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DISCUSSION

REPLY TO THE DISCUSSIONS ON THE PAPER "AN EVALUATION OF CONTROLLED PERMEABILITY FORMWORK FOR LONG-TERM DURABILITY OF STRUCTURAL CONCRETE ELEMENTS"[1]

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We are very pleased to respond to the comments on our paper by Messr. Wilson, Tonus and Duggan. We are not altogether surprised by the vehemence of some of the ill-natured and ill-tempered comments, bearing in mind the commercial interests of two of the discussers, but what is surprising is that many of the points raised are baseless without critically examining the sound scientific and technical basis of our paper.

It is clear from the comments of the discussers that they have either not understood or clearly misunderstood the thrust of our study. The focus of our paper is to examine and understand the role and long-term effectiveness of controlled permeability formwork (CPF) when it is used in the soffit of structural elements with large exposed surfaces, such as bridge decks and pavements, and when the concrete is made with a high water-cement (w/c) ratio of 0.60. The emphasis of the study is in the long-term performance of CPF, and its influence on the durability properties of not merely the near-surface concrete but also of the concrete element as a whole, including the bulk concrete behind the surface layer, when the concrete element has been subjected to prolonged chloride penetration and carbonation. In our view, although durability-related properties are good indicators of concrete quality, the only acid test of durability performance of concrete is the real-time exposure to chloride penetration, and this is the primary subject of the paper.

What the results of our study clearly show is that in structural elements such as slabs with CPF made with concrete of 0.60 w/c ratio, although the CPF does reduce chloride penetration into the surface concrete to a depth of 30 to 40 mm, the amount of chlorides penetrating into this region is still far too high to improve the overall durability of the concrete element as a whole. Further, beyond this surface layer, the chloride ingress into the CPF slab is higher than that in the control slab. Indeed, these conclusions are very consistent with other published data on CPF, which show that it does enhance the quality of concrete in the intermediate surface layer behind the liner, but that beyond that layer, the improvements in concrete quality are marginal or nil. Further, a critical evaluation of all these data seem also to imply that the higher the w/c ratio of the concrete, the greater is the depth of the surface layer whose quality is improved; nevertheless, at w/c ratios of the order of 0.60, the improvements in the

[1]Cem. Concr. Res. 27, 1047–1060 (1997).

quality of the surface concrete are not adequate enough to enhance the durability of the concrete element as a whole. The paper makes no attempt to derive any general conclusions on the overall performance of CPF when the design w/c ratio of the mix is anything other than 0.60. We believe the conclusion is due to the unsubstantiated belief that concrete mixes of 0.45 w/c ratio are always impermeable to chloride penetration, ignoring the nature and duration of exposure. The chlorides have the ability to penetrate in substantial quantities into the concrete cover of structural elements that have an effective w/c ratio, even as low as 0.45 in the surface layer, when it is exposed to chloride penetration for a sufficiently long time (1,2). Based on this fact, we have suggested that the concrete layer generated by CPF can effectively control the rate of chloride penetration only when the w/c ratio of the concrete layer adjacent to the CPF is significantly lower than 0.45.

The differential thermal analysis results of our study show higher cement content than the control slab in the 0–5 and 5–25 mm depth intervals adjacent to the CPF (refer to comments by Mr. Tonus); however, this does not guarantee a reduction in w/c ratio of the concrete well below 0.45. The firm conclusion of our study is that the lower resistance of the CPF-generated face is due to this inability of the CPF to generate a layer of concrete of w/c ratio significantly lower than 0.45, when the w/c ratio of the concrete in the structural element is 0.60.

The results reported in our paper are indeed supported by other published data (3). Thus, the extent of improvement in the performance of CPF is very much dependent on the w/c ratio of the concrete. The higher the w/c ratio, the larger would be the relative improvement in the quality of the cover concrete, but as pointed out earlier, at w/c ratios of 0.60, these improvements are not adequate enough to enhance the durability of the element as a whole. This is again confirmed by the statements in (4), according to which CPF showed a substantial improvement for high-grade concrete such as concrete with 0.40 w/c ratio containing 5% silica fume; but then, at these w/c ratios, the improvements occur only in the surface layer and are limited to 10–20 mm thickness.

All the three discussers have commented on the method of vibration followed in our study. Perhaps we should reiterate what we have said in the paper. We have developed a method of fabrication, which is described in the paper, which results in a very uniform and consistent mix with a minimum bleeding and segregation. We ensured that no clogging of the liner occurred, and this was verified subsequently. This technique of concrete mixing and casting has been applied to walls up to 2 m height with practically no bleeding and segregation. The two slabs refered to in the paper are not isolated elements, but form part of a wider study involving about two dozen similar reinforced-concrete slabs, and several reinforced concrete beams and columns, all of which have been cast in our laboratory with a similar technique and are undergoing very long exposure to aggressive elements, and all of which show consistent and compatible results over a wide range of engineering and microstructural measurements over several years. We totally reject these arguments of the discussers that the method of fabrication has influenced the results in the paper.

However, these comments raise a number of related issues. The discussers have pointed out that a minimum distance of 75 to 100 mm between the poker vibrator and the CPF liner should be maintained, and that violation of this basic requirement leads to clogging of the CPF liner with cement particles during vibration, resulting in the inferior performance of the CPF. It is then clear that if the above special vibration method is a mandatory requirement for CPF, then this itself is one of the limitations of CPF, because this special vibration method cannot strictly be followed in practice, and there are many real structural elements where limitations in size would preclude such method of vibration.

To verify the logic behind this argument, we reviewed the papers published especially by the people dealing with CPF, and those investigations supported by the CPF manufacturers (refs. 3–6, to quote a few). To our great surprise, none of these papers either describe or hint even indirectly about the mandatory vibration method in any part of their text. Indeed, Ref. 4 states that "the use of the fabric does not restrict the use of any *given concrete grade* and the *normal casting and compacting practices* and can be used just with minor details being changed. In the unlikely event of the vibrator touching the fabric, very local damage is caused and the rest of the fabric is not affected." To our surprise again, we have not come across any investigation in published literature which elucidates the influence of the distance between the vibrator and the CPF on the properties of concrete generated by CPF. One can only conclude that the arguments put forward by the discussers are irrelevant and not based on sound scientific evidence; indeed, they may be construed as a ploy to cover up the realistic data presented in the paper. We reiterate, on strong evidence, that the mode of vibration followed in our study has nothing to do with the credibility of the results presented in the paper. Mr Tonus states that "the used casting procedure does not reproduce site conditions and that, as a consequence, the measured CPF performance is only of academic interest." If these arguments were applied to all the published research that Messrs. Tonus and Wilson quote in support of CPF, very few of the results stand up to scrutiny.

We are dismayed, to say the least, but not surprised at the comments made by Mr. Tonus about the comparison of the properties of the face of a slab cast in contact with CPF with the properties of the cast face of another slab, which are basically different. The critical surfaces of the two test slabs are indeed intended not to be same. This is the whole thrust of the paper, which obviously has been missed by Mr. Tonus. The control slab had the CPF liner at the bottom, and the cast face of this slab thus represents the surface remote from the liner, and this surface was exposed to long-term chloride penetration and carbonation, which is what happens in practice. The results of this slab thus represent the benefit that can be derived in real-life situations if CPF liner were used in the soffits of structural elements such as bridge decks and pavements.

The CPF slab was also cast with the CPF liner at the bottom, but then this slab was inverted so that the face in contact with the liner, which will have altogether different microstructure and chemistry, was subjected to similar processes of chloride penetration and carbonation. We feel that this slab represents the only realistic way to evaluate the role and effectiveness of the CPF liner in modifying the properties of not only the surface concrete layer behind the liner but also of the bulk concrete beyond the surface layer. The comparison between this CPF slab and the control slab then clearly identifies what can be achieved in practice if CPF is used in the soffit of slab-like structural elements. The results may not be to the liking of Mr. Tonus, but it is no less scientific than comparison with the face cast against impermeable formwork.

It has been suggested that the control slab has a surface subjected to an unknown amount of bleeding. This is not so. We have taken great care to reduce the bleeding in the control and CPF slabs by the special casting technique discussed earlier. This technique has been proved very successful both in the laboratory and in the field in its ability to reduce bleeding significantly.

As it happens, we have other slabs with the bottom cast on conventional impervious formwork, and the results of these studies will be reported in due course. However, it should be clearly noted that such comparisons would in no way alter the actual long-term durability characteristics of the face generated by CPF (as represented by the CPF slab) when exposed to prolonged chloride penetration and carbonation, nor would it alter what can be achieved in practice in slab-like elements when CPF is used in the soffit. On the other hand, such comparison may point out the weakness of CPF technology, as the surface generated in contact with an impervious steel formwork in a slab may fare on par with the face generated in contact with CPF. The suggestion that the results of such a comparison would be quite different, implying being more favourable to CPF, may be more imaginary than factual.

Mr. Wilson has referred to other minor points in the paper. It is mentioned that not all types of CPF require the use of predrilled formwork. So be it; this does not in any way alter the results presented in the paper. Indeed, our work started more than 7 years ago, and we followed the instructions given at that time by the manufacturers; such predrilled formwork is also quoted in the research funded by the manufacturer (5) and other studies (7,8). We agree that CPF has not revealed any reduction in formwork loads; however, we were in effect quoting from Ref. 5, which states that "the main emphasis in using CPF in the UK has been on the reduction of formwork pressure" with a supporting reference (9), which has not been contradicted by CPF manufacturer. It is also worth quoting from Ref. 4: "A controlled permeability formliner (CPF) is engineered to resist concrete pressure. . . . "

All the discussers claim extensive research, in excess of one hundred projects, on CPF, all of which are claimed to show increased durability of the concrete with CPF. Mr. Tonus quotes "an internal list of studies. . . partly unpublished," but gives no reference to any published long-term performance characteristics of CPF, and we do not know the nature of the unpublished data. Mr. Wilson refers to 3-year exposure studies to a salt-laden marine environment, and yet gives no reference. A careful analysis of all published data on CPF shows that much of the results reported are based on short-term exposure tests (refs. 3,5,7, for example), and there is only very limited long-term performance data on CPF, as indeed stated by Mr. Serafini (4). Mr. Wilson states "even basic research by undergraduates has confirmed that when used correctly, CPF improves concrete durability to a significant degree." This statement speaks volumes for itself, and betrays a gross lack of understanding of not only the role and function of undergraduate work, but also of "fundamental research." We are not surprised to see the length to which people will go to "shore up" inadequate evidence of long-term durability.

Finally, we strongly believe in the need for new, innovative ideas to improve the quality of concrete construction, but we also believe that short-term test data on innovations such as CPF may lead to misleading information. Civil engineering structures are designed for many decades of service life. Short-term results bear little relation to the time-dependent and other interactive effects of exposure and environment that ultimately decide the serviceability and durability of materials and structures. A few well-planned and well-structured researches are worth hundreds of research projects and "basic undergraduate research." We ignore long-term data at our peril. Extrapolating test results beyond the domain of their test methodologies and test constraints can lead to misinformation and disastrous consequences, as indeed shown by the premature deaths of many excellent innovations. It is easy to pick irrelevant arguments that close one's eyes to realistic data, but in doing so, we shall be doing a great disservice to the construction industry.

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