Current Practice Sheet No. 10

CONTROLLED PERMEABILITY FORMWORK

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Reviewed 2014 by
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The tenth in a series of Current Practice Sheets prepared by the Concrete Bridge Development Group

Introduction

It is widely accepted that concrete cast against impermeable formwork (IMF), has a reduced cement content and increased water cement ratio (i.e. less dense and more porous) compared to concrete beyond the cover zone. Here a denser and better quality pore structure is achieved, the result of a compaction process which forces excess mix water and air towards the formed surface. As wood, steel, plastic, fibreglass or expanded polystyrene formwork is impermeable, the forced movement within the concrete ceases when the concrete/formwork interface is reached. Visually this may be seen as blowholes and other water related surface blemishes upon removal of the formwork. As a consequence, the first line of defence (the cover) of an element will always be of poorer quality compared to its core[1].

Designers and concrete technologists have sought to address this issue through the specification and development of, surface treatments; coatings; higher spec concretes; corrosion inhibitors and deeper cover depths. Whilst all have merits to extend a structures service life none of these methods can permanently enhance the cover durability or reverse the deficiencies within the cover. Indeed with a UK repair industry estimated to cost between £100 and £600m per annum, compared to £9 and £16 billion per annum in the US[2], it could be argued that an alternative approach is required.

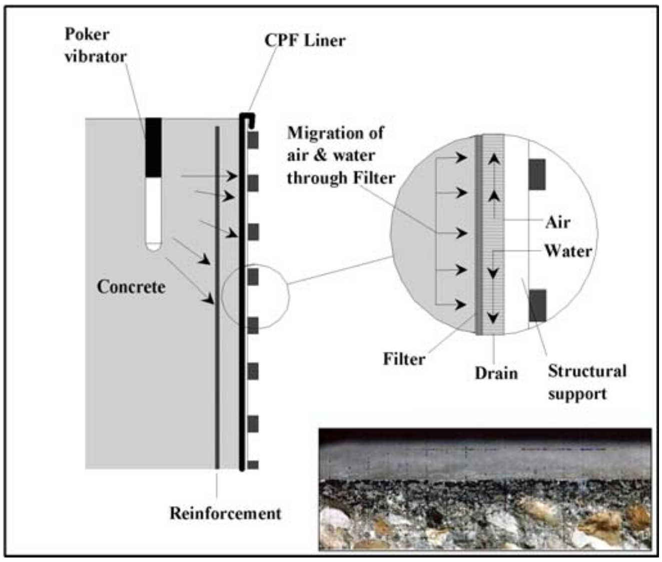

Figure 1: Mechanism of a CPF

Development of CPF

Controlled Permeability Formwork (CPF) are systems that have been proven under laboratory and site conditions, to naturally and permanently increase the cover cement content (by circa 50kg/m^3), while at the same time reducing the w/c ratio (by circa 0.1) porosity and permeability of this zone. Developed during the 1980's CPF has been widely used in Europe, the Middle East and Far East, on road and rail bridges. Approximately 250 articles and research papers are presently available, with guidance available to specifiers via BD57 - design for durability, BRE Special Digest No1 - concrete in aggressive ground, BS 8500, CIRIA and Neville[3-7].

CPF's are thermally bonded permeable liners that comprise filter and drain elements and whose pore structure is designed to retain the majority of cement and other small fines. They may be attached in tension to the internal face of the formwork using staples or glue. Self-adhesive liners can be used on for example curved or profiled walls and with care, complex shapes may be formed. During the concreting process and as a result of concrete pressures, entrapped air and excess mix water which would otherwise become trapped at the surface causing blemishes can instead pass through the liner (Figure 1). A proportion of the mix water is held within the liner and under capillary action imbibes back into the concrete to enhance the curing process.

This results in a densification of the formed surface which has a two-fold benefit in the creation of;

a) a cover zone - with significantly enhanced durability up to a depth of 20-25mm from the formed surface

b) a uniform surface - relatively free from blowholes, other surface blemishes and uncontaminated by release agent residues

With CPF release agents are no longer required and this results in surfaces with enhanced resistance to bacterial growth in both wet and dry environments due to the lack of nutrients present.

Liner reuse

For optimal performance documented guidance on liner re-use and cleaning methods should be sought from the CPF manufacturer. This will also assist in differentiating between single and multi-use liner systems. When considering the economic benefits attainable with multiple uses of a liner, consideration should primarily be given to the performance requirements. Studies undertaken into re-use suggest that liners washed between applications have a better overall performance than those unwashed. By not cleaning the liner, three to four uses are possible before performance is reduced to a marginal improvement over conventional formwork with CEM I, II or III concretes[8].

The most effective method of cleaning between uses involves high pressure water jets when the liner remains attached to the formwork. With finer cementitious materials such as silica fume, the liners filters can clog up more readily[9].

Colour and aesthetics

While CPF has primarily been employed as a means of improving the durability of reinforced concrete structures, it has also been used to aesthetically reduce the formation of blowholes and surface blemishes on concretes surfaces. Most CPF liners produce an aesthetically pleasing surface finish (Figure 2). It should be noted that where an exposed aggregate finish is required, the benefits attained will be reduced and possibly lost by the removal of the formed surface.

Concrete cast against CPF tends to be darker in appearance due to the permanent movement of cement particles to the surface and is more noticeable when compared with adjacent IMF concretes. The literature suggests that although permanent a lightening in colour will occur in time as the concrete dries.

An additional benefit of surface densification is the reduction in the depth to which graffiti media can penetrate. As a result, removal has been reported to be considerably easier compared to concrete cast against conventional formwork[10].

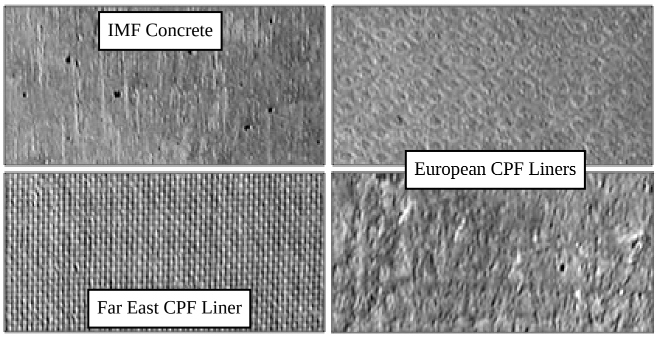

Figure 2: Comparison of IMF with CPF surface finishes.

Effect on durability

A significant body of research exists on the benefits afforded by CPF in improving the durability of concrete structures across a range of strengths, cement types and admixtures.

Chloride-induced corrosion is one of the main causes of deterioration in reinforced concrete structures[7]. Chloride ions present in marine environments or from de-icing salts being the principal threat. The literature shows that for laboratory and in-situ testing, CPF delivers quantifiable reductions in chloride penetration of the surface concrete by 50-60% across a range of concretes[11]. Even in the most adverse marine environments, CPF concrete with a nominal cover of 50mm would increase the time to initiate steel corrosion from about 15 to 40 years[12].

Carbonation-induced corrosion is generally regarded as a minor problem compared to chloride-induced corrosion. However in certain parts of the world such as Hong Kong this process is frequently a durability problem[13]. CO_2 concentrations in the atmosphere can vary from 0.03% in rural areas to 0.3% in large cities. In extreme cases values up to 1.0% have been recorded. CPF can reduce carbonation rates by approximately 50-100% and literature suggests this corrosion caused by a loss of concrete alkalinity would not be a serious problem for at least 100 years were CPF to be used[9, 13&14].

Freeze-thaw resistance of concrete in a wet environment and subjected to continual cycles of freezing and thawing may result in damaged concrete. Given that the mechanism for enhanced resistance (the entrainment of air) works on the premise that the discreet bubbles can relieve internal pore pressures caused by ice formation, it may be expected that a densification of the near surface with CPF would not be ideal for low temperature exposures. However, the literature suggests that concrete cast with CPF irrespective of concrete strength or cement type has an increased resistance to freeze-thaw compared to concretes cast against IMF alone. This appears to be due to the liner action, which causes an increase in tensile strength and a more even distribution of entrained air bubbles at the surface.

In laboratory and field tests, air entrained concrete or the application of hydrophobic pore lining impregnants (see CPS 2) have been found to be at best equivalent to non air-entrained concrete cast against CPF. However, the most significant benefits were noted when air entrained concrete was cast against CPF and with protective treatments.

Formwork

The best results are achieved when CPF liners are used on vertical and/or inclined surfaces (Figure 3). In the latter case, removal of conventional formwork often reveals the increased presence of irregular surface voids. The use of CPF allows this trapped air and/or water to dissipate, minimising their occurrence. CPF systems may also be used on deck soffits, however holes in the formwork may be required to assist the drainage. Approval should always be sought from the relevant authority to avoid contaminating any watercourse that may be below. Combining CPF with slip-forms is considered impractical[15].

Cost benefits

Using a CPF liner will increase initial construction costs on a project by approximately £8-14/m². However this can be offset when the following are factored into a cost benefit or life cycle analysis;

- liners are non-hazardous to health
- concrete cosmetic repairs are less frequent
- lower grade plywood may be used as the liners afford protection
- material savings on curing or release agents may be realised
- with some liner systems up to 4 reuses are achievable
- the increase in cover cement (up to 50kg/m³) above the specified content could result in mixes being used with similar reductions in cement content that still deliver and comply with the durability requirements of BS 8500 for given environments.

By far the biggest benefits relate to the enhancement in durability attained through the use of a CPF system which leads to reduced maintenance costs and/or the need for costly and disruptive intervention repairs.

Figure 3: Hunter Bridge, Kelso, Scotland.

Conclusion

Concrete formed against CPF liner systems have been demonstrated to permanently enhance the durability of the outer cover zone. Compared to concrete cast against impermeable formwork or beyond the cover zone, CPF concrete has been found to create a much improved surface matrix. By harnessing the benefits afforded by certified and approved CPF systems a real and measurable reduction in the whole life cost of a structure may be attained over a structures design period, which for UK bridges is typically 120 years.

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