CEMENTITIOUS REPAIR OF CONCRETE STRUCTURES

1. INTRODUCTION

An essential part of a successful repair of concrete structures is to establish the underlying cause and extent of concrete deficiency and deterioration mechanism. For a repair to be successfully completed it must eliminate the cause, repair the full extent of the damage and ensure that the structure is protected from further damage or recurrence of the original cause for the whole of its projected lifespan. It is therefore important that a thorough initial investigation should be carried out before any repair work is undertaken. It must be emphasised that failure to carry out a detailed investigation/assessment can lead to an incorrect diagnosis of the problem with subsequent unsuitable and ineffective methods of repair. In many cases visual observations should be supplemented with other supporting data based on diagnostic assessment to determine the mechanism that caused the problem.

A key issue that needs to be highlighted in any repair is the importance of maintaining the structural integrity of structures. Work should be done safely and excessive material should not be removed, particularly from load bearing members. Consideration should be given to whether the concrete to be removed provides essential support for the structure. A structural check or professional structural advice should be considered and where necessary propping and temporary supports should be provided (1, 2).

2. METHODS OF REPAIR AND APPLICATION

2.1 General

For the purposes of repair of concrete structures, repairs can be grouped into two general categories, namely the ones associated with corrosion deteriorated concrete, and the ones associated with non-corrosion deteriorated concrete (i.e. accidental damage which does not incorporate the corrosion process). The major difference in the repair process is associated with the initial stages of the repair, where some aspects of the total exposure and de-rusting of steel reinforcement may not be relevant to non-corrosion deteriorated concrete (i.e. accidental damage) repair (1, 3). In addition, the initial stage of removal of concrete and overall surface preparation is generally relevant to all methods of application. For obvious reasons the remaining repair stages are different which reflects the difference of the various methods of application and the materials associated with these methods.

Methods of application of repair materials are mainly dictated by the prevailing in-service conditions, by relative costs, the specified performance characteristics of suitable repair materials, as well as, the level of in-service performance required from such materials (1, 3). Other factors which contribute to the selection of a particular method of application include horizontal, vertical or overhead repair conditions; restricted access; ease and practicality of erection of formwork; structural limitations; underwater requirements; prevailing traffic conditions; tidal and splash zone repairs.

2.2 Methods of Application

There are several methods of application of repair materials in the repair of concrete structures (1,3).

(a) Repairing of cracks (dead or live cracks) - Refer Standard VicRoads Specification Section 687 "Repair of Concrete Cracks", for different types of repairs depending on type and extent of crack and subject to proper assessment.

(b) Recasting with new concrete - Require design of special concrete mix, shrinkage compensating admixtures, need formwork and vibrators, restricted areas difficult to vibrate.

(c) Patching with cementitious repair mortars - These are polymer modified designed for ease of application under a range of in-service conditions (i.e. horizontal, vertical, overhead etc), suitable consistencies and adhesion, trowelled or hand applied non-shrink as part of an overall repair system. The major advantage of cementitious repair mortars is that their properties are compatible with the parent concrete in terms of modulus of elasticity, coefficient of thermal expansion, shrinkage movement and permeability (breathability).

(d) Patching with free-flowing grouts and fluid micro-concretes - These are useful for extensive and large repairs where access for hand/trowelled mortars is difficult, fixing of tight formwork, pumped or hand

poured into formwork, very workable and self-compacting, feed from lowest or furthest point.

(e) Sprayed of new concrete or specially formulated cementitious mortar - Shotcrete, gunite, dry process spraying, wet process spraying.

(f) Pre-packing Dry Aggregates which are subsequently grouted - Single size coarse aggregate (10-20mm), grout subsequently pumped from the furthest or lowest point to fill spaces between the aggregate, simple formwork, no vibration, suitable for underwater conditions.

(g) Underwater Placement Methods - Refer Standard VicRoads Specification Section 610 "Structural Concrete".

3. CEMENTITIOUS PATCH REPAIR

3.1 General

Prior to commencement of any patch repair of concrete, an assessment of the affected concrete structure or component should be undertaken to determine the influence of spalled, deteriorated, damaged or honeycombed concrete on load bearing capacity, serviceability and durability (1, 3, 4, 5). A cementitious patch repair method should be selected based on:

- an assessment of the cause(s) and extent of the spalled, deteriorated, damaged or defective concrete;
- the location of the patch repair on the concrete structure or component; and
- the proposed repair material properties, likely patch behaviour and the effect on load capacity and structural safety, serviceability and durability.

A step-by-step patch repair procedure should address the concrete surface preparation, method of application, curing (Refer Fig.1,2 and 3) and surface finish and exposure classification requirements. The application of a decorative/anticarbonation and/or anti-graffiti coating where required should also be considered as part of the overall patch repair procedure.

3.2 Types of Patch Repairs

The following main types of patch repair of concrete structures using cementitious repair materials are considered (1, 3, 5):

(a) Corrosion deteriorated concrete repair. This is associated with deterioration, delamination, cracking or spalling of concrete due to contamination by deleterious substances such as chlorides and carbon dioxide associated with the overall mechanism of corrosion of steel reinforcement. The corrosion deteriorated concrete repair works must involve:

- the breaking back to sound and dense concrete by at least 20 mm behind the steel reinforcement;
- preparing both the steel reinforcement and concrete substrate;
- the application of an appropriate steel primer and substrate bonding coat; and
- rebuilding to the original surface profile.

(b) Non-corrosion deteriorated concrete repair. This is associated with deterioration or damage due to accidental or physical loadings, damage through temporary overloading, impact and other mechanical or uncontaminated damage, excessive early shrinkage or thermal stresses and low quality honeycombed or off form voided concrete. The non-corrosion deteriorated or defective concrete repair works must involve the breaking back to sound and dense concrete. The depth of removal of non-corrosion deteriorated or defective concrete and the amount of exposure of the steel reinforcement should be subject to review at the time of the concrete repair assessment.

(c) Filling of blowholes and surface imperfections. This is associated with small regular or irregular cavities, usually not exceeding 15mm in diameter or 5mm in depth, resulting from entrapment of air bubbles in the surface of formed concrete during placement and consolidation. Blowholes and surface imperfections should be filled with a scrape coat application of a single component polymer modified cementitious fairing coat repair mortar. A cementitious fairing coat repair mortar could also be used in a thin layer where a uniform concrete surface is required prior to the application of a protective or decorative coating.

4. MATERIALS REQUIRED AND PERFORMANCE CRITERIA

The requirements for the supply and quality of materials, surface preparation, application, relevant inspection and testing and acceptance criteria for the patch repair of concrete structures using cementitious repair materials must always be specified in a very clear and succinct way to avoid any misinterpretations which may affect the long term performance of the product in place (1, 3, 5). The application of any anti-graffiti or decorative/anti-carbonation coatings as part of the concrete repair work must also be specified as necessary. The repair materials used for reinstatement should be single component polymer modified cementitious non-shrink repair mortars, or be part of an approved complete polymer modified cementitious repair system. The repair material strength should always be similar to the in-situ structure strength. All materials should be manufactured by an acceptable material supplier and should be supported by relevant test certificates, material data sheets and health and safety data sheets. It is essential that the cementitious material, steel primer and substrate bonding coat are thoroughly mixed to achieve a uniform colour and consistency using a spiral paddle in a slow speed heavy-duty electric drill. Materials should not be thinned and the whole container/bag contents should be

mixed without split mixing between mixes to ensure the accuracy of the various proportions and therefore the right consistency and final quality of the mixed mortar.

5. ADDITIONAL KEY REQUIREMENTS OF THE REPAIR PROCESS

For more details relating to storage and handling of materials, preparation, application, finishing, surface condition, curing and protection, occupational health and safety and environmental management, reference should be made to Section 689 (5). In order to ensure the integrity and long term performance of the patch repairs no cracks of width greater than 0.10 mm, measured at the concrete surface should be allowed and certainly no cracking should be allowed at the concrete repair interface with the existing concrete. Repairs should be cured with a curing compound in accordance with the material manufacturer's specification, although for concrete patch repairs greater than 500 mm x 500 mm in size the curing compound should also be supplemented with heavy duty polyethylene sheeting fastened and sealed at the edges. This combination should be mandatory for all concrete repairs undertaken in marine or saline environments.

6. THE MAIN PHASES OF THE REPAIR PROCESS

The main phases of the repair process that should be undertaken to achieve a successful patch repair are stopping the corrosion process, replacing the concrete and applying a final protective treatment. Within each main category a number of steps form part of the general sequence of the repair process and these are expanded in more detail in the step by step repair sequence presented below. It should be noted that these phases of remedial measures can be implemented individually or in combination depending on the type of repair undertaken. For instance some steps associated with the corrosion aspect may not be relevant to the repair of accidentally or mechanically damaged concrete.

An essential part of a successful repair process is the effective halt of the process of corrosion in all steel reinforcement affected by rust, including those where the corrosion has not yet manifested itself at the surface of the concrete. This is only possible by removing the rust and applying a suitable priming coat to protect the steel against further corrosion (i.e. repassivating the steel reinforcement).

Replacing the concrete in deteriorated or accidentally damaged reinforced concrete structures is very essential in order to maintain its structural adequacy, by restoring the surface of the concrete to its original profile, and therefore realise the expected life-span of the structure. More specifically this is required to provide adequate alkaline protection to the steel reinforcement, provide an even continuous background for the application of protective coating systems and in general satisfy the visual and aesthetic requirements.

The main attribute of final protective coatings is to increase the durability of reinforced concrete structures by providing additional protection against the exposure to the environment and to enhance their aesthetic appearance. This not only applies to patch repairs and the surrounding concrete, but also to existing low quality concrete structures and new structures. Ideally coatings should possess elastic properties, in order to bridge over any fine cracks which are present in the concrete or which may subsequently appear in the patch repair.

7. END PERFORMANCE TESTING

Testing for the performance of patch repairs should include ongoing testing for compressive strength, adhesion (pull-off) testing (Refer Fig. 4), delamination survey to check for drummy areas and testing for flatness and placement tolerances of the finished product (5). The compressive strength of cementitious repair material should be tested by procuring test cube samples at a prescribed frequency. The bond strength of patch repairs can be undertaken on partially cored direct pull-off tests of the fully cured in-situ repair material to verify the tensile bond between the in-situ repair material and the existing concrete substrate, 7 days after the completion of application (i.e. European Standard EN 1542 (CEN 1999c)). A visual inspection of all concrete repair areas should be conducted immediately prior to the application of any decorative / anti-carbonation coating and checked for delaminations and any defects recorded (i.e.testing for drummy areas). Control of dimensional tolerances is an important part of the overall quality control and aesthetic appearance of patch repairs. End performance testing is covered in VicRoads Standard Specification Section 689 (5).

8. STEP BY STEP REPAIR SEQUENCE OF CEMENTITIOUS APPLICATION

8.1 Corrosion Deteriorated Concrete

The following provides a systematic and organised step by step guide of a typical repair for trowel applied mortars (1, 3, 5).

(a) Investigation and Assessment
- Establish the cause and extent of the concrete deterioration problem using both physical and chemical diagnostic methods.
- Determine areas and depths of concrete to be removed.

(b) Surface Preparation Completion (Refer fig.1)
- Remove unsound and contaminated concrete to expose a sound and uncontaminated concrete substrate by at least 20 mm behind and around the rusted steel reinforcement.
- Continue removal of concrete along the length of visibly corroding steel reinforcement and make sure it extends until at least 50 mm of sound rust free metal is showing at both ends of the rusted section.

- Provide a perpendicular saw cut or equivalent to a depth of at least 15 mm around the perimeter of the area to be repaired in order to prevent featheredging.
- Remove all products of corrosion from exposed steel reinforcement preferably clean to bright metal and add new steel reinforcement if required. Wet sandblasting is preferable. This will also assist with the removal of any other contaminants present on the bars.
- Complete the cleaning process by giving a final wash down or by blowing down with compressed air of both the concrete substrate and steel reinforcement to ensure the removal of all residual contamination.
- Thoroughly pre-wet the prepared concrete substrate with clean fresh water.

(c) Application of Reinforcement Protection and Substrate Bonding Coat (Refer Fig.1)
- Steel reinforcement coated with a suitable primer to provide immediate protection against renewed corrosion.
- Remove excess or standing water from earlier pre-wetting operation.
- Apply a concrete substrate bonding coat by working into substrate using a short bristle brush, to enhance the bond at the repair interface.

(d) Application of Repair Mortar (Refer Fig. 2)
- Erection of formwork or profiles if required (Refer Fig. 1).
- Apply repair material. Ensure that substrate bonding coat is in correct condition to ensure good adhesion.
- Apply normal curing procedures. That is applying a curing compound complying with the requirements of AS 3799 and in accordance with the material manufacturer's specification. For concrete patch repairs greater than 500 mm x 500 mm in size the curing compound should also be supplemented with heavy duty polyethylene sheeting fastened and sealed at the edges (Refer Fig. 3).

(e) Application of Protective Coating (if required)
- Final surface preparation.
- Apply final protective coating or system of coatings.

(f) Supervision and Quality Control
- Utilise satisfactory construction practices, procedures and standards.
- Reinspect at suitable intervals to confirm the success of the repair.

8.2 Non-Corrosion Deteriorated Concrete (i.e. Accidental Damage) - The following provides a systematic and organised step by step guide of a typical repair for trowel applied mortars.

(a) Investigation and Assessment
- Establish the cause and extent of the concrete damage or distress.
- Determine areas and depths of concrete to be removed.

(b) Surface Preparation Completion (Refer Fig.1)
- Remove spalled and unsound concrete to expose a sound and dense concrete substrate and where necessary the steel reinforcement.
- Provide a perpendicular saw cut or equivalent to a depth of at least 15 mm around the perimeter of the area to be repaired in order to prevent featheredging.
- Complete the cleaning process by giving a final wash down or by blowing down with compressed air of both the concrete substrate and steel reinforcement to ensure the removal of all residual contamination.
- Thoroughly pre-wet the prepared concrete substrate with clean fresh water.

(c) Application of Reinforcement Protection and Substrate Bonding Coat (Refer Fig.1)
- Steel reinforcement coated (if exposed) with a suitable primer to provide immediate protection against corrosion.
- Remove excess or standing water from earlier pre-wetting operation.
- Apply a concrete substrate bonding coat by working into substrate using a short bristle brush, to enhance the bond at the repair interface.

Where a proprietary pourable cementitious grout is used (instead of a mortar consistency) some repair systems may not require the application of a primer or concrete substrate bonding coat).

(d) Application of Repair Mortar (Refer Fig.2)
- Erection of formwork or profiles if required (Refer Fig.3).
- Apply repair material. Ensure that substrate bonding coat is in correct condition to ensure good adhesion.
- Apply normal curing procedures. That is applying a curing compound complying with the requirements of AS 3799 and in accordance with the material manufacturer's specification. For concrete patch repairs greater than 500 mm x 500 mm in size the curing compound should also be supplemented with heavy duty polyethylene sheeting fastened and sealed at the edges (Refer Fig.3).
- Final surface preparation.
- Apply final protective coating or system of coatings.

(e) Supervision and Quality Control (Refer Fig.1)
- Utilise satisfactory construction practices, procedures and standards.
- Reinspect at suitable intervals to confirm the success of the repair.

9. SUMMARY

A thorough investigation is an important ingredient in achieving a lasting repair of concrete structures. Correct interpretation of visual observations and testing is essential to enable a correct diagnosis and prognosis of the problem, and thus enable appropriate corrective measures to be taken. The use of sound materials, thorough preparation and proper application of materials, satisfactory finishing and curing are vital components of the step-by-step repair sequence required to achieve a satisfactory repair, with adequate strength, durability, appearance and economy.

10. REFERENCES

1. Andrews-Phaedonos, F (1990), "Manual for Assessment, Maintenance and Rehabilitation of Concrete Bridges", VicRoads.
2. Andrews-Phaedonos, F (1990, 2004), "Investigation of Concrete Structures", VicRoads.
3. Andrews-Phaedonos, F (1990, 2004), "Methods of Repair and Repair Sequence", VicRoads.
4. Andrews-Phaedonos, F (1990, 2004), "Durability of Concrete Structures", VicRoads.
5. VicRoads Standard Specification Section 689 (2005), "Cementitious Patch Repair of Concrete".

11. CONTACT

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Figure 1: Surface preparation, saw cut and exposure of steel reinforcement and pre-wetting. Application of steel primer.

Figure 2: Substrate bonding coat and application of repair mortar.

Figure 3: Curing of cementitious patch repair

Figure 4: Adhesion (Pull-Off) testing of cementitious patch repair.