Interim Amendment to PNGS 1001-1982: Translating an Improved Assessment of Seismic Hazard to Design Practice

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Abstract

Earthquake design standards seek to ensure that structures are adequately resilient to local hazard. The probabilistic hazard that forms the basis of the design loadings used and the methods by which they are calculated typically reflect the best available information and practices at the time. This was the case with the earthquake loadings standard for the design of PNG buildings that was published in 1982. However, with the collaborative development of a better understanding of earthquake hazard across PNG the need to adjust the earthquake loadings for design through an Interim Amendment was highlighted. This key step would precede any more general and broader update of national building regulations.

In this paper the process taken to translate the latest earthquake hazard assessment for PNG, PSHA19, to design practice is described. This included an assessment of the level of current under-design and the engagement with stakeholders in PNG to assess their needs through workshop activity. The central document to this process, *"The Interim Amendment to PNGS 1001-1982: Part 4: Earthquake Design Actions"*, is described and goes beyond the incorporation of the new design hazard to the introduction of new approaches for assessing earthquake loads that more closely align with those used in New Zealand and Australia. Preparation and delivery of seminars in-country to familiarise design professionals with its use are also described along with the series of professional development video products also developed for use in PNG. Finally, future needs in regulatory development in PNG are outlined.

Keywords: earthquake, hazard, design, building, standards, practitioners.

1 Introduction

Papua New Guinea (PNG) has a high seismic hazard which in some parts of the country is as severe as that found in any other tectonic plate boundary region of the world. For adequate protection of life, amenity, and the promotion of resilience of both economic activity and governance, the buildings used for a wide range of purposes must have a strength and toughness that matches the local earthquake hazard. This is particularly needed for PNG, which has experienced considerable growth and infrastructure development over recent decades, that will continue into the future. This national investment needs to be protected.

An accurate knowledge of earthquake hazard is key to achieving resilience to this natural hazard. Significantly, this understanding has greatly improved in PNG through a four-year collaboration between the Port Moresby Geophysical Observatory and Geoscience Australia. Through enabling funding from the Australian government a probabilistic seismic hazard assessment has been undertaken using best practice seismological science, and this has resulted in a new hazard assessment (Ghasemi et. al., 2016). This peer reviewed work is referred to as PSHA19 and has highlighted geographical areas where particular types of new buildings are being under designed using the current PNG building standards. From this a need for revision of the PNG earthquake loadings standard was clearly evident.

This paper describes the extent of the earthquake design hazard mismatch that has become evident and the engagement with PNG stakeholders to arrive at an agreed process for addressing it. The development of the Interim Amendment is described along with the needs for future regulatory change in PNG. Finally, the formal Ministerial Launch of the amendment is described and the associated training seminars provided to design professionals in its use. Other refinements for earthquake design loadings and for design loadings for severe wind are proposed for future work.

2 Seismo-Tectonic Setting for PNG and PSHA19

The tectonic setting of PNG can be seen in Figure 1. The region is complex with the major Australian, Pacific and Caroline tectonic plates forming the boundary conditions to nine additional microplates between. The relative movement between these plates, and the induced crustal stresses, result in the frequent occurrence of earthquakes in the region of PNG. These are typically mega thrust at the plate boundaries and active shallow crustal earthquakes within the plates.

An updated earthquake event catalogue has been developed and has been used along with an appropriate selection of ground motion prediction equations to develop a new seismic hazard map for PNG (Ghasemi et. al., 2016) through a probabilistic seismic hazard assessment (PSHA). This research was subsequently peer reviewed and the analysis repeated with refinements to develop the latest assessment referred to as PSHA19 (Ghasemi et. al., 2020). The hazard was computed for bedrock site conditions with an average shear-wave velocity in the upper 30 m of 760 m/s. The mean hazard result in terms of peak ground accelerations having a 10% chance of exceedance in 50 years (475 year average recurrence interval) is shown in Figure 2. This is the hazard likelihood for the design of ordinary use buildings.

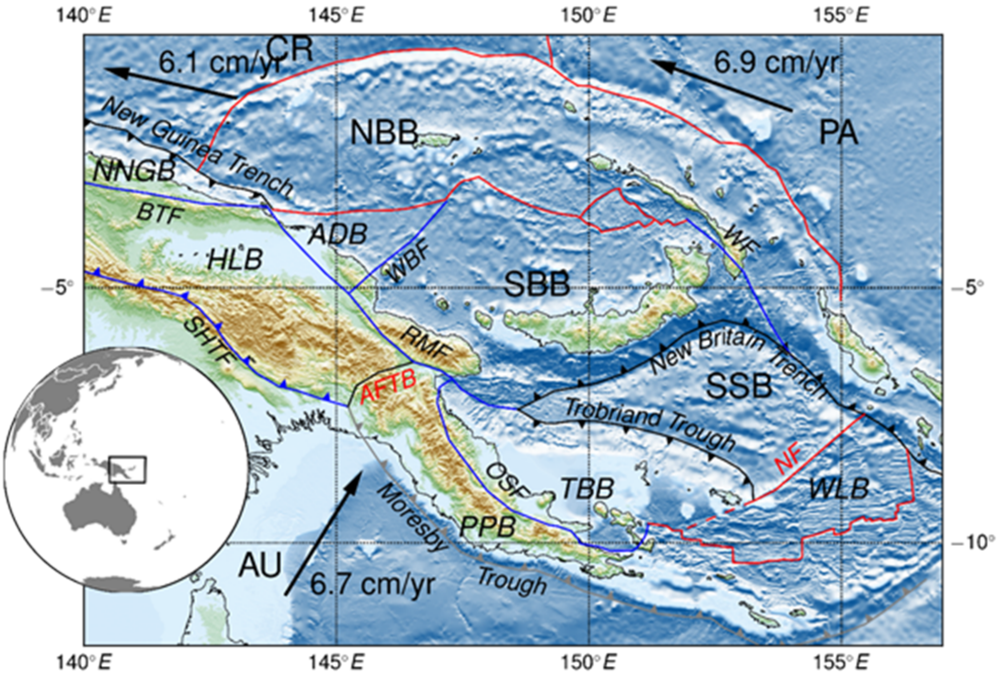

Figure 1. The complex tectonic setting of Papua New Guinea is shown with the three major tectonic plates indicated (AU - Australian, PA - Pacific, CR - Caroline) along with the microplates or blocks (NNGB – North New Guinea Block, NBB - North Bismark, SBB - South Bismark, SSB - Solomon Sea, WLB - Woodlark, TBB - Trobriand, HLB – Highlands, PPB – Papuan Peninsula, ADB - Adelbert) identified. The global movement of the major plates is shown and the relative movement between these plates and the microplates are the primary mechanism for strain energy storage and release associated with the seismicity.

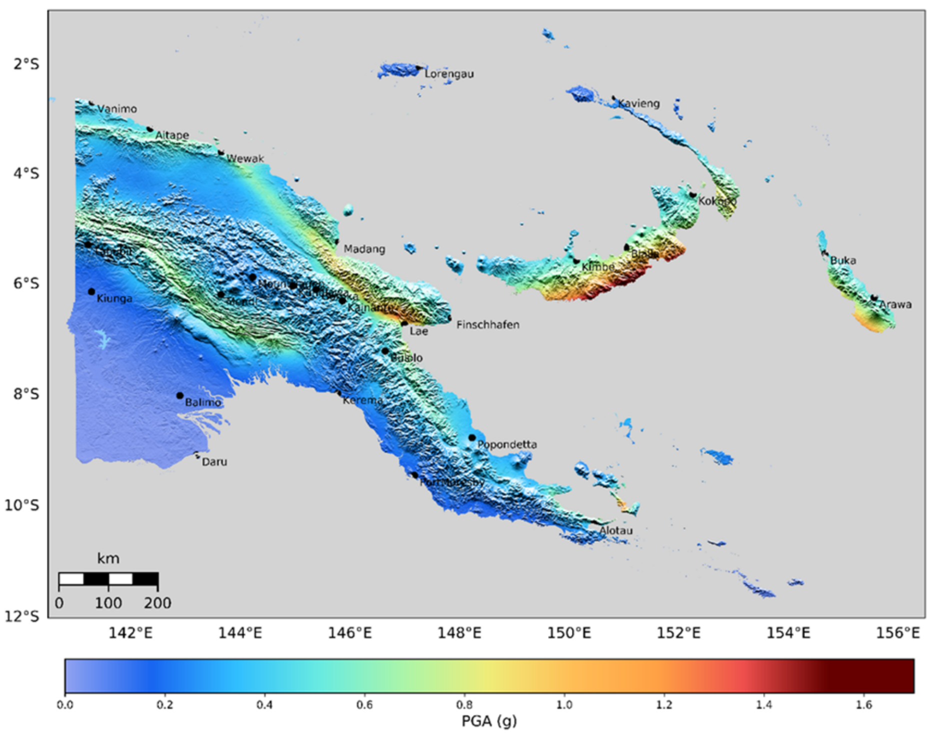

Figure 2. Bedrock hazard across PNG represented by the peak ground acceleration for bedrock conditions with a likelihood of 10% probability of exceedance in 50 years (Ghasemi et al, 2019).

3 Building Regulation in PNG and the Need for an Amendment

3.1 Current Earthquake Loadings Standard

Within Papua New Guinea (PNG) building activity is controlled by Building Regulation 1994. The Regulation cites the various Papua New Guinea Standards (PNGS) that building design professionals are expected to use to demonstrate compliance. The structural engineering standards in use as compliance documents in PNG were developed in the 1980's. They have served the country well but are now in urgent need of being updated and revised to reflect modern design methods, new knowledge on design hazard, and changes in the materials used for construction. Earthquake loadings for design are prescribed in PNGS 1001-1982: Part 4: Earthquake Loadings (NSCPNG 1983).

Not surprisingly, many anomalies are apparent when the new PSHA is compared to the earthquake design actions prescribed in the Standard. The design seismic hazard across PNG is represented in the standard (NSCPNG 1983) by seismic zones of assumed uniform hazard (Figure 3). In comparing this seismic zonation map to the new bedrock hazard in Figure 2, it can be noted that the spatial distribution used for building design does not match the bedrock hazard distribution of PSHA19. In particular, the high seismic hazard of the Huon Peninsula is not captured, leading to a significant under-estimation of hazard in PNG's second largest city, Lae. This results in some buildings being under-designed (i.e., being potentially unsafe with less earthquake resistant capacity than needed) and, in others, potentially being overdesigned (i.e. having greater capacity than required, thus needlessly expensive to construct both financially and in terms of resource consumption).

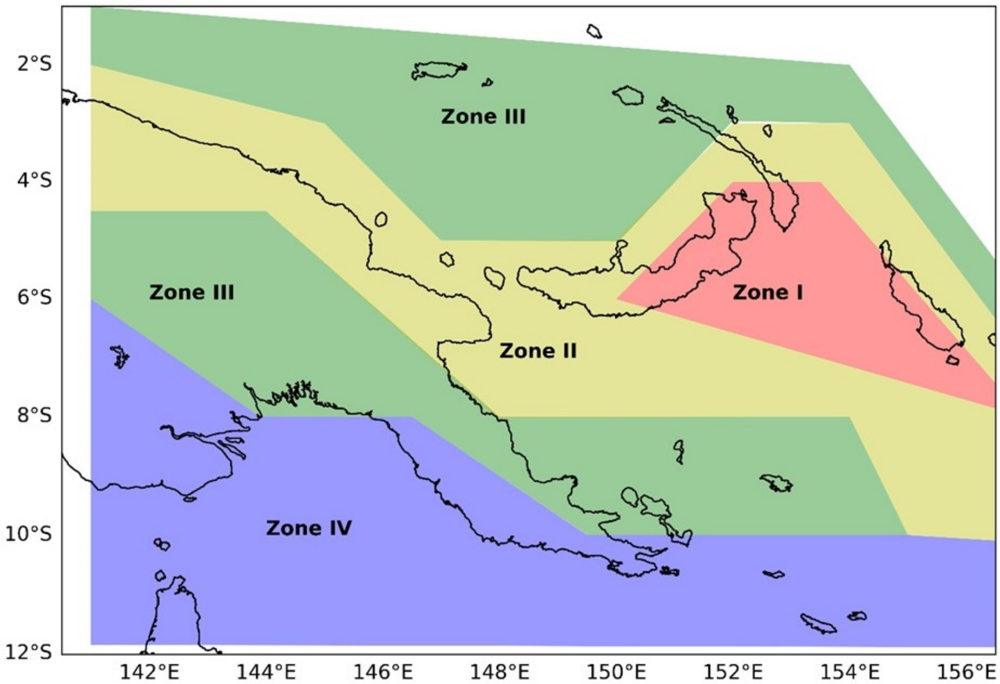

Figure 3. The seismic zoning map of the national building standards of PNG. This map divides the country into four general seismic zones nominally assumed to have a uniform level of seismic hazard for design. The lowest hazard is defined for Zone IV and the highest hazard for Zone 1. The lack of identification of high hazard along the Huon Peninsula and the Southern Highlands is evident (NSCPNG 1983).

The extent of under or over-design depends on the location, local soils and building natural period. This was examined through considering a range of building types in 27 communities distributed across the country as shown in Figure 4. The outcomes are summarised in Table 1 for "Firm" site conditions as defined in the PNG standard and with consideration of the reduced ductility available in design for short period structures as considered by the current New Zealand earthquake loadings standard (Standards New Zealand, 2004), but not by the Australian standard (Standards Australia, 2007). It can be noted that the under-design for short period structures is the greatest issue. For a low-rise structure in the city of Lae, which is the most common structural form, the under-design is by a factor of five. Taller structures with natural periods of 0.7s or longer were found to be overdesigned due to the conservative spectral shape in the PNG standard. These buildings are almost entirely limited to the capital city of Port Moresby with over-design for firm soil sites of 50% or more.

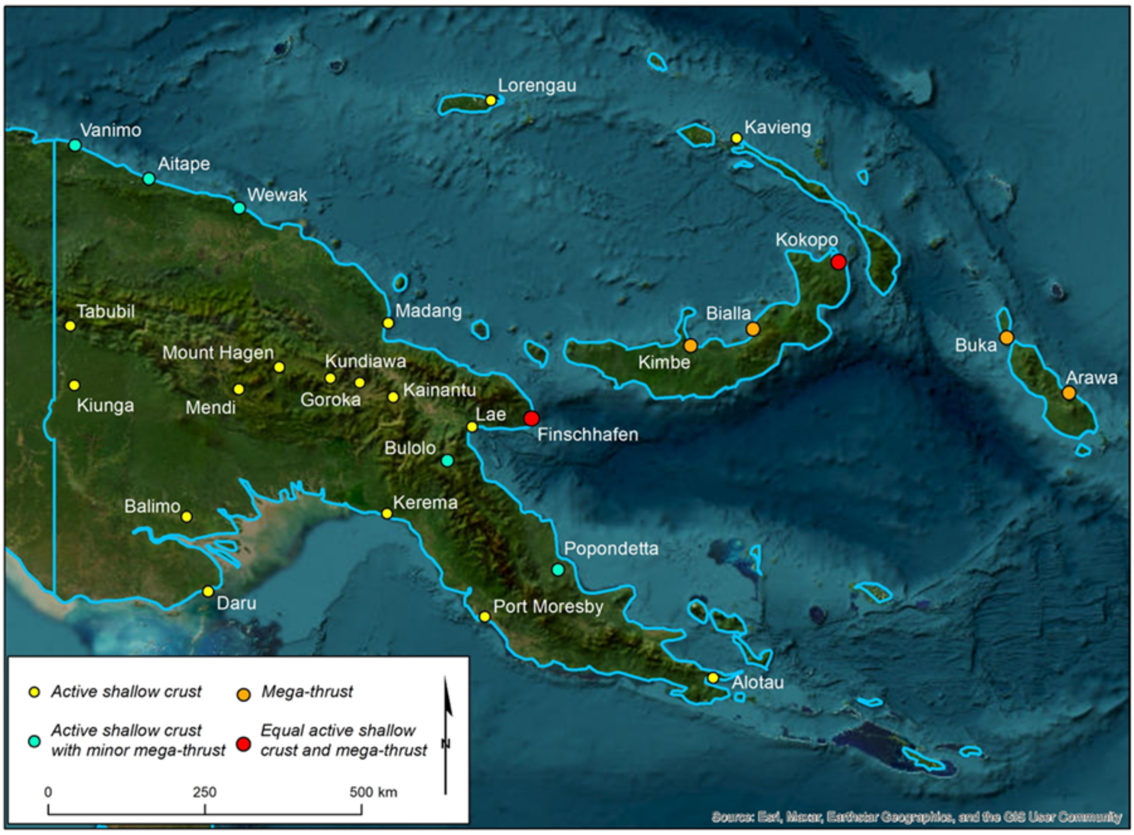

Figure 4. Locations of the 27 communities selected across PNG for the assessment of seismic design adequacy using the current PNG earthquake loading standard for buildings, PNGS 1001-1982: Part 4: Earthquake Loadings (NSCPNG 1983). The nature of the local seismic activity that is dominating the local hazard is indicated in the legend.

Table 1. Design base shear comparisons between those from PNGS 1001-1982: Part 4 with those obtained using PSHA19 and the provisions of NZS 1170.5. The site soil conditions are assumed to be a "Firm" site for PNGS and site subsoil Class A/B in terms of NZS 1170.5. Greater than 10% under-design, as highlighted in bold, is widespread and is largely associated with low rise structures.

City/Town	***Percentage of PNGS Design Base Shear Compared to PSHA19***			
	T_1 = 0.2s	***T_1 = 0.5s***	***T_1 = 0.7s***	***T_1 = 1.5s***
Tabubil	**38**	123	212	328
Kiunga	96	265	429	595
Vanimo	**33**	115	213	404
Aitape	**30**	106	195	357
Balimo	94	227	349	437
Daru	306	760	1,101	1,327
Mendi	**28**	91	159	257
Wewak	**29**	96	176	325
Mount Hagen	**43**	147	255	395
Kundiawa	**36**	134	235	360
Goroka	**30**	112	193	278
Kerema	**59**	185	298	372
Madang	**28**	98	173	268
Kainantu	**36**	131	226	332
Bulolo	**27**	93	158	236
Lae	**20**	**66**	113	184
Port Moresby	**36**	101	153	169
Lorengau	104	334	520	519
Finschhafen	**36**	93	156	247
Popondetta	**34**	98	163	239
Kimbe	**26**	**63**	108	183
Alotau	**13**	**47**	**79**	100
Kavieng	**58**	165	253	283
Bialla	**30**	**77**	131	211
Kokopo	**38**	95	156	237
Buka	**40**	94	154	234
Arawa	**28**	**66**	110	175

3.2 Stakeholder Engagement on Regulatory Change

The extent of the under-design outcomes was examined at a workshop with PNG stakeholders on the 6th June 2019 in the context of the natural periods of four buildings and the 27 communities considered. The need for an updated hazard map for building design was acknowledged from the results of this study. Further, as standard revision processes typically take several years to complete, it was agreed at the workshop that an interim document should be produced that contains the newly derived probabilistically based earthquake actions, but in a form consistent with the format of the existing Standard and the associated PNG material design standards. It would be called "The Interim Amendment".

4 The Interim Amendment

4.1 Scope

The objective of the Interim Amendment was to introduce the new probabilistic bedrock hazard of PSHA 19 and to incorporated as many as possible of the features of both the Australian and New Zealand earthquake loadings standards. This would serve to move professional design practice for PNG as close as possible to current design approaches. The key elements of the Interim Amendment are:

1. The introduction of a probabilistic bedrock hazard map derived from the PSHA19 with a reference peak ground acceleration (PGA) hazard having an average recurrence interval of exceedance of 475 years. This corresponds with the "Earthquake Hazard Factor", Z.
2. The assignment of the "Spectral Shape Factor", $C_h(T)$ to translate the hazard factor Z to a 5% damped uniform hazard response spectrum that approximately matches the excitation expected at the specific site. Factors are provided for three near-surface site soil classes at the specific site of interest, namely; Class A/B: Rock, Class C: Intermediate Soil and Class D: Soft Soil.
3. The determination of the "Return Period Factor", R_s or R_u. This is used to scale the ground motions to reflect the return period of the earthquake motions being considered. The factors adjust the 1/475 exceedance probability hazard values to other exceedance probabilities and are based on the PSHA19 hazards for the 27 PNG communities studied.
4. Importance Levels (IL) for building are given more detailed descriptions. The default is Importance Level 2 with buildings of greater importance (usually those with crowds and places of assembly) assigned to IL3 and buildings and facilities with critical post disaster function (including critical utilities) being assigned as IL4.
5. An additional performance level for assessing design compliance was added. In addition to the Ultimate Limit State (ULS) for life safety compliance (mandatory in the current standards) the Serviceability Limit State (SLS1) associated with the onset of damage was added as an explicit design consideration. SLS1 is advisory only in this Interim Amendment and thus non-mandatory.
6. The design annual exceedance probability (AEP) for each building importance level and limit state combination is specified.
7. The "Equivalent Static Load Analysis" method and the dynamic analysis procedures are based on a 5% damped elastic response spectrum rather than an inelastic spectrum as used in the current Standard.
8. The elastic hazard spectrum is reduced by "Structural Performance Factor", S_p, and the inverse of the "Structural Ductility Factor" μ. The "Structural Performance Factor" is typically set at 0.7 but reduced to 1 for non-ductile buildings for which resilience to multiple loading cycles cannot be assured. The Structural Ductility Factor is prescribed for each of the structural types in the current standard and is intended to reflect the

level of post-elastic behaviour able to be accommodated in those various structural forms – these being a function of the level of detailing prescribed in the various material standards.

9. The “Structural Ductility factor” is reduced for structures with a period shorter than T = 0.7s . The factor is the “Inelastic Spectrum Scaling Factor”, k_{μ}, and corresponds with New Zealand code provisions (Standards New Zealand, 2004) to allow for the increased ductile demands shorter period structures can experience when detailed to take advantage of inelastic behaviour to reduce earthquake response.
10. The Dynamic Analysis Procedure has been completely revised to align with New Zealand code provisions (Standards New Zealand, 2004).

4.2 Development

The development of the interim amendment was led by Geoscience Australia in collaboration with Andrew King of King Consultants and Rob Jury of Beca through contractual engagement. The work directly translated the PSHA19 research into targeted amendments as described in-part below.

Bedrock Hazard:-

The approach in both the New Zealand and Australian standards is to specify a reference hazard for ground shaking corresponding with that used for the ultimate limit states design of ordinary buildings. This is a ground shaking that has a 10% chance of being exceeded in a 50 year building life or has an average recurrence interval (ARI) of exceedance of 475 years (500 years approx.). This rarity of hazard was adopted as the reference which would be factored for all other combinations of importance class and performance level using a probability factor (k_p) which corresponds with a return period factor. The factors for the 27 communities derived from PSHA19 are plotted versus ARI in Figure 5. It can be seen that the variability in the return period factors about the average curve is not excessively large.

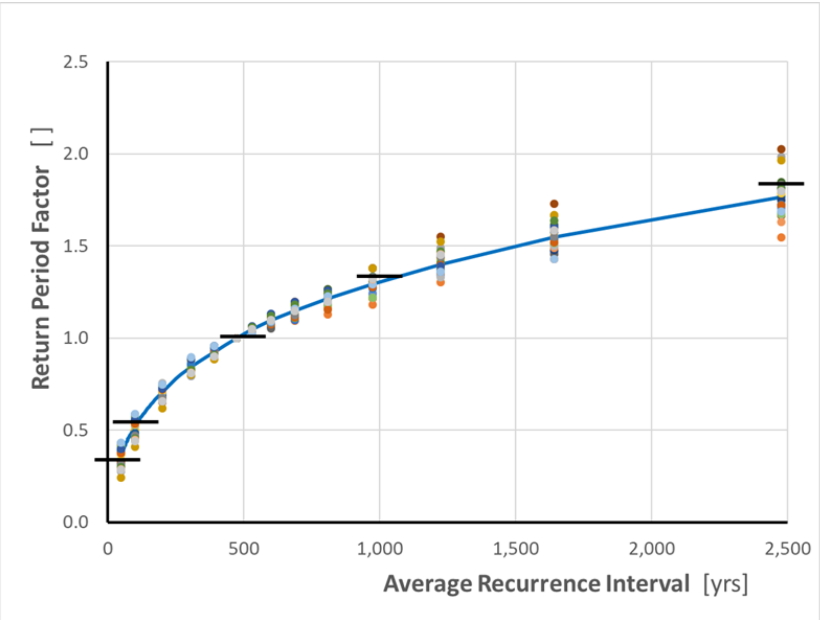

Figure 5. Return period factors for each of 27 PNG communities versus Average Recurrence Interval (ARI) plotted with different coloured dots for each community. The average of all communities is also plotted as the blue trendline. The return period factors adopted in the Interim Amendment are indicated by the horizontal dashed lines.

The average Return Period Factor values of all PNG communities (k_p) are compared to the notional Importance Factor values in PNGS 1001-1982: Part 4 in Table 2 (refer columns 2 and 3). It was noted that the Importance Factors in present design use are reasonable and conservative. The average PNG community Return Period Factor values were also compared to the Return Period Factors in the New Zealand Loadings Standard (R, refer columns 2 and 6) (Standards New Zealand, 2004). The values are remarkably similar, reflecting the similar seismotectonic settings of both countries. The values adopted for the Interim Amendment were also very similar and presented in column 7 of the Table 2. Finally, it was noted that Daru, which sits on the Australian Plate (Figure 1) has similar Return Period Factors to the PNG national average and does not exhibit the large intraplate hazard change with ARI found within the Australian tectonic plate as highlighted by the NSHA18 assessment (Allen et al, 2018) for Adelaide (column 5 in Table 2).

Table 2. Comparison of Importance Factors from PNGS 1001-1982: Part 4 with Return Period Factors from PSHA19, the Australian NSHA18, those adopted for the New Zealand earthquake loadings standard and values adopted for the Interim Amendment. Average recurrence intervals for the Importance Factors from PNGS 1001-1982: Part 4 are notional and based on importance class descriptions in the PNG standard.

ARI [yrs]	***Notional I PNGS***	***k_p PSHA19 Average***	***k_p PSHA19 Daru***	***k_p NSHA18 Adelaide***	***R NZS 1170.5***	***R Interim Amendment***
25	-	0.247	0.273	-	0.25	0.30
100	-	0.518	0.525	0.204	0.50	0.55
500	1.00	1.00	1.00	1.00	1.00	1.00
1,000	1.50	1.29	1.31	1.76	1.30	1.30
2,500	2.00	1.77	1.79	3.48	1.80	1.80

Spectral Shape Factor Sensitivity to Seismotectonic Setting:-

Using the PSHA19 data for the 27 communities, the average spectral shape factors were assessed for each of four earthquake hazard environments identified (refer Figure 4). The results for the 475 year ARI are presented as bar charts in Figure 6. It was noted that the communities where the local hazard is dominated by local *Active Shallow Crustal* earthquakes the spectral values were higher in the very short period range compared to communities where hazard is strongly influenced by *Mega Thrust* plate boundary earthquakes. The relativity is reversed for medium to longer period structures. This is consistent with the hazard setting where local shallow crustal seismic activity typically has higher frequency content whereas plate boundary events generate longer period ground motions. The results for the 2,475 year ARI was similar with no significant return period sensitivity requiring specific codification noted.

Reference was made to the New Zealand (Standards New Zealand, 2004) and Australian loading standard (Standards Australia, 2007) for the selection of generalised spectra that would be consistent with the PSHA19 results. The Australian standard includes a hard rock site sub-soil Class A_e which is uncommon in geologically young PNG. The Australian Class B_e rock type has shear wave velocities more comparable to PNG crustal rocks. The New Zealand standard provides a single design response spectrum for both site sub-soil classes combined together, “Soil Types A & B”. The Australian Class B_e and the New Zealand Class A/B are presented in Figure 7 with the spectral shapes directly obtained from PSHA19 for the 27 PNG communities. It can be seen that the Australian spectrum serves to envelope the intraplate hazard better at very short periods but underestimates the demand for longer period structures. The New Zealand spectrum under-estimates the hazard for short period structures but envelopes the community spectral values for periods longer than 1 second. Considering the response reducing effects of “period shift” as structures with short periods respond in a ductile fashion, the New Zealand Class A/B was adopted for bedrock hazard in PNG. While the New Zealand spectrum factors a bedrock hazard value that is 50% of the 0.5s spectral acceleration for a shallow soil site (Class C), the adoption was justified as the spectra does adequately capture the PNG communities considered.

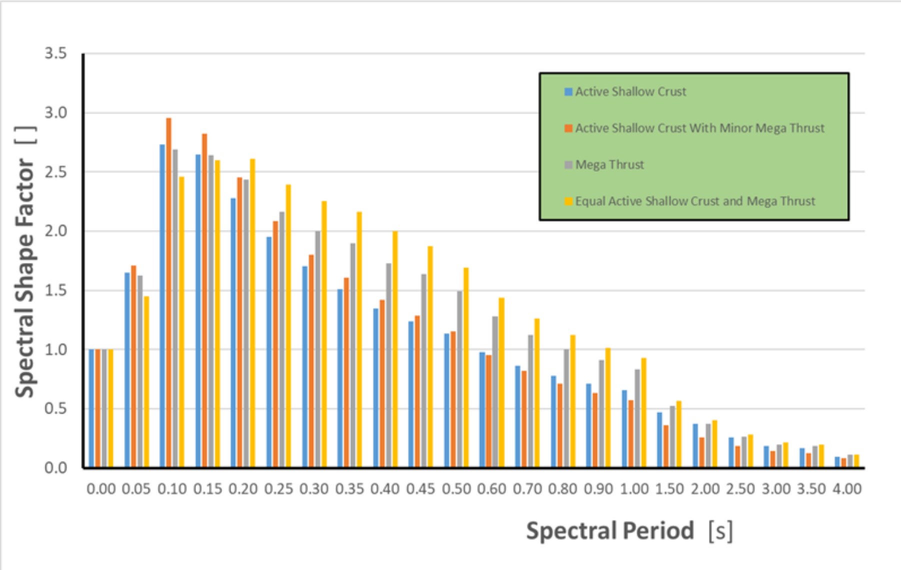

Figure 6. Normalised PSHA19 spectral values for 27 PNG communities and a 475 year average return interval. The values have been grouped and averaged for the four classes of seismic hazard environment and presented for the range of natural periods of structural design interest.

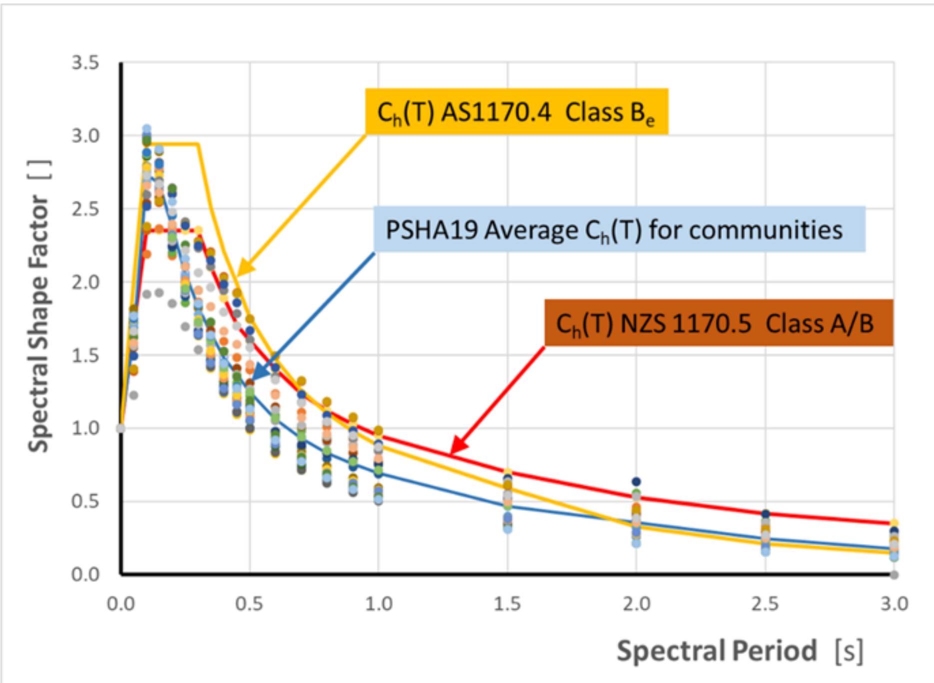

Figure 7. Rock site design response spectra for 27 PNG communities presented with current generalised spectra from the Australian and New Zealand earthquake loading standards. The site subsoil Class A/B of NZS 1170.5 has been adopted for bedrock hazard in the interim amendment.

The Interim Amendment was finally published in December 2022 (Edwards et al, 2021) and can be freely downloaded (http://dx.doi.org/10.11636/Record.2020.036).

4.3 Ministerial Launch and In-country Training Seminars.

The Interim Amendment was formally launched by the Minister for Public Works and Highways, Hon. Solan Mirisim, at the Holiday Inn, Port Moresby, on the 18th July 2023 (Figure 8). Others who attended and who spoke at the launch were; Mr David Wereh, Secretary of the Department of Public Works and Highways, Dr Joanne Loundes, Australian Deputy High Commissioner, and Mr Victor Gabi, Director General National Institute of Standards & Industrial Technology (NISIT).

The Launch was immediately followed by a series of three professional training seminars. The first two were full day seminars that were run twice and directed to design engineers. The third shorter half day seminar was directed to architects, building officials and the construction industry. In total 257 professionals attended the seminars over the three days with several travelling from other provinces to attend. Significantly, academic staff from both the schools of architecture and civil engineering at the University of Technology in Lae attended as they will have a key role in training new design professionals to effectively utilise the Interim Amendment.

Figure 8. Pictured are Mr David Wereh, Dr Joanne Loundes, Hon. Solan Mirisim, Mr Vaghi Gairowagga, and Mr Victor Gabi at the formal launch of the Interim Amendment on the 18th July 2023 in Port Moresby. Mr Solan Mirisim is the Minister for Public Works and Highways.

4.4 Professional Development Resources

The presentation material was shared with NISIT for distribution and the individual lectures for both audiences were professionally videoed. These were subsequently edited into a series of professional development lectures; 8 for structural engineers, and 5 for architects, building officials and the construction industry. The distribution mechanism for this is being arranged with the PNG partners.

5 Future Regulatory Change Needs

The very name "Interim Amendment" implies that the new document is intended to be an interim resource/arrangement to bridge across to a new earthquake loadings standard with a "look and feel" similar to the New Zealand and Australian standards. It is also intended that regulatory development would also include the full range of loadings standards that would reflect modern international norms for buildings. This is expected to entail a multi-year development and implementation timeframe and to include the structural material design standards.

Clearly there is also a need to consider earthquake and severe wind design for other infrastructure types critical to PNG communities and the economic activity that underpins them. These include road transport, electricity, potable water supply, telecommunications and resource extraction infrastructure. As improved understanding of the severity of natural hazard is incorporated into building regulations, this knowledge needs to translate across to the design and construction of these critical facilities.

6 Summary

The understanding of key environmental hazards for design purposes is progressively improving and leads to a better definition of probabilistic hazard. The design approaches for using this knowledge in building design is also evolving and making use of more sophisticated tools. Our design regulations need to keep pace with both developments to ensure our communities are resilient. This can be a challenge in less resourced regional countries and the targeted support by the Australian government to PNG government agencies has enabled the uplift of earthquake design in the country and to transition design practice towards current best practice in Australia and New Zealand. This collaborative work that has translated seismological science to practitioners will enable future construction in PNG to be resilient, supporting future development in the country.

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