Combining in-situ and precast concrete

When combining in-situ and precast concrete, the effect of differential shrinkage is a subject that is often of concern to structural designers. However, checking it is not an insurmountable problem as the following demonstrates.

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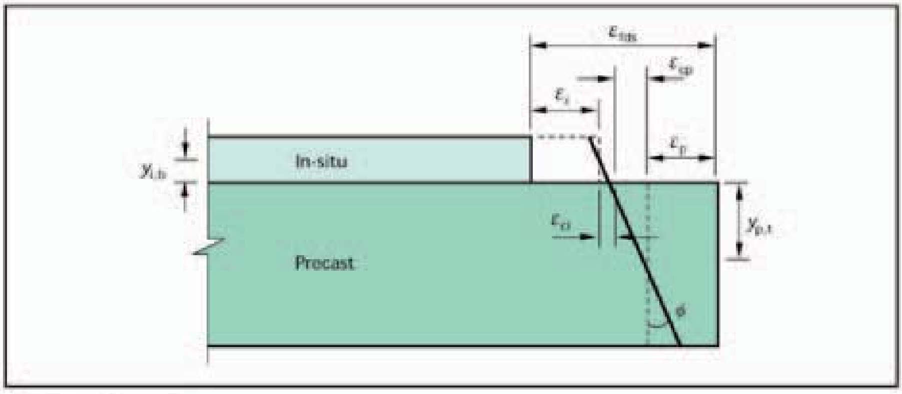
3.10 Differential shrinkage

When an in-situ screed is added on to a first stage cast floor of either reinforced or prestressed construction, the shrinkage of the screed after its initial hydration will develop a compressive strain in the top of the first stage cast and will induce a downwards deflection in the span of the composite unit and, if the floor is of continuous construction, a hogging moment at the supports. Note that these effects are of importance at the serviceability limit state only, as at the ultimate limit state these imposed strains will have little effect.

Figure 3.12 shows how the strains are built up through the height of the composite section for a given free differential shrinkage strain, ε_{fds}. The final curvature, φ, is constant across the section. Design equations can be developed as shown:

Figure 3.12
The effect of differential shrinkage across a section.



Force equilibrium:

$$\varepsilon_i E_i A_i = \varepsilon_p E_p A_p \quad (1)$$

$$\varepsilon_p = \varepsilon_i E_i A_i / E_p A_p$$

Section equilibrium ($\varphi EI = M$):

$$\phi (E_i I_i + E_p I_p) = \varepsilon_i E_i A_i (y_{i,b} + y_{p,t}) \quad (2)$$

Strain equilibrium:

$$\varepsilon_{fds} = \varepsilon_i + \varepsilon_{ci} + \varepsilon_{cp} + \varepsilon_p = \varepsilon_i + \phi y_{i,b} + \phi y_{p,t} + \varepsilon_p$$

$$\phi = (\varepsilon_{fds} - (\varepsilon_i + \varepsilon_p))/(y_{i,b} + y_{p,t})$$

$$\phi = (\varepsilon_{fds} - (\varepsilon_i + \varepsilon_i E_i A_i / E_p A_p))/(y_{i,b} + y_{p,t}) \quad (3)$$

Combining (2) and (3):

$$\phi(y_{i,b} + y_{p,t} + (\varepsilon_{fds} - (E_i I_i + E_p I_p)) (1/E_i A_i + 1/E_p A_p)/(y_{i,b} + y_{p,t})) = \varepsilon_{fds}$$

$$\phi = \varepsilon_{fds} / \{y_{i,b} + y_{p,t} + (E_i I_i + E_p I_p) (1/Ei A_i + 1/E_p A_p)/(y_{i,b} + y_{p,t})\} \quad (4)$$

$$\varepsilon_i = \varepsilon_{fds} / \{1 + E_i A_i / E_p A_p + (y_{i,b} + y_{p,t})^2 E_i A_i / (E_i I_i + E_p I_p)\} \quad (5)$$

$$\varepsilon_p = \varepsilon_{fds} / \{1 + E_p A_p / E_i A_i + (y_{i,b} + y_{p,t})^2 E_i A_i / (E_i I_i + E_p I_p)\} \quad (6)$$

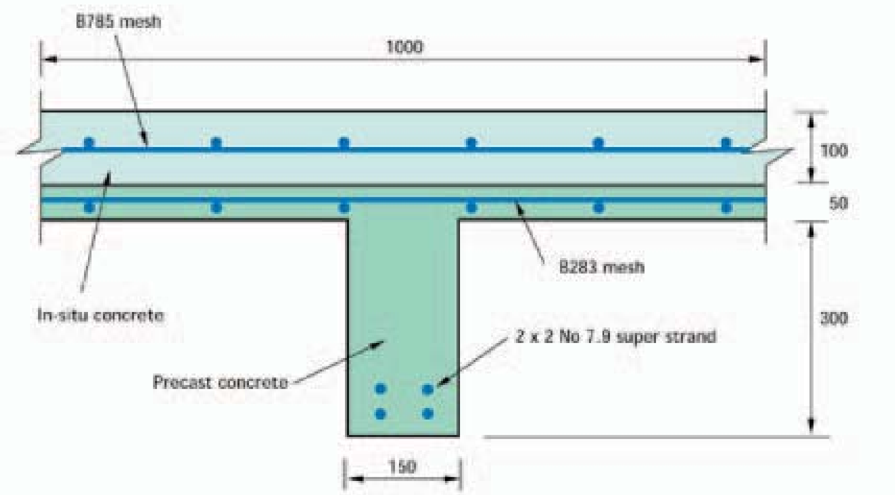
From equations (4) to (6) all the strains, stresses and forces can be determined.

Worked example 4 describes the method for determining the effect of differential shrinkage where in-situ concrete is placed on a precast concrete T section.

Worked Example 4

Calculate the effect of differential shrinkage in a beam constructed in two stages as shown below. The element is simply supported and 20 m span. The free differential shrinkage strain is 0.0002.

- B785 fabric in in-situ concrete
- B283 fabric in precast concrete flange
- 2 x 2 No. 7.9 mm super strand in precast rib



In-situ concrete (Eurocode 2, Table 3.1 and Cl.3.1.4)

$f_{ck,in}$ = 25 MPa, $f_{cm,in}$ = 33 MPa, creep coefficient, $\varphi = 1.5$

$E_{c,in,long}$ = $22\,[f_{cm,in}/10]^{0.3}/(1+\varphi)$

= $22 \times (33/10)^{0.3}/(1+1.5)$

= 12.59 GPa

Section properties, including the reinforcement, are as follows:

A_{in} = 112×10^3 mm^2

I_{in} = $bd^3/12 = 1000 \times 100^3/12$

= 87.5×10^6 mm^4

$y_{in,bar,b}$ = 52.1 mm

$Z_{in,b}$ = 1680×10^3 mm^3

Precast concrete (Eurocode 2, Table 3.1 and Cl.3.1.4)

$f_{ck,p}$ = 50 MPa, $f_{cm,p}$ = 58 MPa, Creep coeficient, $\varphi = 1$

$E_{c,p,long}$ = $22 \times (58/10)^{0.3}/(1+1)$

= 18.64 GPa

Section properties, including the tendons and reinforcement, are as follows:

A_p = 101.5×10^3 mm^2

I_p = 1220×10^6 mm^4

$y_{p,bar,b}$ = 237.4 mm

$y_{p,bar,t}$ = 112.6 mm

$Z_{p,t}$ = 10900×10^3 mm^3

Curvature

Using expression (4) above:

$$\text{Curvature:}\quad \phi = \frac{1000 \times 0.0002}{52.1 + 112.6 + \left(\dfrac{(12.59 \times 87.5 \times 10^6 + 18.64 \times 1.22 \times 10^9) \times (1/(12.6 \times 112 \times 10^3) + 1/(18.6 \times 101.5 \times 10^3))}{50 + 112.6}\right)}$$

= 0.00058/m

Deflection

Deflection from differential shrinkage

δ = $\phi\, l^2/8$

= $0.00058 \times 20^2/8$

= 29 mm

For copies of the Concrete Centre's publication *Design of hybrid concrete buildings: a guide to the design of buildings combining in-situ and precast concrete* by R. Whittle and Dr H. Taylor go to **www.concretecentre.com**

Working in partnership

For this issue, the technical section highlights the role of structural precast concrete in meeting and exceeding the requirements for 21st century projects. These requirements include maximising the benefits of offsite construction, working in partnership, improving sustainability, reducing energy use and CO_2 emissions, and achieving a BREEAM Very Good rating. A particularly good example of applying these in practice is seen in the new John Perryn School in Ealing, west London.

The John Perryn School – which replaces a Victorian building on the same site – is a Pathfinder scheme for the Department for Children, Schools and Families (DCSF) Primary Capital Programme to improve the standard of primary schools throughout the country. Based on a vision for a landmark community building fit for 21st century learning, the building was designed by architects Penoyre & Prasad to meet high educational, environmental and design targets. Accommodation includes a 420-place primary school and a 25-place nursery, while a fully integrated children's centre provides shared accommodation for a variety of community uses including a vulnerable children's unit, daycare provision and facilities for visiting healthcare professionals. John Perryn's Board of Governors expressed the school's vision with the following statement – "We want John Perryn School to be a welcoming, friendly, safe environment, which serves as a great place to learn and offers the best to our community, especially our children".

A combination of a partnering approach, offsite construction and intrinsic low-energy design resulted in a welcoming scheme with strong civic presence. In the words of Steve Harnett of main contractor Wilmott Dixon "There is a better chance of success if everyone is in from the beginning". Whole life costs were considered at every stage of the project and one of the key drivers for the project was the reduction in energy use. Willmott Dixon opted for precast concrete because of factors such as fire resistance, flexibility, high quality, and instant working platform.

With an integrated, low-energy strategy, the design achieves a 51.9% reduction in CO_2 over current building regulations and scores BREEAM Very Good. The precast concrete panel wall and slab system allowed for rapid construction which was carefully phased to ensure the school remained fully functional throughout.

As a Pathfinder project, there was always potential for the £8.4 million scheme to be a flagship for the programme, and by any standards the school is a success – constructed on time (over a fast-track two-year programme), on budget, and lauded by its users and the London Borough of Ealing whose high aspirations for the project have been met and exceeded.

Materials and construction

Some 90% of the demolished school building was recycled or used as piling mat materials. An integrated, low-energy design strategy incorporates thermal mass, night-time cooling, cross-ventilation and high levels of daylighting, while a ground-source heat pump provides 43% of the total heating load of the building using renewable energy to heat water for the under-floor heating system. In addition, a sustainable drainage system (SUDS) was constructed and natural ventilation to all classrooms was made possible by using stack ventilation chimneys working in conjunction with a large proportion of openable windows.

In order to meet the ambitious sustainability targets of 10% of on-site renewables – the actual figure achieved was 15% – and 40% carbon reductions above current building regulations, the design team worked with the precast concrete supplier Buchan Concrete to develop an innovative precast panel system. This robust solution offered thermal mass, natural ventilation, exceptional acoustics, and enabled other parts of the programme to be run alongside the concrete manufacture with considerable time savings. The building received an air-tightness rating below Passivhaus standards and unique in Britain.

A brief summary of the precast contribution

- Precast concrete portal frames 6.5m long and 3.6m high
- Precast concrete panels 190mm thick and 4m high were up to 14 tonnes each. The panels were made in a range of lengths
- Precast concrete crosswalls 180mm thick carrying hollowcore floor units
- Panels lowered into position and laser-aligned before holding-down bolts tightened
- Achieved 1.98 $m^3/m^2/h$ airtightness well below current target figure of $10m^3/m^2/h$
- Total of 479 units erected at a rate of 16 per day (equivalent to $125m^2$), by using a 10 man erection team cut a week off programme
- Units included external and internal walls, stairs, landings and beams plus hollowcore floor slabs
- All building materials were obtained from sustainable sources