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MICROPILES APPLICATIONS FOR SEISMIC RETROFITTING OF HISTORICAL BRIDGES

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Abstract

Masonry bridges are regarded as the oldest examples of engineered structures in the world. Therefore, the preservation of these structures is getting a great deal of attention in the structural engineering community. And as such, restoration, strengthening and reinforcement of historical masonry bridges have become a challenge for civil engineers. In general, and to most extent, engineers have relied on several traditional retrofitting techniques that could be implemented for historic bridges. However, traditional retrofitting techniques have been inadequate for improving seismic behavior and resistance of these structures. With current advancement in materials and construction techniques, new technologies that can be appealing to historical bridges are emerging. Among these techniques include underpinning using micropiles with the technique called "micropiling". Today, micropiles are used for the structural and seismic retrofitting of bridges, mosques, churches and many other ancient cultural heritage and modern structures. This study mainly focuses on historical masonry bridges; and it consists of three major parts. The first part introduces seismic retrofitting using micropiles for historical bridges. The second part discusses advantages and disadvantages of micropiling compared to other underpinning methods, in terms of seismic performance. Finally, the third part presents examples of applications in different parts of the world.

Keywords: Historical bridges, Micropiles, Soil improvement, Seismic retrofitting

1. Introduction

Historical masonry bridges are very complex structures with respect to the seismic behavior and seismic protection. Therefore, they require high level protection standards and advanced engineering knowledge about seismic design. Earthquake effects in masonry bridges generally depend on bridge types, construction materials and seismic behavior of bridge structures. It is well known that earthquakes can happen anywhere and anytime all over the world. Hence, many historical bridges are at risk in terms of seismic events and they have mostly deficient resistance against seismic loads. The seismic retrofitting of masonry bridges has come significantly to prominence along with the understanding of structural behavior, developing analysis methods and advances in seismic definitions. In parallel to the developments of the building technologies and seismic engineering, several seismic protection and underpinning methods have been remarkably developed in order to improve the seismic performance and seismic protection. Nowadays, therefore, it can be mentioned many different underpinning methods with application types, workmanship, equipments and different application places. In terms of masonry structures, restoration and retrofitting projects, there are four main underpinning methods which can be classified as Traditional Method, Jet Grouting Method, Compaction Injection Grouting Method and Micropiling Method [1].

Humankind has retrofitted structures which are affected by earthquakes from past to present. When historical heritages that were built on earthquake areas have been studied carefully, seismic retrofit traces and restoration ruins might be encountered. These traces and ruins may guide for seismic protection and they may contribute to current retrofitting projects for more correct restorations [2]. Therefore, the correct intervention in light of old ruins and trails are very important at the present time. According to the ninth article of Venice Charter (1964), "The process of restoration is a highly specialized operation. Its aim is to preserve and reveal the aesthetic and historic value of the monument and is based on respect for original material and authentic documents. It must stop at the point where conjecture begins, and in this case moreover any extra work which is indispensable must be distinct from the architectural composition and must bear a contemporary stamp. The restoration in any case must be preceded and followed by an archaeological and historical study of the monument." Furthermore, as it is also described in the tenth article of Venice Charter (1964), "Where traditional techniques prove inadequate, the consolidation of a monument can be achieved by the use of any modern technique for conservation and construction, the efficacy of which has been shown by scientific data and proved by experience." Hence, historical structures must be preserved using minimal and renewable intervention. Together with that, the most convenient underpinning techniques should be selected before intervening so that these structures can be safely transmitted to the posterity.

In particular, micropiling method can be accepted as one of the best underpinning techniques in the world. Micropiles were generally used for underpinning of existing foundations; however, recently, they have been frequently used for many different applications such as foundation support, soil settlement problems, deep excavations, adding new stories to buildings, slope stabilizations and bearing capacity problems. It has been also used for the seismic retrofitting and protection methods to new and old structures. In the last few decades, micropile technology has been significantly expanded because of its significant advantages and it is a very attractive solution for the structural and seismic retrofitting of bridges, mosques, churches and many other ancient cultural heritage and modern structures in many earthquake-prone areas. The following part expresses designing and seismic applications of micropiles; furthermore, it discusses advantages and disadvantages of micropile method compared to other underpinning methods in terms of seismic performance.

2. Designing And Seismic Applications

Micropiles were implemented for the first time in Italy by Fernando Lizzi to retrofit the existing masonry structures and foundation systems in the early 1950's. Micropiles are small diameter piles and they are generally used in soil and foundation retrofits. Typically, they are under 25 cms (10 inches) in diameter, 7.5 or more meters (>24 feet) in length and 300-1000 kN (70-225 kips) in load-carrying capacity. However, these measures can be occasionally changed with application situations and the design purposes. Since micropiles are small-diameter piles, they are sometimes called mini piles, root piles, pin piles or needle piles. Micropiles are installed using the drill rigs which are generally hydraulic rotary machines. The successful construction steps for micropile application can be arranged under three major parts. They are drilling, placing reinforcing steel and grouting. These steps are consecutively implemented. That is, after the determination of the pile points, the drilling work is started with different type drilling machines and rigs. Then, small diameter steels are placed in these drilled holes and finally these steels are covered by grouting materials (Figure 1) [4, 5].

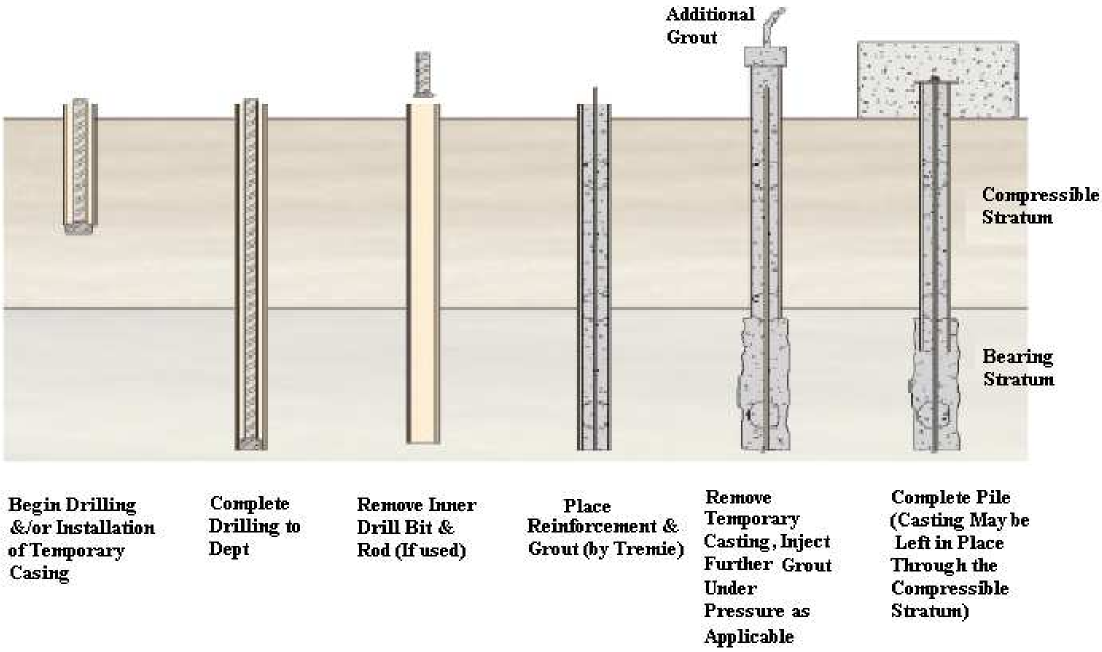

Figure 1: Schematically main construction phases [6]

Therewithal, micropiles can be implemented to different sequence types and different connection forms. Although they could be vertically connected to the structure foundation, they could be connected in inclined forms around and below the foundations (Figure 2). By this, micropiles can become networks and they may behave like tree roots; thus, they may increase the soil-structure interaction toward seismic loads. Many studies have shown that the seismic performance of micropiles changes with micropile connection forms, sequences and directions. According to Sadek and Isam (2004), “inclination of micropile improves micropile’s performance with respect to seismic loading. The inclination allows a better mobilization of the axial stiffness of micropiles and consequently leads to a decrease in both shearing forces and bending moment induced by seismic loading.” and also in terms of liquefaction, micropiles give very attractive results. Generally, nevertheless, vertical micropiles don’t reduce liquefaction during the earthquakes whereas inclined micropiles reduce it [5]. However, studies reported by Bruce et al. (2005) show that “inclined piles should not be used for transmitting lateral loads to the soil, but if such piles are used, they must be safely designed to carry axial and bending loads.”

In another recent study, Sadek and Shahrour (2006) say that “Micropile systems present significant advantages for the construction in seismic areas, mainly flexibility, ductility and capacity to withstand extension forces. Micropiles can be used as foundation support of new structures as well as for seismic retrofitting of structures, which have suffered seismic damage”. Research also proved that these systems increase seismic performance of masonry structures and minimize the foundation deflection because of its high pullout and bearing capacity. [10-13].

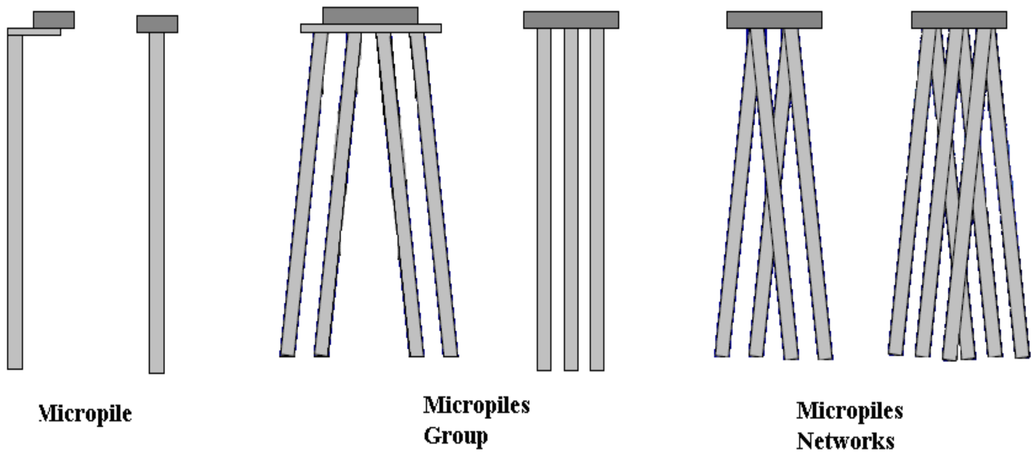

Figure 2: Some micropile application types [14]

When it is compared with the benefits of micropiles that are described above, the traditional method is insufficient for seismic retrofitting and protection. Although it is an economical solution for underpinning, it leads to settlement in the foundation of structures because of its heavy mass. For these reasons, applications of the traditional method have decreased gradually for historical structures. Another method known as the compaction injection grouting may not be preferred for soft clay soils because they have caused extra pore water pressure in the soil and they have led to excessive soil settlement in the long run. Furthermore, when these methods are applied for settled and lopsided structures, there may be structural damage in the superstructures due to uncontrolled injections. Consequently, the soil profile and soil properties have to be particularly defined before the compaction injection applications and correct grouting materials with convenient injection parameters should be chosen. The third method which is called the Jet grouting may be a good solution for seismic retrofitting and protection. However, they are very expensive for historical structures because they require special equipments and teams. Furthermore, it is difficult to produce long columns with this system because generally jet grout columns are shorter than five meters. Nevertheless, jet grouting can be applied for almost all types of soil and they can be produced for a lower price with the developing technology [1].

By using innovative engineering, micropiling can be effective and provide an economical solution for all implements from small and large structures. Micropiles have been successfully implemented in the restricted working space, sensitive structures and unsuitable or unstable soils (such as slopes). Because of its proven capabilities, micropiling represents an advanced underpinning technique in retrofit problems of historical bridges. By means of high flexibility and ductility, they behave well under seismic loads. However, according to Marek and Muhunthan (2005) “Despite the increased use of micropiles, the seismic behavior of a single micropile and a micropile group is not fully understood due to the limited number of full- and model-scale tests, as well as the limited amount of numerical modeling studies of micropiles.”

3. Case Studies

This chapter discusses different micropile applications in masonry bridges. Many applications in this method have been implemented for different purposes. Table 1 presents different examples of micropile application in the world. This list provides two specific examples of the seismic implementation of micropiles in New York, United States and Venice, Italy respectively.

Table 1: Different types of micropile applications for some masonry bridges

Bridge Name	Location	Purpose of Application
The 145th Street Bridge	New York, USA	Seismic Retrofitting
The Pierre Bridge	Bordeaux, France	Foundation Reinforcement
The Vila Fria Bridge	Felgueiras, Portugal	Seismic Protection
The Ponteceso Bridge	Galicia, Spain	Widening and Strengthening
The Sandro Gallo Bridge	Venice, Italy	Widening
The Three Arches Bridge	Venice, Italy	Static and Seismic Retrofitting
The Broadmeadow Viaduct	Dublin, Ireland	Stabilization
The Northwich Viaduct	London, England	Settlement Problem
The Tarano Bridge	Alessandria, Italy	Foundation Strengthening

The first application example is the 145th Street Bridge in New York. The 145th Street Bridge was completed in 1905 across the Harlem River to connect Manhattan and the Bronx. Its center span is 91.5 meters (300 feet) and the total length is 481.5 meters (1580 feet). It is a movable bridge and its substructure was built with steel trusses and its two piers were constructed by masonry stone. In 1998 the bridge is examined in terms of its resistance to earthquakes by the New York City Department of Transportation and the department observed two earthquake levels. Consequently, the bridge piers were strengthened with 20 micropiles which were of 6.35 cms diameters and Grade 75 (520 Mpa) steel bars (Figure 3).

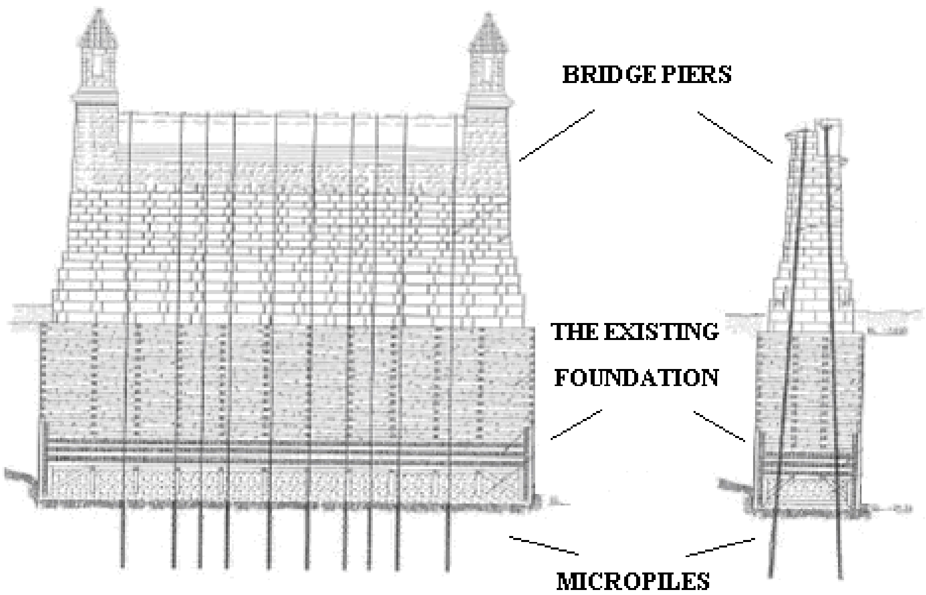

Figure 3: Elevation views of the micropiles as strengthening reinforcement [16]

The second application example cited in the table for seismic retrofitting is the Three Arches Bridge in Italy. The Three Arches Bridge was built in 1688 on the Rio di Cannaregio Canal in Venice, Italy. It was designed as three arches form by Antonio Tiralli. Its central arch span is 15 meters (49 feet) and the end arches spans are 8 meters (26.2 feet) each and the total bridge length is almost 40 meters (131 feet). This bridge is a very important historical bridge because it is a single example of a bridge with three arches in Venice. The bridge parapets were added to the first restoration in 1794; and these parapets created extra loads on the bridge. In the course of time, the bridge was damaged by the boat and gondola traffic. Scours also caused soil erosion and differential movements. In 1960, Fernando Lizzi and his team prepared a restoration project and the bridge was restored with micropile networks (Figure 4).

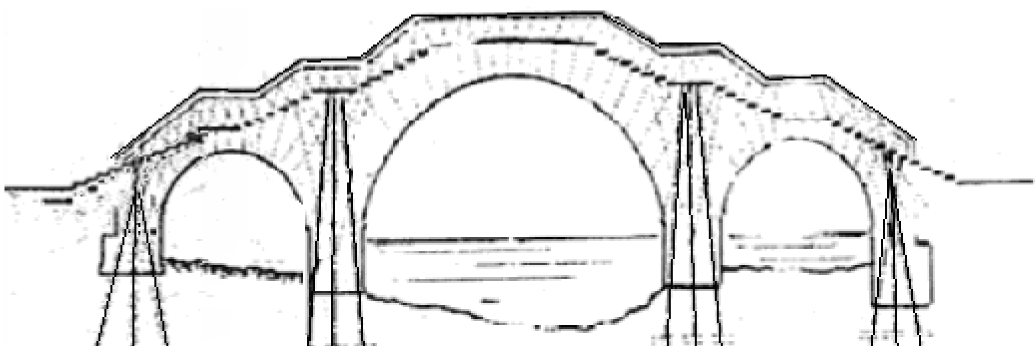

Figure 4: Micropile retrofit scheme of the Three Arches Bridge [17]

The bridge was successfully retrofitted by micropile networks in 1960. In the application phases, firstly, the bridge was drilled by rotary drill rig on the bridge from the piers top to the substratum and the micropiles were located and grouted. In the result of retrofitting project, the There Arches Bridge was strengthened with minimum damages during reinforcement using micropiles in terms of static and seismic performance [17].

4. Conclusion and Assessment

Recently, earthquakes have shown that many historical and modern structures are inadequate in terms of seismic performance and they have to be retrofitted at the earliest. It is known that masonry bridges are one of the oldest examples of engineered structures in the world and they have to be safely transmitted to the posterity. As Venice Charter (1964) mentioned, “the conservation and restoration of monuments must have recourse to all the sciences and techniques which can contribute to the study and safeguarding of the architectural heritage.” In this study, the micropiling method which has proven its reliability is discussed by means of seismic retrofitting and protection for historical masonry bridges. The seismic application principles are summarized and the some application examples are presented with a chart. After that, this study focused on two important application examples with respect to seismic retrofitting in the world.

In summary, major conclusions of this study are the following:

1. Retrofitting materials are very important for the protection of the historical structures. Therefore, in the first restoration step, the most convenient materials must be chosen before the implementations.
2. New restoration and retrofitting methods should be preferred where traditional methods are insufficient; and as such, a proven technique using underpinning with micropiles offers a reliable approach for strengthening and retrofit of masonry bridges.
3. Underpinning techniques offer a proven method for the protection of the historical bridges. Therefore, this method will need to be considered as a means of providing an effective alternative in the structure’s retrofit plan.
4. Before implementing the underpinning, the correct equipment and workmanship must be considered.
5. Retrofitting applications have to be implemented with the minimum damage and maximum protection for the historical structures. Furthermore, if required, all applications have to be removed without detriment to structures.
6. The entire restoration steps should be implemented according to the international protection committees such as ICOMOS and UNESCO.

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