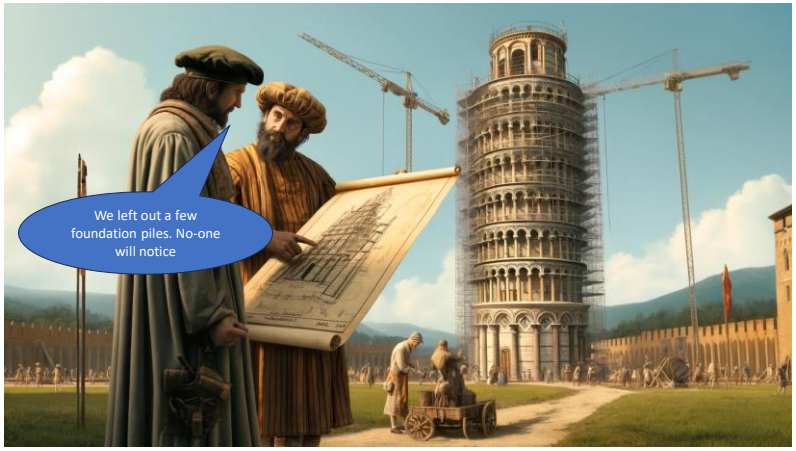
- Reuse:
  - Is a crucial strategy in sustainable development and resource management
  - A significant reduction of waste, conservation of resources, and mitigation of environmental impacts.
- However:
  - Uncertainties related to material properties, the current condition and load-bearing capacity, compatibility with the new design, regulatory and code compliance, and economic viability
- Understanding and managing these uncertainties, and transforming them into opportunities for innovation, cost savings, and enhanced sustainability

What are the those ‘uncertainties’?

The uncertainties related to reuse

- What is the current load capacity?
  - Influences of soil investigation, design method, installation, etc
- What is the condition of the foundation?
  - Deterioration, because of wear, degradation, or damage
  - What will be the remaining lifetime?
- And
  - Is ‘as built’ equal to ‘as designed’?

Addressing these uncertainties requires thorough inspection, testing, and, in some cases, reinforcement or treatment



Designed vs as-built

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What are the main uncertainties?

- What is the current load capacity?
  - Influences of soil investigation, design method, installation, etc
- What is the condition of the foundation?
  - Because of wear, degradation, or damage
  - What will be the remaining life time?
- And
  - As built versus as designed

Addressing this uncertainty requires thorough inspection, testing, and, in some cases, reinforcement or treatment

Load capacity: Inspection and Testing

- Identify values from the original project documents
- Inspection and testing to reduce uncertainties in load capacity
- Uncertainties are caused by:
  - Soil conditions
    - i.e. soil investigation method, fixed point as reference for depth level
  - Design method
    - i.e. soil characterisation, soil parameters, calculation software
  - Pile installation method
    - i.e. contractor, piling crew, weather
  - Degradation over time
    - i.e. corrosion, decarbonisation, dry rot
  - And more

Redesign the old foundation

- Re-evaluate or Redesign: Update the design of the old foundation
  - By checking the archives and following the original design calculations
  - Or better: design again, with new soil investigation, valid design codes, updated calculation methods and software, etc.

What are the changes: from old to new?

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Redesign the old foundation

- Redesign: Update the design of the old foundation
  - Or by checking the archives and following the original design calculations
  - Or better: design again, with new soil investigation, valid design codes, updated calculation methods and software, etc.
- Validate the design, old or new, by performing load tests
  - Load tests prove the assumptions in the design
  - Designs are conservative
    - Made with design factors to compensate for uncertainties in the design, construction, etc

Inspection and Testing

- Prove the design, old or new, by performing load tests
- Result is a load-settlement diagram showing
  - Maximum pile capacity
  - Serviceability

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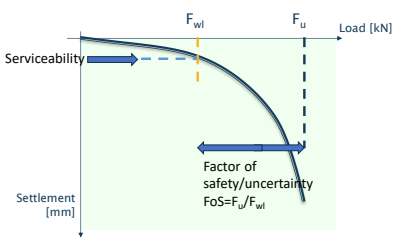
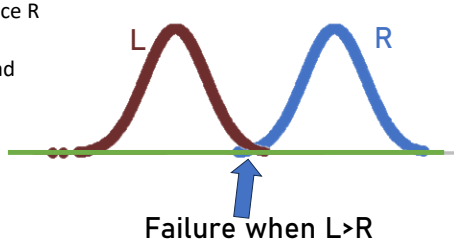


Load Testing

- Load tests
- Result is the load-settlement diagram
  - To confirm the original design and construction method
  - To optimize new design
  - To confirm 'Fit for Purpose'
  - To reduce uncertainties
  - To activate hidden safety

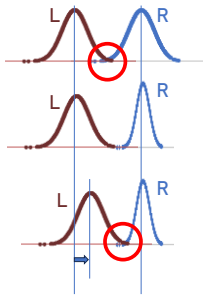
Results of load testing

- Testing leads to reduction of uncertainties in the resistance R of the pile
- As a result the allowable load can increase



Results of load testing

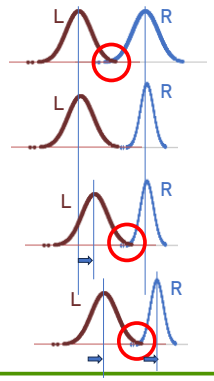
- Reduction of uncertainties
- Smaller variability
- Normal distribution becomes smaller
- Higher loads are acceptable
- Failure when L>R
- Change on failure equal to original change
  - FoS equal to original design



Results of load testing

- Load testing reduces uncertainties from design and construction
- Result:
  - Load testing leads often to higher allowable loads
  - Remaining the same factor of safety

By load testing hidden safety can be activated



Inspection and testing

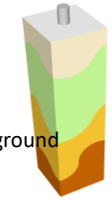
- What is the current load capacity?
  - Influences of soil investigation, design method, install
- What is the condition of the foundation?
  - Because of wear, degradation, or damage
  - What will be the remaining lifetime?
- And
  - Is 'as built' equal to 'as designed'?

The condition of the foundation

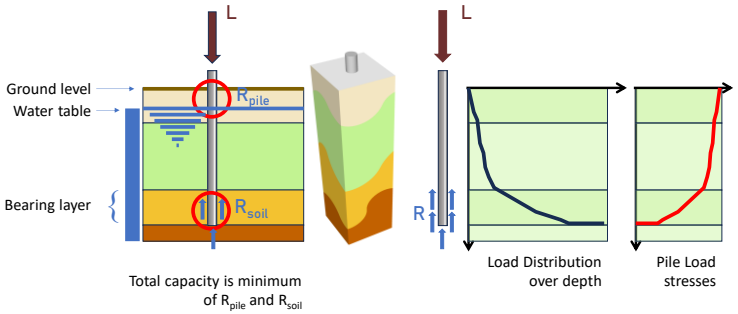
- It is an 'old' foundation or 'used' foundation
  - Can something 'old' or 'used' be reliable?
- It is not about age; it is about being 'Fit for Purpose'
- In case of a new pile
  - Pile tests shortly after installation (days of weeks)
  - Pile is accepted
  - No planned future checks on material quality during design period
  - 100% reliable foundation; without doubts
  - Fit for Purpose !

The condition of the foundation to be reused

- Inspection to assess the actual quality of the foundation pile
- To determine degradation of the pile material
  - Corrosion (reaction of steel with oxygen)
  - Carbonatation (reaction in concrete, with carbon dioxide)
  - Dry rot (biological wood decay)
- The degraded zone is usually around the ground water table, ground level, water level
  - Availability of water and air



Bearing capacity in relation to material quality



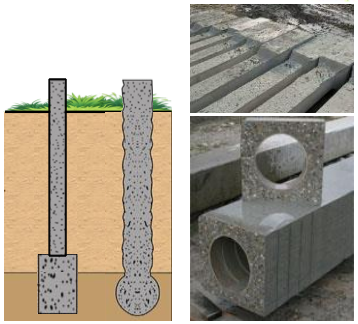
Total capacity is minimum of R_{pile} and R_{soil}

Pile capacity

- Pile's total bearing capacity R depends on:
  - R_{pile} The pile itself: dimensions, material strength
  - R_{soil} The resistance of the soil along the shaft and at the toe
- Total bearing capacity
  - $R = \min(R_{pile}, R_{soil})$
  - The minimum of pile strength and soil strength

Pile capacity

- Mostly, the soil strength is the limiting factor
  - Therefore, piles with enlarged base
  - Pile with a shaft with reduced cross-sectional area
- To optimise R_{pile} close to R_{soil}
- So that $R_{pile} \approx R_{soil}$



Pile capacity and pile material quality

- Is degradation of the pile in the air/water zone limiting the pile capacity?
  - Yes, when R_{pile} is the limiting factor
  - No, when R_{soil} is the limiting factor

Pile degradation

- Degradation of pile material is general in the upper meters
  - Mostly around the groundwater table
  - Where water and air are available
    - Corrosion of steel pipe piles (water and air)
    - Carbonatation of concrete (air)
    - Dry rot (air)
- Degradation affects the pile resistance only when the pile material is the limiting factor:
  - Capacity = minimum (pile strength, soil strength)

Inspection of pile degradation

- Therefore, inspection of the first meter of the pile is important
- To detect and assess the pile strength and dimensions, the R_{pile}
- However, that may have no influence on the pile capacity
  - When $R_{soil} < R_{pile}$

Timber foundation piles in Amsterdam

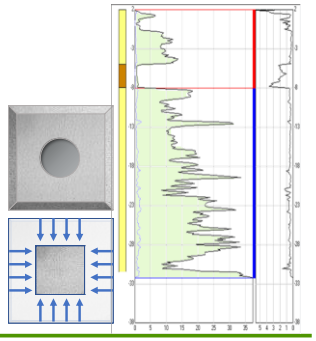
- Timber pile, round 210 mm
- Axial capacity is 100 kN
- That gives a pile stress of 2.3 Mpa
- Material strength class C24 equals 21 Mpa, allowable stress 10.8 MPa
  - Overcapacity above the Factor of Safety equals 10.8/2.3 ≈ 5
  - Hidden safety of a factor of 5
- When the pile diameter is reduced to 109 mm
  - Stress equals 10.8 MPa, no hidden safety. Construction is still safe
- So the reduction of the top diameter of round 210 to round 109 mm does not influence the pile capacity

Timber foundation piles in Amsterdam

- So, although the degradation of foundation piles over 400 years (!)
- Amsterdam houses are still sound and safe

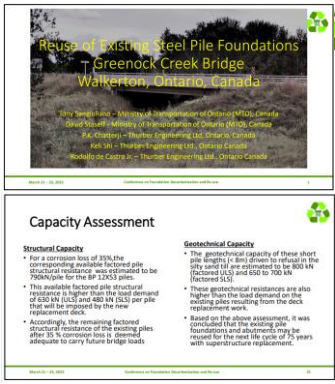
Concrete foundation piles

- Square precast concrete piles, 450x450mm
- Pile length app 16.5 m
- Installed in the 70s (almost 50 years old)
- Allowable load 1.5 MN
  - Stresses 7.4 MPa
  - Strength 35.0 MPa
- Hidden safety of 35.0/7.4≈ 4.7
  - Reduced dimension of 207*207
  - Reinforcement cover is important here



Steel foundation piles

- Presentation of Tony Sangiuliano
- On the 2023 Conference
- Greenock Creek Bridge
  - 1971
  - 22 H-piles, 8 m length (26ft)
- Corrosion loss of 35%
- Pile capacity higher than the new replacement deck



What are the main uncertainties?

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- What is the condition of the foundation?
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- And
  - As built versus as designed

Addressing this uncertainty requires thorough inspection, testing, and, in some cases, reinforcement or treatment

An existing foundation: Fit for Purpose

- The question to be answered
  - Is the existing foundation Fit for Purpose?
  - Now?
  - And in the future?

An existing foundation: Fit for Purpose

- For a new foundation
  - Design is only taking into account the current situation
  - No forecast for future decay
  - There are exceptions
    - Steel piles in marine conditions, etc.
    - Piles in chemical aggressive conditions (Cl-content)
    - Piles in contaminated soils, high chlorides/sulphate concentration
    - Etc.
- Lifetime is incorporated in the design method as a deterministic parameter

An existing foundation: Fit for Purpose?

- Only in the case of reuse the quality of the foundation is questioned
- Why?
  - Without re-use the foundation is assumed Fit for Purpose until the end of its original design period
- Extending the lifetime, in case of reuse, introduces an uncertainty:
  - Is the existing foundation still Fit for Purpose after its original design period?
- Question is often transferred in ‘what is the remaining lifetime?’
  - Needs inspection
  - Material testing
  - Prediction of remaining lifetime

The lifetime of a foundation

- Definitions of lifetime are confusing
- Service Life:
  - The period during which a system, component, or structure operates effectively without needing major repairs or replacement
- Durability:
  - The ability of a material to withstand wear, pressure, or damage. Durability is often quantified as part of the material's lifetime
- Product Lifetime:
  - The duration for which a product remains functional, desirable, or marketable to consumers

The lifetime of a foundation

- Definitions of lifetime are confusing
- Service Life: 50-100 year ?
  - The period during which a system, component, or structure operates effectively without needing major repairs or replacement
- Durability: 150-1000 year ?
  - The ability of a material to withstand wear, pressure, or damage. Durability is often quantified as part of the material's lifetime.
- Product Lifetime: 35 year ?
  - The duration for which a product remains functional, desirable, or marketable to consumers.

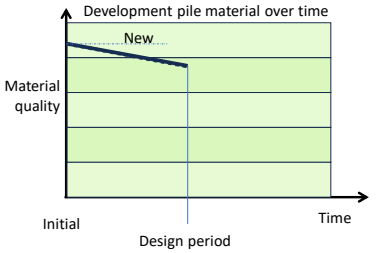
The lifetime of a foundation

- Design Period
- According to Eurocode 7
  - The design period refers to the expected service life during which a structure should reliably fulfill its intended function without major repairs

Temporary structures: At least 10 years.
Replaceable structural parts: 10 to 25 years.
Agricultural and similar buildings: 15 to 30 years.
Buildings and other constructions: Minimum 50 years.
Monumental buildings and critical infrastructure: At least 100 years.

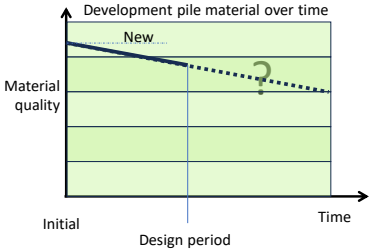
Lifetime of a pile

- Quality can reduce over time
  - Speed and rate are unknown
- Assumed is that the lifetime is at least the design period
- During this period no major repairs or replacement of the foundation are required
- However, product life and durability can be longer



Lifetime of a pile

- Does the lifetime stops after the design period?



Lifetime of Timber foundation Piles

- KIT – Royal Tropical Institute
- Construction started in 1915
- 909 Piles over hundred years old
  - Pile length 15-16 m
  - Pile diam 145 mm, toe 55 mm
  - Final blow counts
    - App 10 cm/30 blows
    - 75 blows/0.25 m

Lifetime > Design Period

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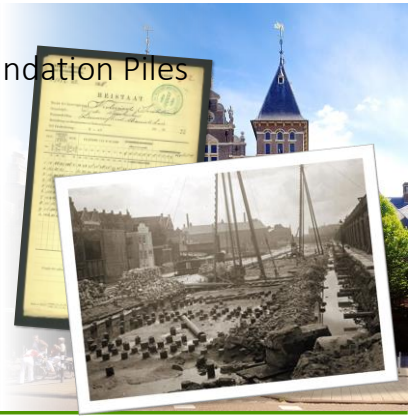


Lifetime of Timber foundation Piles

Amsterdam inner city:

- Piles are over 400 years old!
- Built during the Golden Age

- Royal Palace on Dam Square, originally constructed in the 17th century, is built on thousands of wooden piles.

Lifetime of concrete

- The Colosseum and Pantheon, Rome, Italy
- Date: Completed in 80 AD
- The Roman Empire was known for its impressive architecture, many of which were built using cement and concrete very similar to those used today.
- The concrete was made with lime, pozzolana (volcanic ash), and aggregate.

Lifetime of concrete

- The Eddystone Lighthouse, Cornwall, UK
- Date: Built in 1759
- Description: John Smeaton used hydraulic lime to create one of the first modern concrete structures.
- The lighthouse was built with stone masonry and concrete mortar that could set underwater.

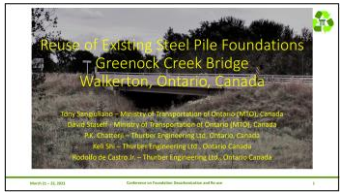
Lifetime of concrete

- Court Street, Bellefontaine, USA
- Date: 1891, still in use today
- America's first and oldest concrete road.
- Court Street is notable for its great strength. Tests showed the pavement achieved an ultimate strength of 55 MPa (8,000 pounds per square inch)

Lifetime of steel

Lifetime of steel

- Presentation of Tony Sangiuliano
  - 2023 Conference on Foundation Decarbonization and Re-use
- Reuse of existing steel pile foundations from 1971
  - Including 35% corrosion
- Greenock Creek Bridge
- Walkerton, Ontario, Canada

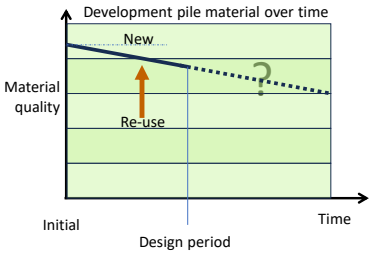


Forecasting or predicting durability

- Prediction of durability of the pile material is not that easy
- Prediction or forecast?

Lifetime of a pile

- Assessment of the pile for re-use
- What is the reference?
  - New/initial quality
  - As it is, in its present condition



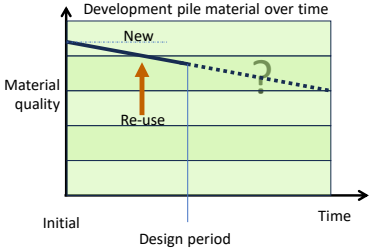
Common practice for reuse

- Asses the remaining lifetime
- Why?
  - As we don't do that with new structures as well
  - Lifetime is difficult to predict: pile material will last much longer than expected
    - Concrete piles
    - Timber piles
    - Steel piles
- And
  - Even with reduced quality, pile capacity can still be untouched

"Concrete Withstands the Challenges of Time
With structures thousands of years ago, it is clear that concrete is a durable and long-lasting material, even before the invention of modern concrete.
If these structures are any indication, the answer is: Much longer than everyone expected."

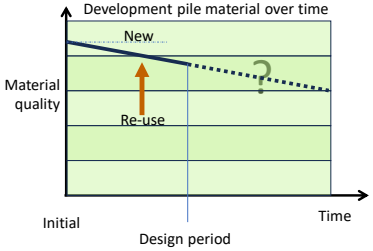
Lifetime of a pile

- Assessment of the pile for re-use
- What is the reference?
  - New/initial quality
  - As it is, in its present condition

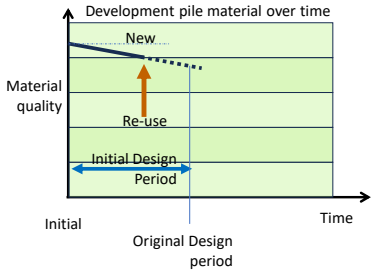


Lifetime of a pile

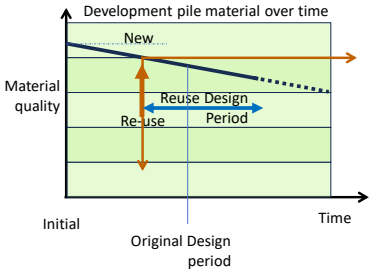
- Assessment of the pile for re-use
- What is the reference
  - New/initial quality
  - **As it is, in its present condition**
- Redesign the existing foundation, including
  - Reduction cross sectional area
  - Reduced strength
  - All influences of ageing
- If this is ok: pile is 'as new'



Lifetime before re-use



Lifetime after re-use



How is dealt with lifetime?

- A new foundation
  - Constructed and tested
    - Fit for Purpose As-Is
  - Is left to nature *As it Is*
  - No monitoring of the deep foundation over time
    - No monitoring of the degradation or inspection to evaluate the physical condition of the foundation
    - Assuming the remaining lifetime, the pile is capable of carrying its load
  - Assuming *Fit for Purpose* during the full design period
  - Design method and Factor of Safety are taking care of that

- An existing foundation
  - Inspect and test
    - Fit for Purpose As-Is
  - Is left to nature *As it Is*
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    - Assuming the remaining lifetime, the pile is capable of carrying its load
  - Assuming *Fit for Purpose* during the full design period
  - Design method and Factor of Safety are taking care of that

How to deal with the future lifetime?

New foundation

- Lifetime is incorporated in the codes
- Pile testing after construction to confirm design and construction
- No monitoring and inspection until end of design time

Existing foundation

- Treat as 'new', but used as-is:
- Lifetime is incorporated in the codes
- Pile testing as-is to confirm design and construction
- No monitoring and inspection until end of new (reuse) design time

Suggested assessment of foundation piles

- Evaluate the elements of existing foundations
  - With reduced cross-sectional area due to degradation, wear, aging, etc
  - Re-evaluate/Re-design with this reduced area as a 'new' pile
  - Reduced are does not necessarily affects the pile bearing capacity
- Traditional assessment
  - Load check based on archives, new soil investigation or new load tests
  - Prediction of remaining lifetime
- Suggested
  - Load check based on new redesign and load tests
  - Activate hidden safety
  - Redesign with existing (reduced, as-is) dimensions and strength based on design rules for new piles

Suggested assessment of foundation piles

- Inspection and testing to determine As-Is
- Determine 'Fit for Purpose'
- Redesign the foundation based on updated, actual dimensions, strength, etc. incorporating deterioration up to date
- Activate hidden safety
- New design methods and codes cover future deterioration

Recap: From Uncertainties to Opportunities

- Foundation Reuse contributes to a sustainable construction industry
- Uncertainties in the reuse process differ from traditional design and construction process
- Inspection and Testing are needed to reduce uncertainties
- Uncertainties are related to:
  - As built vs as designed
  - Bearing capacity
  - Material quality in relation to future Fit for Purpose
- Determine bearing capacity based on:
  - Redesign based on new soil investigation, calculation methods and tools
  - Load tests
- Load Tests will reduce uncertainties and activate hidden safety
- Lifetime prediction is uncertain
- Proposed method
  - Redesign based on actual dimensions and strength
  - Effects of deterioration up to date are taken into account
  - Further time effects are incorporated by design method and codes

Use Engineering Judgement !


Reuse Testing & Inspection: Change Uncertainties to Opportunities