CHAPTER 1: INTRODUCTION

1.1 Overview of Problem

Many existing highway bridges are located in areas, such as river channels and flood plains or coastal areas, where strata of loose, saturated, cohesionless soils are common due to the geologic setting. When these deposits are subjected to earthquake shaking, the soil particles have a tendency to shift into a denser configuration, but are initially restrained from doing so by the presence of relatively incompressible water in the soil voids. As a result, there is a temporary transfer of load from the soil particles to the pore water, which results in an increase in pore water pressure and decrease in effective stress. The reduction of effective stress can be substantial and result in a large loss of strength until the excess pore water pressure (i.e. the pore water pressure above static conditions) has a chance to dissipate with time. This phenomenon of pore water pressure build-up and loss of strength, which primarily occurs in saturated, cohesionless soils, is generally known as liquefaction (Committee on Earthquake Engineering, 1985).

Earthquake-induced liquefaction of soil deposits supporting highway bridges can have damaging, and sometimes devastating, effects on the bridges. The loss of soil strength can result in inadequate support and excessive movements of piers and abutments supporting the superstructure, as illustrated in Figure 1.1. In areas where the ground is level, bridges supported on foundations located above or in liquefiable soil deposits can experience excessive settlement due to bearing capacity failure and soil densification. Bridge foundations extending completely through liquefiable soils, such as piles or drilled shafts, can be damaged from the deformations and stresses to which they are subjected as a result of a loss of axial and lateral support, as well as downdrag from settlement of the surrounding soils. Where the ground surface of the area surrounding a bridge is sloping or there is an abrupt change in grade, such as at a river channel, a bridge can be subjected to lateral forces and displacements due to the tendency of the liquefied soil stratum and overlying layers to undergo lateral deformation parallel to the direction of the slope or grade change (Youd, 1993).

Bridge damage or collapse from liquefaction is illustrated by case histories such as those reported by Youd (1993) for the following earthquakes (date and location): 1868, Hayward, California; 1886, Charleston, South Carolina; 1906, San Francisco, California; 1964, Prince William Sound, Alaska; 1964, Niigata, Japan; and 1991, Limon Province, Costa Rica. More recently damage to bridges was reported as a result of the 1995 Kobe Earthquake in Japan.

Many existing bridges in the United States are still susceptible to liquefaction-induced damage because they were constructed prior to the study and understanding of earthquake-induced liquefaction and its effects on structures, which began after the 1964 earthquakes in Alaska and Niigata, Japan. In addition bridges were built in the eastern, midwestern, and northwestern United States prior to an understanding of the potential seismic risk in those regions.

Although existing bridges and other structures may be susceptible to seismically-induced liquefaction damage, measures can be employed to reduce the risk of this damage. These remediation methods include improving the properties of the liquefiable soils or the foundations supporting the bridges (Mitchell, 1992; Mitchell and Cooke, 1995). Ground and foundation improvement techniques and usage have grown substantially in the last two decades.

Ground improvement is being used increasingly for remediating liquefiable soils due to the wide variety of methods that are available. These methods can be tailored to the conditions and constraints imposed by different sites, including the presence of existing structures. In addition, one or more methods can often provide economical solutions for liquefaction remediation problems. The performance of treated ground in the 1989 Loma Prieta, 1994 Northridge, and 1995 Kobe earthquakes has demonstrated that ground improvement can successfully be used to mitigate liquefaction and greatly reduce the potential for damage to structures (Mitchell et al., 1995).

Although ground improvement has been used to mitigate earthquake-induced liquefaction, further understanding is needed regarding the potential for reducing ground and structure movements to acceptable levels at bridges, as well as the factors affecting design and performance. In particular the effect of the type, size, and location (relative to the bridge abutments and piers) of the treatment on the performance of bridge abutments and piers must be investigated. Recommendations are also needed regarding analytical methods that can be used for designing improved ground zones at bridges.

1.2 Objectives of Research

The primary objective of this research was to investigate the feasibility of using different ground improvement types at existing highway bridges to mitigate liquefaction-induced damage based on the prediction of performance using quantitative analyses, as opposed to a strictly qualitative evaluation. Coupled with this objective was an effort to identify and clarify the factors and phenomena governing the performance of the ground improvement, along with identifying analytical methods that can be used to predict the performance.

1.3 Scope of Study

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

- Completing a literature review on the performance of improved ground for liquefaction mitigation relevant to existing highway bridges, as well as analytical procedures for predicting response;
- Identifying factors and phenomena affecting improved ground behavior and design;
- Selecting and conducting a preliminary evaluation of some simplified analytical methods for evaluating performance;
- Choosing a more comprehensive analytical method for predicting improved ground and supported structure response during earthquake-induced liquefaction and assessing its accuracy, particularly in regards to predicting permanent deformations; and
- Investigating the suitability of various ground improvement types and configurations for mitigating potential damage to a bridge.

In completing the above scope of work, the focus was on bridges supported on shallow foundations only, even though such bridges are likely a smaller percentage of existing bridges requiring liquefaction remediation than those supported on deep foundations. The shallow foundation case was selected because it is fundamentally a less complex problem in soil-structure interaction than the deep foundation case. Therefore it was deemed important to first develop an understanding of the less complex, shallow foundation case. Another factor governing the selection of the shallow foundation case was the greater availability of relevant, comprehensive experimental and field case history data in the literature allowing verification of analytical methods to be performed with greater confidence. In addition, insights gained regarding the performance of shallow foundations in liquefiable soils can possibly be extrapolated to deep foundation cases where the deep foundations do not extend completely through the liquefiable strata.

1.4 Contents of Dissertation

The chapters that follow address the issues discussed above. Background information is presented in Chapter 2 on liquefaction-induced failure mechanisms and ground improvement in relation to existing highway bridges. A literature review is provided in Chapter 3 on the performance of improved ground in liquefiable soils, as well as analytical methods for predicting response, with particular emphasis on information applicable to existing highway bridges on shallow foundations. Chapter 4 discusses performance criteria for bridges and phenomena influencing improved ground behavior within liquefiable soil deposits. A review and assessment of some simplified analytical methods selected for use in improved ground design is provided in Chapter 5. In Chapter 6 a more comprehensive method for predicting improved ground performance is discussed and evaluated. Chapters 7 and 8 present the results of parametric studies conducted to investigate the effectiveness of different ground improvement types and configurations for mitigating liquefaction effects on a bridge pier and stub abutment, respectively. Summaries, conclusions and recommendations are given in Chapter 9.

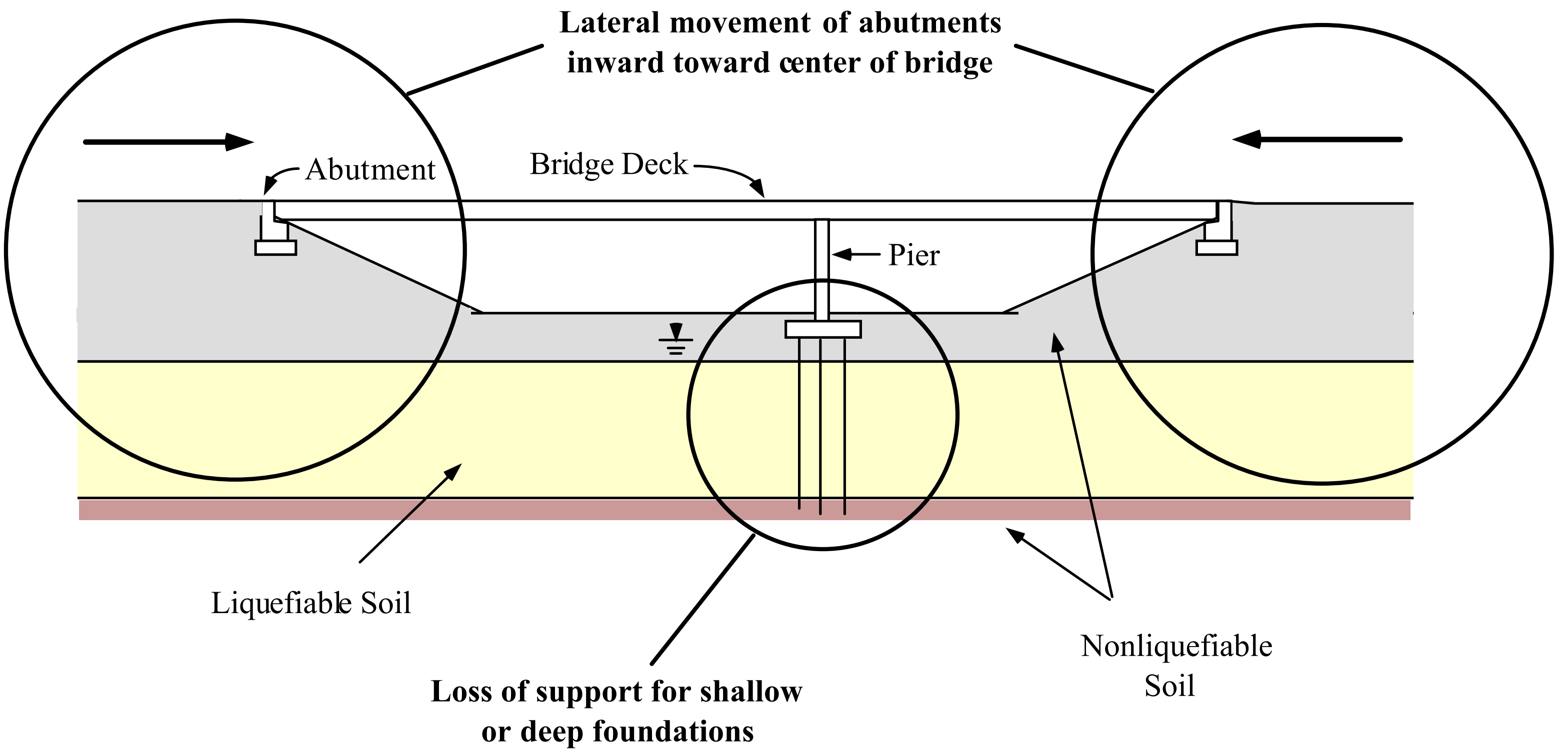

FIGURE 1.1: Potential Effects of Liquefaction on Highway Bridge