Construction and Building Materials 81 (2015) 216–223

Contents lists available at ScienceDirect

Construction and Building Materials

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

Strengthening of masonry arches using carbon plates

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HIGHLIGHTS

- We want to adapt rehabilitation techniques by the bonding of composite materials to sewerage systems made of millstone.
- We have explained in detail the current techniques relative to pathologies.
- Increase in the gain of structural load (over 50%).
- Modifications in the fracture mechanics.
- Formation of plastic hinges in the reinforced sections.

ARTICLE INFO

Article history:
Received 19 March 2011
Received in revised form 17 November 2014
Accepted 27 December 2014
Available online 3 March 2015

Keywords:
Composite
Sewerage systems
Masonry
Strengthening

ABSTRACT

A reduction in rehabilitation costs by about 20% is the main objective of this project while reducing response times in situ and maintaining an equivalent efficiency of the reinforcement. The first part recounts the history of the various stages of the Parisian sewer system construction. It subsequently takes stock of the pathologies, the repair techniques and the investigation methods of these structures. The second part deals with the design of test pieces through numerical calculation while taking into consideration the various parameters applied to each material. The selected model is a vault representing the upper part of an ovoid. The third part is an experimental approach to characterizing materials and in particular the coating/glue/composite interface.

1. Introduction

The appearance of sewers in Paris dates back to the XVIth century. Many descriptive and historical documents have been written on the construction and evolution of the Parisian sewer system. An important turning point occurred with Belgrand [1,2] in 1877 which led to the present sewerage system. While it was deteriorating in the early 1980s, many French authorities became aware of the importance of their sewerage infrastructure. The systems mainly go back to the late 19th and early 20th centuries. Urbanization, a strategic location of the systems and subsurface congestion all contributed to making sewer reconstruction very difficult or impossible and costly. Yet, these sewers were generally over-dimensioned when they were built and, today, they still offer sufficient hydraulic capacities [3]. The search for new restructuring processes, aiming to reduce repair costs, leads to explore avenues into the use of punctual rehabilitation techniques. Since the nineties in France, a technique of partial restructuring has been used in the construction industry. It consists of a rehabilitation process using the bonding of plates or composite fabrics made of carbon fibres. This technique has been adapted to concrete sewerage systems [4]. This study reveals a 50% reduction in repair costs together with a gain in load-carrying capacity by a minimum of 30% compared to the generally used techniques. Since January 2005, this process has been the object of experimentation on a10-metre long main sewer in Val-de-Marne (Paris). This experimental building site has shown that it was possible to apply this technique in-situ. Every 3 months hammer soundings are conducted. Up to now, neither deterioration of the reinforcement nor delamination of the CFRPs (Carbon Fibre Reinforced Plates) has been noted.

However, the sewerage systems that require rehabilitating as a priority in Paris are made of millstone masonry. To our knowledge, no study has been done for the punctual reinforcement of millstone sewerage system by means of carbon fibres.

Our study consists in applying this process on ovoid, man-accessible sewerage systems (also called mains sewers) (T200).

The concerned systems are masonry structures whose diagnosis leads us, in the present state of our knowledge, to recommend rehabilitation works. These structures consist of a vault, abutment walls and an invert (see Fig. 1).

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http://dx.doi.org/10.1016/j.conbuildmat.2014.12.089
0950-0618/

After mentioning the main pathologies and strengthening techniques, a modelling for the design of test pieces is suggested. Indeed, because of the complexity of millstone ovoids, full scale tests are performed on reinforced or unreinforced millstone vaults.

2. Most common types of degradations

Many pathologies can affect main sewerage systems [5]. Kesteloot [4] described the pathologies affecting structures made of reinforced or unreinforced concrete. These anomalies mainly result in longitudinal cracks in the abutment walls and in the vault. These defects are often accompanied by transverse cracks. These degradations can be the consequence of several degradation factors [6] such as overstressing, chemical attacks and a state of dilapidation. Before undertaking any repairs, it is therefore necessary to know the pathologies but also their origins. The latter are obtained from visual, geometric or mechanical investigations. Most of the mechanical tests are based on inside jacking tests which consist in ovalizing the tested sewage line; it thus allows to measure the global rigidity of the main sewer and to deduce Young's modulus. These tests include sampling so as to validate the quality of the masonry. The most common pathologies affecting masonry sewerage systems include the following:

- Superficial degradations: crazing, coating deterioration, coating adhesion failure.
- Degradations due to chemical attacks, particularly in the presence of H_2S.
- Structural degradations: vault subsidence, abutment wall convergence and divergence, invert subsidence, structure spalling.
- Deformations: structure warping, structure localized subsidence.
- Lack of water-tightness: infiltration, exfiltration, oozing, concretion.
- Cracks : longitudinal, transverse, oblique , ring-shaped.

However, it is important to mention the pathologies which are peculiar to millstone main sewers.

A survey [7], based upon about 30 diagnostic studies and repair work recommendation conducted over the last 10 years, enables us to make an inventory of the most common pathologies for millstone structures. There are many types of deteriorations. They are described below.

2.1. Stone deterioration

The stone, which makes up the millstone sewerage networks, can undergo two types of alteration due to water infiltrations in the main sewer (Fig. 2): alveolization and flaking.

Alveolization is a continuous alteration. The stone loses its surface cohesion to a depth of a few millimetres. While the subjacent layer remains sound, the disintegrated layer crumbles into dust or into particles; the alteration continues in depth. Alveolization can affect pointing mortars. Flaking is a cyclic pathology whose symptomatology appears to be more fluctuating than that of alveolization. A hard layer of calcium sulphate, known as "*calcin*", forms on the surface of the stones. It can range in thickness from a few tenths of a millimetre to several centimetres. Underneath this layer, a powdery or sandy zone that is not very coherent and that varies in thickness builds up. After some time, the outermost layer cracks or blisters and eventually drags down the powdery zone in its fall. This cycle can then affect a new surface.

2.2. Mortar joint deterioration: mortar loss

Mortar joint deterioration (Fig. 3) means a complete or partial disappearance of the mortar making up the joints of an uncoated masonry structure. This phenomenon is usually accompanied by an erosion of the stones. Water infiltration can result in the disintegration of the masonry mortar.

2.3. Cracks

A crack opening is not estimated in the same way depending on whether it is a concrete or a masonry structure. Regarding masonry structures, it is important to distinguish the cracks damaging the coating and the joints from those affecting the elements of the masonry structure (blocks). The former are partial or complete mechanical discontinuities whereas the latter are linked to the endurance limit of the elements being exceeded. The cracks affecting the coating are generally superficial and do not damage the structure. A simple treatment of these cracks is often recommended. On the other hand, the cracks affecting the elements of a masonry structure are the sign of a dysfunction of the mechanical behaviour of the structure. A structural reinforcement is thus recommended. The types of cracks appearing in masonry structures are identical to those appearing in concrete ones. On the other hand, these cracks can also present some relative displacements

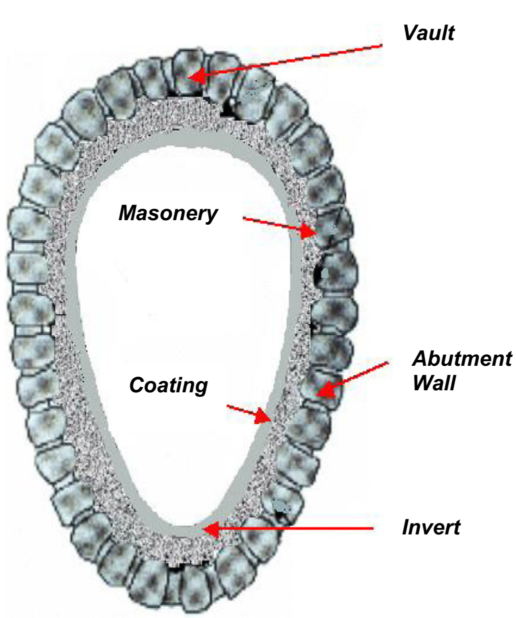

Fig. 1. Masonry ovoid.

Fig. 2. Stone deterioration due to water infiltration.