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Review

Critical review of research on high-cycle fatigue behaviour of brick masonry

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HIGHLIGHTS

- ▶ Investigations on the high-cycle fatigue behaviour of brick masonry are reviewed.
- ▶ Findings at variance with the those of previous investigations are presented.
- ▶ Parameters influencing the fatigue strength of brickwork are indentified.
- ▶ Areas requiring further research recommended.

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ABSTRACT

Prediction of the level of service load above which accumulative damage occurs is a key priority for the masonry arch bridge owners. Limited investigations have been undertaken previously on the high-cycle fatigue behaviour of brick masonry in order to establish the link between the fatigue phenomenon in brick masonry and the serviceability limit state for masonry arch bridges. But to date there are still many uncertainties of the research published regarding predicting the fatigue performance. This paper provides a critical review on the high-cycle fatigue behaviour of brick masonry. Current state of the knowledge and areas requiring further research are also presented.

Contents

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1. Introduction

While improving the accuracy of the predicted ultimate limit state of masonry arch bridges remains an important priority, prediction of the level of service load above which accumulative damage occurs is now a key priority for the masonry arch bridge owners. Existing guidelines [1] on the assessment of masonry arch bridges suggest that loads below 50% of the ultimate failure load impose no lasting damage on the structure. However, pioneering work [2] carried out on multi-ring masonry arch barrels under long-term cyclic loading has indicated a fatigue capacity could be much lower than the 50% of the monotonic collapse load.

The need for identifying accumulative damage and ensuring satisfactory performance of masonry arch bridges has recently led to increasing interest in the high-cycle fatigue performance of both masonry material and masonry arch bridges.

Experimental work [3–6] has been carried out on the high-cycle fatigue behaviour of brick masonry in order to establish the link between the fatigue phenomenon in brick masonry and the serviceability limit for masonry arch bridges. Laboratory experiments at structural level were undertaken independently at Nottingham University [7] and Salford University [2,8] to investigate fatigue behaviour of masonry arch bridges. The recent European 'Sustainable Bridges' Project has also investigated the potential viability of using probabilistic methods in the assessment masonry arch bridges [9–11].

However, to date there are still many uncertainties regarding predicting the fatigue performance, in particular the prediction of service load above which accumulative damage will occur.

2. Background

Masonry arch bridges are subjected to far heavier repeatable service loading than that ever envisaged by their designers. Recent years have seen significant increases in service loading. For example, the maximum permissible lorry load for roads within the UK increased from 38 tonnes to 40 tonnes in 1999. Since 2001 it has been increased from 40 tonnes to 44 tonnes.

Although fatigue has not been positively identified to date in masonry arch bridges, the experience of some maintenance engineers with regards to the very heavy traffic load increases experienced in the last few decades suggests that the repeated application of heavy loads could rapidly accelerate the deterioration of masonry arch bridges [12].

There is now a serious concern for the long-term performance of these bridges, particularly if there are to be further increases in the speed, number and weight of the axles to which these bridges are subjected (e.g. in Europe, it is proposed for railway freight wagon that the axle loading should be increased from 25 tonne to 33 tonne and for passenger traffic that the maximum speed should be allowed up to 350 km/h [13]).

Research studies at the Universities of Salford confirmed that fatigue is an issue for brickwork barrels and should be considered [2,8]. A series of tests were carried out on large-scale multi-ring brickwork arches (3 m and 5 m span, two and three-ring) under long term cyclic loading. Tests showed that although the classical mode of failure of arches under static loading is generally seen as the four-hinge-mechanism, all arches within the test series failed by ring separation under fatigue loading. The fatigue loading reduced the load capacity to as low as 37% of the static load capacity for two-ring arches and 57% for three-ring arches.

There is currently no established serviceability limits for masonry arch bridges in the current assessment codes. There is, therefore, an urgent need to establish the threshold beyond which irreversible progressive damage to a bridge is likely to occur.

A new assessment procedure (SMART) has now been proposed [14] for masonry arch bridges which considers the possibility of structural degradation with repeated loading. The SMART strategy has established a 'road-map' for the future and further application of the method as an assessment tool relies on knowing the endurance limit for each possible fatigue failure mode.

It is beyond the scope of this paper to consider the structural behaviour of masonry arch bridges. However, it is relevant to appreciate that the masonry in arch barrel is subjected to a range of structural responses to the loading. Whilst at a simple level the barrel may be considered to be a quasi-elastic continuum, it has (in fact) a particulate structure comprising heterogeneous materials. Consequently, the stress levels at the interface between the masonry units and the mortar significantly influence the mode of failure.

From a material point of view involving fatigue failure of a masonry arch, such as longitudinal shear failure (ring separation) or sliding of masonry blocks in an arch barrel is induced by insufficient shear resistance in longitudinal or radial mortar joints, whilst crushing failure will depend on the fatigue strength of masonry under compression.

The presence of cracks due to partial hinge formation causes a reduction in cross section area in the arch barrel. The outer fibres of the arch barrel could subsequently subject to significant cyclic stress ranges under the combination of repeated axial and flexural stress. This could cause the cracks to widen further and accelerate the deterioration, which adversely affect the serviceability of the bridge.

The fatigue behaviour of masonry under compression and shear are therefore most relevant and knowing the stress below which fatigue failure does not occur – endurance limit, is most critical.

This paper focuses on the review of research studies on the high-cycle fatigue behaviour of brick masonry.

3. Fatigue behaviour under high-cycle loading

3.1. Experimental studies

The few available experimental data on the fatigue behaviour of masonry under high-cycle loading is primarily under compression. There is little information available of the fatigue behaviour of masonry under shear.

It has been established that brick masonry displays a decreasing *S–N* response to cyclic compressive loading and has a fatigue strength significantly less than its static strength [3,4,6]. A lower bound fatigue strength curve was proposed [6,14] suggesting that the fatigue strength of brick masonry depends upon the stress range, the mean or maximum stress and the quasi static compressive strength of the brick masonry under similar loading conditions.

The earliest tests were undertaken by Clark [3] on brickwork prisms to study the behaviour of the masonry arch under repeated loading. Clark did not take into account of the fact that masonry displays a fatigue life dependent upon not only the maximum stress, but also the stress range or the mean stress.

The five course prisms were centrally loaded up to 5 million load cycles at 5 Hz frequency [3]. Samples surviving 5 million cycles were subsequently loaded to failure under quasi-static loading. From the test results *S–N* curves were identified for both dry and wet masonry.

Results by Clark indicated that dry brick masonry has a fatigue limit of approximately 50% of its quasi-static compressive strength. The report concluded that, providing the magnitude of cyclic loading is restricted to 50% of the crushing strength of the masonry, a practically infinite number of load cycles could be carried by brick masonry.