Assessment of Liquefaction Potential Index Using Deterministic and Probabilistic Approaches

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ABSTRACT

Liquefaction is a devastating effect of earthquakes resulting in sudden decrease in shear strength due to excess pore water pressure generation, resulting in differential settlement of structure, inducing severe damages. Assessment of liquefaction hazard for a given site is important for planning mitigation works. In this paper the liquefaction susceptibility using deterministic and probabilistic methodologies was assessed and results are presented in terms of liquefaction potential index (LPI) for a nuclear power plant site. The results of this study are explored further in the article.

Keywords: Liquefaction, Liquefaction Potential Index, Peak Ground Acceleration, Site Characterization, Standard Penetration Test

1. INTRODUCTION

In engineering design point of view, nuclear power plant structures are meant to survive all possible natural disasters, especially induced effects of earthquakes. Due to huge population and rapid urbanization, the demand of energy in India is very high. Since the energy obtained from the conventional sources is inadequate, more and more nuclear power plants are being set up to meet the increasing energy demand.

The recent Fukushima Nuclear power plant disaster has created concern among people about the safety of these facilities during any natural disasters like earthquake. In this paper, the liquefaction hazard due to earthquake was assessed based on deterministic and probabilistic approaches for a nuclear power plant site situated on the east coast of South India. Liquefaction is one of the major earthquake hazards, in which the loose, cohesionless, saturated soil loses its shear strength under earthquake loading. The devastating effects of soil liquefaction were first observed during major earthquakes.
of Niigata ($M_s = 7.5$) and Alaska ($M_w = 9.2$) in the year 1964. In India, earthquake induced soil liquefaction was observed during Bhuj earthquake of 2001. The devastations caused by these seismic soil liquefaction have stressed the need for the assessment of liquefaction potential, especially for critical locations like nuclear power plant site.

The most widely accepted methodology for assessing liquefaction potential was proposed by Seed and Idriss (1971). In this method, the factor of safety against liquefaction was evaluated as the ratio of cyclic shear strength of soil to the cyclic stress induced in soil during earthquake. The cyclic stress induced in soil due to earthquake dependent on the peak ground acceleration (PGA), overburden pressure ratio, depth of soil layer under consideration and magnitude of the earthquake. The cyclic shear strength of the soil is evaluated either by conducting laboratory tests such as cyclic tri-axial test, cyclic simple shear test and cyclic torsional test on the undisturbed soil specimen, or from data obtained from in-situ field tests such as standard penetration test (SPT), cone penetration test (CPT), shear wave velocity test ($V_s$) and the Becker penetration test (BPT) etc. Difficulties associated with obtaining good undisturbed soil samples for laboratory testing and high cost of testing equipments made the evaluation of liquefaction potential based on field tests more popular.

The factor of safety against liquefaction obtained from laboratory or field tests represents the liquefaction potential of soil only at a particular depth. Hence, Iwasaki et al. (1982) has introduced liquefaction potential index (LPI), which is obtained by integrating factor of safety against liquefaction at all depths. Since it provides a unique value for a particular borehole or soil column, LPI represents liquefaction potential for that borehole in a better manner. Sonmez (2003) proposed classification of a site based on LPI values (Table 1). In the present study, LPI was estimated based on field test data using both deterministic as well as probabilistic approaches for a nuclear power plant site.

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In deterministic methodology, PGA at ground surface level was first evaluated using deterministic seismic hazard analysis (DSHA). Using the surface level PGA value, simplified methodology proposed by Seed and Idriss (1971) was used to estimate cyclic stress ratio (CSR) at various depths of each borehole. Cyclic resistance ratio (CRR) of the soil was computed based on the corrected SPT value $[N_{60,cs}]$ as per the method suggested by Idriss and Boulanger (2006). For each borehole, the factors of safety at various depths were then evaluated and these values were integrated to obtain LPI for that particular borehole.

One of the major shortcomings in the deterministic method is that it considers only one critical magnitude-acceleration scenario for the evaluation of liquefaction potential. In order to overcome this short coming, the LPI values were also evaluated using a probabilistic performance based methodology proposed by Kramer and Mayfeild (2007). Probabilistic model captures various uncertainties involved in earthquake process such as uncertainty in magnitude, location and the recurrence rate.

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<thead>
<tr>
<th>LPI range</th>
<th>Liquefaction vulnerability</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2</td>
<td>Low</td>
</tr>
<tr>
<td>2 - 5</td>
<td>Moderate</td>
</tr>
<tr>
<td>5 - 15</td>
<td>High</td>
</tr>
<tr>
<td>15&lt;</td>
<td>Very high</td>
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