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PERFORMANCE OBJECTIVES FOR NON-STRUCTURAL ELEMENTS

Helen Ferner[1], Rob Jury[2], Andrew King[3], Martin Wemyss[4] and Andrew Baird[5]

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ABSTRACT

The recent earthquakes in New Zealand have raised awareness of the seismic vulnerability of non-structural elements and the costly consequences when non-structural elements perform poorly. Impacts on business continuity due to the damage of non-structural elements has been identified as a major cost and disruption issue in recent earthquakes in New Zealand, as well as worldwide. Clearly improvements in performance of non-structural elements under earthquake loads will yield benefits to society.

This paper explores the intended and expected performance objectives for non-structural elements. Possible historic differences in performance objective expectations for non-structural elements between building services engineers, fire engineers and structural engineers are discussed. Wider construction industry expectations are explored along with our experience of client and regulatory authority views.

The paper discusses the application and interpretation of the New Zealand earthquake loadings Standard NZS1170.5:2004 for the design of non-structural elements including possible differences in interpretation between building services, structural and fire engineers leading to confusion around the expected performance of non-structural elements under different limit states. It is based on the experience of several of the authors as members of the Standards committee for NZS1170.5:2004.

The paper concludes by discussing changes to NZS1170.5:2004 the authors have proposed as members of the NZS1170.5 Standards committee to clarify and address the identified issues. These changes clarify the classification of parts, requirements for consideration earthquake imposed deformations, parts supported on ledges, potential falling of parts, the combination of fire and earthquake loads, and the requirement for parts to be designed for both serviceability and ultimate limit states along with the effective introduction of a serviceability limit state for parts for occupational continuity.

INTRODUCTION

The 2010/2011 Christchurch earthquakes and the more recent 2013 Lower North Island earthquakes at Cook Strait, Lake Grassmere and Castlepoint illustrated the vulnerability of building non-structural elements (e.g. ceilings, cladding, partitions, building services equipment and piping, etc.). Widespread damage and loss of business continuity due to the poor performance of non-structural elements was widely observed and noted [1, 2, 3].

The Canterbury Earthquakes Royal Commission [4] identified the need to improve the performance of non-structural elements in earthquakes with one of the recommendations (recommendation 70) focussed on improving non-structural element performance.

> *"To prevent or limit the amount of secondary damage, engineers and architects should collaborate to minimise the potential distortion applied to non-structural elements. Particular attention must be paid to prevent the failure of non-structural elements blocking egress routes."*

We are observing that, as a result of the damage in the recent earthquakes, building owners and tenants undertaking building construction work are increasingly asking about the likely seismic performance of non-structural elements and potential impacts on their businesses and facilities including business continuity impacts.

In response, structural, building services and fire engineers, as well as contactors are reviewing their designs, specifications and construction practices relating to non-structural elements. We have identified differences in interpretation in the earthquake loadings Standard NZS1170.5:2004 [5] between the different design disciplines mentioned above. We observe that these differences in interpretation are being then applied to the Standards dependent on NZS1170.5:2004 for seismic actions. These include NZS4219:2009 Seismic Performance of Engineering Systems in Buildings [6] and NZS4541:2013 Automatic Fire Sprinkler Systems [7], as well as the associated industry codes of practice for the various non-structural elements.

OBJECTIVES FOR NON-STRUCTURAL ELEMENTS IN NZS1170.5:2004

Earthquake / Seismic Actions

NZS1170.5:2004 (herein referred to as "the Standard") was drafted with the objective that buildings achieve a level of performance during earthquakes so that, as noted in the Standard Commentary [8] clause 2.1:

[1] *Technical Director – Structural Engineering, Beca Ltd, Auckland, helen.ferner@beca.com (member)*
[2] *Senior Technical Director – Structural Engineering, Beca Ltd, Wellington, rob.jury@beca.com (life member)*
[3] *Engineering Risk Specialist, GNS, a.king@gns.cri.nz, (life member).*
[4] *Technical Director - Building Services, Beca Ltd, Auckland, martin.wemyss@beca.com.*
[5] *Structural Engineer - Beca Ltd, Auckland, andrew.baird@beca.com (member).*

"Frequently occurring earthquake shaking can be resisted with a low probability of damage sufficient to prevent the building from being used as originally intended; and

The fatality risk is at an acceptable level."

It is generally accepted fatality risk will only be present if a building collapses or if heavy elements, like facades or cladding fall from buildings. Because building collapse is very difficult to define, with inherent uncertainties and many variables [9] the Standard defines and uses a lower level of structural response where structural performance can be more readily predicted; the ultimate limit state (ULS). The ultimate limit state is defined in the Standard clause 2.1.4 (a) as:

(i) "Avoidance of collapse of the structural system

(ii) Avoidance of collapse or loss of support to parts of categories P.1, P.2, P.3 and P.4 (Section 8) (See Table 2 of this paper) *and*

(iii) Avoidance of damage to non-structural systems necessary for emergency building evacuation, that renders them inoperative."

The New Zealand Loadings Standard, AS/NZS1170.0:2002 [10] was drafted to include two serviceability limit states in addition to the ultimate limit state. Serviceability Limit State 1 (SLS 1) defines the limit at which:

"the structure and the non-structural components do not require repair"

and Serviceability State 2 (SLS2) defines the limit at which:

"the structure maintains operational continuity.".

AS/NZS1170.0:2002 [10] provides the general design criteria for buildings, including categorising the importance level (IL) depending on the consequences of failure. IL3 and IL4 buildings are those with a **high** consequence for loss of human life or **very great** economic, social or environmental consequences. IL4 buildings are those structures with special post disaster functions and IL3 are major structures (affecting crowds). IL2 buildings are those with a **medium** consequence for loss of human life or **considerable** economic, social or environmental consequences i.e. normal structures.

SLS2 is defined as only applying to IL4 buildings; those buildings with special post disaster facilities. The Standard notes in clause 8.1.2 it is only those systems within the building that are essential to fulfil the buildings designated special post-earthquake function. This reflects the importance of essential facilities to remain operational in the immediate post-earthquake environment.

The intention for IL3 buildings (buildings with crowd loads) is to reduce the probability of building failure (collapse) by increasing the ULS loading to a 1 in 1000 year earthquake event compared with a normal use (IL2) building but without including an additional serviceability requirement beyond that for a normal use building.

The objectives of the Standard were thus defined by these limit states and building importance levels: namely protection of life in the event of a significant earthquake; continued use of the structure as originally intended following frequently occurring earthquakes; and operational continuity under less frequent earthquakes for those buildings with special post disaster functions.

The design ground motion annual probability of exceedance for ultimate limit and serviceability states for buildings with a 50 year design life with different importance levels are presented in Table 1.

Table 1: Design Ground Motion Annual Probability of Exceedance [10]

Importance Level	Design Loads Annual Probability of Exceedance		
	ULS	**SLS1**	**SLS2**
IL1	1/100 (~40% in 50 years)	-	-
IL2	1/500 (~10% in 50 years)	1/25 (~ 90% in 50 years)	-
IL3	1/1000 (~5% in 50 years)	1/25 (~ 90% in 50 years)	-
IL4	1/2500 (~2% in 50 years)	1/25 (~ 90% in 50 years)	1/500 (~10% in 50 years)

Parts and Components

Parts are defined in the Standard Commentary [8] as:

"an item within, or attached to, or supported by the structure"... and *"not generally included in the design of the primary load resisting system".*

As presented in Table 2, parts are classified by seven different categories. These define design actions imposed by different limit states and part risk factors. They range from ULS for parts categories P.1, P.2, P.3 and P.4: parts hazardous to life outside the structure; crowds within the structure; individuals within the structure; and parts necessary for the continuing function of the evacuation and life safety systems within the structure. SLS2 applies to parts category P.5: parts required for the operational continuity of the structure and only applicable to IL4 structures. SLS1 applies to parts categories P.6 and P.7 i.e. all parts not otherwise categorised but with different risk factors between the two parts categories.

The intent of the Standard was that parts defined as essential for the operational continuity of buildings with special post disaster functions (IL4 buildings) be designed to remain operational under demands generated by a 1 in 500 year earthquake event. Examples of P.5 parts provided in the Standard Commentary include communications equipment in fire, ambulance and emergency management facilities; appliance exit doors in ambulance and fire stations, and operating facilities; emergency lighting and reticulation facilities in major hospitals.

The Standard also recognised that in some instances a building part may cause consequential damage by its failure that is disproportionately great and so included a P.6 category. The P.6 category was noted as intended to apply to special circumstances where building owners have specific commercial requirements necessitating higher values than for typical IL2 or IL3 buildings. Examples included in the Standard Commentary include a chiller in a freezer installation, or a water pipe above perishable goods. The practical effect of this part category designation is to increase the SLS1 design ground motion return period from 1 in 25 years to 1 in 100 years for design of that part thus increasing its resilience in the event of an earthquake. It is effectively an additional serviceability limit state.

Thus the Standard was drafted to provide for different levels of earthquake loads on parts in a building depending on the importance level of the building and the importance of the part for the functionality of the building post-earthquake as summarised in Table 2.

Table 2: Summary of Seismic Criteria for Parts and Components from NZS1170.5:2004 [5]

Part Category	Description	Building Importance Level Return Period Earthquake Event			Limit State Design Criteria
		IL2	IL3	IL4	
P.1	Part representing a hazard to life outside the structure.	1/500	1/1000	1/2500	ULS, Avoidance of collapse or loss of support
P.2	Part representing a hazard to a crowd of greater than 100 people within the structure.	1/500	1/1000	1/2500	ULS, Avoidance of collapse or loss of support
P.3	Part representing a hazard to individual life within a structure.	1/500	1/1000	1/2500	ULS, Avoidance of collapse or loss of support
P.4	Part necessary for the continued function of the evacuation and life safety systems within the structure.	1/500	1/1000	1/2500	ULS, Avoidance of collapse or loss of support
P.5	Part required for operational continuity of the structure	-	-	1/500	SLS2, Operational continuity maintained
P.6	Part for which the consequential damage caused by its failure are disproportionately great	1/100	1/100	1/100	SLS1, No repairs required
P.7	All other parts	1/25	1/25	1/25	SLS1, No repairs required

INCONSISTENCIES IN APPROACH

Ultimate Limit State and/or Serviceability Limit State

Based on observation of industry practice and discussions with design practitioners and contractors it has become apparent that the design criteria for parts in the Standard are open to misinterpretation. For example, it is not clear when, or indeed if, parts have to be designed for both a serviceability limit state and the ultimate limit state. This has led to inconsistencies in approach and raises questions such as:

- Do parts defined as P.2; parts representing a hazard to a crowd, also need to be designed to avoid damage so they don't require repair in a 1 in 25 year earthquake?
- Do parts defined as P.7; all other parts, have to be designed for anything more than no repairs required in a 1 in 25 year earthquake event with no regard to their performance in a more significant earthquake event?

Ceilings provide a useful example. The Standard's Commentary provides several examples of parts categories for different ceiling types. Auditorium ceilings are provided as an example for parts category P.2 parts representing a hazard to a crowd and light suspended ceilings are an example of parts category P.7.

The Standard clause 8.1.2 notes that for elements to be considered parts categories P.1, P.2 and P.3, where the limit state is defined as ULS, the part must weigh more than 10 kg and be able to fall more than 3 metres onto a publicly accessible area.

The designers of suspended ceiling systems, manufacturers and ceiling contractors have sometimes interpreted the Standard to mean that provided a single ceiling tile weighs less than 10 kg, the ceiling system is defined as lightweight, and therefore the ceiling is required to be designed under P.7 parts category only; i.e. for a SLS1 design load; a 25 year return period earthquake with no repairs required.

This approach ignores that a part may be required to be designed for several parts categories. A ceiling system as a whole, which will weigh more than 10 kg, must also, for example, be designed for avoidance of collapse or loss of support under parts categories P.2 or P.3 for publicly accessible areas.

This approach also ignores that the seismic performance of non-structural elements are often inter-dependent. For example, the performance of suspended ceilings is influenced by in-ceiling and above ceiling services and vice versa [11]. This complexity is exacerbated by the fact that the different components may have a different parts classification(s) defining performance objectives and design criteria. It ignores, for example, that often many of the fire life safety components are ceiling mounted and dependent on suspended ceilings for support potentially driving the seismic design criteria for the ceiling system.

Again this suggests inconsistencies in approach between different design disciplines when considering non-structural elements.

These potential contradictions point to differences in interpretation of the Standard between different engineering disciplines and crucially differences in performance expectations between different design disciplines for both ULS and SLS level earthquakes. It also suggests that each design discipline is considering the issues pertaining to non-structural systems for their design discipline in isolation.

Emergency Evacuation and Life Safety Systems

Fire and building services engineers operate within a slightly different paradigm and from a different viewpoint than structural engineers. Our experience is that "*emergency building evacuation*" in the definition of ultimate limit state requirements in the Standard is interpreted as "*fire emergency building evacuation"* by fire and building services engineers. Hence they interpret the Standard as requiring avoidance of damage to non-structural elements associated with fire emergency evacuation following an ULS earthquake event.

NZS 4219:2009 – Seismic Performance of Engineering Systems in Buildings [6], NZS 4541:2013 – Automatic Fire Sprinkler Systems [7] and NZS 4510:2008 – Fire Hydrant Systems for Buildings [12] have all interpreted the P.4 definition in the Standard "*parts necessary for the continuing function of the evacuation and life safety systems within the structure*" as including fire related emergency building evacuation systems.

NZS 4541:2013 clause 105.1 notes:

> *"All sprinkler components shall be designed, detailed and installed so as to remain operational at the ultimate limit state (ULS) earthquake."*

NZS 4219:2009 notes in Appendix B Component Classifications that P.4 components include emergency lighting, emergency power supply, fire door and fire fighting system (including smoke extraction).

Hence the New Zealand standards pertaining to building services and fire systems in buildings require sprinkler systems, hydrant systems, fire detection alarm systems, emergency lighting, exit signage, smoke curtains, stairwell / lift shaft and zone pressurisation systems and their associated power and controls to be categorised as P.4 and designed for a ULS level earthquake.

This is all based on the assumption that the Standard requires designers to consider the combination of fire and earthquake for the ULS event.

It also raises further questions around the interdependency issues between the multitude of structural and non-structural components within a building, as well as services and other related infrastructure outside the building which support the building's operations following an earthquake. For example:

- To what extent should the operational continuity of the sprinkler systems in a building following an ULS earthquake be dependent on the on-going supply from the town water supply system? The recent Christchurch earthquakes illustrated the vulnerability of underground services particularly in areas subject to liquefaction.
- Will fire doors and fire stopping of services penetrating fire separations be operable and maintain their fire stopping integrity after an ULS earthquake?
- Will the ceiling system maintain sufficient integrity in an ULS earthquake for the continued support and operability of the life safety systems that it supports e.g. emergency lighting, exit signage, fire protection and alarm systems?
- What are the requirements for ceiling support system compared with the requirements for support of individual tiles?

Vertical Loads

The 22 February 2011 Lyttelton earthquake included the highest ever recorded vertical accelerations worldwide; 2.2g in the Heathcote Valley [13]. While consideration of vertical seismic loads is defined within the Standard, it does not feature in NZS4219:2009. This leads designers of non-structural bracing systems to ignore consideration of vertical earthquake loads when designing seismic bracing for non-structural elements. Wire hangers to support non-structural elements are common as a result.

While specific design for vertical loads might not be required, recognition that they can occur is necessary to ensure that the support systems are appropriately configured.

SOCIETAL EXPECTATIONS

As previously noted, the Standard was drafted with the objectives that buildings achieve a level of performance during earthquakes so that:

> *"Frequently occurring earthquake shaking can be resisted with a low probability of damage sufficient to prevent the building from being used as originally intended; and*
>
> *The fatality risk is at an acceptable level."*

This reflects societal expectations that people do not expect or anticipate damage to buildings or the non-structural parts or components within buildings except in the event of a major earthquake. The cost and disruption resulting from the recent Seddon, Lake Grassmere and Castlepoint earthquakes due to non-structural element damage have been widely noted with concern that they arguably did not meet societal expectations. This suggests that the current serviceability limit state SLS1 earthquake event, the 1 in 25 year earthquake where the structure and non-structural parts and components do not require repair, may be set at too low a level to ensure that societal expectations around being able to continue to occupy a building following shaking above SLS1 levels are met.

At the same time, setting performance objectives for non-structural elements, such as fire protection systems, that are higher than, and inconsistent with, the structural performance objectives for buildings as a whole at the ULS level earthquake will not provide the anticipated performance for the non-structural elements in an earthquake. It may instead provide a false set of performance expectations. It may imply to some design professionals, early responders, (Police, Fire Service and the like), as well as society generally, that buildings are designed for both earthquake and fire at the ULS level earthquake event. This could potentially have tragic consequences if, for example, early responders base their plans on this assumption.

Alignment is required between the engineering design disciplines to achieve consistency in design, as well as consistent unambiguous design Standards. It also requires engineers to consider the issues holistically rather than strictly on an element by element basis within an individual discipline.

WAY FORWARD

In order to address the identified inconsistencies of interpretation and better meet societal expectations, revisions for parts and components have been proposed to the Standard by the authors, as members of the Standards committee revising NZS1150.5, to clarify and address:

- Combination of fire and earthquake loads,
- Classification of parts,
- Requirements for design for combinations of ultimate and serviceability limit states,
- Occupational use requirements,
- Earthquake imposed deformations,
- Parts supported on ledges, and
- Potential falling of individual parts.

These changes are proposed to be implemented in a multistep process. The initial step will be to make limited modifications to the Standard. It is expected these will be issued in the revisions currently in preparation.

It is proposed these amendments will be followed by a wider review of NZS1170. It is anticipated that changes to the associated Standards will then follow as they in turn are reviewed.

Combination of Fire and Earthquake

The objective of these revisions is to clarify the original intent of the Standard when it was drafted, that NZS1170.5:2004 clause 2.1.4 (a) refers to emergency evacuation following an ultimate limit state earthquake only, not a combination of fire and earthquake. This is based on the rationale that fire is not expected to follow so soon after earthquake shaking that it needs to be a consideration in the immediate evacuation from a building following an earthquake.

The revisions will make clear that the P.4 parts category in NZS 1170.5:2004 Table 8.1 relates to parts and components that are required for the evacuation of a structure after an earthquake and for human life support systems within the structure. This includes, for example, stairs and emergency lighting in escape routes (but not exit signage), partitions adjacent to an egress way, as well as rescue systems and life support systems. It also clarifies that sprinkler systems, hydrant systems, fire detection and alarm systems, smoke curtains, stairwell / lift shaft and zone pressurisation systems and their associated power and controls are not intended to be categorised as P.4. Any of these items could still be required to be categorised as P1, P2 or P3 if loss of vertical support leading to a life safety hazard was possible.

While it may appear this will result in a less conservative approach than is currently articulated in NZS4219:2009 and NZS4541:2013, it better reflects expected building performance in earthquakes and will result in the same level of life safety protection as effectively provided currently. It will also result in less cost for the design of the parts associated with fire egress as these will no longer required to be designed for operational continuity in an ultimate limit state earthquake, something the building itself is not required to be designed for.

This change will have the effect over time of changing NZS4541:2013 and NZS4219:2009 to reflect the objectives of the Standard clarifying that fire protection systems are not typically required to be designed for operational continuity under an ULS event earthquake.

Classification of Parts

As part of the revisions, the definitions of several of the parts' categories are proposed to change. This change simplifies Table 8.1 of the Standard by eliminating the different part risk factors for P.2 and P.3 and combining these into a single category; represents a hazard to human life within a structure. The part risk factor R_p=1.0 will apply for this combined category.

The notes for this combined category are also proposed to change so that it is clear the category does not just apply to publicly accessible areas. This reflects the original intent that the restraint of parts under the ultimate limit state needs to be considered where the part represents a hazard to human life within the structure i.e. for all areas where people are typically present. This change is summarised in Table 3 below.

Combinations of Ultimate and Serviceability Limit States

The amendments to the Standard underway at present are intended to clarify the original intent of the Standard that parts are required to be considered for both ultimate and serviceability limit state loadings under several part categories and are required to be designed for the combination of the most severe load case(s).

Thus it will be clarified that a part, such as a stair flight in an IL4 building with a sliding detail, needs to be considered under parts categories P.2/P.3, P.4, P.5 and P.7. The part represents a hazard to life within the structure if it fails. The part is required for the function of the evacuation system in the event of a significant earthquake. Both these design criteria are for the ultimate limit state 1 in 2500 year earthquake with provision for ductility of the part, if appropriate. The part is required for the operational continuity of the structure under a SLS2 1 in 500 year earthquake, again with provision for ductility if appropriate, and the part is required to be designed to not require repair under a SLS1 1 in 25 year earthquake.

It is intended the later wider review will investigate if these concepts can be expressed in a simpler more straightforward manner while retaining the concept that, like structures, parts need to be considered for both serviceability and ultimate limit state earthquakes.

Occupational Use Requirements

The proposed revisions to the Standard introduce an operational continuity requirement for all structures, not just IL4 structures, to address concerns that the SLS1 requirements, on their own, do not provide sufficient confidence that the parts will perform to acceptable levels for shaking between SLS1 and ULS levels. It has become clear that design for SLS1 alone is set at too low a level to meet societal expectations in this regard.

It is proposed that parts category P.5 will apply to all building importance levels with a SLS 2 limit state criteria: operational continuity maintained but with different return periods depending on the importance level of the structure. The SLS2 limit state allows some ductility as appropriate, recognising some limited damage may occur, but that the part should be operational after only limited repairs.

Table 3: Summary of Seismic Criteria for Parts and Components proposed for the amended Standard

Part Category	**Description**	**Building Importance Level Return Period Earthquake Event**			**Limit State Design Criteria**
		IL2	**IL3**	**IL4**	
P.1	Represents a hazard to life outside the structure.	1/500	1/1000	1/2500	ULS, Avoidance of collapse or loss of support
P.2 and P.3	Represents a hazard to human life within a structure.	1/500	1/1000	1/2500	ULS, Avoidance of collapse or loss of support
P.4	Necessary for the continued function of the evacuation (after earthquake) and human life support systems within the structure.	1/500	1/1000	1/2500	ULS, Avoidance of collapse or loss of support
P.5	Required for operational continuity.	1/100	1/200	1/500	SLS2, Operational continuity maintained
P.6	Part for which the consequential damage caused by its failure is disproportionately great	1/100	1/100	1/100	SLS1, No repairs required
P.7	All other parts	1/25	1/25	1/25	SLS1, No repairs required

In the case of IL4 structures operational continuity without repairs, is intended to be the outcome as has been the case hitherto. The notes for this parts category in the proposed revisions to the Standard will make this change clear.

It is proposed that the part risk factor R_p for parts category P.5 will be revised to $R_p = R_u/2$ (based on the existing SLS2 for IL4 1 in 500 year return period earthquake) as part of the initial revisions underway at present. This change will have the effect introducing SLS2 considerations with a return period of approximately 1 in 100 years for IL2 buildings, 1 in 200 years for IL3 buildings and 1 in 500 years for IL4 buildings as presented in Table 3.

The proposed revisions to the Standard will also make clear that the P.5 parts category relates only to those parts within a structure required for operational continuity following an earthquake. Examples requiring consideration under the P.5 parts category (in addition to consideration under other parts categories) include those parts and components required for means of escape from fire, critical plumbing systems, electrical systems, and lifts. Other examples include battery racks required for post disaster operations within IL4 buildings as well as communications equipment in Fire, Ambulance and Emergency Management facilities, appliance exit doors in Ambulance and Fire Stations and operating facilities, essential lighting and reticulation facilities in major hospitals.

It is also proposed to modify and clarify parts category P.6 so that it is clear that it applies when the consequential damage caused by the failure of the part or component is determined to be disproportionally great. This is not intended to be a discretionary choice. An example are fire sprinkler pipes above a ceiling which, if one failed, could flood the office space below with resulting water damage and potentially collapse of the ceiling system, causing disproportionally higher consequential damage compared with the initial pipe failure.

The part risk factor R_p is not proposed to change for parts category P.6 from existing so that the SLS1 ground motion return period for this part category designation remains at 1 in 100 years for design of that part or component.

Thus a fire station (IL4 building) will require the stairs to be considered under P.2/P.3, P.4, P.5 and P.7 categories as noted above. Any lifts will need to be considered under P.2/P.3, P.5 and P.7 categories i.e. ULS avoidance of collapse for loss of support under a 1/2500 earthquake, SLS2 operational continuity under a 1/500 year return period earthquake with provision for ductility as well as no repairs required under a 1/25 year earthquake with little or no requirement for ductility.

The appliance exit doors of a fire station will need to be considered under P.5 as well P.2/P.3 and P.7. These are required for operational continuity of the structure under a SLS2 1 in 500 year earthquake, with provision for ductility if appropriate. They also present a hazard to human life if their support failed and so are required to be designed for a 1 in 2500 year return period ULS limit state earthquake with provision for ductility if appropriate. The services systems throughout the building will need to be considered under P.2/P.3 (unless the part is less than 5 kg and would fall less than 3 m or is appropriately tethered), P.5 and P.6 or P.7. In addition, any services required for evacuation after earthquake, such as the emergency lighting in the building escape routes, will need to also be considered under parts category P.4.

In-ceiling fancoil units or water pipes and the like in a fire station will be required to be designed for P.6; SLS1 no repairs required under a 1 in 100 year earthquake as if they failed the consequential damage caused by their failure would be disproportionately great while electrical and data cabling will be required to be designed under parts category P.7; SLS1 no repairs required under a 1 in 25 year earthquake.

A public assembly building (IL3 building) will require the partitions adjacent to an egress way, for example, to be designed for P.2/P.3 and P.4; ULS avoidance of collapse or loss of support under a 1 in 1000 year earthquake with provision for ductility, as well as P.5; SLS2 required for operational continuity under a 1 in 200 year earthquake and P.7; SLS1 no repairs required under a 1 in 25 year earthquake.

An office building (IL2 building) will require the services systems necessary for operational continuity to be considered under category P.5, SLS2 operational continuity maintained in a 1 in 100 year return period earthquake. These parts will also be required to be designed under category P.2/P.3 (unless the part is less than 5 kg and would fall less than 3 m or is appropriately tethered) for avoidance of collapse or loss of support under ULS loading for a 1 in 500 year earthquake event and P.6 or P.7 depending on whether their failure would cause disproportionately large consequential damage. Any services system necessary for evacuation would also have to be considered under parts category P.4.

Ceiling systems throughout an IL2 office building will be required to be considered under categories P.2/P.3 for ULS under a 1 in 500 year earthquake and P.7 for SLS1 under a 1 in 25 year earthquake. It will also be considered under parts category P.5 for SLS2 under a 1 in 100 year earthquake unless the ceiling system is one where any lights, sprinkler heads or other items supported by the ceiling system cannot be damaged to an extent that the occupational continuity is affected even if the ceiling system grid is damaged. If the ceiling is supporting a part required for evacuation after an earthquake e.g. emergency lighting it will also be required to be considered under P.4; ULS under a 1 in 500 year earthquake.

The individual ceiling tiles, if under 5 kg each and with a fall potential of less than 3 m, will be required to be considered under parts category P.7 for SLS1 loading under a 1 in 25 year earthquake only. If the individual tiles could fall more than 3 m or are 5 kg or heavier they would have to be considered under parts category P.2/P.3 also i.e. ULS loading under a 1 in 500 year earthquake unless appropriately tethered. If an individual tile is supporting other services then it will also have to be considered under P.4 and/or P.5 as appropriate.

Earthquake Imposed Deformations

The amendments to the Standards underway make it clear that all parts of structures and non-structural components and their connections are required to be designed for earthquake actions and also the secondary stresses induced by deflection induced actions and differential displacements. Alternatively, they must be seismically separated to avoid displacement induced actions.

Parts Supported on Ledges

A new section is introduced to address parts supported on ledges based on learnings from the recent Christchurch earthquakes. Experience has shown that parts and components supported on ledges are particularly vulnerable in earthquake shaking as once the sliding exceeds the available ledge length the failure is both sudden and complete with potentially severe ramifications[14].

The Standard is being modified to make it clear to designers that all ‘secondary’ sources of lateral displacement that could potentially reduce the supporting ledge length are required to be added to a factored differential lateral displacement determined between the sliding and fixed supports. Examples include movements due to temperature change, creep and shrinkage in both the part and the structure, construction tolerances, reduction in ledge length due to spalling, foundation soil deformations, displacements arising from elongation or rocking of structural members and rotation of the structural members supporting the ledge.

The objective of this change is to avoid failures of precast stairs and the like as observed in the Christchurch earthquakes. It formalises MBIE Practice Advisory 13 [15] into the Standard.

Potential Falling of Individual Parts

A review of the performance of parts within buildings in the recent earthquakes highlighted many instances where elements hung from the floor above or roof failed including, for example, various ceiling systems and building services systems [16, 17].

The amendments to the Standard revise the requirements for hung elements by reducing the weight of an individual part that needs to be considered to 5 kg from the present 10 kg. The aim is to reduce the risk to life safety of falling parts in the event of an earthquake.

The revisions to the Standard provide for tethering as an alternative means of complying so as to avoid parts becoming a hazard in an ULS event and meet the code objective that buildings achieve a level of performance during earthquakes do that *"the fatality risk is at an acceptable level"*.

CONCLUSIONS

A combination of a lack of focus on the seismic performance of non-structural elements by engineers, architects, contractors and subcontractors and a history of low expectations has resulted in generally poor performance of non-structural elements of buildings in earthquake in New Zealand as illustrated by the recent earthquakes.

This situation has not been assisted by differences in performance objective expectations between the different design disciplines as well as confusion and inconsistencies between the different documents guiding designers and constructors as to the requirements.

Improvement is possible and will be assisted by the proposed revisions to the Standard to make the performance objectives and design requirements for non-structural elements clearer and more consistent.

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