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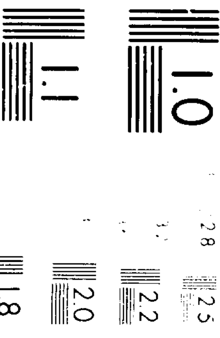

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PROBLEMS IN CONCRETE PRODUCTS*

by

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INTRODUCTION

Concrete products cover a very large range of concrete elements which are produced off site. Such products range from concrete building blocks to such massive elements as precast concrete piles, bridge sections and so on. Products can also range from mass-produced standardised units such as building blocks to elements, often many in number, but peculiar to a particular job. In this latter case the elements are usually cast adjacent to the building or structure in which they are to be used.

From the quality-control point of view concrete products differ very significantly from cast-in-situ concrete. Firstly defective products can be rejected before they are used and secondly, being produced under factory conditions, all stages of production can be tailored to suit the particular operation.

No attempt is being made by me to identify and offer solutions to problems that arise in the production process as others who have addressed you have no doubt done so.

This paper attempts to identify potential sources of problems which arise with the finished product due to handling, transportation and placing in the structure, and during the service life of the structure. The former group are peculiar to concrete products. The problems that arise once the products have been built-in are basically the same as those encountered with cast-in-situ concrete.

AVOIDANCE OF PROBLEMS

The best method of overcoming problems in concrete products and cast-in-situ concrete is to avoid their occurrence. Most problems in concrete products can be attributed to some defect in the design or production of the products. The main causes of problems in concrete products are

1. inadequate design strength resulting in excessive deflection and cracking;

2. inadequate cover for reinforcement, resulting in the corrosion of reinforcement and spalling of concrete;
3. incorrect handling, transporting and placing techniques causing cracking of the members and corrosion of the reinforcement.

All these potential problem areas can, and usually are, adequately guarded against in the design, production and construction stages of the product so that there are significantly fewer problems with structures incorporating precast members than with cast-in-situ structures.

Unfortunately the need to handle concrete products places practical limits on the size of such members and problems associated with connections restrict their use to relatively simple, though not necessarily small, structures.

TRANSPORTING AND HANDLING

Many concrete products are massive and require special handling techniques. Precast concrete piles are one example of a product that requires particular care in handling and transportation. Because this need is self-evident suitable techniques have been developed and the requirements are well known. With other products, especially products that are unique to a particular project, the possibility of cracking, spalling or the development of some other defect due to reversed stresses must be given careful consideration and appropriate handling techniques developed. In fact these problems should be considered at the design stage and provision should be made for handling and transporting stresses.

An example of conflicting requirements was the concrete 'tri-bars' used on the southern extremity of the extension of the north-south runway of Sydney airport into Botany Bay. The tri-bars adopted weighed five and a half tonnes and contained no reinforcement. Handling by a specially designed cradle prevented damage.

Concrete pipes are another product where handling care is required. The reinforcement in pipes is located so as to withstand the earth pressures and superimposed loading when in place. When being placed, however, pipes are suspended from the top, the exact reverse of the loading for which they have been designed. The self-weight of small-diameter pipes is not sufficient to cause cracking but in large-diameter, thicker-walled pipes as used in aerodrome construction the contingency must be provided for. This is usually done by having a second layer of reinforcement which can be accommodated in the thicker walls.

CRACKING

Large precast concrete elements are prone to develop cracks at changes of section, sharp corners and so on. Such cracking is due to poor design and should be eliminated by redesign. Before the design of any large element of which a number are to be cast is finalised a prototype should be produced well in advance to allow any design, casting or handling problems to be identified and overcome. In the case of the tri-bars just mentioned a prototype mould was made and lent to potential tenderers to enable them to make some trial castings and consequently arrive at more realistic tender prices than otherwise would have been the case.

SPALLING

Precast concrete members are just as prone to spalling due to corrosion of the reinforcement as conventional concrete. The principal cause of corrosion of reinforcement is insufficient cover of the reinforcement. In precast members which have to be handled and transported there is a strong temptation to reduce the cover to save weight. This temptation must be resisted.

Recent work at the Experimental Building Station has shown that the width of cracks has no effect on the rate of corrosion. Cracks of whatever width only act as the starting point for corrosion and how rapidly it develops depends upon the porosity of the concrete.

A reinforcing bar surrounded by concrete is protected from corrosion by the alkaline nature of the concrete. In an alkaline environment, a very thin layer of oxide is formed on the surface of the steel which inhibits further corrosion. In this state the steel is said to be passivated. In the vicinity of a crack this passive layer is broken down and this depassivated area becomes the anode of a corrosion cell while portions of the bar still protected by sound concrete become the cathode.

The rate at which corrosion will occur depends upon the resistance of the path through the concrete between the anode and the cathode. The rate of corrosion is thus dependent upon the properties of the sound concrete, especially its density. This highlights the importance of mix design and quality control of the concrete used. A mix design procedure that has been used for many thousands of cubic metres of concrete is outlined in Appendix A.

The corrosion of the reinforcement in bridge decks is a problem of national importance in the United States. The cause of the problem is the use of salt to de-ice roads during their severe winter.

While few of the countries represented here have this particular problem it is of interest to consider the remedial measures that have been developed and which could be applied to other projects where severe environmental conditions exist. Methods which could be used in concrete in general are outlined below.

Wax-bead concrete. Tiny wax beads are introduced into the concrete at mixing time and after the concrete has set and cured heat is applied which melts the beads and allows the wax to seal the voids. The only drawback to this system is the expense of heating.

Polymer-impregnated concrete. This protective system functions the same as the wax-bead system; that is, by internal sealing of the concrete. The concrete is subjected to a temperature of around 370°C until all moisture is driven off. A liquid monomer is then forced into the concrete to fill the voids and then polymerised to a solid form which seals and strengthens the concrete. To date the method has been used only in experimental studies.

Metallic coatings. The most widely used metallic coating is zinc galvanising. However it is now generally recognised that where there is ready entry of chlorides galvanising will not necessarily provide permanent protection against corrosion, although it may prolong the period before corrosion occurs.

Zinc acts as a sacrificial coating and in the presence of chloride ions will corrode and within the service life of a structure the coating may break down sufficiently to allow corrosion of the underlying steel to take place.

If galvanised reinforcement is connected to uncoated steel or other dissimilar metal, accelerated corrosion can occur. If zinc coatings are used it is necessary to ensure that all other steel in the concrete is similarly protected, including tie wire and steel chairs.

For this reason the application of zinc paints or coatings to parts of corroded steel reinforcement cannot be recommended.

Other metallic coatings such as stainless-steel cladding and nickel cladding have been tried but are too costly for full-scale use.

Epoxy coatings. This method which to date appears to be the most successful and practical method of protecting reinforcement involves the electrostatic coating of the bar with a powdered epoxy. This coating provides an impervious protective layer to the steel and, being inert, should provide protection for the design life of the structure.

Solvent-based epoxy resins were found to allow the passage of appreciable amounts of chloride ions through the coatings and did not provide satisfactory protection. Solvent-free epoxies performed better than solvent-based materials but generally liquid epoxies were found to be inadequate.

DIFFERENTIAL MOVEMENT

Shrinkage is not a problem with concrete products except that it may cause cracking as mentioned above. By the time precast members are used all shrinkage should have taken place.

Precast members subject to load will creep at the same rate as in-situ concrete of similar consistency, having the same amount of reinforcement and subjected to the same loading conditions.

Likewise precast concrete members have the same thermal properties as similar in-situ concrete. However, because they have been precast and have undergone the shrinkage process, precast concrete products have different properties to fresh concrete and extreme care must be exercised when combining the two materials. For example, the backing concrete for an exposed-aggregate panel should be cast at the same time as the panel. Otherwise physical keying between the two layers would have to be provided as the stresses created by the shrinkage of the later concrete would almost certainly result in delamination of the panels.

Another example of differential movement which has caused considerable trouble is the cladding of concrete-framed buildings with clay bricks. The frame shortens due to creep of the concrete under load while the clay-brickwork cladding increases in height due to expansion of the clay bricks as they absorb atmospheric moisture. Unless adequate provision is made for this differential movement displacement of the bricks to the extent of collapse of the facade can result.

This latter problem has been the subject of a number of seminars devoted solely to it so it cannot be treated exhaustively here. The essentials of the problem and of the methods of designing for it are set out in EBS Notes on the Science of Building 134 and 135.

CLADDING JOINTS

The trend in building design in Australia is towards massive thermally efficient structures and away from the lightweight curtain walls of the recent past. This trend has received considerable stimulus from the need to conserve energy not only because of a general community awareness of the need to conserve finite resources, but also for the more compelling reason of reducing building-operating costs.

Heavy precast-concrete elements are now being used extensively as the external cladding with the considerable advantages of speed of erection, minimising of on-site construction, architectural variety and so on, and at the same time satisfying the requirement of thermal efficiency. With the use of such panels came the requirement for water-tight joints.

Joint design and joint treatment needs very careful study at the design stage and it must be recognised that successful application of a joint-sealing technique will depend on several inter-related factors, the major ones being:

1. Designed joint profile and dimensions.
2. The dimensional accuracy which is achieved on site (especially in relation to vertical joint widths).
3. The amount of movement which occurs in service.

There are three general methods of dealing with joints in concrete cladding:

1. Gaskets (including strip sealing compounds).

2. The use of baffles in drained joints.
3. The 'filled' joint using a face-sealing compound.

All three have been used effectively but their respective advantages and disadvantages are tabulated below so that an informed choice can be made.

Sealing System	Advantages	Disadvantages
Gaskets	Making of the seal is not affected by wet weather; because performance depends on compression, adhesion is not necessary. Complicated panel-edge profiles, involving grooves, etc. are not necessary. In some cases gaskets could be installed from inside the building thus obviating the need for scaffolding.	The surfaces of the panel edges must be exceptionally smooth and free from defects. Joint tolerances must be very closely controlled. It is doubtful if a true gasket could cope with tolerances above about ± 6 mm and even that range would be excessive for many simple tubular gasket designs. Intersections between horizontal and vertical joints may be a very difficult problem to overcome and must always be vulnerable to dimensional deviations and workmanship. Joint movement may be such that, in an unusually wide joint, the gasket may cease to be under compression and will therefore fail to seal the joint effectively.
Drained Joints	Generally installation during wet weather should not be a problem, although some types of air seal may	The panel edge profile, involving relatively deep grooves, increases manufacturing costs and renders the panel edge

require a dry surface if they are to be stuck to one panel before erection.

The basic sealing mechanism depends on the geometry of the joint profile and pressure equalisation in the cavity - not on adhesion.

The only gap-filling or gap-bridging seal (i.e. the air seal at the back of the joint) is protected from the major agents of degradation - UV light and the weather generally.

Given correct design with respect to groove depth and baffle width, the system can tolerate large variations in joint width including those induced by thermal and moisture movement.

Performance is unlikely to deteriorate significantly with age as the baffle is not subject to movement stress.

Installation is normally possible without scaffolding or cradles.

more vulnerable to damage during handling.

Installation of the components of the system must be carried out during the erection of the cladding with little opportunity of subsequent modifications or remedial work to put right omissions or poor workmanship.

Inspection of the completed installation may be very difficult, so very conscientious workmanship or intensive supervision throughout the installation procedure is necessary.

The geometry of the concept may place limitations on the architect with regard to the aesthetic form of the cladding.

Although not important functionally, vibration of the baffle in the grooves can set up drumming noises which may constitute a nuisance to occupants of the building.

Face-sealed Joints

Possibly the major advantage of the face-sealed joint may be summed up in one word -

Access to the face of the building by cradles or scaffolding is essential.

simplicity. The items which follow can be considered as variations on this theme.

The edges of the panels only need a very simple profile - no grooves or special shapes are necessary.

Given correct selection and application techniques, sealing compounds can cope with variations in joint width from 6 mm to 40 mm without undue problems.

The geometric configuration of the panels (i.e. acute angles, curves etc.) do not create any special problems for application of a sealing compound.

No problems occur at intersections of vertical and horizontal joints.

To ensure good adhesion, the concrete surfaces must be smooth, free from laitance, clean and dry.

Even a small failure in adhesion of the compound may allow water penetration due to capillarity or pressure differentials.

The sealing compound is fully exposed to the major agents of aging and deterioration - UV light and the weather generally. Therefore, for good long-term performance relatively expensive compounds must be used.

It will be seen from this comparison of the three systems that there are many factors to be considered by the designer. However it cannot be too strongly emphasised that all the care of the designer must be matched by good materials and workmanship in the construction stage if the joints are to be without problems.

CONCLUSION

The factory conditions in which concrete products are produced enables better quality control of the mixing, placing and curing operations, thus overcoming many of the problems inherent in in-situ concrete.

Once in place in a structure or building concrete products are subject tö the same destructive forces as conventional concrete.

The use of concrete products raises its own special problems and these must be anticipated and provided for in the design stage of the project.

APPENDIX A

CONCRETE MIX DESIGN PROCEDURE

1. Determine design strength (strength below which 5% of concrete sh test).
2. Estimate variability.
3. Determine target strength.
4. Determine W/C ratio.
5. Estimate total water content for required workability.
6. Determine cement content.
7. Determine total weight of aggregates (fine and coarse) assuming specific gravities of 1 (water) 3.1 (cement) 2.65 (aggregates) and weight of 1 m^3 of wet concrete weighs 2400 kg.
8. Blend aggregates by trial as near as possible to maximum density grading.
9. Check for adequate sand and adjust if necessary.
10. Calculate batch weights.
11. Check yield.
12. Adjust batch weights for true specific gravities.
13. Adjust batch weights for moisture contents of aggregates.
14. Batch trial mix and check for workability, finish obtainable etc.