The state of practice in SSI modelling in New Zealand: Insights from an engineering profession survey

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ABSTRACT

There is a relatively brief consideration for soil-structure interaction (SSI) effect in the New Zealand guidelines for the seismic assessment of structures. Recent earthquake events including the Kaikōura earthquake of 2016 have resulted in significant foundation and structural damage, highlighting the need to better understand the effects of SSI when assessing structures. To that end, a New Zealand engineering profession survey was carried out in 2020 to investigate the state of practice in SSI modelling. The survey used a mixed methods, sequential explanatory research design to collect, analyse, and integrate both quantitative and qualitative data. The survey involved participants from members of NZSEE, SESOC, and NZGS across the country. This paper provides a brief overview of key trends and common challenges as reported by New Zealand practitioners in regard to SSI modelling.

Keywords: soil structure interaction, mixed methods research

1 INTRODUCTION

The primary objective of this research was to investigate the current state of practice in soil-structure interaction (SSI) modelling within the New Zealand engineering profession. An industry-wide, online questionnaire was distributed via the Structural Engineering Society (SESOC), the Geotechnical Society (NZGS), and the Society for Earthquake Engineering (NZSEE). The questionnaire was live from July to October 2020, and follow-up focus groups were held from November to December 2020. This paper presents some of the preliminary analysis of the quantitative data by investigating industry-wide trends in SSI modelling and their statistical significance.

2 METHODOLOGY

To the authors' knowledge, there have been no similar studies with regards to the state of practice in modelling SSI effects in New Zealand. The most relevant state of practice outreach in literature was conducted by NEHRP (Stewart et al., 2012), however this was based on informal and anecdotal conversations with a small sample of targeted/selected individuals.

The current study used a mixed methods, sequential explanatory research design (Ivankova et al., 2006), incorporating an online questionnaire and follow-up focus group sessions. The next section gives an overview of mixed methods designs, including their advantages and disadvantages. This is followed by an outline of the mixed methods sequential explanatory design and the rationale behind why it was chosen for use in this survey.

2.1 Mixed methods research

Mixed methods research designs are carried out to collect, analyse and integrate both quantitative and qualitative data with the aim of gaining an in-depth understanding behind the research questions (Tashakkori & Teddlie, 2003). Quantitative data is usually represented numerically and is interpreted via statistical analyses. However, qualitative data is typically more descriptive and can provide further insights into the research problem. The overarching goal of mixed methods research design is to expand one's understanding and gain depth of insight into the topic being studied, as opposed to corroborating findings within one study (Onwuegbuzie & Leech, 2004). The benefit of combining both quantitative and qualitative data into a single study is to take advantage of the strengths of each method and to therefore develop a more comprehensive overview of the topic being studied (Ivankova et al., 2006). Disadvantages of mixed methods designs typically relate to the length of time needed to undertake the research and the complexity of analysis (Creswell et al., 2003).

2.2 Sequential explanatory design

Sequential explanatory design is perhaps the most popular strategy for mixed methods research in the field of education (Creswell, 2009). This design is characterised by two distinct phases, the first being quantitative and the second being qualitative (Creswell et al., 2003). The qualitative data collected in the second phase helps to explain and elaborate on the quantitative data collected in the first phase. This strategy typically gives more weight to the quantitative data, with these results informing the qualitative data collection. The qualitative component of the research is usually smaller and explores a few cases out of those studied in the quantitative phase (Creswell, 2009).

The mixed methods sequential explanatory design allows for the strengths of both quantitative and qualitative research methods to be utilised in combination, without the occurrence of overlapping weaknesses between the two techniques (Johnson & Turner, 2003). Furthermore, this design can be particularly useful when quantitative data provides unexpected results, as the second stage can be used to examine the results of the first stage in greater detail (Creswell, 2009). Some of the challenges of using this type of mixed methods design include determining how much priority should be given to the quantitative data and how to select the sample that is to be studied in the qualitative phase (Ivankova et al., 2006).

2.3 Questionnaire

There were no selection or exclusion criteria applied for participating in the questionnaire, aside from the fact that the survey was only distributed through New Zealand professional engineering societies SESOC, NZGS, and NZSEE. The questionnaire could be completed anonymously, with an option to opt-in to follow-up focus group participation. Due to the sample size and make-up of the questions, it was not possible for the research team to infer specific identities of any of the participants.

The questionnaire was structured in three distinct parts. Part 1 comprised of general questions such as: *"Which engineering field do you most associate with?"*, *"Which region of New Zealand do you predominantly work in?"*, and *"How many employees work at your company?"*. The answers were either multiple-choice selections or drop-down fields. These types of questions and their answers were used to identify groups and subgroups within the data, with a view of investigating relationships such as *"Is there a statistical difference to how often structural engineers use performance-based design, when compared to geotechnical engineers?"*.

Part 2 of the questionnaire comprised of quantitative and qualitative questions relating to each participant's use of SSI. Two such examples for the former were *"How often do you use performance-based design?"* and *"How often is SSI considered for projects you are involved in?"*, with their answers consisting of 7-point Likert-type scales (Clason & Dormody, 1994) covering a range of Never (1) to Always (7). Qualitative questions included *"What types of projects typically demand SSI consideration?"*, *"Which aspects of SSI do typically consider?"*, and "*What codes and / or guidelines do you follow?"*. Answers to these types of questions were entered as short-form text by participants. This section also included a binary filter question: *"Do you have experience in applying soil-structure interaction (SSI) analyses to design projects?"*. Participants who selected *"No"* would finish the survey upon completion of Part 2, while those who selected *"Yes"* would carry on to the final section.

Part 3 of the questionnaire contained mostly quantitative questions relating to modelling strategies, familiarity with implementing specific SSI models, and perceived barriers to implementing these. The referenced models, as shown in Figure 1, are similar to those used by NEHRP (Stewart et al., 2012) and range from fixed-base, structure only (A) to a full substructure model with horizontal and vertical springs, dashpots, foundation rotation, and multi-support excitation.

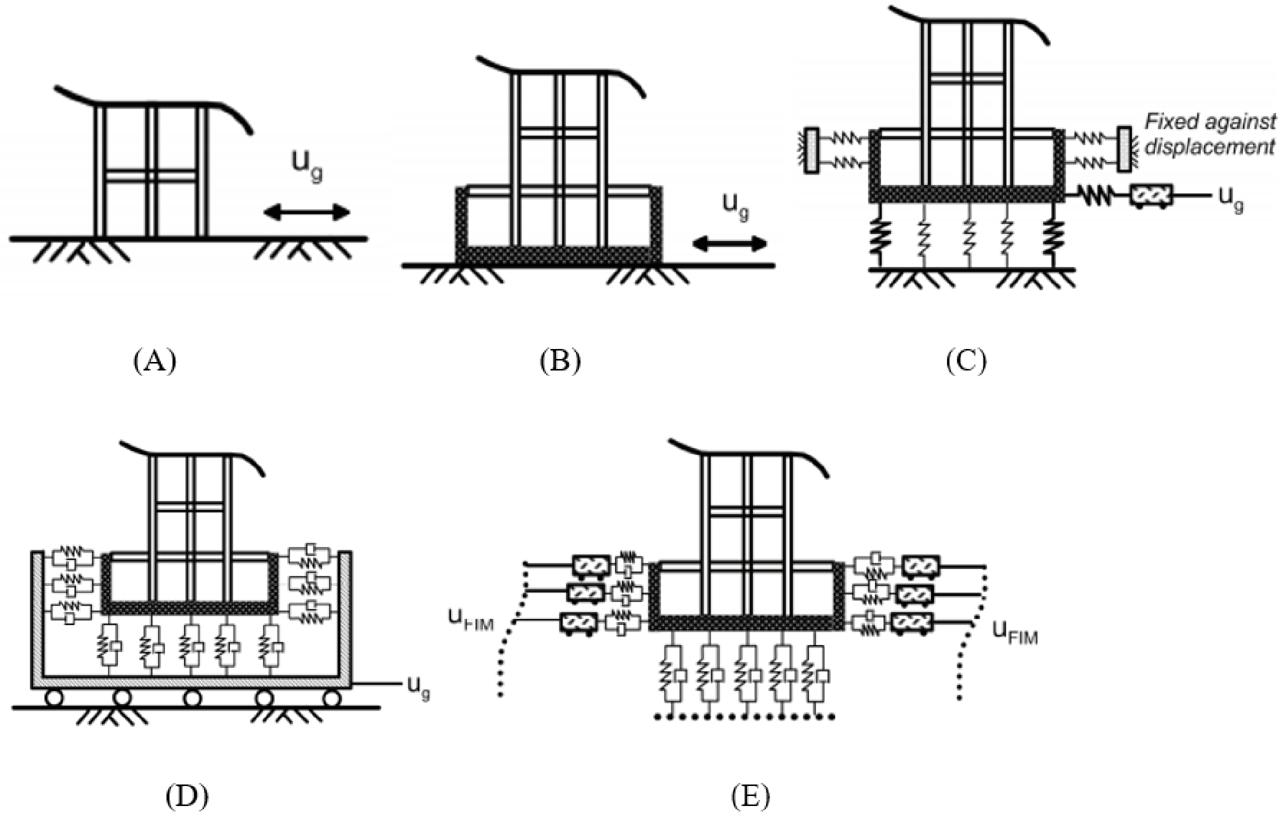

Figure 1: Example modelling options for a hypothetical multi-storey building with a basement.

2.4 Focus groups

Groups of four to five participants who opted-in through the questionnaire gathered to discuss some of the emerging themes. No prior preparation was required before attending a focus group, and no attempt was made to link any questionnaire results to participants. Each session was recorded, transcribed, and anonymised of personal information. The focus groups made use of the Chatham House Rule to aid free discussion of the topic without revealing the identity or affiliation of the speakers or participants. Transcripts of the focus group discussions were not linked to any personal details of the participants to maintain confidentiality of the responses. Participant lists were not retained following the completion of the sessions, and the original audio records were confidentially destroyed after non-identifying transcripts were produced.

Although this paper does not cover the post-processing or analysis of the focus groups, the data will be used to add further insight to the topics covered in the online questionnaire in future publications.

3 RESULTS

A total of 142 responses were recorded for the questionnaire, however small discrepancies in total numbers are due to incomplete fields in participant data. 99 participants reported as Structural Engineers, 30 as Geotechnical Engineers, and 12 as Civil Engineers. 72 participants worked in a mixed-discipline company, 51 and 12 worked in a structural only or geotechnical only company, respectively, and 8 identified as being part of another discipline split. The above data are shown graphically in Figure 2. From a regional split, 102 participants reported as working in the North Island, compared to 36 in the South Island. This is shown in Figure 3, along with the self-reported years of experience in their engineering field.

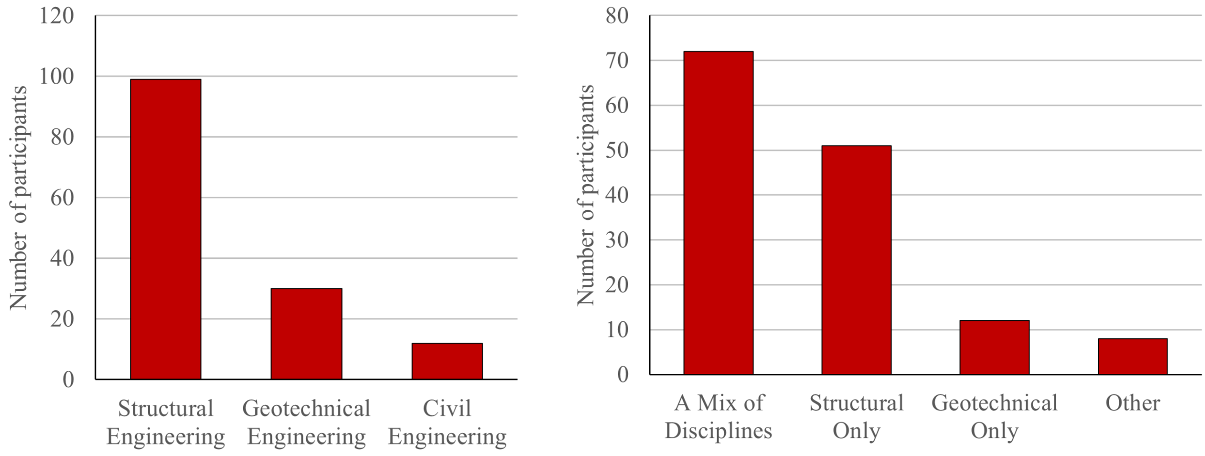

Figure 2: Number of participants by engineering field (left) and company discipline(s) (right).

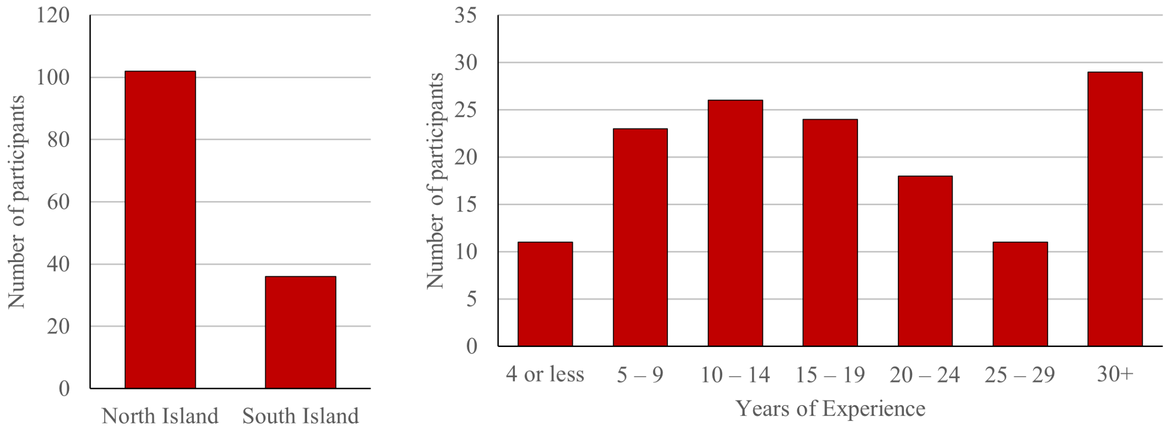

Figure 3: Number of participants by location (left) and years of experience in engineering field (right).

Figure 4 shows the reported company size for each participant.

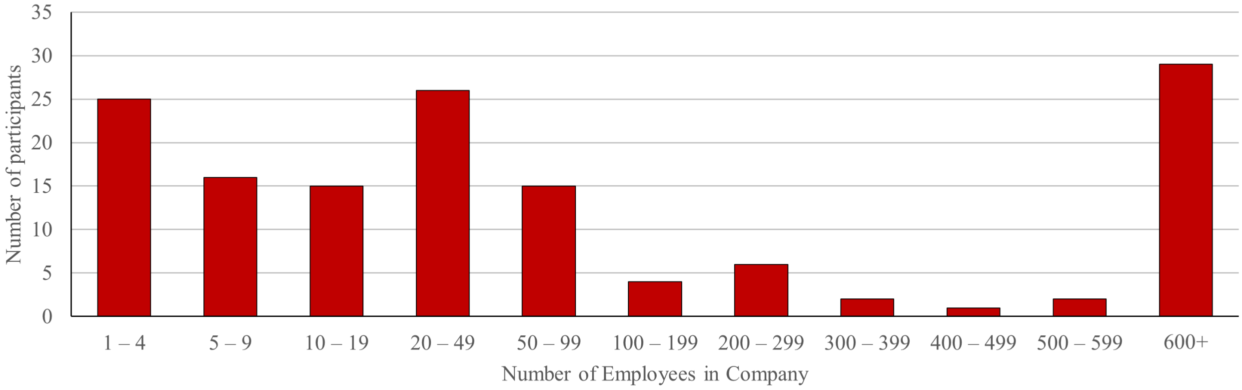

Figure 4: Number of participants by company size.

The field (i.e., Structural, Geotechnical, Civil) was viewed as an evident starting point to observe potential differences in response between groups of engineers. A set of five questions were shortlisted to report as part of this paper, shown in Table 1 along with their mean (*M*), standard deviation (*SD*), and number of participants (*N*).

Table 1: Summary of basic statistics for five questionnaire items.

Question *(Likert scale number of points)*	**Structural**			**Geotechnical**			**Civil**		
	M	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*
How often do you use performance-based design? *(7)*	2.77	1.66	97	3.67	1.42	29	3.50	1.73	11
How often is SSI considered for projects you are involved in? *(7)*	3.33	1.66	70	3.88	1.71	16	4.10	2.07	5
How familiar are you at implementing SSI analyses? *(5)*	2.32	0.65	51	2.75	0.89	8	1.90	1.14	5
How well do you think that SSI analyses represent real-world performance? *(5)*	2.46	0.67	50	2.63	0.64	8	3.00	1.29	4
If simple SSI modelling tools were available, how likely are you to apply them in future projects? *(7)*	5.68	1.16	51	5.25	0.89	8	4.75	2.22	4

The group of 97 Structural Engineers ($M = 2.77$, $SD = 1.66$) compared to the 29 Geotechnical Engineers ($M = 3.67$, $SD = 1.42$) demonstrated significantly lower use of performance-based design $t(124) = 2.6$, $p = .009$. For the other questions, there was no statistically significant difference between the three groups. As such, the following sections use data for all engineering fields in investigating relationships between subgroups, except in cases where performance-based design is also a variable.

A very significant, weak positive association between consideration of SSI in projects and company size was observed, $r_\tau = .336$, $p < 0.001$ (Fig. 5). A weak positive association between company size and having experience in applying SSI analyses was noted, however, this was marginally not significant $r_{pb} = .296$, $p < 0.054$ (Fig. 6). A very significant, weak positive association between consideration of SSI in projects and familiarity at implementing SSI analyses was observed, $r_\tau = .317$, $p < 0.003$ (Fig. 7).

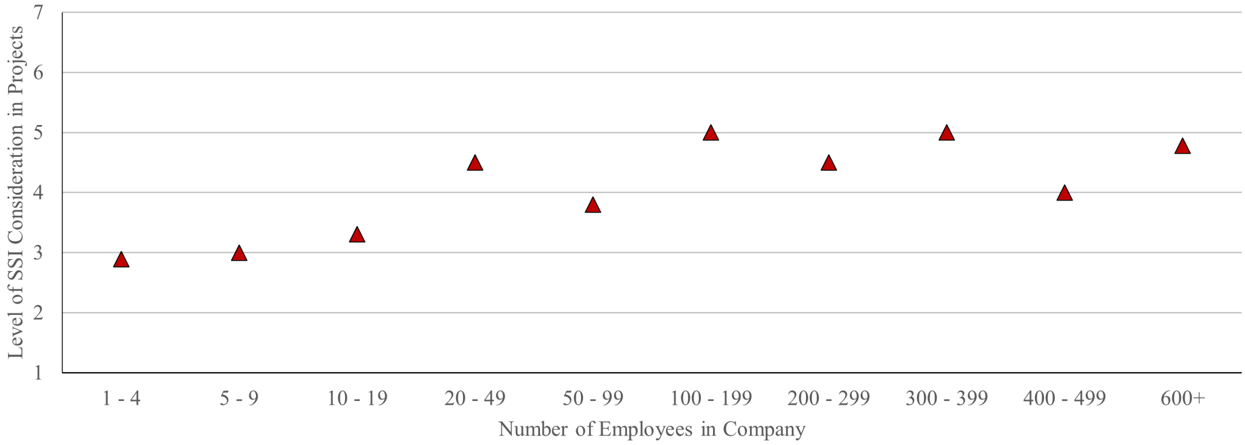

Figure 5: Relationship between the level of SSI consideration in projects and company size (means)

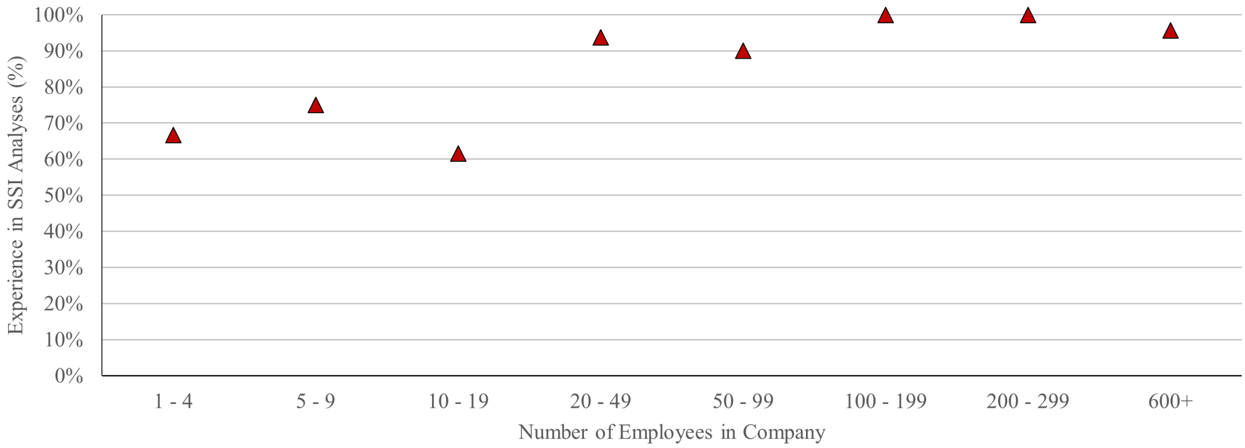

Figure 6: Relationship between the percentage of participants reporting experience in applying SSI analyses and company size (means)

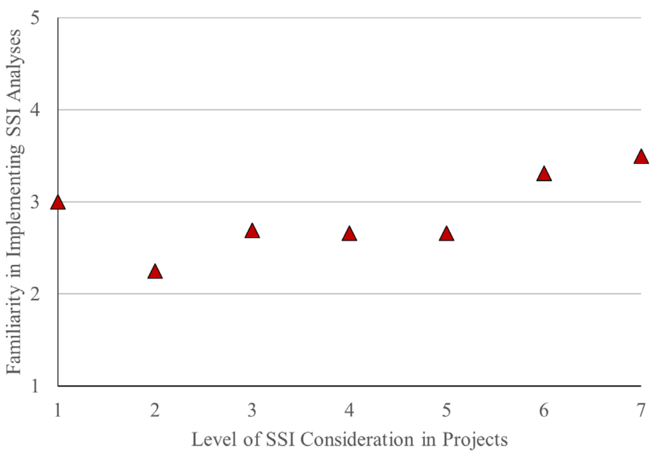

Figure 7: Relationship between the level of SSI consideration in projects and the familiarity in implementing SSI analyses (means)

It should be noted that Figure 6 is not indicative of skill level, as the percentage is related to the number of participants having selected "Yes" against their company size.

A significant, weak association was seen for Structural Engineers between the prevalence in use of performance-based design and company size, $r_\tau = .176$, $p < 0.026$ (Fig. 8). Finally, a significant weak positive association was observed for Geotechnical Engineers between the prevalence in performance-based design and years of experience, $r_\tau = .302$, $p < 0.043$ (Fig. 9).

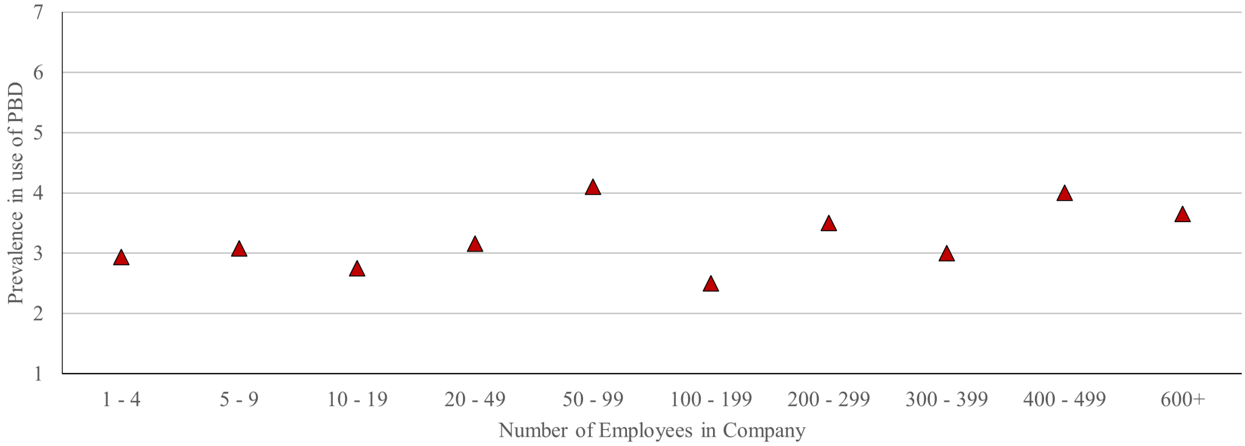

Figure 8: Relationship between the prevalence in use of performance-based design and company size for Structural Engineers (means)

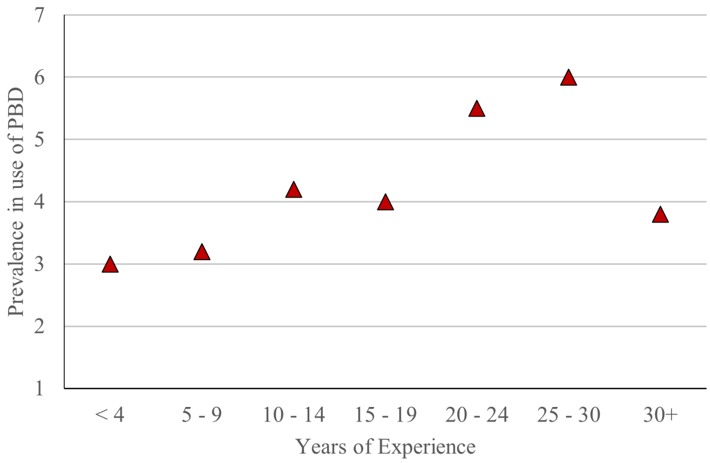

Figure 9: Relationship between the prevalence in use of performance-based design and years of experience for Geotechnical Engineers (means)

In carrying out the preceding statistical analyses, left-censoring (Zhang & Sun, 2010) was used for the company size and years of experience variables, as their highest values were open-ended which would introduce a level of subjectiveness in choosing an appropriate midpoint of the censoring interval (Gómez et al., 2009). Other notable questionnaire results were the likelihood to use simple modelling tools ($M = 6.06$, $SD = 1.21$), and how well modelling tools were perceived to reflect real-world performance ($M = 3.02$, $SD = 0.713$).

4 DISCUSSION

The prevalence in use of performance-based design (PBD) was overall rather low. In a qualitative sense, the calculated averages spanned between "sometimes" and "about half the time" for Geotechnical Engineers. The use of PBD was observed to increase significantly with the years of experience, as shown in Figure 9. For Structural Engineers, the calculated averages spanned between "rarely" and "sometimes". While PBD prevalence was shown to increase mildly in larger companies (Fig 8.), there was no similar increase with years of experience. PBD forms an integral part in SSI analyses, particularly through the implementation of displacement or deformation limit states (Giorgini et al., 2014). A preliminary review of the qualitative questionnaire data suggests that Structural Engineers predominantly carry out SSI analyses, supported by data provided by Geotechnical Engineers. In such cases, it would be recommended for a Structural Engineer to establish performance-based criteria in close collaboration with a Geotechnical Engineer.

The data analysis suggests that SSI is considered more often in larger companies (Fig. 5), and this was very statistically significant. In a qualitative sense, companies with less than 20 employees only consider SSI analyses "sometimes", while this increases to "reasonably often" for companies with many hundreds of employees. This perhaps reflects the types and scale of projects carried out in large companies. It can also be seen (Fig. 6) that companies with less than 20 employees reported as having less experience in implementing SSI analyses when compared to larger companies. Financial or resource constraints may also contribute to SSI being considered less in small companies.

Perhaps the most intuitive association was observed between the familiarity in implementing SSI analyses and the level of SSI consideration in projects. In other words, an engineer already accustomed to carrying out SSI modelling is more likely to consider implementing SSI analyses in projects they are involved in. However, SSI analyses were only thought to reflect real-world performance "moderately well".

If simple modelling tools were available to the engineering profession, participants reported as "very likely" to use them. This shows that there are other potential factors contributing to relatively low consideration for SSI observed in prior questions, and the subsequent analysis of the qualitative data could further aid the interpretation of these results.

5 CONCLUSION AND FUTURE WORK

An industry questionnaire using a mixed methods, sequential explanatory research design was carried out to investigate the current state of practice in SSI modelling within the New Zealand engineering profession. A snapshot of the quantitative data gathered shows several statistically significant relationships for SSI modelling approaches between different engineering fields, company sizes, and years of experience. Future work will incorporate the qualitative data from both the questionnaire and focus groups to further aid the interpretation of the quantitative data.

It is anticipated that the results of this study can be used to inform the development of more advanced assessment and modelling techniques or to raise the bar and encourage use of more appropriate SSI models in practice. The results may also be used to inform regulatory bodies such as the MBIE to guide future updates of the assessment guidelines.

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