Copy of Paper presented at the 6th International Congress on Concrete, 5-7 July 2005, Dundee, and published as part of the Proceedings.

'COVER TO REINFORCEMENT – GETTING IT RIGHT'

ABSTRACT: The Paper describes the problem of the failure to achieve the specified cover to the reinforcement in reinforced concrete structures. This is a widespread problem which in the UK alone is reliably estimated to cost £550 million each year. That is more than £1.5 million a day, and it is a world wide problem. Achieving the specified cover is important for the structural, durability and fire performance of structures. The Paper describes the problem, the development of British Standard 7973 (which solves the problem), and shows an example of the Standard in use. BS7973 has been incorporated by reference into British Standard 8110 'The Structural Use of Concrete', and is applicable to other reinforced concrete standards.

Keywords: Cover, Spacers, Chairs, Reinforcement, Fabric, Detailing, Tying, Durability.

Chris Shaw is a Chartered Civil Engineer and a Chartered Structural Engineer practising as a Consultant. He has more than 30 years experience in achieving the specified cover to the reinforcement in reinforced concrete structures, and devised the system for achieving this which was subsequently published as British Standard 7973 in 2001. He is now Chairman of the committee that prepared the Standard and gives advice, lectures and talks on the subject. He continues to carry out research and development on the products, their applications and innovative uses.

INTRODUCTION

The problem of the failure to achieve the specified concrete cover to the steel reinforcement in reinforced concrete structures is widespread. An example is shown in Figure 1. 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 world wide problem. For many years there was no published national guidance in the UK on how to achieve the specified cover correctly 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 or fabric, is crucial in achieving the design performance of the structure.

Figure 1. Example of corroded reinforcement resulting from the failure to achieve the specified cover.

It is important that the reinforcement is in the correct position 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[2]. 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 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.

Currently some structures do not achieve their intended design lives due to deficiencies in the cover achieved. Some have had to be demolished prematurely, or undergone

expensive repairs. A key part of sustainable construction is the prudent use of resources. Structures can be built with the specified cover achieved, and this will ensure that they achieve their design life and do not fail prematurely from this cause.

DEVELOPMENT OF THE BRITISH STANDARD

The development and publication of British Standard 7973[3] in October 2001 was a landmark towards achieving the specified cover first time, every time. It was the result of many years of research into the problem and possible measures to overcome it.

My recognition of the problem started in 1968 and by 1979 a system had been devised and tested on actual construction projects for the first time. In 1980 the then Cement & Concrete Association decided to publish an updated version of its Construction Guide[4]. This contained much of the knowledge available at that time.

Research and development work continued, both on the range and performance of the spacers and chairs themselves, and on their use on site. It was found that both the products and their use were equally important in achieving the specified cover.

Following the presentation of Papers to a course on 'The Durability, Maintenance and Repair of Concrete Structures' at the University of Surrey and 'The Second International Conference on Structural Faults', both in 1985, the then Cement & Concrete Association (C&CA) asked that the system which had been developed and used for several years be published as a national document. On the demise of the C&CA this important project was taken over by the Concrete Society and published as Report CS101[5] in 1989.

The work continued at a European level and in 1990 the Comité Euro-International Du Béton published their Bulletin D'Information No. 201[6], further publicising the system that was now fully developed and had been in use for over 10 years.

Further articles appeared in *CONCRETE* magazine[7,8] and Concrete Engineering International[9]. A Site Supervisors Guide was published in 1995[10]. At the same time the Construction Industry Research and Information Association (CIRIA) published their Special Publication 118 on Steel Reinforcement[11]. All these publications contained details of the same system in order to give a consistent message across the industry.
It was then decided that this proven system warranted its own British Standard which could then be incorporated into Specifications and British Standard 8110-1[12], thus completing the construction information chain. The resulting publication of British Standard 7973 in October 2001 and an article in *CONCRETE* magazine[13] in advance of its publication meant that for the first time this important aspect of reinforced concrete construction was included in the Standards for concrete. BS7973 has widespread applications in both reinforced and pre-cast concrete, and other structures such as bridges which have their own design standards, e.g. BS5400.

THE PROCESS CHAIN

The construction process involves many people. Observation has shown that there are still many structures where reinforced concrete is being used but the specified cover is not being achieved. The participants of a study[14] generally agreed that the defects could be roughly equally divided between operatives (53%) which included steel fixers, formwork fixers, and placing and compaction operatives; and management (47%) which included architects, consulting engineers, designers, contractor's management, reinforcement suppliers, and site engineers. The process chain is a long one and the omission can

occur at any one or more of the stages. The Client is probably not aware of the problem, and assumes that their Consultants will design the structure in accordance with all of the Standards. The Consultant's project manager takes an overview of the project and does not usually get involved in the actual design. The designer concentrates on the calculations, and passes these to the detailer who may be some distance away in another office, organisation or country. Having not received instructions on the spacers and chairs to use the detailer does not include them on the reinforcement drawings. The Contractor's estimator does not see anything about spacers or chairs specified on the drawings or the Specification, so does not include for them in the price for the work. The Contractor often sub-contracts the fixing of the steel reinforcement entirely to another Contractor, who receives no instructions regarding the spacers and chairs from the drawings, Specification, or Contractor. Research has shown that steel reinforcement sub-contracting fixing companies are sometimes not even aware of the requirements in the British Standards. The end result is that all too often the reinforcement does not end up with the specified cover in the correct position, or in accordance with the Standards.

This can be remedied by:-

- The requirement to comply with BS7973 being specifically written in to the Specification.
- Including on the drawings 'The specified cover shall be achieved by the application of BS793'.
- Raising awareness of the problem and the solution, throughout the process chain.

Some Designers and Contractors are known to be using this approach, and deriving commercial advantage as a result. With a published Standard on the subject designers have a duty of care to specify BS7973. Consultants using the Standard have reduced their potential liability for Professional Indemnity Insurance claims being made against them. Such claims, successful or otherwise, are inevitably costly and best avoided whenever possible. Contractors using the Standard benefit from getting the work right first time every time. They do not then need to become involved in disputes regarding the actual cover achieved, costly remedial works and delays whilst the matter is sorted out, or, in the worst case, demolition and rebuilding of the affected work.

In the UK, Clients and their designers have a direct responsibility under The Construction (Design and Management) Regulations for the design, construction, maintenance and demolition of a building or structure. The failure to achieve the specified cover can lead to spalling of the concrete, and pieces falling to the ground with possible injuries to people underneath. If the reinforcement is not in the correct position demolition contractors could face unnecessary hazards as they would have no way of knowing that the strength or behaviour of a structure during demolition was not what they would have expected from the design drawings.

THE PRODUCTS

Spacers provide the specified cover between the reinforcement nearest the surface of the concrete and the surface itself. The surface may be horizontal (e.g. slabs), vertical (e.g. walls), or inclined. Chairs are used to support the top (usually horizontal) reinforcement or to separate vertical reinforcement in walls. Historically, spacers and chairs have been the poor relation of the concrete industry. Pieces of wood, brick, broken concrete, tile and slate have all been seen used as spacers, even on recent projects. At one time site made sand / cement blocks with pieces of tying wire cast in them were a preferred option. Factory made spacers have now replaced site made ones, which are excluded in BS8110-1.

BS7973 contains the performance requirements for both plastic and cementitious spacers, and steel wire chairs. These have been developed to carry the normal construction loads associated with their particular applications. The selection of the relevant category partly depends on the size of the reinforcement to which they are to be fixed. Although spacers and chairs complying with BS7973 are available there are also many non-compliant products on the market. Use of these non-compliant products has led to the specified cover not being achieved.

Spacer and Chair Categories and Applications.

Four categories of spacers and chairs are included in the Standard. The spacer and chair categories required for particular applications shall be in accordance with Table 1 of BS7973-1. The categories are as follows.

Light category

Light category spacers provide the cover in vertical members to the reinforcement nearest to the surface of the concrete or to horizontal reinforcement in small sections not subject to foot traffic, e.g. pre-cast concrete products. They are not suitable for use on reinforcement greater than 16mm in size.

Normal category

Normal category spacers are used for most in-situ concrete work and can be used for larger pre-cast products. They provide the cover to the reinforcement where the size of the reinforcement to which they are fixed is 20mm or less.

Heavy category

Heavy category spacers provide the cover to the reinforcement where the size of the reinforcement to which they are fixed is greater than 20mm. This is typically in bridge decks and heavy foundations.

Chairs

Chairs are used to support the top reinforcement in slabs so as to provide the required top cover or to separate layers of reinforcement e.g. in walls. They are manufactured as individual, continuous or circular. Continuous chairs are widely used for separating layers of reinforcement. Individual chairs with protective tips can be used to support the top reinforcement in slabs where there is no bottom reinforcement provided.

Standard Range of Sizes

The standard range of sizes for spacers is for nominal covers from 15mm to 75mm in 5mm increments. The standard range of heights for chairs is from 75mm to 200mm. Non-standard heights of chairs are available down to 30mm and up to 400mm. Special chairs can be manufactured to greater heights. Tapering continuous chairs can also be manufactured.

ACHIEVING THE SPECIFIED COVER

The detailing of the reinforcement is an important factor in achieving the cover. Reinforcement should be detailed ‘flexibly’ to avoid the fixed length of a bar between two

faces of the concrete reducing the specified cover. Tolerances in the formwork dimensions can also reduce the cover, but 'flexibly' detailed reinforcement can overcome this problem.

Reinforcement needs to be tied together to prevent displacement of the bars before or during concreting. The spacing of ties for slabs, beams, columns, foundations, and walls is given in BS7973-2. Slash ties are recommended for tying the reinforcement in slabs; ring slash and crown ties in walls; and crown or hairpin ties in beams and columns.

Spacers are required to be fixed to the links, fabric or reinforcement nearest to the face of the concrete to which the cover is specified. If coloured, textured, profiled, or exposed aggregate finishes are required the reinforcement can be spaced off either the opposite face, or by the use of chairs.

Reinforcing bars wired together and welded fabric to BS4483 behave differently when subject to construction loads. After much research rules for the spacing of spacers and chairs to support reinforcement and fabric were devised. For reinforcement the bar should be supported along its length at centres not exceeding 50d, but not exceeding 1000mm, where d is the nominal size of the bar nearest the surface of the concrete. Welded fabric reinforcement to BS4483 is produced in four ranges of preferred types; A, B, C and D. The Standard is applicable to types A393 to A142, B1131 to B283, and C785 to C385. Fabric types A98, B196, C283, D49 and D98 are not suitable for supporting foot traffic.

An example of spacers used in accordance with the Standard is shown in Figure 2.

Figure 2. Example of spacers being fixed in accordance with BS7973 for the roof of a culvert built using permanent formwork and pre-bent fabric.

SUMMARY

The publication of British Standard 7973 is a major step forward to the achievement of the specified cover in reinforced concrete structures. Although comprehensive published guidance on the achievement of the cover has been available since 1989 the incorporation by reference of BS7973 into BS8110 completes the system of Standards for this aspect of reinforced concrete. The provisions in BS7973 have world wide applications wherever reinforced concrete is used.

REFERENCES

1. BUILDING RESEARCH ESTABLISHMENT, Concrete Corrosion – a £550m-a-year problem, Research Focus, 1999, No. 37, May, pp4.

2. CONCRETE SOCIETY. Spacers for reinforcement, 'Concrete' magazine, 1994, volume 28, May / June, pp27-30.

3. BRITISH STANDARDS INSTITUTION. British Standard 7973, BSI, London, 2001, 42pp.

4. ROBERTS, R F, Spacers for reinforcement, Cement & Concrete Association, Wexham Springs, 1981, 8pp.

5. CONCRETE SOCIETY. Spacers for reinforced concrete, Concrete Society, London, 1989, 30pp.

6. COMITE EURO-INTERNATIONAL DU BETON. Bulletin D'Information No. 201, Comité Euro-International Du Béton, Lausanne, 1990, pp57-79.

7. LANCASTER, R I, Spacers for reinforced concrete, 'Concrete' magazine, 1989, volume 23, November, pp27-28.

8. KIRKBRIDE, T, Spacers Manual, 'Concrete' magazine, 1991, volume 25, pp9-10.

9. KING, E, AND DAKIN, J,. Cover to Reinforcement, Concrete Engineering International, 2000, volume 4, June, pp37-40.

10. Q I TRAINING LTD. Preparing for Quality – Site Supervisors Guide, British Cement Association, Crowthorne, 1995, pp69-85.

11. TUBMAN, J, Steel Reinforcement, Construction Industry Research and Information Association (CIRIA), London, 1995, pp81-94.

12. BRITISH STANDARDS INSTITUTION. British Standard 8110-1, BSI, London, 1997, 173pp.

13. CLARKE, N, AND WATSON, N. Reinforcement and accessories overview, 'Concrete' magazine, 2001, volume 35, March, pp29-33.

14. CLARKE, L A, SHAMMAS-TOMA, M G K, SEYMOUR, D E, PALLET, P F, MARSH, B K, How can we get the cover we need?, The Structural Engineer, 1997, volume 75/No. 17, September, pp289-296.