Copy of a Paper for the 7th International Congress on Concrete, 8-10 July 2008, Dundee, and published as part of the Proceedings of the Conference.

The Long Term Durability of Plastic Spacers in Reinforced Concrete: A Case Study.

ABSTRACT. Plastic spacers have been used in reinforced concrete in the UK since the early 1960's. Periodically there have been rumours that they could reduce the durability of reinforced concrete by providing a path along their surface for water to reach, and then corrode, the reinforcement. However, there has been little or no research carried out on this subject. This Paper looks at a case study of a 36 year old reinforced concrete structure where the spacers were examined and recovered during demolition, and then tested. The concrete and reinforcement were also examined and recovered during demolition. The Paper describes the work done, the results, and how these are being used to achieve 'state of the art' sustainable concrete construction.

Keywords: Sustainability, Durability, Spacers, Cover, Reinforcement, Concrete.

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INTRODUCTION

Plastic spacers have been used in reinforced concrete in the UK since the early 1960's. Since their introduction various types have been used, and different materials have been tried. The subject of the long term durability of plastic spacers has been raised from time to time, but there appears to have been little or no research undertaken. One possible reason for this is that, once cast into the concrete, the spacers remain there for the life of the structure, and cannot be removed without physical damage to the concrete and possibly the spacer. Another consideration is the difficulty of finding the spacers within the concrete. Usually the concrete flows between the feet of the spacer and the formwork so that there is no part of the spacer visible on the finished concrete surface.

This research was carried out on a multi-storey car park which was built in the 1960's and demolished after 36 years due to re-development of the site. There was the opportunity to examine the structure as it was demolished, and in particular the concrete and the reinforcement. It was also possible to recover and test a quantity of the plastic spacers that had been used during its construction to assess their long term durability when cast into reinforced concrete. It is believed that this is the first time that such research has been done.

BACKGROUND

Periodically there have been rumours that plastic spacers could reduce the durability of reinforced concrete by providing a path along their surface for water to reach, and then corrode, the reinforcement. However, there has been little or no research on this subject. This Paper is a case study of a 36 year old reinforced concrete structure where the spacers were examined and then recovered during demolition, and subsequently tested. The concrete and reinforcement were also examined and recovered during the demolition. The Paper describes the work done, the results, and how these are being used to achieve 'state of the art' sustainable concrete construction.

The problem of the failure to achieve the specified concrete cover to the steel reinforcement in reinforced concrete structures is widespread. In 1999 the Building Research Establishment [1] estimated that this type of failure costs £550 million each year in the UK alone, and it is a worldwide problem. The cost of repairing corroded misplaced reinforcement in Europe has been estimated at £1 billion a year [2]. For many years there was no published national guidance in the UK on how to achieve the specified cover first time, every time. It was often left to the contractor to achieve the specified cover, or not as was frequently the case. The positioning of the steel reinforcement, either bar of fabric, is crucial in achieving the design performance of the structure.

The type and location of the spacers and chairs used to position the steel reinforcement are important for three reasons:-

1. Structural — If the reinforcement is not in the position where it was designed to be, the strength (and safety) of the structure can be seriously affected. This is crucially important for cantilevers where the reinforcement is designed to be near the top of the concrete, but sometimes ends up in the middle or at the bottom due to inadequate support before or during concreting. Collapses can

occur as a result.
In earthquake prone areas the correct positioning of the reinforcement is particularly important because the forces generated by earthquakes will find any weaknesses in the designed strength of a structure. Special design measures are used to resist earthquake forces, but they can be ineffective if the reinforcement is not correctly positioned.

2. Durability When the specified cover is not achieved the durability of the reinforced concrete is greatly reduced. The steel reinforcement starts to corrode, spalling off the face of the concrete and weakening the structure. As an example, for external concrete sheltered from the rain 30mm of cover will give 135 years of protection to the reinforcement, but 10mm of cover will only give 10 years life [3]. In marine conditions any deficiency in the specified cover can greatly reduce the life of the structure in this demanding environment.

3. Fire In a fire the time before the heat reaches the reinforcement is dependent on the cover. When the reinforcement heats up, the steel softens and can no longer take the stresses for which it was designed. The structure can collapse, possibly with the firefighters and / or the occupants still inside a building.

Over the last 30 years much work has been done to identify the factors affecting the achievement of the specified cover, and to select and improve the best performing spacers and their use. Consistent promotion of best practice has been an ongoing process. [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14]. The incorporation of requirements into British Standard 8110-1:1997 and the publication of British Standard 7973 in 2001 were major steps forward. [15], [16].

THE STRUCTURE

The car park was one of the first such structures to be built in the UK. It was essentially a reinforced concrete frame, similar to those used in a conventional building. The concrete mixes were 1:2:4 by volume for the foundations, beams, slabs and walls, and 1: 1 1/2: 3 by volume for the columns. The aggregate was 3/4” (19mm) Thames Ballast, and Ordinary Portland Cement was used. The compaction of the concrete was generally good.

The cover to the reinforcement was specified from 3/4" (19mm) up to 1 1/4" (32mm) for the different parts of the structure. End covers were specified at up to 3” (76mm). The covers specified were those used at the time for internal reinforced concrete frames, and the significance of using them for external structures was not appreciated until many years later. Current cover for an equivalent external structure would typically be 40mm (1 1/2").

The structure was demolished by crushing the concrete with a Verachtert Hydraulic Muncher mounted at the end of the arm of a long reach Liebherr excavator. The Muncher crushed the concrete into small pieces causing it to separate cleanly from the reinforcement and some of the spacers.

TESTING

General

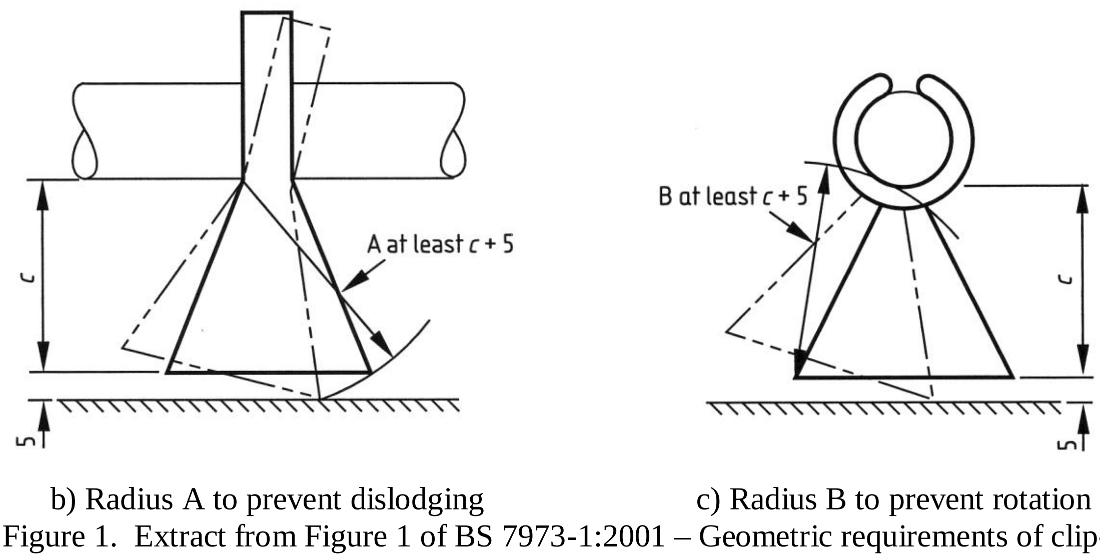
A total of 103 spacers were recovered from the demolished structure. One of these was subsequently found to be too badly damaged for testing. Of the 102 remaining some had slight damage from the demolition, but most were in a very good or pristine condition. All of these were subjected to stability, longitudinal dislodging, rotation, fixity, and point load tests using the requirements of British Standard 7973-1:2001 as a reference. The plastic which the spacers were made from was also tested to identify the type. It was found to be a medium density polyethylene. The spacers were of a design known to perform well in practice and are believed to have been manufactured by a company called Plasclip Ltd.

Stability Tests

Stability tests are defined in Section 8 of BS7973-1:2001. Two types of geometric stability are required in order to ensure that the spacer does not become dislodged due, for example, to the flowing of the wet concrete during placing.

BS 7973-1:2001 Clause 8.1 says "The stability of a clip-on spacer, other than a clip-on wheel spacer, shall be provided by having a radius of rotation at least 5mm greater than the required cover, both perpendicular and parallel to the line of the reinforcing bar to which it will be attached".

Stability in the perpendicular direction is referred to in the Standard as rotation about the line of the reinforcing bar or wire. Stability in the parallel direction is referred to in the Standard as the prevention of dislodging in the direction of the line of the reinforcing bar or wire. (Longitudinal dislodging). In this case study diagrams b) and c) of Figure 1 of BS 7973-1:2001 are relevant to the recovered spacers. See Figure 1 below. Checks were made on both types of stability by measurement of the recovered spacers.



b) Radius A to prevent dislodging c) Radius B to prevent rotation

Figure 1. Extract from Figure 1 of BS 7973-1:2001 – Geometric requirements of clip-on spacers.

Rotation

The resistance to rotation of the spacer about the reinforcing bar was checked by comparing the cover measurement with the radial measurement of the cover plus 5mm. The cover for the spacers was specified as 3/4" (19mm). The radial dimension was found to be 23mm which is almost the 24mm required by the Standard. Although technically not quite sufficient, the radial measurement appeared to work in the structure. No instances of rotational displacement were found. However, the requirement was subsequently set in the Standard at 5mm greater then the cover measurement in order to meet the tolerance requirements for the bending of reinforcement.

Longitudinal Dislodging

The resistance to longitudinal dislodging was checked by comparing the cover measurement with the radial measurement of the cover dimension plus 5mm. The cover for the spacers was specified as 3/4" (19mm). The radial dimension was found to be 28mm which is more than 19 + 5mm. The spacers therefore complied with the requirements of BS 7973-1:2001 Clause 8.1 in respect of resistance to longitudinal dislodging.

Fixity

Fixity is defined as the ability for the spacer to resist sliding along the reinforcement, either under the pressure of the wet concrete when poured, or, for vertical reinforcement, under gravity. It is a measure of the grip provided by the clip onto the reinforcement. For clip-on plastic spacers Clause 10.2 of BS 7973-1:2001 says that the fixity shall be verified by observing whether the clip prevents a 0.5kg ± 0.01kg commercially ground, unrusted, degreased, silver steel bar of the smallest bar size (in the size range produced by the manufacturer) from sliding vertically through the spacer as shown in Figure 2 below.

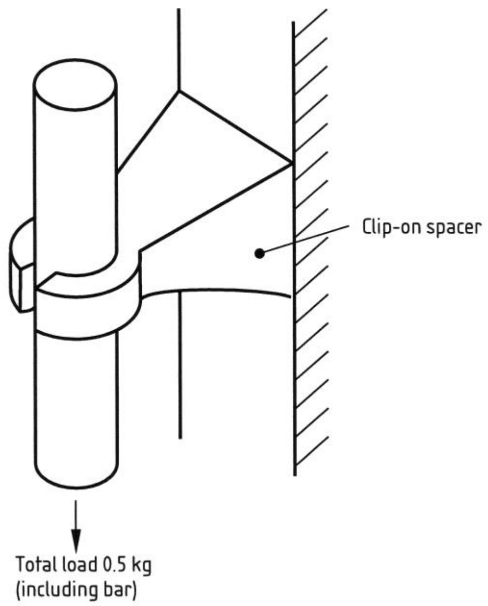


Figure 2. BS 7973-1:2001, Figure 2. Isometric view of the fixity test for clip-on spacers.

Of the 103 spacers recovered 100 had clips in sufficiently good condition to be tested. Some clips did have some slight damage to them which had occurred during the demolition process, but all 100 clips passed the fixity test when tested with the appropriate size of bar. Four spacers had small clips and these were tested with an 8mm diameter bar even though they had been fixed to a 3/8” (10mm) size reinforcement. All four spacers passed the test with both 8mm (5/16”) and 10mm (3/8”) diameter bars in turn. The 96 remaining spacers had been fixed to 5/8” (16mm) size reinforcement and were tested with a 16mm (5/8”) diameter bar. They all passed the test.

Point Load Tests

The spacers were tested using the method in Annex A of BS 7973-1:2001. Given their positions in the structure they were regarded as Normal category spacers to Table 2 of BS 7973-1:2001 and 0.5kN load was used. Each of the five groups of spacers recovered was split into two approximately equal parts. One part was tested hot at + 30^{o} C $\pm$ 2^{o} C and the other cold at -5^{o} C $\pm$ 2^{o} C using the apparatus shown in Figure A1 of BS 7973-1:2001.

BS 7973-1:2001 requires the load to be applied in less than 10 seconds, maintained for a further 10 minutes, and then removed. The total deflection under the test load shall be measured and recorded. The test load is then removed and one minute after the removal of the load the height of the spacer shall be within 1mm of its height before loading in order to pass the test.

Fifty spacers were tested hot. They deflected an average of 1.58mm under the test load and recovered to an average residual deflection 0.30mm after the load had been removed. The maximum deflection under load was for an undamaged spacer was 1.98mm, recovering to 0.25mm, and the minimum was 1.00mm under load recovering to 0.23mm.

Fifty two spacers were tested cold. They deflected an average of 1.35mm under the test load and recovered to an average deflection of 0.19mm after the load had been removed. The maximum deflection under load for an undamaged spacer was 2.13mm, recovering to 0.34mm, and the minimum was 0.9mm under load recovering to 0.00. i.e. 100% recovery.

All of the spacers passed the test.

In addition, 90 of the spacers had their initial deflections on loading recorded. For these spacers the average deflection within 10 seconds of the load being applied was 1.15mm. For the spacers that were tested hot the average deflection within 10 seconds of loading was 1.25mm. For the spacers that were tested cold the average deflection within 10 seconds of loading was 1.03mm.

REINFORCEMENT

The reinforcement used in the structure comprised both mild steel and high tensile steel in sizes from 3/8” (10mm) up to 1 1/4" (32mm). The links in the beams and columns were formed of 3/8” (10mm) size mild steel reinforcement. The main reinforcement in the beams was 1 1/8” (28mm) size and in the columns 1 1/4” (32mm) size, both being high tensile reinforcement. The floor slab main reinforcement was 1/2" (12mm) and 5/8” (16mm) size high tensile, and the distribution reinforcement 3/8" (10mm) size mild steel. The reinforcement in the walls was generally 1/2" (12mm) size mild steel. The foundations used 1/2" (12mm) and 5/8" (16mm) sizes of mild steel, and 7/8" (22mm) and 1 1/4" (28mm) sizes of high tensile steel. A variety of types of high tensile reinforcement were used.

The type of demolition equipment used crushed the concrete in-situ, and this allowed the steel reinforcement to be cleanly exposed for its full length. The reinforcement was inspected at several stages as the structure was demolished, and eventually loaded into large skips for recycling.

In some cases the spacers were still attached to the reinforcement after the concrete had been removed. This demonstrated the potential for a good design of spacer clip to resist the forces generated both during construction and demolition. See Figure 3.

Figure 3. Reinforcement in-situ with spacer still attached.

Periodically there have been rumours that the use of plastic spacers could reduce the durability of reinforced concrete by providing a path along their surface for water to reach, and then corrode, the reinforcement. If this were to occur then corrosion of the reinforcement adjacent to the position of the spacer would be greater than that seen along the remainder of the bars. From the examination of the reinforcement there was no difference in the amount of corrosion of any of the bars at the positions of the spacers. If corrosion at the positions of the spacers had occurred then even where the spacers had become detached from the reinforcement during the demolition process there would have been short lengths of greater corrosion along the length of the reinforcing bars at these positions. From the examination of the reinforcing bars there were no such positions of greater corrosion and the reinforcement showed the normal slight even corrosion that is desirable in order to achieve adequate bond with the concrete.

The requirement for the design of plastic spacers to BS 7973-1:2001 Clause 6.2 is that they shall satisfy the condition that any cross section perpendicular to the reinforcing bar shall have at least 25% voids within the enclosed perimeter. Whilst this requirement is mainly to allow the concrete to flow through the void and form an homogeneous mass it also provides additional protection to the reinforcement in respect of resistance to the passage of water and also heat penetration during a fire. This requirement did not exist when the recovered spacers were manufactured.

It was therefore concluded that this possible problem of water penetration along the surface of plastic spacers, if it exists, would not affect spacers that met the requirements of BS 7973-1:2001. No cases of water penetration along the surface of plastic spacers have been found by the author despite enquiries spanning over many years.

PROPERTIES OF THE PLASTIC

The spacers were subjected to non-destructive testing using Fourier Transform Infra Red Spectroscopy (FTIR) which confirmed with a high degree of certainty that they were made from medium density polyethylene. The testing also suggested that an impact modifier had been added to the material to improve its flexibility and resistance to impact. The material is believed to be very similar to that used today for some high quality spacers complying with the requirements of BS 7973-1:2001.

The degradation of the plastic over time would primarily be the result of exposure to ultra violet light. It is not chemically attacked by the alkalis in the concrete and once cast into the concrete is not exposed to ultra violet light. Such exposure would cause a chalk whitening on the outside of the polymer. From experience, if the surface was exposed to ultra violet light for long periods of time the cross linking of the chalk whitening would form a resistance to further degradation. There was no evidence of any chalk whitening on the recovered spacers. They can therefore be considered durable and likely to last for the life of the structure.

SUMMARY

This case study provided the opportunity to examine the long term durability of plastic spacers cast into reinforced concrete. Although the spacers were manufactured and cast into the concrete long before the publication of BS 7973 they passed the current tests for good quality products complying with the Standard, and have proven themselves to perform well in practice on many projects. The Standard is based on many years of research and practical construction, and this case study adds to the confidence that reinforced concrete constructed according to the requirements of the Standard is a sustainable construction material.

CONCLUSION

This research has shown that good quality plastic spacers perform well at the time a structure is constructed and for many years afterwards. They can easily be expected to last for the design life of a structure and probably for its full actual life. After 36 years in the concrete in an external environment the recovered spacers still passed the current test requirements of BS 7973-1:2001. The spacers did not provide a path for water to reach the surface of the reinforcement, and later revisions to spacer designs have improved the requirements resulting in those published in BS 7973. Achieving the design life of a structure is fundamental to the requirements for sustainable construction. This can be achieved first time, every time, through the application of the requirements of BS 7973. This will ensure that the structure easily meets its design life in this respect, and the structural, durability and fire performance requirements, thus making it sustainable.

ACKNOWLEDGEMENTS

The author would like to thank the following people for their assistance with this project.
Mr. Chris White for access to the site and the original drawings of the structure.
Mr. Jim Foley from Demo One Ltd, the demolition contractor.
Mr. John Stirley and staff of Injection Plastics Ltd for making the testing facilities available.
Mrs. Christine Deane, Editor, '*CONCRETE'* Magazine, for historical information.
Mr. Peter Atterby, Managing Director, Luxus Limited, for the FTIR testing.
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7thConcreteCongressv1.1 05.06.2016