Lecture 3 - Footings

Footings
- Factors influencing footing type
- Design considerations
- Reinforced concrete properties
- Footing types

Design for structure
Actions – concentrated or distributed forces (direct actions) acting on a structure or deformation or forces constrained within it (indirect actions)
- Building life (N) (assumed to be 50 years)
- Permanent actions – dead load (G)
- Earthquake actions €
- Earth pressure (Fe)
- Ground water action (Fgw)
- Liquid pressure action (Fip)
- Ice and snow actions (Fice & Fsn)
- Imposed snow action (live load)
- Wind action (W)

Factors affecting choice of footing system (& structure)
Building typology
- Design (Seijmas point loads VS Diestas uniformly distributed load)
- Use (e.g. factory loading vs house)
- Materials (Seijmas lightweight vs Diestas mass)
- Building systems (Seijmas steel column system vs Diestas masonry)

Factors affecting choice of footing system
- Foundation properties
- Impact on adjacent properly or retaining wall conditions
- Below ground infrastructure and site features
- Soil stability
- Climatic effects
- Constructability
- Construction time and program
- Occupational health and safety

Summary
- Foundation conditions are the most important factor in design of footings
- BUT
  - Design typology
    - Brief
    - Use
    - Cost
  - Construction efficiency
    - Time
    - Safety
Footings types

Shallow footings
- Transference of load relatively close to main building or sub-structure due to foundation of adequate bearing capacity (raft pads tend to be shallow)

Deep footings
- Footing transfers load through soil of inadequate bearing pressure to deeper layers of soil having adequate bearing pressure or acts through friction between footing and surrounding soil

Blinding Concrete
- Blinding – layer of concrete between 50-100mm thick, put down on soil to seal the ground and provide a clean and even surface for construction work. Also assists to clean the base of the excavation if required as the base of excavation is sealed by the concrete
- Primarily used just to level the ground off
Mass concrete

- Unreinforced concrete, of a known compressive strength
- Used where
  - Soil conditions are poor – usually due to depth of a bearing
  - Bearing is at a depth where standard footing design is not achievable or uneconomical or where safety is an issue
  - To avoid load transference at a particular level, due to site conditions (trees, adjacent structures)
- Acts as a quasi-foundation/footing system in compression – no reinforcement used
- Replacement of poor soil with “good soil” (concrete of a known compressive strength)
  - Excavation is carried out and trench filled with lesser strength concrete
  - Standard footing design then poured over this mass concrete base
- Cheap and quick to do so builders like it
Underpinning
- New support structure underneath the existing footing without the removal of the superstructure
- Transfers load to a new bearing level at a lower depth
- Prevents collapse due to excessive or uneven settlement
- Allows additional loading of building
- Enables ground level inside or outside to be lowered

How to do underpinning
- Continuous strip footings – simplest method
- Removal of sections of soil at consistent intervals below footings
- Filing on of these sections with new footing system
- Sections allowed to set
- Remaining soil intervals removed and these provided with new footing

Line of influence of existing footing bears on new structure

Line of influence of new footing bears on existing structure
Spread footings
Types of shallow (spread footings)
- Strip
  - Takes a continuously distributed load
  - Continuous footings
  - Stepped footing
- Pad
  - Takes a point or concentrated load
  - Isolated footing
- Raft
  - Can take either or both loads – concentrated or distributed
  - Thickened slab footing

Strip footings
- Supports a continuously distributed load
- In reactive soils they may act as beams, hence, need to be mindful of bending behaviour
- Generally rectangular in shape, with greater depth than width due to support requirement of wall above it
- Longitudinal bars control concrete shrinkage and cracking
- Reinforcement at bottom of footing is tensile resistance bending form above
- Reinforcement at top of fitting is tensile resistance bending from below

Site slope
- Sloping site topography may require footing to be stepped
- Structural continuity and integrity to be maintained
- Concrete and reinforcing overlapped

Pad footings
- Supports a point load – square or rectangular in plan, supporting a single column
- Area is a factor of the load and the bearing capacity
- Depth is a factor of shear (column cant punch through) and bending (dishing of side, tensile stress at the bottom)
- Reinforcement critical at base not at top, reaction of the ground acts upwards on all sides of the columns – counteracts the upward pressure exerted by the soil and downward pressure exerted by the column
- Greatest bending and shear is under the column
Raft footings

- Extends completely under the building footprint so as to spread weight over the entire foundation area
- Used when loads become so large that it is more economical to join up all the pad footings that would be required
  - Column grid say 8m x 8m – pads 3m x 3m (for 4 floor) increase load (more floor levels) pads must be bigger (may end up touching) so easier to join up into a raft
- Used where ground conditions poor, raft required to distribute the loads over a larger area
- Very stiff footing good in dealing with settlement and differential movement
  - Better than individual footings which are more susceptible to local differential settlement
- Depth of raft
  - To deal with shear of columns
  - A factor of the large load from floors above
  - Often at least 1-1.5 metres deep
- Raft wants to bend between columns, so need to make it very stiff but using lots of reinforcement

Pile footings

- End bearing – taken through soil of poor bearing capacity to a level of good bearing capacity
- Friction piles – soil generally all poor so length of pile is determined by resistance generated by friction
- Bored piles – can be a combination of the above. In effect drilled holes, sometimes wide at bottom. Generally insitu reinforced concrete. Can use them where soil is prone to collapse, like silt soils
- Driven piles – like nails, driven to refusal (can be concrete or steel, precast/prefabricated). Docklands driven to 25-30m – Coode island silt
- Designed as long columns – reinforcement for driven piles robust enough for impact load, bored piles reinforcement deals with slenderness of column and buckling even though restrained by soil
- Generally have a pile capping beam to connect piles and distribute load across piles
- Uplift / shear can be generated by driven piles – the reinforcement design is important

Pile Footing Systems

- Driven Piles
  - A pile of steel, timber or precast concrete which is forced into the soil by blows from a pile hammer
- Bored piles
  - A pile, with or without steel casing, formed by excavating or boring a hole in the ground and sub sequentially filling it with plain or reinforced concrete
Reinforced concrete slabs
- There are a number of types
- Most common stiffened raft
  - Slab and beams poured at same time
  - Integrated system
  - Slab panel (relatively think 100mm +) is stiffened by introduction of edge beams and internal beams
  - Spacing of beams as a factor of spanning capacity of panel, loading condition and foundation
  - Beams need to be supported by foundation of adequate bearing
  - Panels need to be supported by ground or compacted fill

Summary
- Different footing systems respond to different design conditions
- Primary systems
  - Mass concrete (blinding not a footing)
  - Underpinning (lowering load transfer or increasing capacity)
  - Strip footings
  - Pad footings
  - Pile footings
- Reinforcement design is critical
  - Type
  - Configuration
  - Protection

Concrete composition

<table>
<thead>
<tr>
<th>Air</th>
<th>Portland cement</th>
<th>Coarse aggregate (gravel or crushed stone)</th>
<th>Fine aggregate (sand)</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>6%</td>
<td>11%</td>
<td>41%</td>
<td>26%</td>
<td>16%</td>
</tr>
<tr>
<td>Workability</td>
<td>Binder</td>
<td>Density, strength thermal conductivity, heat storage capacity, workability</td>
<td>Setting agent for binder</td>
<td></td>
</tr>
</tbody>
</table>

Specifying and ordering concrete
Concrete classes
- Normal class
- Special class
Ordering
- Strength - 30 MPa
- Aggregate size - 20mm
- Slump - 80mm
Testing
- Slump test
- Compaction test (7, 14, 28 days)
Reinforced Concrete
Concrete:
- High compressive strength but low tensile strength
- Low strength to weight ratio
- Tensile stresses develop under load, shrinkage or temperature change
- As low tensile strength it will fail suddenly and completely when first cracks forms – susceptible to cracking

Steel
- Steel – very high tensile strength and high compressive strength, but expensive
- High strength to weight ratio
- Can take increased load when it enters an elastic stage and then fails when ultimate stress reached. Deformation occurs prior to failure

Reinforced concrete
- Combines high tensile strength of steel and relatively low-cost compressive strength of concrete

Reinforcement
Yield stress
- Max useable strength
- Point at which steel behaves plastically and is permanent deformed (reo steel 500 MPa)

Ductility
- Ability to undergo deformation and deflection when loaded
- Avoidance of brittle failure (L- low, N-normal, E-Seismic)

Reinforcement placement is critical – must be in correct plane for tensile resistance and must be projected by concrete cover

Mesh – Square and Rectangular (Slabs and Pads)

<table>
<thead>
<tr>
<th>Configuration of bars</th>
<th>Ductility Class</th>
<th>Size</th>
<th>Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S = Square</td>
<td>L = low</td>
<td>Numerical value of the nominal diameter expressed in millimetres. 8/100; 6.7.8.9/200</td>
<td>Numerical value of the spacing of bars, expressed in millimetres, multiplied by 100.</td>
</tr>
<tr>
<td>R = Rectangular</td>
<td>N = normal</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>E = earthquake</td>
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</tr>
</tbody>
</table>

Example: Square SL102 Square mesh, low ductility, 10mm diameter (nominal) bars, spaced at 200mm spacings.

NOTE: Rectangular mesh e.g. RL1218
Rectangular, low ductility, 12 mm diameter longitudinal bars, spaced at 100mm spacings and with 8mm diameter cross-bars. (Cross bars generally spaced at 200mm spacings)
Trench Mesh (Strip Footings)
- Ribbed bars
- 500 MPa
- Main wires and cross wires at 300mm centres
- Strip footings and slab beams

<table>
<thead>
<tr>
<th>Ductility Class</th>
<th>Size</th>
<th>Identifier</th>
<th>No. of wires</th>
</tr>
</thead>
<tbody>
<tr>
<td>L = low</td>
<td>Numerical value of the nominal diameter expressed in millimetres. 7, 9, 11, 13, 18, 22, 27 mm diam.</td>
<td>Abbreviation of Trench Mesh – TM</td>
<td>3, 4 or 5 bars (wires)</td>
</tr>
<tr>
<td>N = normal</td>
<td></td>
<td></td>
<td>3 – 200mm width</td>
</tr>
<tr>
<td>E = earthquake</td>
<td></td>
<td></td>
<td>4 – 300mm width</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>5 – 400mm width</td>
</tr>
</tbody>
</table>

Example: L11TM3
Low ductility class, 11mm diameter, Trench Mesh, 3 bars (wires)

Reinforcing Bars

<table>
<thead>
<tr>
<th>Shapes</th>
<th>Strength grade</th>
<th>Durability class</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>R = Round</td>
<td>Numerical value of the lower characteristic yield stress expressed in megapascals</td>
<td>L = low</td>
<td>Numerical value of the nominal diameter expressed in millimetres.</td>
</tr>
<tr>
<td>D = Deformed ribbed</td>
<td></td>
<td>N = normal</td>
<td></td>
</tr>
<tr>
<td>I = Deformed indented</td>
<td></td>
<td>E = earthquake</td>
<td></td>
</tr>
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Example: D500N16
Deformed ribbed bar, grade 500 MPa, normal ductility steel being 16mm diameter
**Week 3 – Footings - Case Study Project**

**Bored piers**
- Bored piers to be founded into highly to moderately weathered basalt at depths of minimum 4.6 metres below existing ground

**Underpinning**
- Underpinning adjacent structure
- Depth of underpinning determined by lowest depth of new footing system
- Existing footing spans across underpins

**Soldier Piles**
- Retaining (shoring) system to hold back soil to allow excavation on one side of the shoring members
- Can also be used as a support mechanism to transfer load from existing structures

**Capping beams**
- Beams poured on top of piles
- Important structural component as they distribute load across a number of piles (in this sense they act like a footing)
- Can be designed to tie piles together and prevent lateral displacement (pile beams)
- Blinding concrete under the capping beam provides an even and level base
Footing beams
- Element is built directly onto this footing
- Not incorporated as part of the floor slab
- Precast wall bears directly onto footing (beam)

Ground beams
- Integral to functioning of the slab
- Acts to stiffen the slab
- Slab panels span from integrated beam to integrated beam
- Slab and beam are poured together
- Critical as entire slab acts as if it is suspended – not reliant on ground for support
- Beams are supported by piles

Summary
- Different types of footings are suitable for different design conditions
- Primary issues are related to load and soil type
- Form that footing takes related to how loads are dealt with and how they are transferred into the foundation material