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Best practice and challenges for earthquake resilient school infrastructure in the Pacific

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ABSTRACT

To highlight best practices and challenges in earthquake resilient school infrastructure this paper presents key and contrasting approaches from six countries across the Pacific (Australia, Chile, Japan, New Zealand, Peru, and Tonga) with varying levels of seismic hazard, earthquake engineering practice and school infrastructure.

Contrasting levels of awareness of seismic hazard/risk, regulatory framework that establishes the building code requirements for the design of new school buildings, local seismic skills capacity and capability, and effective implementation of school risk reduction infrastructure programmes are exemplified. Recent experiences of major earthquakes that highlight school building performance and have triggered implementation of seismic risk reduction programmes provide insight to improve the seismic resilience of school buildings.

The lessons learned from these approaches may be applied to other countries who wish to address the seismic resilience of their school buildings, to assess how well existing regulations and processes ensure new schools will be seismically resilient, and to enable them to develop a suitable program to address "at-risk" school buildings.

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1 INTRODUCTION

There is mounting evidence that the direct impact of disasters on school infrastructure can translate into a series of indirect long-term detrimental effects, to individuals and their communities. Recent events in Nepal, Iran, China, and Indonesia have shown that earthquakes continue to cause significant loss of life of school children and their teachers, and adversely impact the aspirations of the communities, the development goals of the education sector of the affected country. These present an ongoing challenge for us collectively as world citizens to achieve the United National Sustainable Development Goals.

Earthquake Engineers have made significant advances in understanding the nature of seismic hazard, how to design new buildings that perform better than the past and improve existing buildings through cost-effective retrofitting techniques. Governments can use this knowledge to assess existing school building stock to triage which buildings meet modern seismic design requirements and will perform well, which urgently need to be retrofitted or replaced and those which may be lower priority (based on the vulnerability of building typology and exposure to seismic hazard), and ensure new school buildings are planned, designed, constructed and maintained to be resilient from earthquakes.

Recent experiences of major earthquakes highlight school building performance and have triggered implementation of seismic risk reduction programmes to increase resilience.

To highlight best practices and challenges in earthquake resilient school infrastructure this paper presents key and contrasting approaches from six countries across the Pacific (Australia, Chile, Japan, New Zealand, Peru, and Tonga) with varying levels of seismic hazard, earthquake engineering practice and school infrastructure. These approaches are presented in four categories:

- Awareness of seismic risk from past earthquakes
- Regulatory environment
- Sufficient local skills capacity and capability
- Effective implementation of school risk reduction infrastructure programmes

2 EARTHQUAKE RESILIENT SCHOOL INFRASTRUCTURE

In the context of school infrastructure, earthquake *risk* can be defined as a multiple of the earthquake *hazard* × *exposure* × *vulnerability*. The earthquake *hazard* defines both the likelihood and severity of earthquake shaking affecting a school site and is calculated as the annual probability that a particular level of shaking intensity is exceeded. The *exposure* of students, teachers, school buildings, and assets at the site; and the *vulnerability*, both physical and socioeconomic, of the people and physical assets exposed to the earthquake shaking together define consequences or impact of the hazard.

Current building codes do not focus on earthquake resilience, the ability of an organization or community to quickly recover after a future design-level earthquake, but rather life safety and therefore avoidance of building collapse. This means significant damage is expected and may mean the building is unsafe to occupy and potentially uneconomic to repair following a major event. Checks to ensure operational continuity and repairability following more frequently expected earthquake events are required for some important buildings and industrial facilities but are rarely required for schools.

Engineering design focusses on reducing exposure and vulnerability, either by building in locations away from earthquake prone areas, e.g., avoiding known active faults, weak ground, or sites subject to tsunami, landslides and rockfall; building defensive infrastructure (e.g. slope stabilisation, sea walls to protect communities from tsunami); and/or designing structures to be more robust, and therefore better able to withstand earthquake shaking. Often, engineering efforts overlook significant socioeconomic or environmental factors contributing to individual or community vulnerability. Engineering solutions can have multiple opportunities to reduce vulnerability, and it is important that these factors are considered more broadly when proposing engineering solutions (da Silva, 2012).

The primary aims of earthquake-resilient schools are to be able to withstand strong earthquakes without fear of collapse, and, while there may be some damage, to ensure low risk of loss of life by allowing occupants to exit safely. A secondary aim, but very significant, is to minimize damage to school buildings as they play an important role in the resilience of the entire community following major disasters. Initially serving as an emergency relief shelter and/or distribution or resource centre in the immediate aftermath of a disaster but also the continuity of the schooling of children is seen as a crucial element of a rapid recovery, maintaining overall community morale post-disaster, and longer-term socio-economic development.

Following a major earthquake event, the potential losses include not only life and personal injuries, but also, the loss of time spent in the classroom in turn affects the levels of educational attainment. Smaller, more frequent earthquake events can also cause significant disruption to students and teachers even if significant damage is not incurred, with school closures necessary to assess damage and make minor repairs.

3 AWARENESS OF SEISMIC RISK

3.1 Historical record, cultural memory and earthquake awareness

3.1.1 Japan

Japan has possibly the oldest earthquake records, dated back to 600-700AD, and earthquake disasters are reflected in traditional songs, music, art, and paintings of Japan from previous eras; thus, the general population is highly aware of earthquake risk. The devastating 1923 Great Kanto earthquake which devastated Tokyo is commemorated as National Disaster Prevention Day, during which schools and offices conduct emergency drills and people check emergency supplies. Owing to the country's previous experiences of some of the world's most extreme earthquakes and tsunamis, Japan has developed advanced early warning systems, preparedness and evacuation drills, and is renowned for its development and implementation of very strict building design codes incorporating learnings from past seismic events.

3.1.2 Chile

Since 1730 more than 20 earthquakes are estimated to have exceeded M7.0, eight have exceeded M8.0, and two have exceeded M9.0. The history of the Chilean seismic regulations goes back to 1928. In that year the city of Talca was affected by an earthquake and, as a result, in 1929 the government passed a law creating a committee to propose earthquake related regulations. Finally, in 1972, a seismic code known as Calculo Antisismico de Edificios (Earthquake Design of Buildings) was officially approved.

3.1.3 New Zealand

Due to New Zealand's location on a tectonic plate boundary, relatively low population, large events have impacted population centres approximately every 80 years. Important historic events where cities were affected include the 1855 Wairarapa earthquake (Magnitude M8.3) which devastated Wellington, and the 1931 Hawke's Bay earthquake (M7.8) which devastated the towns of Napier and Hastings. This event led to the first earthquake related building regulations in the country. More recently the 2010 – 2011 Canterbury region earthquakes (M7.1, 6.3, and 6.0), severely impacted the city of Christchurch and nearby towns, and the M7.8 2016 Kaikōura earthquake which impacted regional towns and the city of Wellington.

3.1.4 Tonga

Tonga is located on an active subduction zone and exposed to a very high seismic hazard. There is a good awareness of earthquake hazards in the country, including tsunami and ground shaking, however the understanding of seismic risk is less, and is overshadowed by the annual impact of tropical cyclones. The

Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) Tonga country report shows the cost of both cyclone and earthquake damage to buildings is relatively equal over a design-life exposure period. While average annual fatalities from natural disasters is dominated by cyclones, at larger return periods (annual probability of exceedance) the hazard in terms of loss of life becomes dominated by earthquake ground shaking over cyclones and tsunamis.

3.1.5 Australia

Although Australia is a stable continental crust with a relatively lower seismic hazard compared to active tectonic regions, earthquakes do occur periodically. Significant earthquakes of note include M6.6 Tennant Creek 1988 and M6.5 Meckering events. The M5.6 1989 earthquake that hit Newcastle, NSW, killed 13 people and injured 160, causing $3.2 billion in insurance losses and lead to the modernisation of the Australian Seismic Design Code, AS1170.4. The vulnerable highly concentrated building stock in the Australian capital cities has the potential for extreme losses. These events are not in the collective forefront of the general Australia population, as such awareness of seismic risk is low.

3.2 Performance of school buildings

3.2.1 Japan

A large proportion of Japan’s school were constructed by the Ministry of Education’s model school programme during the Allied Occupation years (1945-52). Over time, in response to observed earthquake damage, the Japanese code has evolved to include more stringent requirements. These include: Strict building drift limits, ductile detailing of concrete and promoting building designs which are regular in form and highly redundant. This has led to improved performance of schools.

In the 1995 Great Hanshin (Kobe) Earthquake, many of the schools in central Kobe were damaged, and undamaged school buildings were often relied upon to function as temporary refuge centres. Despite the devastation caused by this earthquake, within one week of the event, 325 out of the 591 schools in Kobe and the Hanshin area had reopened (EEFIT, 1995).

An important note is that major damage to non-structural elements was commonly observed (including within schools) after the 2011 Tohoku earthquake (Maeda et al., 2012) and at least four deaths were directly attributable to non-structural element damage, specifically falling ceiling boards (Motosaka & Mitsuji, 2012).

3.2.2 Chile

Typical building configurations in use in Chile have generally provided good performance in past large-magnitude earthquakes. The relatively low cost of construction labour relative to materials in Chile favours the use of distributed, redundant and regular structural systems in which many elements provide lateral resistance.

As a rule of thumb, Chilean engineers generally understand the need to provide shear walls with a cross sectional area equal to approximately 1% of the gross floor area above the first story. Based on past experience, they believed that special ductile detailing of these walls was not necessary. Building performance in past earthquakes, including events in 1971 and 1985, generally confirmed that these practices provided good performance.

During the 2010 earthquake, a significant number of Chilean schools were damaged and the Chilean government surveyed the status of schools in the affected regions. The government also completed a review of school infrastructure for the whole country. In total, 38% of the schools were lightly to moderately damaged and 19% of them had severe damage or were destroyed. Given the scale of the 2010 earthquake, Chile’s schools performed relatively well which demonstrates the effectiveness of the Chilean approach to seismic structural design that focusses on simple forms and redundancy and can be less complex to design and build than highly ductile seismically designed systems.

3.2.3 New Zealand

The poor performance of unreinforced masonry (URM) buildings (typically constructed between 1850 and 1935) has been well documented in New Zealand, most notably in the 1931 Hawke's Bay earthquake. By the mid-1990s, all URM school buildings had been demolished and replaced, or structurally upgraded. After 1935, URM construction was prohibited and many buildings were constructed in reinforced concrete and steel frames as well as timber. Most houses in New Zealand and many low-rise non-residential buildings including schools are built using timber-frame construction (~90%). These buildings have demonstrated very good earthquake resistance, owing to their lightweight structure (high strength to weight ratio); ductility on account of numerous nailed connections and joints allowing flexure, absorption, and dissipation of earthquake energy; and multiple load paths creating redundancy in the structure.

The New Zealand government's Ministry of Education (MoE) is the largest owner and provider of school buildings in the country. Following the 2010–2011 Canterbury earthquakes, research on existing school building performance, including detailed seismic analysis of a range of the MoE's standard classroom blocks, culminated in the full-scale physical testing of standard classroom blocks. This research confirmed that timber-framed buildings with older glazed facades have strength and resilience significantly in excess of their calculated capacity and are expected to perform very well in earthquakes.

3.2.4 Peru

On 12 November 1996, a M7.7 earthquake with its epicentre in the Pacific Ocean near Peru's mid-southern region. The earthquake caused extensive damage to 76 adobe construction and reinforced concrete school buildings. Most of the damaged schools were over 20 years old model schools but some had been constructed more recently.

School buildings were constructed of reinforced concrete frames with either infill wall or bearing walls and one way spanning concrete slabs with hollow bricks to reduce slab weight. Windows in the longitudinal direction increased the flexibility of the buildings in that direction. This part of the lateral system of the schools was more damaged and the original design could have benefitted from increased stiffness (this was later implemented with stricter requirements in the 1997 version of the code).

The 2001 M8.4 earthquake caused widespread damage in Arequipa, Tacna and Moquegua where more than 25,000 homes were destroyed, but performance of Post-1997 buildings confirmed the correction of the displacement problem with the introduction of the 1997 code.

4 REGULATORY ENVIRONMENT

4.1 School design requirement for higher performance in earthquakes

4.1.1 Chile

All schools are assigned an importance factor of 1.2. In other words, schools must be designed for earthquake loads 20% greater than required for residential and office buildings to compensate for the higher consequences of school building damage or collapse, in order to meet the intent of the code that the risk be reduced uniformly for all buildings regardless of purpose.

4.1.2 Japan

The Japanese building codes require that significant school buildings are designed for an importance factor of 1.25. This has the effect of increasing the seismic design loads by 25% over those that a normal commercial building would be designed for. Additionally, elementary school and junior high school gymnasiums which are designed as emergency refuges are designed with an importance factor of 1.5.

The intent of these requirements is clarified in a series of school seismic reinforcement case studies published by Ministry of Education, Culture, Sports, Science and Technology (MEXT) in 2006 present the following school building performance guidelines:

- For moderate earthquakes (shaking intensity of approximately 5-lower shindo), a school building is not to sustain any damage.
- For severe earthquakes (shaking intensities of 6-lower shindo and above), a school building may sustain moderate damage but no level of damage that may pose risk of collapse or endanger lives.

4.1.3 Australia and New Zealand

The Australia and New Zealand loadings standard AS/NZS1170.0 defines the "importance levels" (IL) of buildings based on the consequences of failure. School buildings are allocated an IL depending on the number of people present in the building. The NZ Building Code states that school facilities serving more than 250 people, colleges or adult education facilities serving more than 500 people, and public assembly buildings in excess of 1,000m^3 are designated as Importance Level 3 (IL3) structures. IL3 has a scaling factor of 1.3, requiring 30% greater seismic design loading than a normal building. Smaller schools are considered normal structures and designated to residential requirements (IL2).

4.1.4 Peru

The Peruvian seismic code requires that schools be constructed for earthquake design loads that are 50% higher than for typical buildings. Higher performance is desirable for schools not only to limit damage, loss of life and disruption to education and livelihoods but also so that schools can serve as emergency facilities after earthquake events. Code provisions in the 1997 code reduced drift limits and included an explicit check of drift without reduction (R) factors.

4.2 Improving school performance through updated seismic codes

4.2.1 Peru

Peru is a good example of best practice for updating seismic codes building on lessons learnt from earthquake damage. The code updates were particularly focussed on learning from the performance of schools in earthquakes and improving school safety. For example, in 1997, following on from observations of damage to Ministry of Education model government schools in the 1996 Peru earthquake, the code was updated to reduce building drift limits and require infill walls to be isolated from the frame to prevent short column damage. Model schools designed to the updated code were shown to perform well in the 2001 and 2007 earthquakes in Peru. This demonstrates that focussing on school safety is a way to facilitate better standards for all construction and reduce earthquake risk on a wider country scale.

The current design hazard level in the Peruvian code which was recently updated in 2016 has been compared to recent seismic hazard studies (Tanner, 2004) and (Wong, 2012).

4.2.2 Tonga

Tonga is undergoing a project to Review, Strengthen & Update the Tonga Building Code (World Bank, 2019). The Tonga Building code is based on earlier versions of the AS/NZ1170.0. Pending recommendations are to add Importance Levels, so large schools will have 30% increase in loads. The seismic hazard is also recommended for an ~75% increase based on a 2012 Seismic Hazard study (Peterson et al., 2012).

4.2.3 Australia and New Zealand

Australia and New Zealand (AS/NZS1170.0) have regular Standard Review committees on an approximate 10-year basis. For example, AS1170.4 the Earthquake Actions in Australia recently went through a review process and updated the code in 2018 with revisions to minimum earthquake loads.

4.3 Seismic design of non-structural elements

4.3.1 Chile

Although the Chilean code has provisions for the seismic design of non-structural components such as ceilings, light fixtures, partitions, services, equipment, façades and parapets, relatively little attention has been given to the seismic design of non-structural components in practice. The enforcement of these provisions is patchy as it is entirely at the discretion of the building owner.

4.4 Locally appropriate guidance on seismic assessment and retrofit

4.4.1 New Zealand

The New Zealand MoE provides further guidance for the assessment and retrofit of existing state school buildings. Existing buildings must be assessed against the seismic design loads that are enforced for the design of new buildings in the current building code, termed "New Build Standard" or NBS in the 2004 Building Act. Buildings assessed to have structural capacity less than 34% of NBS are deemed to be "earthquake prone", requiring retrofit or demolition within a specified timeframe. Existing state school buildings must exhibit sufficient strength to resist at least 67% of NBS seismic loads. Buildings with insufficient strength must be retrofitted to achieve at least this level of performance.

4.4.2 Japan

MEXT has published technical guides that provided guidance on technically sound and economical retrofit solutions for schools to adopt (Nakano 2004). In 2010, MEXT published the first edition of its seismic design guidebook for non-structural components in school facilities in order to help mitigate the often-unaddressed injury/life risks posed by improperly-secured, or inadequately-designed, non-structural components in school buildings such as ceilings, hanging lights/monitors, windows, shelves, doorways, AC units, large pieces of furniture, glazing (MEXT, 2015).

4.4.3 Peru

Peru's seismic code for buildings is well established and based on American codes and standards. In addition, Peru scores highly for 'quality of building regulations index' according to the World Bank Doing Business data which suggests the building code is accessible and requirements to obtain building permits are clear. In papers related to retrofitting buildings in Peru, American standards for existing buildings (FEMA, ASCE) are often referenced but it is likely local guidance also exists given the extent of past retrofitting programmes.

4.5 Regulatory process/assurance for schools

4.5.1 Peru

In Peru, for new construction the licensed design engineer must submit a design package of structural and architectural drawings and specifications for approval to the local authority. Then, the local authority will review and approve before issuing a permit for construction. The municipalities use both in-house engineers to perform the check as well as subcontracted private consulting engineers. It is not clear what the degree of detail of checking is performed or if all projects are checked before permits are approved. According to the 'World Bank Doing Business 2016' report, Peru scores highly for construction monitoring before, during and after construction which suggests that regulations and enforcement relating to monitoring have increased in the construction industry in Peru in the last few years. This will improve the construction quality for new buildings, but older buildings are likely to have been subjected to less scrutiny during construction. It is also important to note that corruption could influence the effectiveness of the regulatory process. Based on World Justice Project Data (2015), Peru is considered moderately corrupt in comparison to other countries.

4.5.2 New Zealand

New Zealand Engineers produce Producer Statement (PS) documents to confirm in their professional opinion that aspects of a building design comply with the Building Code, or that elements of construction have been completed in accordance with the approved building consent. These documents are not legally required by the 2004 Building Act but are usually required to be submitted to the Building Consent Authority (BCA), typically the city or regional council (local government office). Signatories of Producer Statements must be chartered professional engineers who are deemed to be licensed building practitioners under the Building Act. School buildings fall under the 2004 Building Act and require the same documentation as normal buildings in this regard.

4.5.3 Tonga

School buildings in Tonga require a building permit prior to construction like any other building. The building permit application requires a statement that the building meets the Nation Building Code of Tonga. The country doesn't have a formal registration system of Engineers, but most local engineers have international qualifications. In practice non-compliance of finished buildings is common caused in part by the lack of resources within the buildings authorities to ensure design compliance and non-conformance with design documentation.

4.6 Best practice, internationally recognized seismic codes and regulations

4.6.1 Japan

The Japanese seismic code is internationally recognized as promoting best practice for seismic design. The code has evolved over a long period in response to the historic experience of earthquakes in Japan: the first introduction of seismic design into building standards was made in 1924 after the Great Kanto Earthquake and since then, building standards were revised after every major earthquake. The code has been considered as a rigorous, modern seismic code since 1981. In addition, Japan has stringent building regulations for design and construction and a good track record of enforcement. Japan also has mature and cohesive land regulations for land use planning, zoning regulations and control of population density at the national, regional and local levels which take into account risk from natural hazards.

5 SUFFICIENT LOCAL SKILLS CAPACITY AND CAPABILITY

5.1 Engineering education and Engineering licensing

5.1.1 New Zealand

New Zealand has a strong local skills capacity in seismic engineering: earthquake-resistant design of structures is included in university undergraduate level engineering courses; and professional bodies such as Engineering New Zealand, and the New Zealand Society for Earthquake Engineering (NZSEE), promote ongoing professional training and advancement of the profession through facilitating a chartership registration process, and provide publications, seminars, and conferences.

5.1.2 Japan

Japan has stringent engineering licensing requirements for structural engineers and architects based on the completion of degrees in higher education as well as practical experience and an examination which tie into the regulatory framework for design and construction. Registered architects are allowed to design small buildings, but all other buildings must be designed and signed off by a registered structural engineer. The design must also be reviewed and approved by an independent third party registered structural engineer. These strict requirements for licensing combined with third party review and approval ensure that the seismic design codes and standards are properly adhered to and enforced.

5.2 Quality assurance during construction

5.2.1 New Zealand

In New Zealand, building consent authorities (BCA) are heavily involved with providing quality assurance for construction. They are responsible for issuing building consents, inspecting building work and issuing either notices to fix non-compliances or issuing compliance certificates and schedules. BCAs have varying capability and capacity; typically, this will be in direct relationship to the profile of building activity in their district. After the 2010 and 2011 earthquakes, the Canterbury Earthquakes Royal Commission Report found that while urban authorities have enough capacity and capability to carry out assurance for more complex projects, small to medium authorities could benefit from sharing resources with other authorities that do have the appropriate skills and capacity. Recommendations were also made by the commission to require a higher level of assurance for critical buildings including schools (based on size, occupancy and buildings intended post-disaster functions). This type of review after significant earthquakes of the capacity and capability in the regulatory environment related to quality assurance during construction is an example of best practice.

6 EFFECTIVE IMPLEMENTATION OF SCHOOL RISK REDUCTION INFRASTRUCTURE PROGRAMMES

6.1 Global Program for Safer Schools

The Global Program for Safer Schools (GPSS) is a World Bank program to boost and facilitate informed, large-scale investments for the safety and resilience of new and existing school infrastructure at risk from natural hazards, contributing to high-quality learning environments. The focus is primarily on public school infrastructure in developing countries. Funded by the Global Facility for Disaster Reduction and Recovery (GFDRR), the GPSS was launched in 2014, building on the experience and lessons learned from the World Bank's safe school projects in countries such as Colombia, Philippines, and Turkey. Currently, the World Bank is implementing the Global Program for Safer Schools in the Pacific in Samoa, Tonga and Vanuatu. The risk assessment considers seven natural hazards including earthquake ground motions, tsunami, and liquefaction.

6.2 Country Programmes

6.2.1 Peru

Peru has successfully completed a series of model school construction programmes and has incorporated lessons learned from past earthquake events to improve the safety of their model schools over time as well as successfully retrofit older schools where vulnerabilities have been identified. Most recently, the Ministry of Education, through the National Educational Infrastructure Program (PRONIED) has been creating a strategy to improve existing vulnerable school infrastructure in Peru, including addressing seismic safety (World Bank, 2015). This has included developing the first countrywide school infrastructure inventory and undertaking a seismic risk assessment at country level in order to identify schools at risk and prioritise the schools that require seismic rehabilitation.

6.2.2 New Zealand

New Zealand has carried out a series of successful school risk reduction programmes, some of which are ongoing. Between 1998 and 2001, the MoE commissioned a survey of the country's school inventory (approximately 23,500 buildings). All two-storey and higher, pre-1976 buildings were evaluated using a rapid evaluation method and assessed for specific structural defects that may cause loss of life or serious injury. A small number of buildings were found to have unacceptable structural defects and were corrected immediately while 11% were found to have some defects requiring remedial work. The objectives of the program are to identify at-risk schools (public and private), and arrange improvements based on the lateral strength of the buildings, with weaker buildings taking priority. The programme has also developed guidance for new school designs as well as retrofit of existing schools.

6.2.3 Japan

Since the 1995 Kobe Earthquake, Japan has focused on, and invested heavily in, retrofitting its vulnerable structures (with schools as one of the priorities) to bring them into compliance with modern, post-1981 seismic standards (Glanz & Onishi 2011). In 1996 the Japanese government launched a five-year program to upgrade vulnerable buildings and infrastructure throughout the country, and due to the importance of the retrofitting work the program was extended for another five years from 2001-2005. Making schools earthquake-resistant has been a long-time effort of the MEXT and local governments. From the viewpoints of MEXT, promoting earthquake-resistant school buildings is not a time-limited program but is the on-going effort with constantly updated priorities by incorporating feedback from earthquake experience and technical advancement. To date over 73,000 school buildings have been seismically retrofitted to bring them into compliance with modern, post-1981 seismic standards. MEXT assisted the school seismic upgrading efforts by contributing to a subsidy program for local school districts, and publishing technical guides that provided guidance on technically sound and economical retrofit solutions for schools to adopt (Nakano 2004).

6.2.4 Chile

After the 2010 earthquake damaged ~4,000 schools, the Government implemented a four-year reconstruction plan that aimed to recover all damaged or destroyed infrastructure. Subsidies were given directly to schools for the purpose of rebuilding or repairing their infrastructure. Private schools were excluded from the process and only public and voucher schools were eligible to receive reconstruction funds. The Preventative Plan is part of an on-going School Infrastructure Strategic Plan, which aims to strengthen public education at approximately 2,000 educational establishments. Improve conditions of school infrastructure to ensure safety conditions, hygiene, health and living conditions. Interestingly, seismic upgrades are not listed as a key objective of the program. This maybe because of the long acceptance and incorporation of seismic design in the construction practice.

7 CONCLUSIONS

Significant advances in knowledge have been made in the past 30 to 40 years in seismic hazard assessment, the seismic design and performance of buildings, and how to improve performance through cost-effective retrofitting techniques. This knowledge has been applied through periodic updates of building codes, the publication of building assessment and retrofit guidelines, provision of training to engineers and government officials, and rigorous independent auditing of designs and construction practices to ensure they follow best practice. These standards also inform engineers and owners/operators about the level of vulnerability of buildings. Governments can use this knowledge to assess their existing school stock to determine which buildings most urgently need to be retrofitted or replaced and ensure that the same mistakes are not repeated in the construction of new school buildings.

To highlight best practices and challenges in earthquake resilient school infrastructure key and contrasting approaches from seven countries across the Pacific (Australia, Chile, Japan, New Zealand, Peru, and Tonga) with varying levels of seismic hazard, earthquake engineering practice and school infrastructure have been presented. Review of these approaches can provide insights into the seismic resilience of existing school buildings and encourage Government regulators and engineering practitioners to implement programmes and practices that have been demonstrated to result in earthquake resilient construction going forwards.

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