AS1170.4 Special Study Requirements for Importance Level 4 Buildings and Facilities

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Abstract

The 2007 edition of AS1170.4, referenced by the National Construction Code (NCC) in 2009, introduced a significant new design requirement to Australia. Since then, designers of Importance Level 4 structures and facilities have been required to undertake a "special study" to demonstrate that the structure or facility will remain "serviceable for immediate use" following a moderate earthquake event. Importance Level 4 structures and facilities generally have a post-disaster role, or they store hazardous materials. Examples include major hospitals, emergency response agencies and critical infrastructure.

There is currently little or no guidance available to designers on how to undertake a special study and beyond stating a performance objective, the Standard itself is silent on the specific requirements of the study. Consequently, in practice, compliance with the requirement is highly variable and generally poor. This is probably one of the most poorly understood design requirements in the suite of Australian Standards regularly used by designers. This paper seeks to demystify the special study for designers and proposes a strategy for undertaking such a study. The suggested procedure has been included in the recently updated Commentary to AS1170.4 published by the AEES.

Keywords: #AS1170.4 #Special Study #Importance Level 4 #Post-Disaster

1 Purpose of a Special Study

Clause 2.2 of AS1170.4 – 2007 requires a "special study" to be carried out for Importance Level 4 structures and facilities. Importance Level 4 structures include facilities such as hospitals that have a specific post-disaster role, or buildings that house hazardous materials which need to be contained. The special study's purpose is to demonstrate that these structures will remain "serviceable for immediate use" following an earthquake event equivalent to that which would usually be required for the strength design of an Importance Level 2 structure located at the site. The general intent is to demonstrate that Importance Level 4 structures and facilities can remain operational to fulfill their post-disaster role following a moderate earthquake.

Importance Level 4 structures and facilities must therefore be explicitly designed for two distinct earthquake events:

a. **Ultimate Limit State (ULS)** earthquake, which considers a large, rare event, with a low annual probability of exceedance (i.e., long return period), for which the primary design objective is to preserve the lives of building occupants and those near the structure. It is envisaged that both the structure and its contents will suffer significant damage during the ULS event, but that collapse of the structure and loss of life will be prevented. There is no ongoing operational performance requirement associated with this design scenario, however non-structural parts and components must still be properly designed for the ULS earthquake actions and able to accommodate the design inter-storey drift of the structure associated with that event.

b. **Serviceability Limit State (SLS)** earthquake, which considers a moderate earthquake with a higher annual probability of exceedance equivalent to that required for Importance Level 2 structures, after which the structure or facility is required to remain serviceable for immediate use. During such an event, some minor damage is acceptable provided it is easily repairable and that such damage will not interfere with the ongoing operation or function of the structure or facility. The NCC currently nominates that the SLS event considers an earthquake with an annual probability of exceedance of 1 in 500.

   In some circumstances, a building owner may request that an Importance Level 2 or 3 facility be designed to remain operational following an earthquake. In this instance the requirement from the building owner exceeds the minimum standard required by the NCC (and AS 1170.4), and as such, no specific guidance is provided in the Standard. Irrespective, the special study outlined below (for Importance Level 4 facilities) is recommended to be adopted in this instance. The return period adopted for the serviceability event should be decided in conjunction with the building owner and/or with relevant stakeholder engagement. Further advice on this issue can be found in the Commentary to AS1170.4 published by the AEES.

2 Origin of the Special Study

The 1971 San Fernando earthquake provided the initial trigger for significant changes to public policy and our approach to designing post-disaster facilities. A detailed review of hospital safety and performance which followed that earthquake culminated in an Act being issued by the State of California in 1972, introducing for the first time the stated intent that future “hospitals…must be [designed to remain] completely functional to perform all necessary services to the public after disaster”. Reitherman (2020) reproduces and discusses a speech made by Karl Steinbrugge in California during 1973 that provides further insight into the thinking of the day.

Here in Australia, our initial foray into earthquake engineering followed the 1968 Meckering earthquake in Western Australia with the publication of AS 2121 – 1979, *The design of earthquake-resistant buildings.* Whilst that Standard was based on the 1977 edition of the *SEAOC Code* (Seismology Committee, Structural Engineers Association of California) together with the International Conference of Building Officials, California, *USA Uniform Building Code* 1976 edition, our Standard was silent on the issue of ongoing operational performance requirements for post-disaster facilities.

After the 1989 Newcastle earthquake, AS 2121 was replaced in 1993 by AS 1170.4 *Minimum design loads on structures, Part 4: Earthquake loads* which also remained silent on the topic. A completely revised edition of the Standard AS 1170.4 retitled *Structural design actions, Part 4: earthquake actions in Australia* was published in 2007. By this time there was growing recognition that hospitals and other critical facilities should be required to remain operational at the very time they are needed most, and that a much greater focus on the issue was required by both designers and contractors. The 2007 edition of AS 1170.4 therefore introduced to Australia the requirement to undertake a “special study” to ensure Importance Level 4 buildings, such as hospitals, remained "serviceable for immediate use" following the SLS earthquake event.

3 Special Study Content

To ensure the performance objective is achieved, a special study must address the behaviour and performance of every aspect of the building necessary for it to fulfill its post disaster function. This requires a detailed assessment of the performance of all non-structural parts and components, together with an assessment of the primary structure's performance. It may also include an assessment of other hazards and issues that could materially interfere with the serviceable use of the structure or facility following the earthquake. Such hazards include potential access constraints created by nearby structures which could reasonably be expected to suffer damage and are likely to be considered unsafe or collapse; or an assessment of the building's reliance on external lifelines (power, water, gas, communications, etc) necessary for the ongoing performance of the post-disaster role.

The study also needs to clearly outline the basis for decisions made during the design, construction, and commissioning processes that are relevant to the post-earthquake, serviceable operation of the building. It should discuss the performance expectations of a building during the SLS design earthquake; record consultation processes undertaken; record assumptions made during design; and record construction verification procedures in sufficient detail to provide the user and the certifying authority sufficient confidence that the constructed facility will perform as required.

For general reference when designing Importance Level 4 facilities, the USA's Federal Emergency Management Agency (FEMA) has produced two documents which are very useful sources of information. They are, FEMA 577 (Federal Emergency Management Agency, 2007) and FEMA E-74 (Federal Emergency Management Agency, 2011), both of which can be downloaded from the FEMA website for free.

4 Proposed Special Study Procedure

The following steps outline how a special study can be undertaken for an Importance Level 4 building or facility.

4.1 Step 1: Establish the post-disaster operational requirements

Establish performance objectives necessary for the structure or facility to remain serviceable for immediate use following the SLS earthquake event. This would normally require consultation with both the building owner and the approving authority but may also involve community consultation. Reference should be made to relevant Business Continuity Plans together with State and Federal Emergency Management Plans as appropriate. Specific operational requirements will vary depending on the functionality and intended use of the building. Stakeholder engagement on a project-by-project basis is essential to understand the specific post-disaster operational requirements for each Importance Level 4 facility, some of which may be unique to the project. As an example, hospitals with operating theatres on upper floor levels could reasonably require that the lifts servicing those theatres remain fully operational following the SLS earthquake event. Whereas a lift in a low-rise building, whose purpose is to manage the emergency response in the event of a disaster, (e.g., police headquarters, ambulance, or State Emergency Services buildings) would not necessarily require the lifts to remain operational where practical alternative access may be available using stairs.

The report should identify whether the structure or facility is required to be self-sufficient and function unsupported in "island mode" for a certain period. Island mode capability would create, for example, the need to have emergency back-up generators on site; adequate reserves of potable water; the ability to temporarily store sewage and other waste on site; sufficient stores of food and so on. End user consultation should also address the performance of items that would usually be considered as "fit out" but which are important to the ongoing operation of the facility. Many such items would ordinarily be considered beyond a designer's scope; however, a special study needs to identify and address all items that could prevent a facility from performing its post-disaster role. This could include for example, data and communications systems in a hospital which are used to store and access medical records electronically, together with the infrastructure that supports the ongoing delivery of that service such as a localised datacentre.

4.2 Step 2: Determine structural performance targets and design criteria

Determine appropriate structural performance targets consistent with the performance objectives determined in Step 1. This will generally require the establishment of appropriate limits on inter-storey drift to ensure vulnerable non-structural components such as ceilings, services, partitions, and facades will remain intact, or at worst, suffer only superficial damage. Priestley, Calvi and Kowalsky (2007) suggest that drift limits in the order of 0.5% of the storey height are appropriate to managing damage to brittle (masonry) infills and partitions during the SLS event. McBean (2015) cites a study where drift limits of up to 0.8% were found to be appropriate where conventional lightweight studwork partitions were used. Similarly, Eurocode 8 recommends a damage limit state for in-plane drift of 0.5% for brittle non-structural elements and 0.75% for ductile non-structural elements.

It is envisaged that reinforced concrete elements could develop some minor cracking during the SLS earthquake, but without significant yielding of reinforcement or crushing of the concrete. Target performance limits must have regard for the functional requirements of specific elements. For example, it may be reasonable in a low-rise building to permit reinforcement in the concrete walls enclosing a stair to reach yield and for residual cracking of moderate widths to remain in the walls. However, a lift shaft that is required to continue functioning without inspection or repair immediately following the SLS earthquake should be designed to perform largely elastically during the SLS earthquake with little or no residual cracking. An appropriate analysis in such circumstances would be based on a ductility factor, μ = 1.0 (elastic response) and a structural performance factor, S_p = 0.77 (accounting for material overstrength), whilst using cracked section stiffnesses for member properties appropriate to demand.

Having established appropriate inter-storey drift and other performance targets, the primary structure can then be designed to meet these targets, recognising that in many instances, member design will be governed by SLS performance targets rather than ULS strength requirements. An iterative analysis and design process is likely to be required to optimise the solution.

4.3 Step 3: Document the structural response (e.g., inter-storey drifts and floor accelerations)

Determine and document the anticipated structural response to the SLS earthquake. Calculate inter-story drifts and floor accelerations throughout the building using modelling based on member stiffness estimates consistent with the anticipated SLS strains and cracking pattens. Based on that analysis, verify Step 2 performance targets have been achieved. The analysis results should then be summarised into a consolidated report that is used to form the basis of a performance-based specification for the procurement of non-structural parts and components, such as building services, façade systems, ceiling, and partitions.

When modelling the structural response, carefully note AS 1170.4 Section 5.2 requires that stiff components, such as precast concrete walls, masonry partitions, stairs, ramps and alike must be considered to be part of the seismic force resisting system and designed accordingly or be deliberately isolated from all structural elements such that no interaction takes place as the structure undergoes the calculated interstorey drift.

Note that pile cap and footing rotational flexibility can contribute significantly to building drift and it is therefore recommended that the rotational stiffness of footings be considered when modelling earthquake design actions for Importance Level 4 structures. Soil-structure interaction is an important consideration during modelling for which the relatively simple incorporation of linear Winkler springs into a structural model will often be sufficient. Upper and lower bound estimates of soil stiffnesses should be modelled to envelope building responses also remembering that for the design and detailing of many elements, drift estimates will be more critical than design actions.

4.4 Step 4: Design the non-structural parts and components

Use the drift and acceleration SLS building performance report compiled in Step 3 to design non-structural parts, components, and all systems required to remain operational following the SLS earthquake event, noting that collapse prevention of these elements must also be prevented for the ULS earthquake event. The design of non-structural parts and components should be undertaken in accordance with Section 8 of AS1170.4. It must be noted however, that the exemptions permitted for small diameter pipe and ductwork listed in 8.1.4(b)(xviii) do not apply to Importance Level 4 structures, as the exemptions do not guarantee the ongoing function of these services. To remain fully operational, most services will need their bracing systems and restraints designed to survive the SLS event elastically. Yielding restraints and assuming system ductility which are acceptable during the ULS design earthquake will not generally guarantee the ongoing functionality of services and is inappropriate.

Drift estimates can be used to design articulation and isolation gaps between elements of the structure, and to ensure interaction of non-structural elements with the structural system is avoided, unless such interaction has been considered during the analysis. Seismic joints in floor systems need careful consideration. An approach to their design is outlined by McBean (2015). In addition, the movement of individual services should be estimated to determine whether they are likely to impact with other structural or non-structural components and be damaged. The penetration of a rigid fire system sprinkler head through a ceiling tile is one such example.

Plant and equipment mounts incorporating vibration attenuation or isolation may need to have stoppers or “snubbers” specified to limit lateral movement during earthquake shaking. In addition, the plant and equipment itself may require special design and testing to substantiate that it will perform as required following the SLS earthquake event. Diesel powered generators, for example, may require shake table testing to demonstrate that they will survive the design shaking intensity without loss of function. Lift shaft mechanisms required to function after the SLS earthquake, together with lift car guide rails and their fixings will need to be designed for lateral and vertical earthquake design actions due to accelerations together with reactions arising from lift shaft curvature imposed on the rails during the earthquake response. Lift equipment must also be detailed to prevent unseating of cables. All equipment and systems identified as necessary for the facility to remain serviceable for immediate use during Step 1 need to be explicitly considered in this way.

4.5 Step 5: Procurement

The report produced at Step 3 must be used to inform the procurement process. Seismic design requirements and performance must be front of mind during the procurement of all materials, equipment, services, and systems. The sort of questions the project team must ask include: are the post-installed concrete anchors specified suitable for use in cracked concrete under seismic conditions? Has the lid on the fire storage tanks been designed for uplift from hydrodynamic sloshing?

The special study must document and collate evidence that demonstrates how the procurement methods used ensure that all the equipment and systems sourced comply with the performance requirements determined during the above steps. Evidence of material and performance testing, such as shake table performance test reports for individual equipment items, may be required to establish compliance. To avoid post-tender disputes, clear design documentation is critical, as is the recording and cross checking of compliance against all performance design criteria during tender evaluation.

The design and installation of large and complex sub systems, such as façades, are often put to the market as separate design and construct packages. It is imperative that the contract documents for these packages clearly define the seismic design requirements, level of project engagement expected, together with testing and inspection requirements and input to the special study required from the successful contractor.

4.6 Step 6: Construction, installation, and commissioning

Accurate record keeping must be maintained by contractors and suppliers demonstrating compliance with design performance requirements. Of particular importance is the need to carry out careful and progressive inspection of the works during construction to identify any errors and omissions for progressive rectification. For example, it is not uncommon in larger floor plate structures that incorporate seismic movement joints to see piping runs hung from the soffit of floor slabs installed in such a way that they rigidly bridge the floor movement joint. The design would require all piping crossing such a joint to be articulated in such a way as to accommodate the anticipated movement across the floor joint. Such situations arise when the sub-contractor undertaking the works hasn't fully understood design requirements, or they have simply made a mistake. If such an error is identified early, it is relatively simple and inexpensive to correct by fitting the appropriate pipe articulation. However, once work progresses and ceilings have been installed, the rectification becomes expensive, or the error could be missed altogether leading to rupture of the pipe during an earthquake. Note that in the past, flooding due to unarticulated pipe failure at floor movement joints has led to the closure of otherwise perfectly serviceable hospitals following earthquakes.

4.7 Step 7: Final Report

Compile a final report that consolidates all the evidence required to substantiate that each of the above steps has been undertaken and completed. This final report is the "special study". The report should be issued to the building owner and relevant stakeholders for future reference and the development of business continuity plans. It is particularly important that the report be available to, and be well understood by, all building maintenance personnel to ensure future work undertaken to a building or facility does not inadvertently compromise its seismic performance.

5 Concluding remarks

Whilst AS 1170.4 is thought of as a structural design standard, ensuring an Importance Level 4 building will remain operational after an earthquake involves the engagement, cooperation, and sustained commitment of the entire project team. The client, architect, services engineers, structural engineers, contractors, material suppliers, equipment suppliers and building operators will all typically play important roles. It only takes the failure of any one of those links in the chain for the good work of others to be undone.

It is the author's firm belief that a single individual should have responsibility for the continuous oversight of the special study throughout a project's design and construction phases. With so many opportunities for design issues to be overlooked, forgotten, or misunderstood, it is imperative that a single experienced individual has carriage of the exercise from start to finish. Accompanying such oversight must come the authority within the project to direct others and police outcomes.

To identify all the systems and construction details that have the potential to fail and consequently result in loss of operational capability requires a forensic level of inquiry and curiosity not normally expected from a project design team. The success or otherwise of those efforts can unfortunately only be known for certain after the building has successfully survived a moderate earthquake. It is hoped that the process outlined here will assist those taking on the responsibility for designing buildings of such importance.

6 References

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7 Biography

Peter McBean is Joint Managing Director of WGA which currently employs more than 400 people. He is a Fellow of The Institution of Engineers Australia and a Chartered Professional Engineer. Peter's professional interests are in structural dynamics and earthquake engineering. He was National President for the Australian Earthquake Engineering Society from 2016 to 2019 and has held a number of professional advisory and industry roles. He is an active member of Standards Australia code committees BD-006-11 which is responsible for "Earthquake Actions in Australia", AS 1170.4 and BD-002 responsible for "Concrete Structures", AS3600 which was extensively revised in 2018.

Peter has been the Structural Engineer Design Director for many major projects including the $2.2b New Royal Adelaide Hospital which opened in 2017. In addition to design activities, Peter is an active Australian Urban Search and Rescue (USAR) Task force Engineer. Following the devastating Christchurch earthquake of February 2011, Peter spent two weeks within the city providing structural engineering advice to the Australian USAR response team, for which he was awarded the Humanitarian Overseas Service Medal by the Australian Government.

Peter has authored many journal articles and conference papers on seismic design and was the joint recipient of Engineers Australia's RW Chapman Medal in 2019 for his contribution to the paper "RC walls in Australia: seismic design detailing to AS1170.4 and AS3600". Peter also co-authored the Steel Reinforcement Institute of Australia's "Guide to Seismic Design and Detailing of Reinforced Concrete Buildings in Australia". In 2020, Peter was awarded the John Connell Gold Medal from Engineers Australia in recognition of his "outstanding contribution to structural engineering in Australia".