Engineering Structures 147 (2017) 517–529

Contents lists available at ScienceDirect

Engineering Structures

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

Characterization of the clay masonry units and construction technique at the ancient city of Nippur

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ARTICLE INFO

Article history:
Received 6 May 2016
Revised 13 April 2017
Accepted 7 June 2017

Keywords:
Nippur city
Ancient masonry buildings
Mechanical behaviour
Durability
Brick units

ABSTRACT

This paper describes a programme of experimental measurements performed in support of a parallel programme of field investigations to evaluate the construction methods used at the site of the ancient city of Nippur. The experimental programme investigated both the mechanical properties and durability of the ancient clay masonry units used in the construction of buildings at Nippur including tests for dimensional consistency and flatness, density, compressive strength, initial rate of water absorption and thermal properties. The test results have been compared with those for modern brick units available nowadays in Iraq and with hard natural stone samples.

The field investigations showed that the important buildings were constructed using composite walls inclusion firing clay masonry units with two nominal dimensions ($30 \times 30 \times 7$) cm and ($30 \times 15 \times 7$) cm (l, w and h). The formulation of working design technique was followed to achieve the member stability under applied loads. Layers of bitumen material were used as a binder for both bed and head joints in order to provide the desired strength level for the masonry wall.

The experimental results show that the ancient brick units and stone samples exceed the tolerance and range of dimensions limits recommended by current EN Standards. Lower density values were recorded for the ancient brick units compared with that for both modern clay brick and stone specimens and these values showed agreement with the modern classification of high density (HD) units. Approximately similar values of compressive strength were observed for both ancient brick units and natural stone samples reaching about 17 MPa, whilst modern clay brick samples showed lower compressive strength value suitable for application of partition walls. The initial rate of water absorption increases with an increase of the soaking time, but tends to decrease after 90 min for both ancient and modern brick units. Superior performance in terms of thermal conductivity, thermal resistance and durability under fire action were observed for the ancient brick samples compared with modern clay brick and stone samples.

1. Introduction

Many past civilizations possessed high levels of skill in what were in some cases unique methods of construction. Many of these ancient skills have been lost and it has been difficult to reproduce their levels in service performance even with the modern techniques adopted nowadays.

One of the most ancient cities in the world is Nippur, which has a recorded history back to 5000 B.C [1]. Some of the landmarks of this city still exist from that era [2]. So, parts of Nippur are thought to predate the Ziggurat of Ur (2600 B.C) and the Pyramids in Egypt (2580 B.C) [3]. The city of Nippur with its many buildings and temples in addition to the earlier library was probably more literate than other towns [1].

The city of Nippur is located in the south of Iraq about 170 km southeast of capital Baghdad in what was Mesopotamia and approximately midway between the ancient cities of Babylon and Ur [2]. This central location helped Nippur to play an important role in the historical events of the Mesopotamia. The topographical characteristics of Nippur site show a large land with some mounds representing the debris of collapsed buildings with a total area of about 135 ha [2].

From the archaeological point of view, the civilizations with Nippur are firstly pre-Sargonic era followed by Akkadian, Ur III and Old Babylonian periods. The later history of the city (after the 2nd millennium) indicated it fell under the rule of a number

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http://dx.doi.org/10.1016/j.engstruct.2017.06.017
0141-0296/

of other civilizations at different time, including Assyrian, Parthian, Sassanid, Seleucid and Persian periods. It also appears that the city was considered to be the seat of the Assyrian Church of the East Christian bishopric [4,5].

The first archaeological excavation of Nippur was performed under the direction of Sir Austen Henry Layard in 1851. About 38 years after this date, the University of Pennsylvania led a detailed period of work continuing for 11 years which involved four seasons of excavation. A more comprehensive investigation was then conducted by the Oriental Institute of Chicago between 1948 and 1990 with 19 seasons of excavation. All of the previous investigation works were focused upon the archaeological objects such as tracing the site and borders of buildings as well as the pottery, documents written on clay tablets [1,6]. Today, the overall site is covered by sand dunes, so the monuments of the aforementioned excavations disappeared.

The dominant character of Nippur construction is the historical masonry using clay brick units as no stone was readily available in this area [7]. Brick units were being made by hand in moulds using a particular technique incorporating insertion of the air-dry units into a clamp containing brushwood soaked with fuel and the outside covered with a layer of clay in order to reduce heat loss [3]. The quality of the bricks produced is influenced by the firing time and how well the heat is distributed within the clamp. A well designed mortar to give the required strength and providing uniform bedding for masonry units was used and its quality highly depends on the importance of the structure. It could be as a bitumen, clay-straw mixture or clay mortars [3]. Such mortars were found to be used in construction of the Ekur Ziggurat, temples, the main surrounding wall and houses respectively. The composition of mortars, water content used for mixing and temperature level at which the bitumen can fairly flow are the main factors governing the weathering characteristic and resistance of these to the exposure conditions.

The clay bricks of the composition used in Nippur and Mesopotamia civilizations are encountered in other ancient buildings in the world, for example in ancient Greece at the fourth century BC and that used in Portuguese monuments dated to the period of 12th–18th centuries. Previous studies have described the methodology of producing fired bricks used in the former buildings in four stages [8,9]. The first stage incorporates selection of an appropriate soil as a raw material which is usually clay. Crushing process and mixing with water using suitable water content are the main operations of the second stage. In the third stage, the clay mixture is casted in the moulds then demoulded after stiffing and dried in a covered space. Finally, the bricks allows for sun dried and then putted in a kiln or clamp with a temperature up to 1000 °C.

In general mechanical, the physical, thermal, mineralogical and durability properties of clay bricks and their masonry structures are affected by the raw clay, weathering mechanism, material aging and long term behaviour. The former effects are usually by the action of atmospheric agents such as wind and water [8–10].

Although the great historical value of the ancient Nippur city and its long historic period is widely recognised, there appear to have been no scientific research conducted in investigation the construction techniques followed at this city. This study considers the first attempt to evaluate the old construction of Nippur through two approaches: site investigation and experimental measurements on the materials used in that construction. This gives an opportunity to explore the composition of materials used, skills of old builders and level of their engineering thinking. A comparison has also been made with the modern materials used nowadays (brick and stone) by adopting the relevant EN standards, and evaluating the applicable ranges and limitations for using modern codes of practices on the outputs of ancient construction techniques.

2. Site investigations

The whole site is covered by sand dunes at the present. This is due to the conversion of the soil of the site to the sandy soil resulting from the environmental effects and desiccation of the main ancient canal river (Shatt-en-Nil) at this area [2]. Moreover, the city is located at the main sedimentation plains area of Iraq. So, it was difficult to perform the detailed investigation for the method of construction. On this basis, the evaluation was limited by observing the apparent structures (Ekur Ziggurat) with helps of excavations data published by Oriental Institute of Chicago [1,4,6,11–13].

The Ekur Ziggurat represents the major element in the site with a height reached about 15 m above of the ground level. It located at the eastern north regain of the site, as shown in Fig. 1a [1,2].

The base of the Ekur Ziggurat occupies a rectangular space of about 2400 m^2 (60×40) m. There are five levels linked together through a main staircase to reach the terrace element located at the top of Ziggurat, as shown in Fig. 2 [2]. The latter element incorporated some openings in the walls of the Ekur Ziggurat for example to the King's chamber of about 1–1.5 m in width and these openings were constructed without lintel or beams, as shown in Figs. 1b and 3a. This is by following equilibrium aspect when brick units set into wall or so-called grading technique. This allows for supporting the masonry above openings when the thrust line of the inclined upper part of opening produces allowable stresses due to a uniform end bearing [3]. The same manner was also adopted in performing the roof, as shown in Fig. 3b. The roof opening could then be closed by tree legs or grass, and then covered by a clay layer.

Two types of clay bricks were apparently used: sun-dried and firing bricks. The first type was widely used for normal buildings such as houses and made by allowing the brick lumps to drying out in the air or the sun. This may take long time to achieve the strength and usually do not need high quality control. The firing bricks were produced under fire effect within likely a clay-chamber with more efforts in order to get bricks with low variations in quality and sizes [3]. The latter was used in the significant buildings such as temples and Ziggurat.

The construction technique used on Ziggurat involved increasing the width of the wall as to be able to reach the total height of the building. In some regions, the wall thickness was about 1 m or more. This concept is consistent with the so-called working design technique which gives a range of safety in dimensions of the member in order to obtain the structural stability. If levels-1 to 5, shown in Fig. 2, were filled with a clay soil and assumed to be solid, the vertical transmission dead loads from the top of King's chamber to the base of Ziggurat can be simply calculated based upon the available dimensions, density of clay soil (14.4 kN/m^3) [14] and results of densities presented in Section 4.2, as shown in Table 1.

It can be seen that the total vertical transmission dead load is 264,705 kN. This equivalent to a distributed vertical load at the base of the Ziggurat of 110.3 kN/m^2. If the latter calculated load is compared with the average bearing capacity of soil near the city of Baghdad (125 kN/m^2) [14], the whole Ziggurat building is considered as a stable structure. This manner can be accepted if no allowance for bending moment due to the load eccentricity is permitted. The aforementioned concept was taken into the consideration at construction of this building where the centre of gravity of the whole Ziggurat coincides with its centroid due to its symmetrical shape about the main axis.

Most of the exterior walls of the Ziggurat were fabricated as composite walls, as shown in Fig. 4. The used of composite walls have many advantages, which include, reduction the implementa-