CHAPTER 1 INTRODUCTION

1.1 Overview of Problem

One of the most dramatic causes of damage of structures during earthquakes is the development of liquefaction in saturated cohesionless deposits. These deposits tend to densify when subjected to earthquake loading. However, when saturated, the tendency to densify causes the excess pore water pressure to increase. Consequently, the effective stress of soil decreases. The cohesionless deposit will suffer a great deal of loss of strength until the excess pore water pressure has a chance to dissipate. The phenomenon of pore pressure build-following with the loss of soil strength is known as liquefaction (Committee on Earthquake Engineering, 1985).

The study of liquefaction has become extensive since the Niigata and the Alaska earthquakes occurred in 1964 (Seed and Lee, 1966; Seed and Idriss, 1967). The study that has been considered as a major breakthrough on the subject of liquefaction is the one conducted by Seed and Idriss (1971, 1982). They proposed a procedure to evaluate the liquefaction resistance of soils based on Standard Penetration Test (SPT) blow counts. The procedure is known as the “Simplified Procedure”. This procedure has become a standard practice not only in North America but also worldwide. The procedure has evolved over the years as considerable efforts have been devoted to the study of liquefaction. Many efforts have been done to develop this procedure, especially in relation to in situ tests. The latest development on the subject of liquefaction resistance of soils was the 1996 NCEER and 1998 NCEER/NSF workshops (Youd, et al., 2001).

Due to the damages that may be caused by liquefaction, efforts have been developed to reduce the damage effects of this phenomenon. Of particular importance are efforts to densify the liquefiable soil and to provide drainage path to accelerate pore pressure dissipation during seismic loading. Vibro-compaction, vibro-replacement and vibro-displacement stone columns, vibratory probe method, and aggregate piers are some examples of ground improvement techniques that have been used to reinforce the soil and increase the soil resistance against
liquefaction. The improved performance of treated ground and the use of ground improvement to successfully reduce the risk of damage to the structures have been well demonstrated (Mitchell, et al., 1995; Martin, et al., 2001).

The use of aggregate pier foundation system has been gaining wide acceptance particularly in the last two decades. Its capabilities to increase the bearing pressure of weak soil, to reduce the settlement, and the uplift capacity have been studied extensively. Due to the success of aggregate pier foundation system in improving the static response of foundations, there has been an increasing interest to use aggregate pier to improve the seismic response of ground as well. The behavior of aggregate pier foundation system under seismic loading has been a subject of recent research, for example by Wissmann, et al. (1999), Lawton (1999, 2000), and Lawton and Merry (2000). Soil improvement and liquefaction mitigation from the use of an aggregate pier foundation system can be attributed to four factors: 1) Increased lateral soil stress, 2) Soil densification, 3) Increased stiffness of the soil, and 4) Improved drainage and faster dissipation of pore water pressure. However, current seismic analysis and design methods are based on the Simplified Procedure and on vibro-replacement using stone columns and vibro-concrete columns (Baez and Martin, 1993, 1994; Goughnour and Pestana, 1998). These procedures do not take into consideration the distinct features of aggregate pier foundation system and have not been verified for this type of foundation.

1.2 Objectives of Research

The primary objectives of this research were to investigate the response of aggregate pier foundation system during earthquakes by the use of numerical modeling and to quantify the efficiency of aggregate pier foundation system in reducing the liquefaction potential of soils. Two things will be focused on this research that is the study of excess pore water pressure ratio and the shear stress in soil matrix. Along with the objectives mentioned previously, the implications of the findings obtained from this research to the design of aggregate pier foundation system under seismic loading will be explored.
1.3 Scope of Study

The proposed research objectives were accomplished by completing the following scope of work:

- Perform a literature review on liquefaction-induced failure mechanisms and on performance of ground reinforcement for liquefaction mitigation, including the performance of aggregate pier foundation system;
- Conduct a literature review on some simplified procedures that have been developed to analyze the performance of ground reinforcement in reducing the liquefaction potential of soils. Of particular interest is the analyses of shear stress generated under seismic loading;
- Conduct a literature review on numerical modeling used to analyze the behavior of improved soil under seismic loading;
- Conduct sets of numerical modeling to analyze the performance of aggregate pier foundation system in reducing the liquefaction potential of soils; and
- Investigate the effects of factors that affect the improved ground behavior and the implications in design.

In completing the above scope of work, the analyses using the numerical modeling was focused on one type of aggregate pier. The type that was analyzed is of 3 feet (36 inches) in diameter and 14.5 feet long. The numerical modeling was carried out using FLAC version 4.0 (FLAC, 2000), an explicit finite difference program using multi-stepping procedure to solve static and dynamic problems.

1.4 Content of Thesis

The following chapters address the issues discussed above. Chapter 2 presents background information on liquefaction-induced failure mechanisms. A review on aggregate pier foundation system and other types of ground improvement used in liquefaction mitigation are also provided. Chapter 3 discusses the procedures that have been published to analyze the liquefaction potential of the improved soils. In Chapter 4, the features of numerical modeling of
soils improved with aggregate pier foundation system are presented. Chapter 5 shows the use of the numerical modeling in liquefaction analysis of aggregate pier foundation system. The results of parametric studies and the studies of factors affecting the behavior of the improved soils are provided in Chapter 6. In Chapter 7, the results explained in Chapter 6 were explored more in depth and the implications of the results to the design procedure of soils improved with aggregate pier foundation system under seismic loading will be investigated. Summaries, conclusions, and recommendations are given in Chapter 8.