Seismic Vulnerability of Historic Hydraulic Structures of Shushtar City, southwestern Iran

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ABSTRACT

This article assesses the seismic vulnerability of historic hydraulic structures in Shushtar city in Khuzestan Province, southwest of Iran. The city has a few numbers of these structures being called as Shushtar hydraulic ring which were constructed over Karun River and should be repaired and rehabilitated. The so called ring is consisted of 8 dams, weirs, bridges and about 38 water mills, all of them were erected during the Sasanid Imperial period about 1700 years ago. The quality of construction material and workmanship are almost well. The bridges, dams and weirs are heavy, single or multi-span arch construction. The bridges and water mills are primarily of brick masonry construction, but in the dams and weirs some notable stones and mud-bricks also a highly cementacious mortar called Sarooj have been often used. The structures are founded on Agha Jari Formation of light yellow sandstones with marlstone inter-layers. A review of the available historical and recent sources on the earthquake events indicate that as part of the Zagros active fold belt, the area had some weak to moderate earthquakes although, the instrumental records are rare. According to the seismicity maps of the region and previous researches, a range of 4.5–5 magnitude earthquakes (Ms scale) with 0–20 km focal depths have been estimated. Besides, the area has a high risk potential based on the national seismic codes. The hydraulic structures show some damages not necessarily due to earthquake events but partly due to rural development. A classification of the structures could be made according to their seismic vulnerability. Regarding to the earthquake intensities and the location of the structures, damage and survival intensity levels are to be calculated for these structures which could prove that immediate rehabilitation and repairing operation of the mentioned structures are necessary.

Key words: *Seismicity, Historic hydraulic structures, Shushtar,*

1. Introduction

Earthquake events have had a long history of destruction in the Iranian plateau. Their records date back to the 4th and 3rd millenniums BC. In this regard, vulnerability of historical monuments especially hydraulic ones as treasures of nations has been focused by researchers in recent years, in need of protection from the future earthquakes. In the present article, the seismic vulnerability of historic hydraulic structures in Shushtar city (Fig. 1.) in Khuzestan Province of south western Iran regarding their tectonic environment and site geology is investigated. The study is based on a review of previous researches and recently geotechnical investigations. The study concentrates on the geological structure and regional tectonics besides geotechnical properties of the mentioned structures. These structures varying in size

and form have common site geology features, which makes a comparative study possible. They are all masonry structures made with fired brick, mud brick or stone masonry with lime, gypsum or 'sarooj' mortars. The studied hydraulic structures include bridges, dams, wiers, tunnels, and water mills. These structures were built with better material and workmanship compared with the ordinary buildings. Retrofitting of these structures is cruicial in view point of geotechnical earthquake engineering as well as geoarchaeology and geotourism.

2-Geological setting and stratigraphy

The Zagros Fold-Thrust Belt being located to the northeast of the Persian Gulf is a branch of the Alpine-Himalayan Orogenic belt divided into three major structural zones [1] namely: the Sanandaj-Sirjan Metamorphic Belt (zone 1) , the high Zagros(zone 2) and the Simply Folded Belt (zone3). Most part of Khuzestan Province is located in zone 3, being comprised of parallel, long anticlines and synclines. The Formations on which the structures were built, are Agh Jari Sandstones of Mio-Pliocene and Bakhtiari Conglomerates of Pleistocene [2,3,4]. Both of them are gently dipping in the area and follow the general trend of the Zagros Fold-Belt i.e., NW-SE. The former is mainly composed of sandstones and marlstones and the latter is consisted of poorly rounded mainly calcareous conglomerates. The average attitude of joint systems in the area is N40-60W and N40-60E with nearly vertical dip. From a seismotectonic point of view, the area is located in the Zagros active fold belt with some weak to moderate background seismicity. Accordingly, a range of 4.5–5 magnitude earthquakes (Ms scale) with 0–20 km focal depths have been estimated. A comprehensive account of the relevant historical sources is given by Ambraseys and Melville [5,6]. They used 262 Iranian earthquakes of the 20th century for which values of magnitude (M), the radius of perceptibility (r'), re-defined as the mean epicentral distance at which the shock was felt with an intensity IV (MM) and the macroseismic intensity (Io), measured on the Modified Mercali scale, to derive at the following relation;

$$M = -0.74 + 1.98 \log(r') + 0.28(Io) \quad (1)$$

The surrounding region suffered weak to moderate shocks in time according to the previous studies [6].

3. Historical sites and construction materials

Due to of favorable condition of life besides good climate, water abstraction by different structures became popular around Karun River in Shushtar city. Shushtar Hydraulic System can be traced back to 5th century B.C. Some of the hydraulic structures are belong to Hakhamaneshian (Hakemanids), e.g., Daryoon Canal and some of them are related to Sasanid (Sasanian) Period, e.g., Gargar Wier [3,4]. There are 12 main hydraulic structures which can be classified as a) bridges and dams b) wiers and c) water mills. Of them the most important and famous are: Band-e Mizan, Gargar wier, Shadervan bridge, Daryoon canal, Lashgar bridge, and Band-e Khak (Fig. 2,3,4). Some of these structures were destroyed by floods and wars but some are still working or repaired to work. A review of the general features of the structures can be found in relevant papers. The majority of monumental buildings in Iran were built with fired bricks. Some large stone masonry and mud-brick structures have also survived

to the present day. Fired brick is an Iranian invention dating back to the early 2nd millennium BC. In construction of different buildings in different periods, a verity of mortars has been used. The foundations were made of 'Shefteh', a lime mortar-stone masonry construction. In construction of the studied structures a highly cementacious mortar called Sarooj was often used. Sarooj is a mixture of lime (35%), sand (40%), ash (20%) and clay (5%). Sometimes by adding a quantity of goat's hair, the mortar was reinforced. Generally, extensive erosion and corrosion happened at the location of clayey lenses within the sandstones layers of Agha Jari Formation. In addition, some collapse and damage occurred in the tunnel roofs mainly along the existing joint sets. The intrusion of waste water from sewerage system into the tunnels also caused failures and corrosion in the roofs and walls. Part of the collapses is due to heavy vehicle traffic load e.g., over Gargar weir which acts as a bridge to facilitate urban transportation. As the RQD values of the surveyed layers were too low [7] it is suggested that some failures might happen that could be intensified during earthquake events.

4-Conclusion

Due to tectonic activity of the study area, weathering of the foundation formations, geotechnical weakness of the geological layers and unfavorable urban development, most of the structures are sensitive to earthquake events. According to the research, al of the structures are vulnerable regarding seismotectonic, geotechnical and structural properties. Previous studies also indicated that the hydraulic structures are solid elements with short period frequency. It is proposed that suitable seismotectonic modeling, geotechnical investigations and structural studies be carried out to properly protect the structures from much extensive destruction. Besides, a classification of the structures could be made according to their seismic vulnerability. Regarding to the earthquake intensities and the location of the structures, damage and survival intensity levels are to be calculated for these structures which could prove that immediate rehabilitation and repairing operation of the mentioned structures are necessary.

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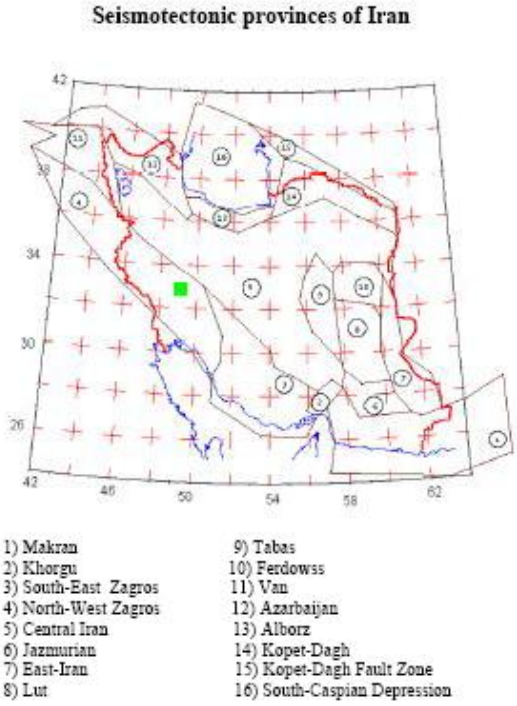

Figure1. Location of the study area (green square) relative to the main seismotectonic elements of Iran

Figure2. Northward view of Band-e Mizan , north of Shushtar .

Figure3. Figure2. A view of Pol-e Lashgar (Troop bridge) in south of the city.

Figure4. Helicopter photo of Band-e Gargar and watermills in the east of the city.