4.Zero waste

A short guide to reusing foundations

Henry Tayler takes readers through the key considerations for reusing foundations, including potential benefits, risks and investigations required.

Introduction

Almost 15 years since the construction industry began developing guidance on foundation reuse, Arup has been overcoming perceived and real difficulties to successfully apply this approach on projects. This article shares some typical opportunities for reusing foundations, risk management processes and options if limited archive/record data is available.

Opportunities

As existing building stock moves towards modern desired standards, the opportunity for building refurbishment over demolition and rebuild has never been more present. Chapman *et al.*[1] highlighted that the presence of old foundations in the ground is an increasing problem and will ultimately inhibit future development on valuable urban sites.

Reuse of key structural elements such as foundations can lead to significant savings in cost, programme and materials, together with improved project sustainability credentials. Space added to existing structures can make an attractive development opportunity, particularly when combined with improvements to fit-out within the existing structure.

Arup has recently completed a significant refurbishment and foundation reuse project at 1 Triton Square, London, enabling savings of an estimated 35 000t of concrete, 840t of reinforcement and 340t of steel, targeting a BREEAM outstanding classification **(Box 1)**. Reuse of the piled foundations contributed approx. 25% of the reused structure.

Boxes 2–6 provide further examples of foundation reuse on projects.

Design responsibility and insurance

To reuse existing foundations, the risks need to be identified and addressed at an early stage by the whole project team. The structural and geotechnical designers will need to work closely together on the engineering aspects, alongside the client, contractor and third parties such as Building Control or future owners/tenants.

Generally, building refurbishments are carried out after original design/construction defects periods or warranties have expired. However, for more recent buildings, it may be possible to approach the original team to extend the period and take on the risk of performance under new loading. For older projects, it may be most effective to approach the original design/consultant team for engineering advice and assistance locating any archive information, if this is possible.

Where limited information is available on existing foundations, it is common practice for the project team or original designer/contractor to carry out a due diligence review and foundation reuse assessment. However, this ultimately requires the client to hold the necessary insurance for the performance of reused structural elements for the new design life. It is important that responsibilities and insurance needs are identified early to allow for engagement with the insurance market and any independent engineering review by insurers or development investors.

Typical reuse considerations

A successful foundation reuse scheme depends on the relationship between the existing configuration and future needs, particularly:

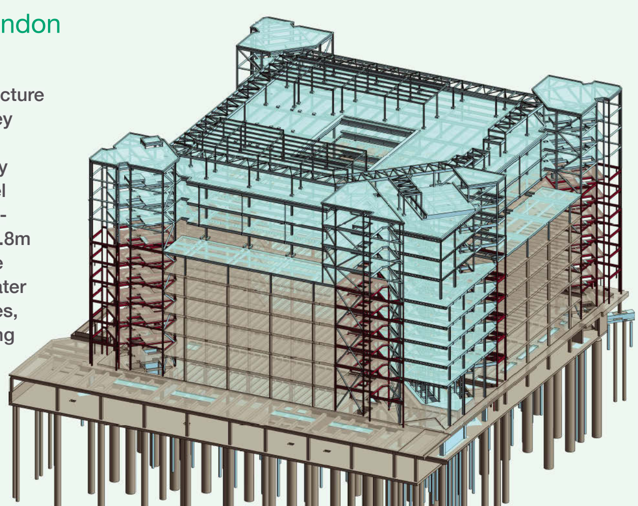
- building height/number of storeys and massing
- structural grid and core provision requirements, including fire and escape requirements
- existing use in relation to proposed use (floor-to-ceiling height and loading)
- ability of the foundations to support additional or different loading requirements.

The feasibility of reuse fundamentally depends on the load-carrying capacity of the existing foundations; and assurance that foundation movements under the new load are acceptable. This is a function of:

- the available records on site investigations, foundation design and as-built construction for the existing structure
- the geotechnical capacity of the foundations based on current design practice, and any load tests carried out
- the new building loads required in comparison to those experienced by the foundations to date

Box 1. 1 Triton Square, London

The scheme to modify the 1995 structure added three storeys and a five-storey infill to a central atrium area. The foundation scheme for the six-storey commercial building with a one-level basement comprised single straight-shafted London clay piles of 1.2m/1.8m diameter up to 18m in length. As the new loads for the scheme were greater than the capacity of the existing piles, a retrofitted raft was installed utilising the existing piles and a small number of new small-diameter piles were installed in reduced headroom. This was possible with minimal site investigations due to the comprehensive record information available from the original construction and use of a 3D finite-element model to estimate the performance of the strengthened system.



↖Additional commercial space added at 1 Triton Square

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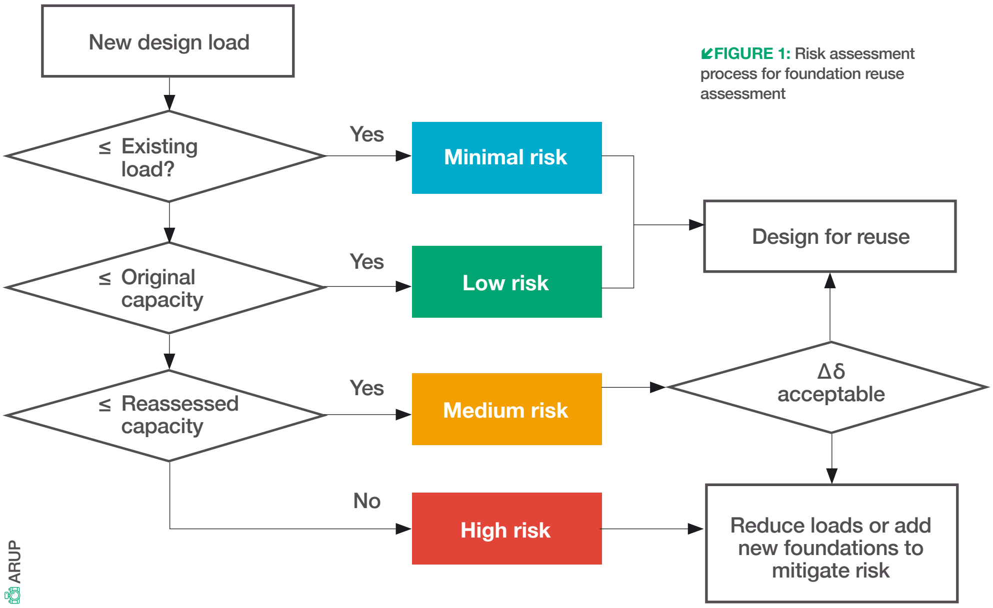

FIGURE 1: Risk assessment process for foundation reuse assessment

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- the condition and future durability of the existing foundations
- the anticipated performance under the new temporary and permanent loads (i.e. settlement performance).

Foundation design

CIRIA publication C653[2] introduces reuse 'load factors' to relate the demand to the allowable capacity and quantify the opportunity for reuse. The existing foundation capacity is considered as: the original capacity from archive records, the capacity based on a later assessment of the as-built foundation geometry; or the existing realistic load to which foundations have been proven to perform adequately. The thresholds can be used to define risk categories for reuse **(Figure 1)**.

The greatest uncertainty is usually in estimating the existing capacity, so it is essential to understand the likely construction methodologies and design approaches available at the time, together with available project records. Where limited information is available, it may be invaluable to seek specialist advice on heritage buildings and historical engineering works, together with local or metropolitan archive searches to determine if any photographs or records exist.

It is commonly cited that existing foundation loads may generally be increased by 10% without experiencing unacceptable settlement or ultimate performance. While there may be cases where this is a reasonable starting point, it likely originates from experience of shallow foundations for simple low-rise structures with inherent redundancy and may not be appropriate for all systems, such as piled foundations beneath isolated columns.

> **"TO REUSE EXISTING FOUNDATIONS, THE RISKS NEED TO BE IDENTIFIED AND ADDRESSED AT AN EARLY STAGE BY THE WHOLE PROJECT TEAM**

There may be opportunities to find additional foundation capacity from the original construction when compared with the demands placed by the new structure. Possible reasons for this are set out below:

- For simplicity of original construction, foundations may have been grouped into types geometrically where the maximum loading applies to only some locations.
- Due to design/construction/procurement timescales and separation of design responsibility, contingency may have been left in the loading or foundations to allow the piling package to be released ahead of completion of the structural design.
- Greater understanding of the performance of foundations, or more sophisticated analysis approaches (may include raft foundations or under-reamed piles), may allow reappraisal of the design capacity.
- There may have been provision for future modifications to the structure as space demand increased or development funding became available.

Structural design

As with reuse of any structural element, assessment should reflect the available materials and design/construction approaches of the time. For example, and dependent on age, it is likely that concrete of lower strength grade than in current practice would have been used in foundations such as pads/strips or even piles. Reinforcement in foundations is likely to be less than current design approaches, and piles were routinely only nominally reinforced to approx. 3–5m below trim level or into a competent stratum. It is not uncommon for concrete piles to have steel casings to facilitate construction, which may have been left *in situ*.

Where an adequate geotechnical factor of safety cannot be demonstrated in the existing foundations under new loads, it may be necessary to augment the existing system with structural connections to new foundations. Early consideration of connection detailing between existing and new construction is important.

Shear transfer at the construction joint between the new and existing concrete may be achieved through a combination of Coulomb friction, interlocking and reuse of existing reinforcement continuous through the joint and new dowels. Examples of structural details for strengthening of single piles and pile grounds are shown in **Figure 2**.

Intrusive investigations

Key unknowns are typically the foundation element dimensions, unidentified construction defects and any possible deterioration that may have happened since original construction. Investigations are an important tool to fill in gaps in information to complete the design. The ground environment or poor specification and workmanship of the original construction can also give rise to serious hidden defects, such as those encountered in the substructure of a 1960s era building during investigations by Arup **(Figure 3)**.

Depending on the availability and confidence level in archive data and potential benefits of the reuse scheme versus the viability of alternatives, investigations can be designed to reduce uncertainties on:

- foundation dimensions (width, diameter, depth) – observation

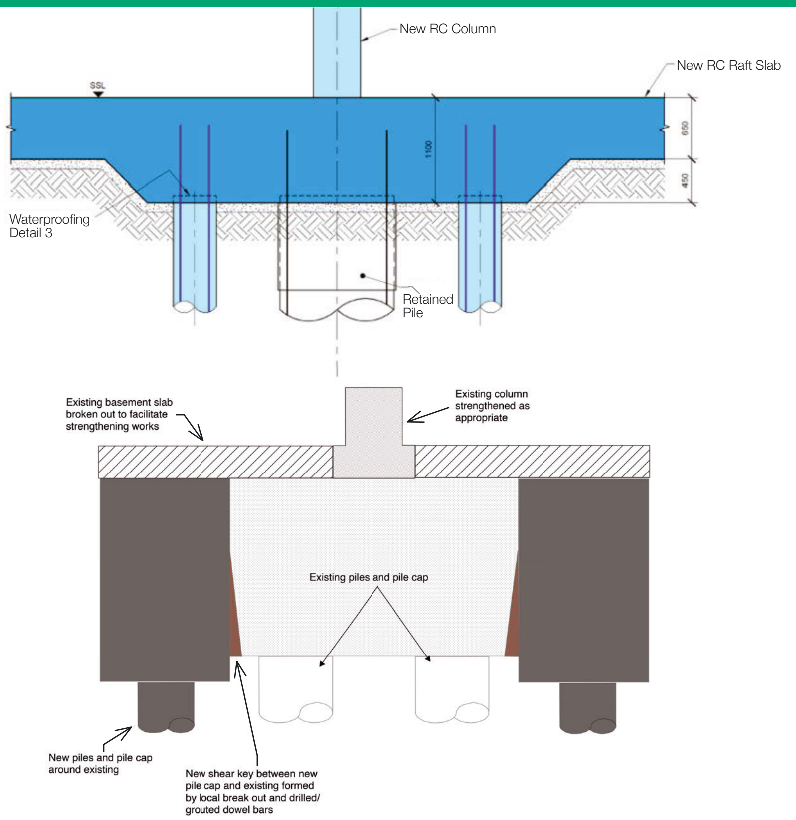

FIGURE 2: Example pile strengthening details

a) Pile strengthening and dowelling detail to new raft

b) Piled foundation strengthening detail for existing pile cap

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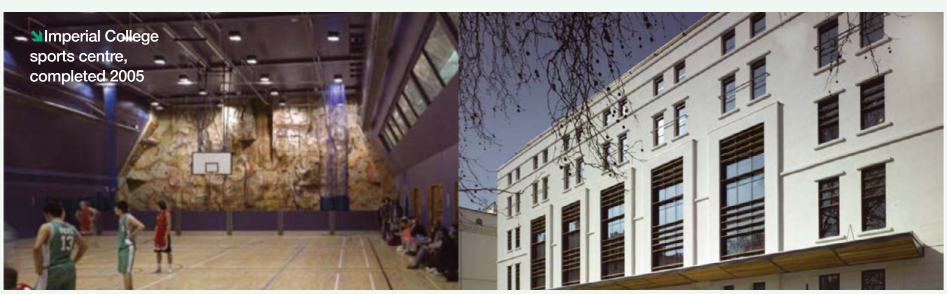
Box 2. Imperial College sports centre, London



Imperial College sports centre, completed 2005

The redevelopment of the sports centre for Imperial College in central London realised the benefit of under-reamed piles within the London clay, which curiously had not been loaded due to a 1962 building project not being completed as a result of funding issues. An intrusive site investigation proved the foundation dimensions at selected locations and that its condition had not degraded since the original construction. Through archive research and knowledge and experience of pile design and construction techniques at the time, it was possible to gain confidence to reuse all the existing piles designed for the earlier structure, mitigating the need for further piling within the limited available space.

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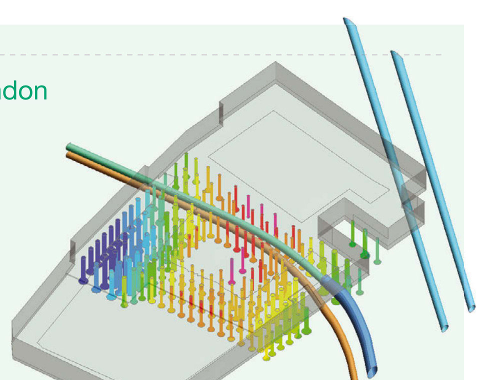
Box 3. Shell Centre/Southbank Place, London

The Southbank Place project by Braeburn Estates redeveloped the Shell Centre in central London, including retention of the iconic tower and the construction of eight new commercial and residential buildings. Parts of the original buildings were founded on under-reamed piles in the London clay, which also acted to restrain the long-term heave of the underlying London Underground Bakerloo line tunnels. An intrusive investigation proved the position, dimensions and condition of a sample of piles to justify reuse for the new buildings, augmented with new piles. Estimation of the loads on the reused piles and demonstration of satisfactory load-displacement behaviour was carried out using a sophisticated 3D finite-element analysis.



LS Dyna analysis model and underlying Northern and Bakerloo line tunnels

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pitting, structural coring, directional drilling

- pile length or under-reamed bell investigation (rotary drilling, concrete coring, parallel seismic testing)
- presence of reinforcement or toe of steel piles (cover meter survey, fluxgate gradiometry)
- concrete or reinforcement testing (unconfined compressive strength, yield strength)
- concrete durability testing (cement content, petrographic analysis, carbonation, chloride content)

Foundation investigations may be phased with geotechnical investigations for design and assessment of foundations. However, as they contain specialist works, budget allowances should be made and timescales agreed early in the process. It is typical for the existing building to be in place and even occupied at this stage; therefore, careful planning is needed, and possible consideration of working out of hours.

Where little information is available on the existing foundations, an intrusive investigation to reduce risk to acceptable levels may be costed against the benefits and risks of reuse. Consideration of the redundancy of foundation elements under the new loading is key to the decision to proceed with reuse, and investigations may indicate a change in strategy for the foundations.

Monitoring

While the risk of existing defects or unexpected foundation performance can be mitigated to an extent through desk-based assessment and intrusive investigation, it is rarely practical or cost-effective to investigate each foundation element individually. Structural movement and/or load monitoring is typically included within the risk mitigation approach, e.g. by:

- precise levelling of BRE type bolts or 3D geodetic prisms on key structural elements by manual survey

FIGURE 3: Exposed pile cap indicating potentially serious durability issue to steel reinforcement

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- automated monitoring using robotic total station or tilt meters/ hydrostatic cells.

The number, location and frequency of monitoring measures is based on confidence in the performance of the existing foundations and the consequences of a potential defect. As loading from new structure is generally progressive, monitoring frequencies should be appropriate to indicate a potential issue in a timely manner. Trigger values and emergency action plans then respond to unexpected behaviour to mitigate the risk of damage or an unsafe condition.

Specialist advice

Approaches for design and risk mitigation of foundation reuse are not typical of design of new foundation systems. It is therefore recommended to seek advice from specialist geotechnical/structural engineering advisers at the project feasibility stage when the options may be evaluated for the particular site.

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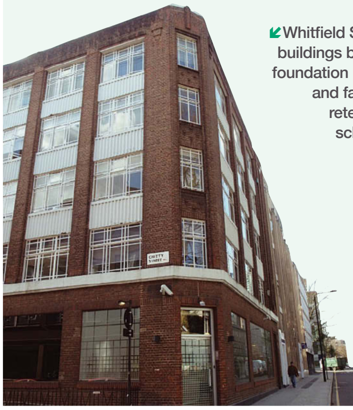
Box 4. Whitfield Street, London



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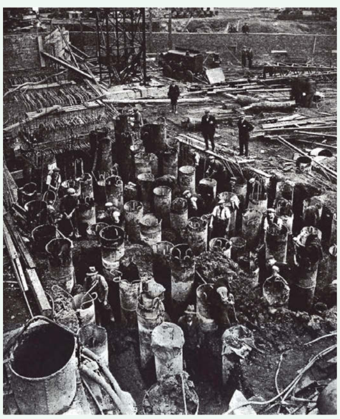
Whitfield Street buildings before foundation reuse and facade retention scheme

As no records were available for this five-storey 1930s building, intrusive investigations proved it was supported by shallow footings approx. 3m deep. As the factor of safety assessed under existing conditions was acceptable, an increase of 10% in load was proposed to support the new structure, which assisted with retention of a listed facade. Where new loads were in excess of 10%, the footings were assessed for strength based on concrete investigations, bearing at the column/pad interface and lightly/unreinforced concrete design to justify sufficient capacity. Analysis confirmed settlements under new loads were acceptable, and the residual risk of defects or unexpected conditions was managed through monitoring during the new construction.

Box 5. Unilever House, London



UNILEVER

'Raymond' steel piles installed in 1932[3]

'Raymond' steel piles installed in 1932 in response to unforeseen poor ground conditions were reused in combination with new hand-dug caisson piles.

> **"EARLY CONSIDERATION OF CONNECTION DETAILING BETWEEN EXISTING AND NEW CONSTRUCTION IS IMPORTANT**

Box 6. Ropemaker Place, London

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Basement works at Ropemaker Place

This 1970s building was refurbished to provide a 28-storey structure. The existing single-level basement was formed by buttress perimeter walls which were reused as part of the foundation system supporting the new structure. Reuse of these elements allowed for reduced requirements for new foundations and saved on obstruction removal or piling through. A raft foundation was used within the new basement areas.

REFERENCES

1) **Chapman T., Marsh B. and Foster A. (2001)** 'Foundations for the future', *Proc. ICE – Civ. Eng.*, 144 (1), pp. 36–41

2) **Chapman T., Anderson S. and Windle J. (2007)** *C653: Reuse of foundations*, London: CIRIA

3) **Toms C. and Patel D. (2010)** 'The redevelopment of Unilever House utilising hand dug caissons and the reuse of 1930s foundations', *Proc. 11th International Conference on Geotechnical Challenges in Urban Regeneration*, London, UK, 26–28 May

FURTHER READING

Butcher A.P., Powell J.J.M. and Skinner H.D. (eds.) (2006) *Reuse of foundations for urban sites: A best practice handbook*, Watford: BRE Press

Butcher A.P. Powell J.J.M. and Skinner H.D. (2007) *BRE Information Paper 5/07: Principal drivers for reusing foundations*, Watford: BRE Press

EFFC/DFI carbon calculator: www.effc.org/how-we-operate/ eco%e2%82%82-foundations/

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