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Appendix B: CPT Liquefaction triggering method and multiple earthquake modelling

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This appendix presents a brief summary of the Idriss & Boulanger CPT based liquefaction triggering method, the Zhang Robertson & Brachman method for calculating volumetric strain and the modelled seismic loading for the 13 June and 23 December 2011 earthquakes.

B.1. Liquefaction triggering – Idriss & Boulanger

This method adopted for calculating the liquefaction triggering parameters is found in Idriss and Boulanger (2008) and is summarised in Figure B1. The method uses CPT tip resistance (q_c) and sleeve friction (f_s), corrected for effective overburden stress (σ_v') using an iterative procedure.

The method requires the fines content (FC) of the material to be input. As discussed in Section 4.2 an apparent fines content based on Robertson & Wride (1998) has been used for this to estimate the proportion of fines to calculate the $CRR_{7.5}$.

An MSF is calculated based on the earthquake magnitude, and the $CSR_{7.5}$ is then found based on a_{max}, g, r_d, σ_{v0}, σ_{v0}', MSF and K_σ. The FoS is found based on the normalised $CRR_{7.5}$ and $CSR_{7.5}$.

Table B1 below presents a summary of the actions adopted to deal with computational issues in the automated procedure.

Table B1- Idriss and Boulanger Triggering Method

Computational issue	**Solution**
If $q_c < 0$, the calculation for C_n cannot be evaluated	A minimum value of zero is applied to q_c
Values are limited in the method	Values are confined to: $C_n \leq 1.7$ $K_\sigma \leq 1.1$ $FoS \leq 2$ $21 < q_{c1N} < 254$
Ic>2.6	Too fine grained to liquefy; FoS set to be 2.0 (refer to Section 4.4)

B.2. Volumetric strain calculation – Zhang, Robertson Brachman (2002)

The method presented in Zhang, Robertson and Brachman (2002) has been adopted for calculating post-liquefaction volumetric densification strains. The method correlates a factor of safety with relative density (based on a normalised CPT tip resistance) to generate a calculated strain. The way of addressing computational issues associated with the method are summarised in Table B2.

Table B2 - Zhang Robertson & Brachman calculated volumetric strain

Computational issue	Solution
Equations for strain are not provided for q_{c1} /q_{c1ncs} < 33	When q_{c1Ncs} = 33, the strain is at the maximum value. For q_{c1Ncs} < 33, the strain has been calculated as if the q_{c1Ncs} is 33 (worst case strain)
Equations for strain are only given for certain FoS values	Linear interpolation between the lines has been undertaken
Values are limited in the method	Maximum strain set to be 102 $q_{c1ncs}^{-0.82}$

B.3. Modelling of 13 June and 23 December 2011 earthquakes

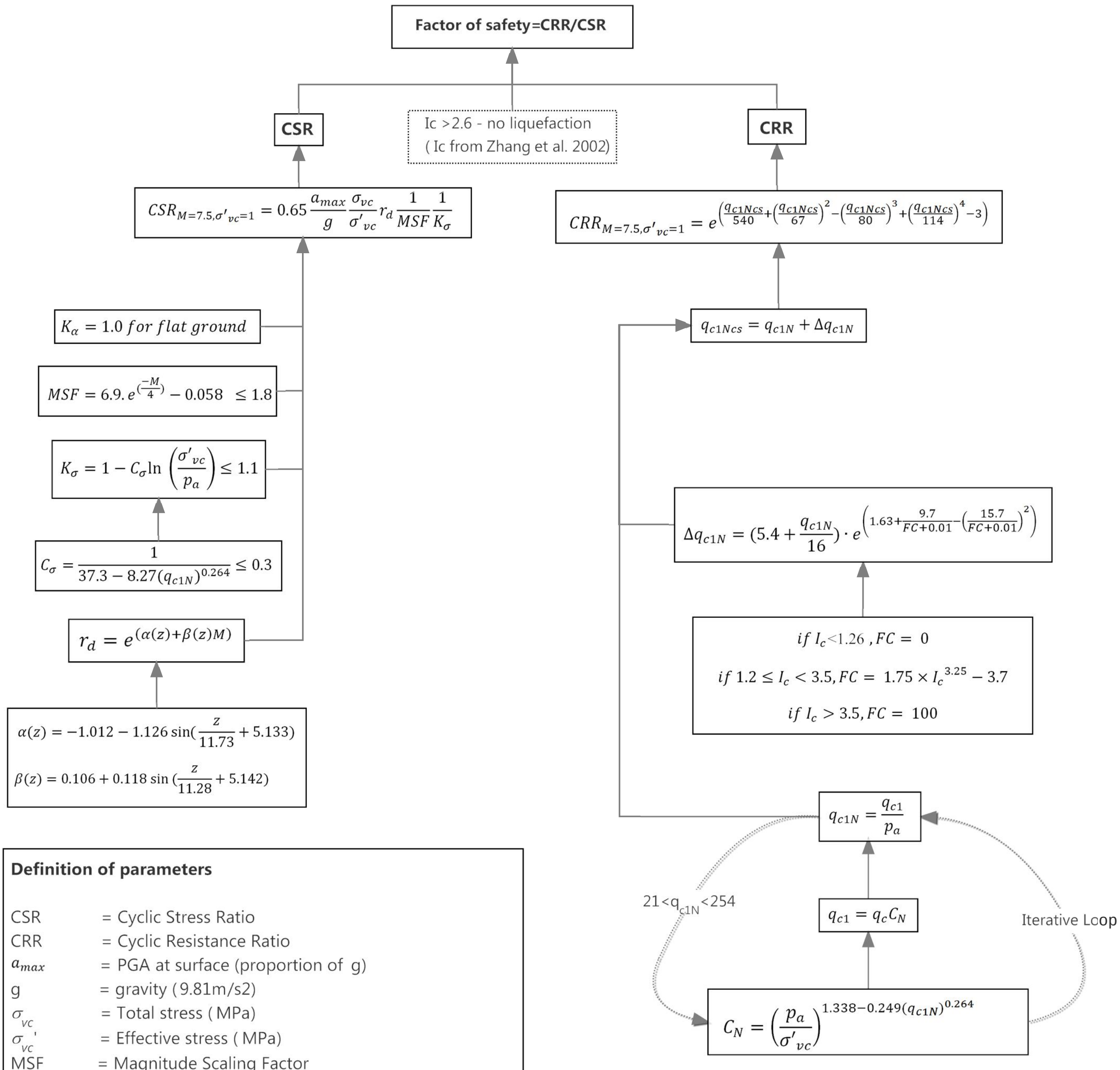
The 13 June and 23 December 2011 earthquakes each comprised two aftershocks, 80 minutes apart. The first earthquakes are believed to have caused an increase in excess pore water pressure within the ground. Elevated pore water pressures make the soil material more susceptible to liquefaction in subsequent earthquakes. However, the increase will dissipate between the two earthquakes. Records are available from five level logging piezometers grouted into the ground at 5 m depth around Canterbury (not formally reported here). They were operating at 5 second recording intervals during the13 June 2011 earthquakes. These records indicate that more than 75% of the excess pore pressure generated in the first earthquake dissipated in the 80 minutes between the two earthquakes. The 23 December 2011 earthquakes had approximately 80 minute between the two earthquakes, and it has been assumed that the pore pressure behaviour was similar.

For the purposes of the liquefaction assessment, we have modelled the second earthquake with an increased magnitude to include the effects of the initial, smaller earthquake. Idriss and Boulanger (2008) present a graph (Figure 62 in their report) based on work by Seed and Idriss (not referenced, 1982 and 1999). The graph shows the number of equivalent stress cycles plotted against earthquake moment magnitude. Based on the measured pore water pressure records, a 25% contribution from the first earthquake was adopted. This has been modelled by calculating 25% of the equivalent cycles from the first earthquake and adding it to the number of cycles of the second earthquake. The magnitudes used for modelling are shown in Table B3 below and were derived by the individual earthquake magnitudes supplied by Berryman (2012).

Table B3 - Multiple Earthquake Magnitude Modelling

Earthquake	Magnitudes and time	Design earthquake magnitude
13 June 2011	M5.6 and M6.0 separated by 80 minutes	M6.2
23 Dec 2011	M5.8 and M5.9 separated by 80 minutes	M6.1

Idriss & Boulanger (2008) Liquefaction Triggering Method



Definition of parameters

CSR = Cyclic Stress Ratio
CRR = Cyclic Resistance Ratio
a_{max} = PGA at surface (proportion of g)
g = gravity (9.81m/s2)
σ_{vc} = Total stress (MPa)
σ_{vc}' = Effective stress (MPa)
MSF = Magnitude Scaling Factor
M = Moment magnitude of EQ
K_σ = overburden correction
p_a = atmospheric pressure (100kPa or 0.1MPa)
q_c = tip resistance of CPT (non normalised, MPa)
FC = Fines Content (%)
I_c = soil behaviour index, from Robertson-Wride (1998)

Figure B1