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Sensitivity of Liquefaction Triggering Analysis to Earthquake Magnitude

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ABSTRACT

Application of liquefaction triggering analysis with design ground motions derived from a probabilistic seismic hazard analysis (PSHA), as in AS1170.4 (2007) or most modern seismic codes, requires selection of an appropriate design earthquake magnitude. Guidance on selection of appropriate design earthquake magnitudes is often directed by the seismic code as the maximum considered earthquake (ASCE 7-10) or from a magnitude distance deaggregation (CalTrans 2012). Where guidance is lacking the selection process is based on professional judgment. This paper explores the sensitivity of selection of earthquake design magnitude to liquefaction triggering factor of safety in the context of liquefaction assessments in Australia following AS1170.4 (2007) where guidelines for design earthquake magnitudes for liquefaction are not specified. The assessment shows that following the simplified liquefaction trigger analysis methodology (Seed and Idriss, 1971) very loose to loose saturated sands, would liquefy regardless of the design magnitude selected and high importance sites on medium dense saturated sands would also liquefy regardless of the design magnitude selected. The assessment also shows that liquefaction triggering analysis is very sensitive to the design magnitude selected for normal importance sites on loose to medium dense sands.

Keywords: Liquefaction triggering analysis, earthquake design magnitude, AS1170.4, sensitivity

1. INTRODUCTION

Although Australia is considered a stable continental region and seismic hazard is relatively low compared to active tectonic areas of the world, earthquakes do occur and where susceptible geological conditions exit with high groundwater, liquefaction can occur. As such liquefaction is a credible geohazard considered in current Australian geotechnical engineering practice.

Liquefaction triggering analysis methodology has been well established in earthquake engineering practice following Seed and Idriss (1971) and refinements over the last 40 years. These assessments use four critical input parameters; soil properties and groundwater conditions to estimate liquefaction triggering potential as a cyclic resistance ratio (CRR) and ground motions with earthquake magnitude reflecting cycles to estimate a cyclic stress ratio (CSR).

In active seismic regions around the world, local seismic design code often provides guidance on liquefaction analysis, specifically the selection of appropriate design earthquake magnitudes to estimate a CSR. For example ASCE 7-10 recommends using the maximum considered earthquake (MCE) and post-Canterbury Earthquake practice in NZ following NZS1170.5 and MBIE 2012 guidelines specify M7.5 for all liquefaction calculations regardless of the importance level. .

Where design magnitudes are not explicitly provided by code, the common method for selecting magnitude is to consider earthquake scenarios that contribute the greatest amount to the ground motion hazard (CalTrans 2012). This is done by examination of the magnitude deaggregation of a probabilistic seismic hazard analysis (PSHA).

In Australian practice, ground motions provided in the AS1170.4 (2007) are from McCue et al. (1993) using PSHAs conducted by Gaull et al. (1990) and many others. AS1170.4 (2007) does not provide enough information to readily extract earthquake design magnitudes or to compute magnitude deaggregation. As a result, earthquake engineering practitioners in Australia have applied a number of different methodologies to assign earthquake design magnitude for site-specific studies. These methods range from estimating mean values from regional recurrence curves (Mitchell and Moore, 2007), using the maximum historic earthquake in Australia for a given region, consideration of a range of magnitudes (Yang and Wright, 2010) or choosing a conservative magnitude based on professional judgment. None of these methods are directly compatible with AS1170.4 (2007) as they do not include ground motion variability, which is a hallmark attribute of PSHA. The sensitivity in selecting design magnitude for use in Australia limits the rigor in liquefaction triggering analysis in Australian. To address this Mote and Dismuke (2011) developed an approximate magnitude distance deaggregation of the PSHA used to develop the hazard map in AS1170-4 (2007).

This study addresses the sensitivity of liquefaction triggering analysis based on selection of design magnitudes within ground motions provided by AS1170.4 (2007).

2. LIQUEFACTION TRIGGERING ANALYSIS METHODOLOGY

Seed and Idriss (1971) proposed a simplified procedure for evaluation of liquefaction triggering that compare the soils' resistance to liquefaction with the cyclic stress caused by an earthquake, expressed as the factor of safety against triggering liquefaction, FS_{liq}. The resistance to liquefaction, commonly termed cyclic resistance ratio (*CRR*), depends on the relationship between the in-situ density of the soil with its critical state, as well as the behavior of the soil under earthquake-induced cyclic loading. The driving cyclic stress caused by an earthquake is commonly termed cyclic stress ratio (*CSR*). *CSR* used in the simplified procedure for liquefaction triggering analysis is the ratio of average, or equivalent, shear stress induced by the earthquake to the in-situ effective vertical stress. Seed and Idriss (1971) proposed that the average equivalent *CSR* for liquefaction triggering assessment is about 0.65 times the peak shear stress, and may be estimated as:

$$CSR = 0.65 \cdot \frac{\sigma_v}{\sigma_v'} \cdot A_{\max} \cdot r_d$$

Where σ_v is the total vertical stress, σ_v' is the effective vertical stress, A_{max} is the maximum acceleration (taken as peak ground acceleration (PGA), and r_d is the nonlinear shear-mass participation factor.

While A_{max} defines the maximum ground acceleration it provides no information on the duration of shaking. The importance of design magnitude in liquefaction assessments is the provision of an indication of duration of shaking or the number of strong motion cycles.

The convention for assessing liquefaction triggering is to determine *CSR* normalized to the duration of a *M*7.5 earthquake, denoted $CSR_{7.5}$. This is achieved by modifying the *CSR* by a magnitude-duration weighting factor, *DWF* after Idriss and Boulanger (2008). *DWF* is calculated as:

$$DWF = (6.9*EXP(-M / 4)-0.058)$$

The magnitude-duration weighted cyclic stress ratio, $CSR_{7.5}$, is calculated as:

$$CSR_{7.5} = CSR / DWF$$

And the factor of safety against triggering liquefaction is:

$$FS_{liq} = CRR/CSR$$

Values for *CRR* come from the boundary curve drawn through *CSR*-data from liquefaction and non-liquefaciton case histories. A FS_{liq} less than 1.0 implies that liquefaction triggering is likely.

3. METHODOLOGY

This study applies a range of design magnitudes to ground motions derived from AS1170-4 (2007) for two Site Soil Subclasses to understand the sensitive of liquefaction triggering to earthquake magnitude.

Liquefaction and no-liquefaction case history databases recently used by Cetin et al. (2004), Moss et al. (2006) and Idriss and Boulanger (2008) for SPT and CPT-based triggering assessment procedures indicate the minimum $CSR_{7.5}$ where liquefaction was observed is about 0.05 for very loose to loose saturated sand and about 0.1 for loose to medium dense saturated sand. For this study we assume a *CRR* for Site Soil Subclass D and E as follows:

Loose to medium dense sands (Site Soil Subclass D) - CRR = 0.1
Very loose to loose sands (Site Soil Subclass E) - CRR = 0.05

The ground motions, A_{max}, are taken as minimum and maximum of *Z* values and scaled accordingly for Importance Levels 2, 3 and 4 (k_p) and respective spectral shape factor for the appropriate Site Soil Subclass (C_h) following AS1170-4 (2007).

$$Amax = Z\, k_p\, C_h$$

The DWF calculation is iterated on magnitudes at 0.1 intervals from 5 to 7.5.
Finally, FS_{liq} is calculated for all Z values between 0.05 and 0.1, Importance Levels 2, 3, & 4, and Site Soil Subclass D & E.

4. RESULTS

Figure 1 to 6 show FS_{liq} for a range of Z values plotted against Magnitude for Class D (CRR = 0.1) and Class E (CRR = 0.05) with Importance Levels 2, 3 &4. Where FS_{liq} is less than 1 the soil is considered liquefiable.

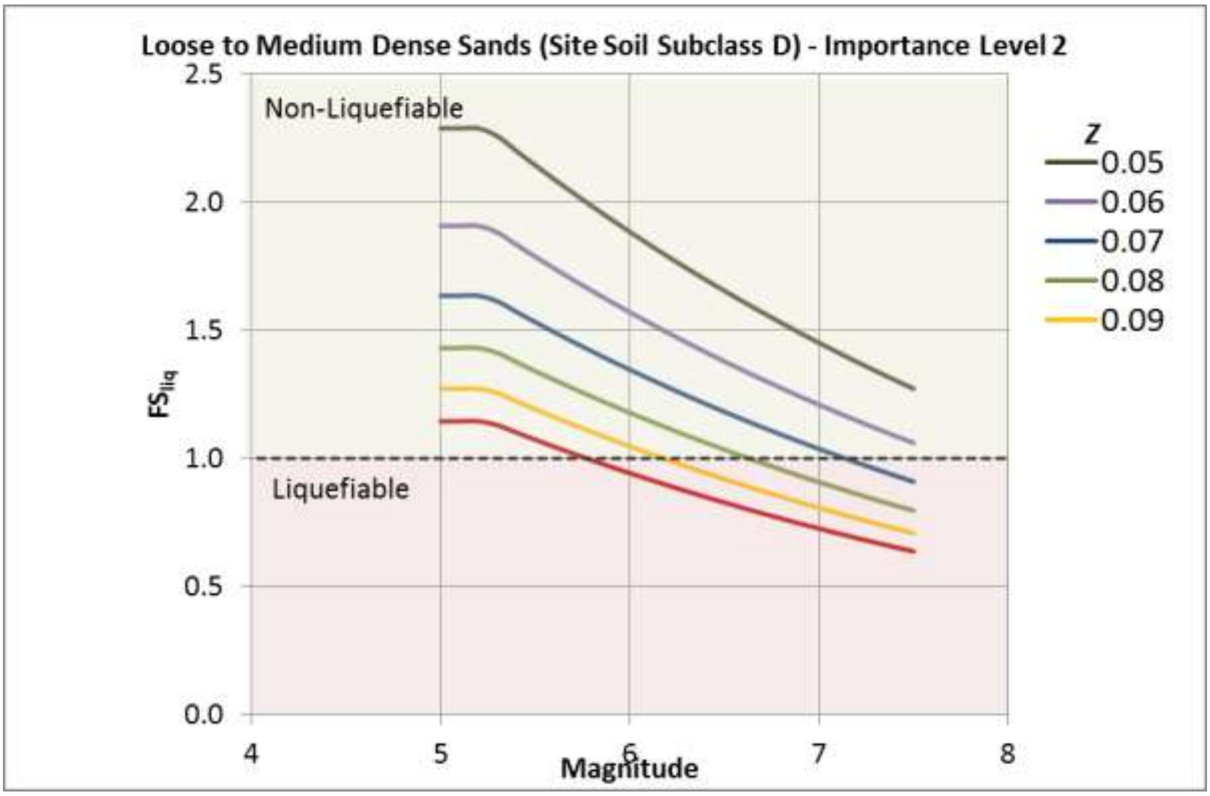

Figure 1 FS_{liq} for a range of Z values for Class D (CRR = 0.1) and Importance Level 2

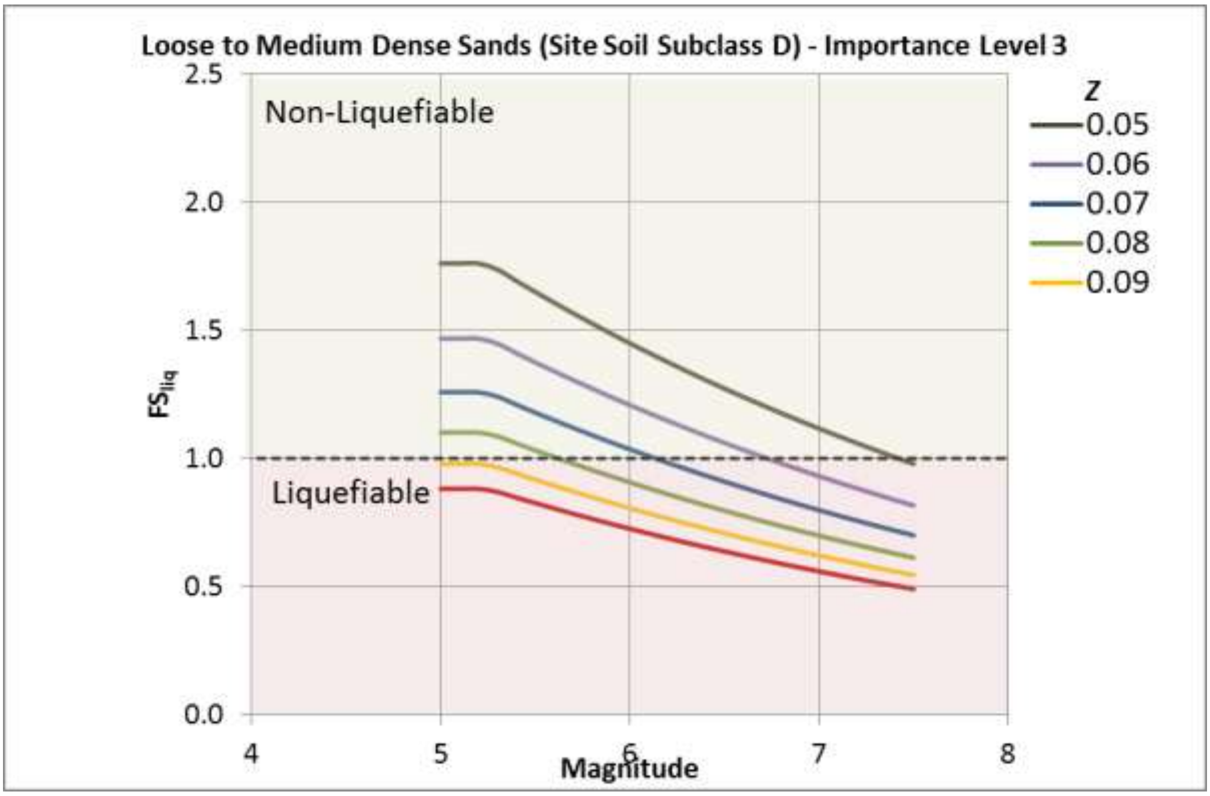

Figure 2 FS_{liq} for a range of Z values for Class D (CRR = 0.1) and Importance Level 3

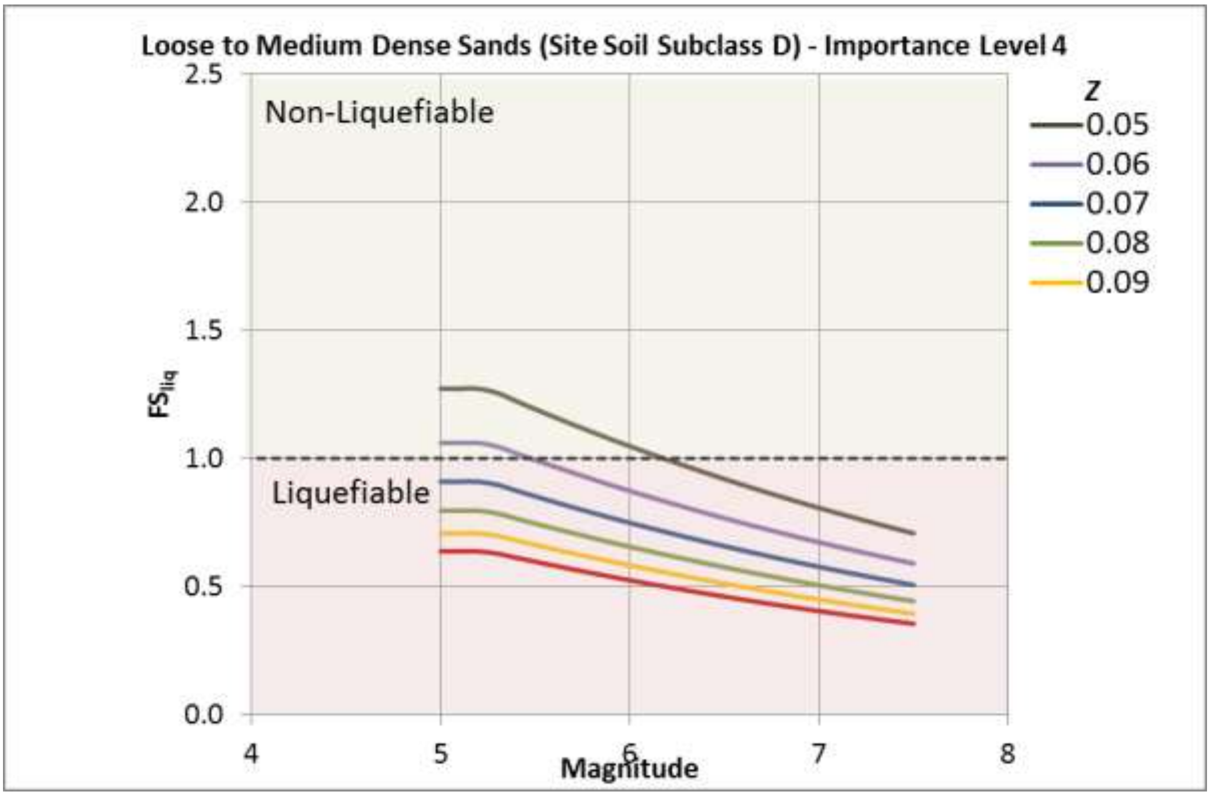

Figure 3 FS_{liq} for a range of Z values for Class D (CRR = 0.1) and Importance Level 4

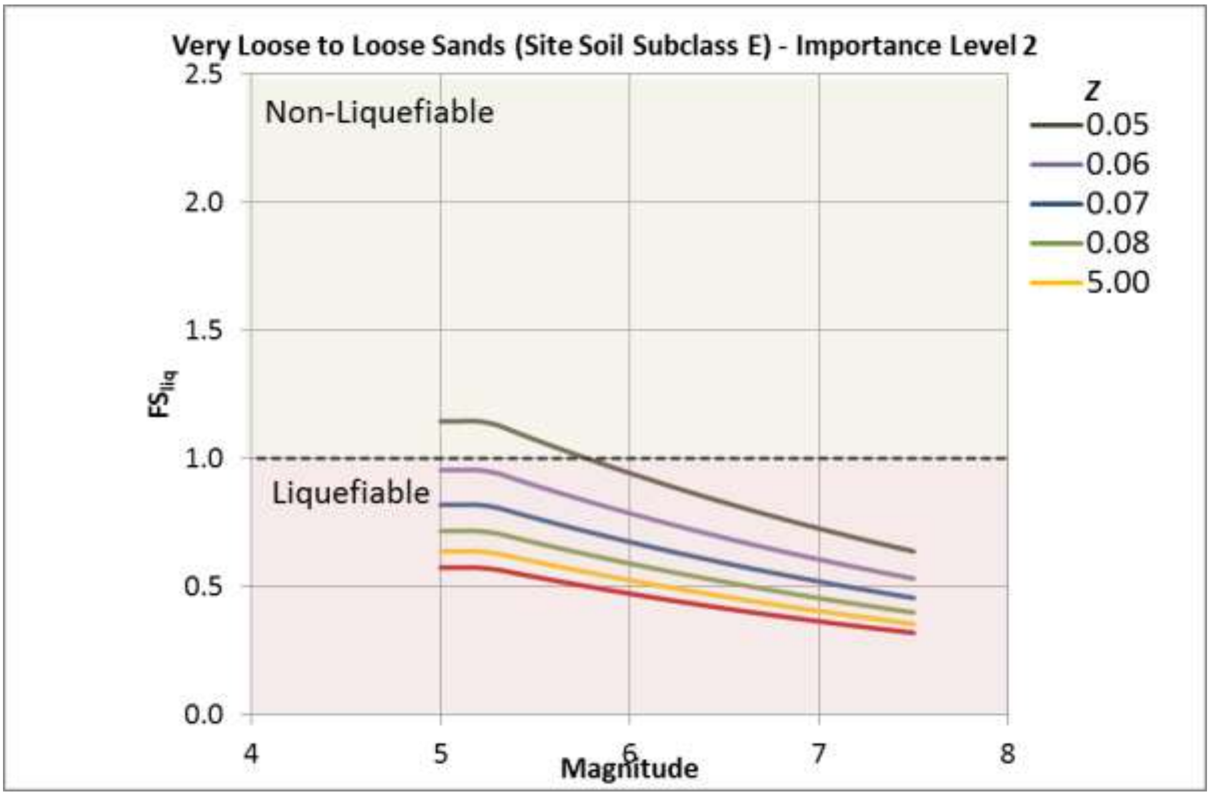

Figure 4 FS_{liq} for a range of Z values for Class E (CRR = 0.05) and Importance Level 2

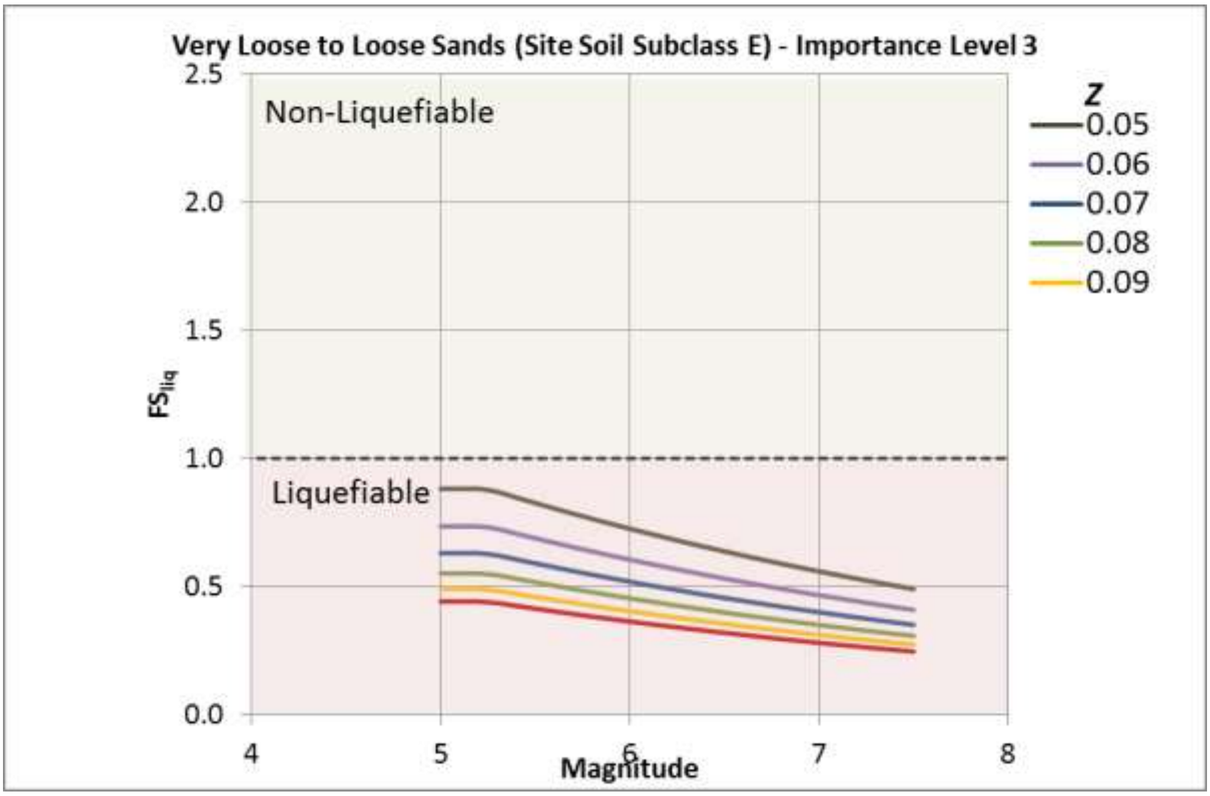

Figure 5 FS_{liq} for a range of Z values for Class E (CRR = 0.05) and Importance Level 3

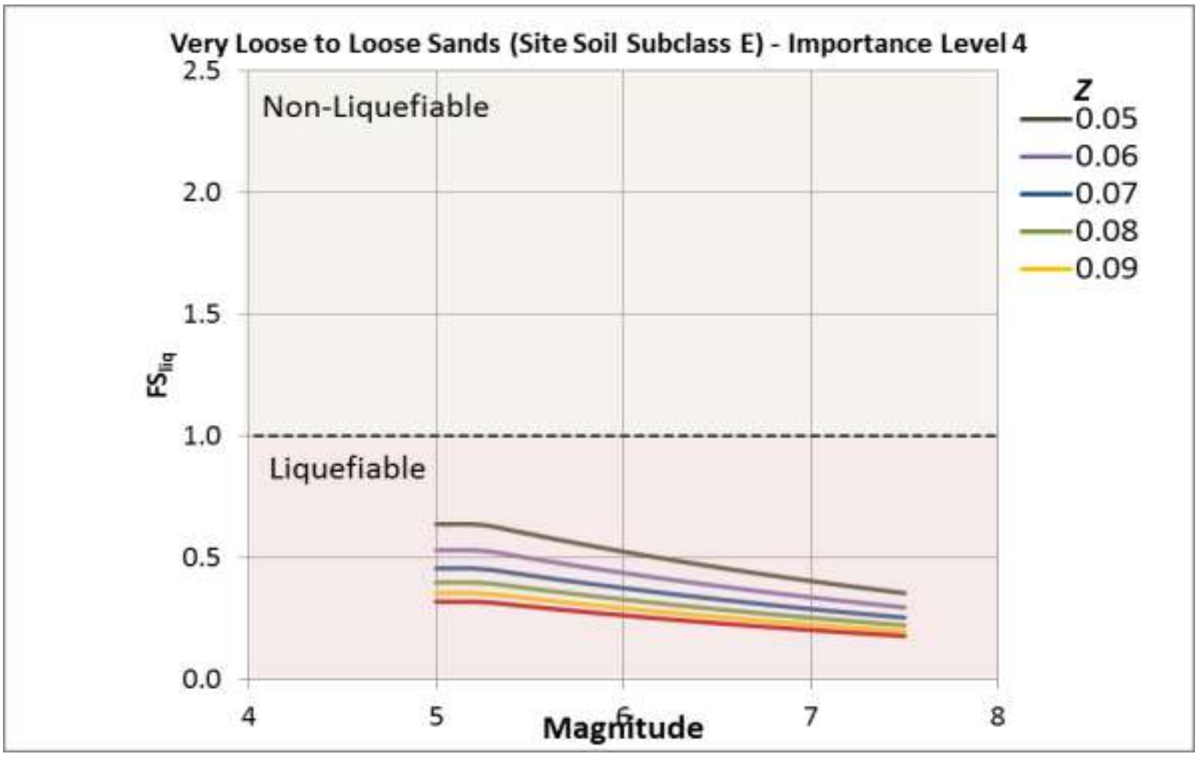

Figure 6 FS_{liq} for a range of Z values for Class E (CRR = 0.05) and Importance Level 3

5. CONCLUSIONS AND DISCUSSION

The results show that the liquefaction triggering analysis for very loose to loose saturated sand) have a CRR low enough that liquefaction will likely trigger under any design magnitude for all anticipated ground motions in Australia and is not sensitive to design magnitude for all Importance Levels (Figure 4, 5, and 6).

Loose to medium dense saturated sands also will likely trigger liquefaction and are not sensitive to design magnitude for Importance Level 4 (Figures 3 and 6) for all anticipated ground motions in Australia.

For loose to medium dense saturated sands (Site Soil Subclass D) at Importance Level 2 and Level 3, the results show that the selection of magnitude is sensitive to triggering analysis for a number of anticipated ground motions in Australia (Figures 1 and 2). That is, the selection of magnitude for lower Importance Levels in loose to medium dense saturated sands will control whether the liquefaction will trigger or not.

It is important for earthquake engineering practitioners in Australia to understand the sensitivity to design magnitude selection. When performing liquefaction triggering analysis on Importance Level 2 or 3 sites founded in loose to medium dense saturated sands, deterministic selection of design magnitudes such as from maximum magnitude estimates (Clark et al., 2010) or from magnitude distance deaggregation (Mote and Dismuke, 2011) should be considered.

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