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RESEARCH

New technique used for strengthening jack arch slabs

Hayder Al-Khazraji[1] · Abdulkhaliq A. Jaafer[1] · Haider H. Haider[1] · Majed Ali Mozan[1] · Haider Sattar Faraj[1] · Sajjad Sadiq Maktuf[1]

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Abstract
The use of fiber-reinforced polymer rope (FRPR) increases the seismic performance of unreinforced clay brick masonry slabs and the flexural strength of jack arch slabs or roofs. This study represents an attempt to explore the capability of using FRPR for strengthening the jack arch slabs. For this purpose, ten jack arch slab specimens were built and tested under three-point load conditions. The main parameters investigated were the brick type (solid and perforated), camber (0 and 30 mm), span width (700, 730, and 950 mm), strengthening scheme on the behavior of the jack arch slab of FRPR, and number of FRPR points (i.e., number of FRPR strengthening points used for each span). The results show that using perforated brick types enhanced the ultimate carrying capacity of the slabs compared with the solid type. With increasing camber, it was observed that the ultimate capacity of the slabs also increased by the range of 13–11% for the solid and perforated specimens, respectively. Furthermore, increasing the span width resulted in a 69% reduction in maximum deflection. FRPR can be utilized for strengthening masonry buildings and historical structures.

Keywords Jack arch slab · Flexural strength · Load deflection · FRPR

Introduction

Brick slabs, known as "jack arch slabs," are held up by steel I-section beams that rest on load-bearing walls or lintels with centers ranging from 700 to 900 mm. The center is the span between two steel I-sections or between two timber joists. Due to the rapid setting of gypsum mortar, it is used to bind clay brick units together when building the spans between steel I-section beams (Maheri & Rahmani, 2003).

✉ Hayder Al-Khazraji
hayder_alkhazraji@uomisan.edu.iq

Abdulkhaliq A. Jaafer
aljabery@uomisan.edu.iq

Haider H. Haider
3haidar@uomisan.edu.iq

Majed Ali Mozan
aajjssdf@gmail.com

Haider Sattar Faraj
hydrstar037@gmail.com

Sajjad Sadiq Maktuf
sjadasjada23@gmail.com

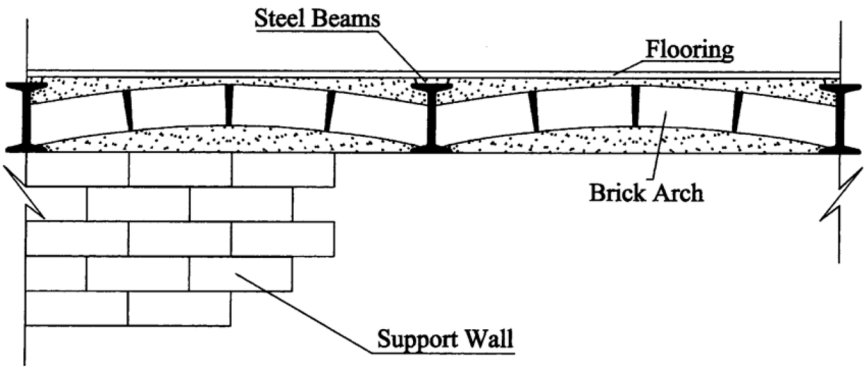
[1] Department of Civil Engineering, Engineering College, University of Misan, Amarah, Iraq

In addition to steel joists with I-sections, timber joists are also typical of jack arch slabs in other countries (Garcia-Castillo et al., 2021). See Fig. 1.

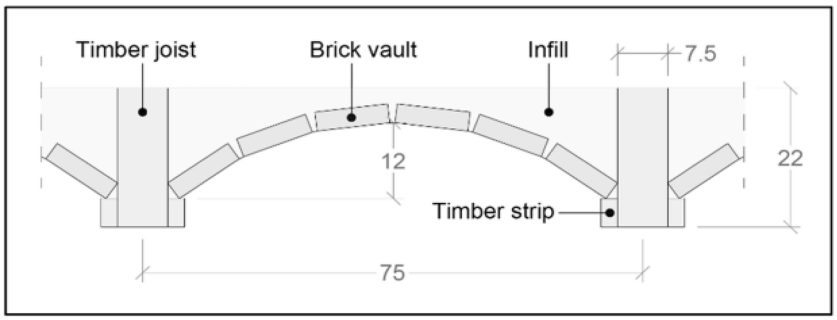
The project assigned Early Victorian British masonry jack arch flooring, which was widely used to cover vast floor expanses in factories and other industrial structures (Maheri et al., 2012). The Albert Dock warehouses in Liverpool, constructed by early Victorian architect Jesse Hartley, and the late Victorian kiln buildings and warehouses around London (Maheri et al., 2012), are excellent examples of this type of flooring.

Traditional jack arch slabs are still quite popular in the Middle East, where they are used to floor not only industrial buildings and regular houses, but also numerous high-rise steel and concrete framed buildings, due to their technical simplicity, speed of construction, and low cost (Maheri et al., 2012). Figure 2 shows the behavior of customary jack arch slabs with and without steel I-beams, respectively.

The use of fiber-reinforced polymer (FRP) materials as reinforcement in civil structures has long been appealing due to FRP's noncorrosive properties. In addition, tensile stress is higher than that of the reinforcement bar. Some studies have looked into the utilization of a ferrocement layer as a structural element strengthening approach (Paramasivam



(a) Construction detail of a traditional, one-way jack arch slab (Maheri et al., 2003).



(b) Cross-section of a historic timber flooring system – dimensions in cm (E. Garcia-Castillo et al., 2021).

Fig. 1 Types of jack arch slabs using steel beam and timber joist. **a** Construction details of a traditional, one-way jack arch slab (Maheri et al., 2003). **b** Cross section of a historic timber flooring system—dimensions in cm (Garcia-Castillo et al., 2021)

et al., 1998). Also, some Iraqi researchers have investigated the effectiveness of jack arch slabs reinforced with single and double ferrocement layers and concluded that the ferrocement layer improved the flexural strength, stiffness, and ductility of the jack arch slab without significantly increasing the slab's weight (Resan & Dawood, 2015). Furthermore, a numerical study is presented for a jack arch slab's seismic performance in southern Iraq. The findings revealed that flexural stresses, rather than membrane stresses, controlled the behavior of the jack arch slab. The tensile stresses in the slab were significant, even if the compressive stresses were less than the permitted stress. Deflection and stresses in steel beams were within accepted limits (Dawood & Resan, 2015). Many jack arch slabs have been damaged and collapsed; therefore, some researchers have reported strengthening the jack arch slabs by using ferrocement (Obaid & Jaafer, 2022).

Steel wire rope is one such novel retrofit approach that has recently attracted the attention of researchers, due to its beneficial high strength as well as its ductility capacity (Yang et al., 2009, 2012).

Literature review shows that many researchers focused on the strengthening of jack arch slabs using the technique of ferrocement, but only a few of them presented a new method of using wire rope to improve the jack arch slab. Therefore, the authors present this work to strengthen the jack arch slab with a new technique by using fiber-reinforced polymer rope (FRPR). Four groups were manufactured, each one included a reference specimen and a strengthening specimen. The experimental results focus on the influence of the type of clay brick unit (solid or perforated) on flexural strength and deflection measurement under loading (line load is applied at the mid-span). Furthermore, the relationship between span length (i.e., the dimension between two steel I-section beams) and deflection is investigated using the FRPR point (i.e., localized the point and used fiber-reinforced polymer rope at the span). The following sections are for brick masonry slabs; however, the fiber-reinforced polymer rope (FRPR) approach can also be used to provide the flexural strength of slabs or roofs, in addition to improving seismic resistance and reducing the high seismic risk of jack arch slabs. See Fig. 3.

Case study

Two case studies are presented in this study to demonstrate how to strengthen arch slabs using fiber-reinforced polymer rope.

(a) A historic house's jack arch slab, about 1830.

(b)The historical market of Al Amarah, Iraq, about 1871.

Fig. 2 The arching of historical and traditional brickwork in Al Amarah, Iraq, from the nineteenth century. **a** A historic house's jack arch slab, dating to 1830. **b** The historical market of Al Amarah, Iraq, about 1871

Fig. 3 Fiber-reinforced polymer rope (FRPR) sample

The structural behavior of jack arch slabs made of two types of bricks, solid clay bricks and perforated clay bricks subjected to line load, will be investigated.

The behavior of strengthening slab panels by using FRPR is studied. Jack arch slab is brittle due to the brittleness of its components (clay bricks and gypsum mortar). A procedure is used to improve its flexural strength, stiffness, and ductility by reinforcing the cement matrix layer.

Materials investigations

The chemical and physical properties of materials are discussed in this section. Researchers use clay bricks and gypsum to make brick arches; this method is common in southern Iraq. Then FRPR is used to improve or strengthen the brick arch.

Clay brick

There are numerous types of clay bricks used in building construction, including clay, lime–sand, concrete, and glassy bricks. In this study, two kinds of clay brick are presented: solid and perforated. Because of the availability of raw materials, low production costs, suitability for bearing weight, heat isolation, fire resistance, and resistance to atmospheric changes (Binici et al., 2007; Lam, 2020; Sadek & Roslan, 2011), clay bricks are the most commonly used bricks in Iraq. Their standard dimensions are 240 mm × 115 mm × 75 mm, according to Iraqi specifications No. 25/1988 (IQS No. 25/1988). See Table 1. Figure 4 shows clay brick under loading.

Gypsum material

Gypsum is used as mortar to join clay bricks together. Gypsum (CaSO4.2H2O) is a calcium sulfate that dehydrates. Sulfate mineral is highly soft. Gypsum mortar is made up of water and gypsum. Due to the availability of raw materials, it is one of the earliest known kinds of mortar in Iraq. Because of its hardness speed of setting, it is the only mortar used in Iraq for jack arch construction. All tests of gypsum materials are according to Iraqi specification No. 28/1988 (IQS No. 28/1988). Figure 5 shows gypsum mortar specimen. The compressive strength of gypsum is 4.7 MPa. The mechanical and physical characteristics of bricks and mortar were tested. The flexural bond strength between brick and mortar is explored for masonry units (both bricks and mortar) (IQS No. 28/1988). Table 2 shows the results of the testing.

Cement

According to ASTM C150/C150M-22 (2022), type I cement utilized in this study was ordinary portland cement, which was