Construction and Building Materials 161 (2018) 53–62

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

An experimental study on RC columns repaired on all four sides with cementitious mortars

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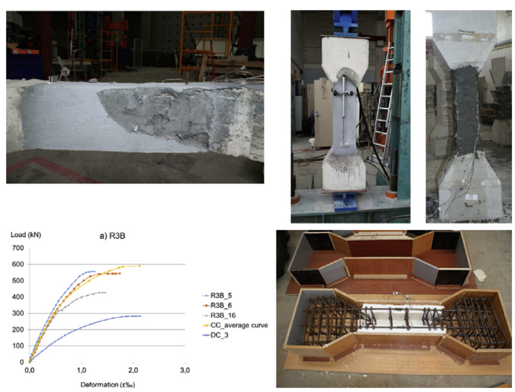
HIGHLIGHTS

- A study was carried out on RC columns repaired with cement-based mortars.
- 18 specimens were tested, being subjected to compressive axial loads.
- The influence of the type of repair mortar (R3 and R4 Class) was studied.
- The presence of bonding agents between the mortar and the column was also studied.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 24 August 2017
Received in revised form 16 November 2017
Accepted 23 November 2017

Keywords:
Column
Repair
Reinforced concrete
Building
Experimental
Mortar

ABSTRACT

This paper describes a study carried out in the ICITECH laboratories (Universitat Politècnica de València) on RC columns repaired on all four sides with cementitious-based mortars. A total of 18 specimens were tested, representing a group of square $20 \times 20\,mm^2$ columns subjected to compressive axial loads. Different repair scenarios were considered in order to study the influence of the type of mortar used and the presence or absence of bonding agents between the mortar and the column concrete. The results obtained showed that bonding agents have no appreciable effect on the behaviour of the repaired columns. Of the two types of mortar used in the study (Classes R3 and R4), the columns repaired with the lower grade mortar (R3) were seen to behave better. The main novelty of this work lies in the fact that this is the first time that two types of mortar are compared in the repair of four column sides, in addition to the possible use of bonding agents between the mortar and the column.

1. Introduction

The need for repairs to structural reinforced concrete (RC) elements increases as buildings and infrastructures get older. In the USA, the American Society of Civil Engineers (ASCE) [1] has estimated that an investment of $3.6 trillion will be required before 2020 to bring the country's infrastructures up to date. According to a report by the Spanish Confederation of Business Associations (CEOE) [2] in 2011 almost 2% of Spain's buildings were in extreme need of conservation, 7.6% required urgent repairs, and a total of almost 1 million buildings were below standard.

Columns are critical elements in a structure since if one fails the others may follow suit and lead to the collapse of the entire building or most of it. If the structure is of RC, the columns may suffer mechanical or chemical damage due to ageing materials, aggressive

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https://doi.org/10.1016/j.conbuildmat.2017.11.126
0950-0618/

environments, earth settlement, natural disasters (earthquakes), accidents (fires, explosions, collisions), among others. As repair and strengthening of RC columns are therefore often necessary, the scientific community has given a lot of attention to this area in the form of research on the different techniques available.

Frangou et al. [3] carried out one of the first studies on the repair and strengthening of columns using different techniques based on concrete confinement and compared the results with those proposed by Eurocode 8 [4]. Another interesting study was that by Ramírez [5], who analysed the characteristics and effectiveness of different methods of strengthening columns by concrete or steel elements.

Later innovations included concrete jacketing [6,7], self-compacting concrete jacketing [8], high performance fibre-reinforced concrete jacketing [9], ferrocement jacketing [10], steel jacketing [11–16], and FRP jacketing [17], which were used to increase the column's level of concrete confinement to improve their resistance [18]. Most of the studies [6–17] focused on strengthening columns to increase their resististant capacity [19].

One of the first studies to distinguish between repairing and strengthening damaged columns was that by Fukuyama et al. [20], who proposed that they should either be repaired or strengthened according to the extent of the damage they had suffered. They proposed filling cracks and replacing damaged concrete in the case of slight or moderate damage, i.e. a system of patching. When the damage was more serious, they suggested steel or concrete jacketing.

This paper focuses on repairing rather than strengthening RC columns, in order to restore the columns to their original state of safety [19] without increasing their size. The European Standard EN 1504-9:2008 [21] recognises three types of repair:

- Local applications of mortar by hand or trowel.
- Filling with liquid mortar using formwork.
- Spraying with concrete or mortar.

The three methods are described in EN 1504-3:2005 [22], which defines the requirements to be satisfied by products used to repair concrete elements. Repair mortars are divided into four classes: Classes R1 and R2 for non-structural repairs and Classes R3 and R4 for structural repairs. In all cases, bonding between the column concrete and the repair mortar must be guaranteed. This bonding must be due solely to the characteristics of the materials and the conditions of the joint, although the use of a bonding agent is allowed under certain conditions to create an adhesive joint between the column and the new mortar. The specifications of the bonding agents are given in EN 1504-4:2004 [23].

Repairs can also be classified by the zones in which they are carried out in three ways:

- Patching repairs on one or more local column zones.
- Complete repair on one side in which the entire surface is covered with mortar.
- Complete repair of all four sides, replacing all the concrete to a depth that includes the longitudinal reinforcement.

An interesting study was carried out by Aurrekoetxea [24], simulating the repairs on square columns with corroded rebars and comparing the behaviour of the repair according to the method and type of mortar used, validating the experimental results by FE modelling. The repairs were on simulated damage to two and four corners. The results obtained showed that the columns that had lost all their cover and 43% of their resistance could recover 40% of their resistant capacity, and that liquid mortar placed in formwork worked better than when applied manually.

Da Porto et al. [25] carried out an experimental study on repairing four sides of square RC columns subjected to axial loads by three types of polymer-modified cementitious mortar but were unable to recover 100% of their original load-bearing capacity. They also found that repair mortar worked best with a compression strength and elasticity modulus similar to those of the column concrete.

When RC elements are repaired, it is fundamental that the basic substrate and repair mortar be compatible. Certain authors, such as Emberson and Mays [26,27], Morgan [28] and Hassan et al. [29], state that the most important requirement to guarantee this compatibility is to ensure that the elasticity modulus of the column concrete is similar to that of the repair material and that the compressive strength of the latter be equal to or higher than that of the concrete in the column.

The scientific community is aware of the importance of the joint between concretes of different ages, or between concrete and repair mortar. In this regard, one could point to the work by Júlio et al. [30–32], Qian et al. [33], Elbakry and Tarabia [34], and Mousa [35]. When columns are repaired by cementitious mortar, the way in which the materials are joined (dry joint or with bonding agents) must be carefully considered.

This paper describes a study carried out in the ICITECH laboratories of the Universitat Politècnica de València on repairs on four sides of RC columns subjected to axial loads by means of one of the most frequently used techniques at the present time: cementitious mortar applied by trowel. In no case was the column cross-section or reinforcement increased. Eighteen columns were repaired with R3 and R4 Class mortars, as defined in EN 1504-9:2008 [21], both including and excluding the use of bonding agents between column and mortar to compare the effectiveness of four repair methods: a) R3 mortar with bonding agent, b) R3 mortar without bonding agent, c) R4 mortar with bonding agent, and d) R4 mortar without bonding agent.

The main novelty of this study is that it is the first to analyse the relative importance of the different repair components in the complete repair of the four sides of RC columns by mortar applied with a trowel. The study includes the effectiveness of bonding agents between column and mortar and also of the influence of the different types of mortar proposed in EN 1504-9:2008 [21] on the behaviour of the repaired columns.

The remainder of the paper is laid out as follows: Section 2 gives the main characteristics of the tests, including specimens, repairs, and column loading and monitoring. Section 3 describes the failure modes of the specimens studied and defines terms such as *effectiveness* and *improvement of load-bearing capacity* used to evaluate the success of the repairs. Section 4 analyses the results obtained and the different series of specimens are compared. Section 5 gives the main conclusions drawn from the tests together with future lines of research.

2. Experimental study

2.1. Specimen geometry

The study consisted of tests on eighteen 1370 mm long specimens to simulate axially loaded RC columns. Although these dimensions are not those of normal columns, the results can be extrapolated to real columns, as has been previously shown: Emberson and Mays [26,27], Ramírez [5], Mourad and Shannag [10], Pellegrino et al. [36], Achillopoulou and Karabinis [37], Fukuyama et al. [20] and Dubey and Kumar [8].

The specimens were dogbone-shaped to avoid failure in the load application zones. The central section of the specimens was 520 mm long and a 200×200 mm^2 cross-section. The heads were 420 mm long with a cross section of 400×200 mm^2. The specimen dimensions are shown in Fig. 1.

Damage requiring repair was simulated in 15 columns, while three were left untouched (Control Columns). The damage was simulated by using expanded polystyrene (EPS) placed in the formwork before pouring to create hollows (see Fig. 2).