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Retrofit in Practice: Structural/Architectural Considerations

Alistair Cattanach

Director, Dunning Thornton Consultants, Wellington New Zealand

ABSTRACT: Seismic retrofitting is intended to increase a structure's value, but how the retrofit is carried out can have a significant effect on the planning, flexibility and visual appeal of a building. Engineers are often the first consultant appointed, yet few are trained in the non-technical aspects of design.

Good design stems from a deep understanding of your constraints: for Structural Engineers these are strength, stiffness and load-paths. However, the building should be considered as a whole, from its site constraints, through to its planning grid and layout, as well as its internal and external fabric. With the structure often making up less than half the cost of a strengthening project, its effect on non-structural elements has significant consequences. Consideration of options and alternatives is essential, and collaboration with other design professionals important.

This paper discusses examples of successful retrofit projects where this thinking has been applied. Frameworks for appraising the appropriateness of interventions in heritage buildings are illustrated, in the belief that this process can apply to all existing structures.

1 INTRODUCTION

Seismic strengthening is a technically challenging field. However to have retrofits that are considered a success for everyone, design aspects beyond the technical must be considered to give a well-proportioned, aesthetically pleasing intervention which is complimentary to the existing structure. Good design cannot be taught by a single technical paper, but I will attempt here to illustrate some strategies which can help inspire a good outcome.

A project should start with a good design brief, but for an engineer this often begins with a simple request from a client that they "my building needs strengthening". For the design of a new building, an architect or a services engineer would each have a detailed brief that outlines ambitions, performance targets and aesthetic/comfort requirements. This level of "client brief" is unusual in structural engineering: generally all that is required is to comply with building codes and the loads the structure should sustain. However, a seismic retrofit is a piece of new design: it introduces a structural element, often quite a significant one. Arguably it should have the same or greater attention to the quality of its design, architecture and performance. For an inexperienced engineer this can be daunting. However using the design principle where constraints guide the form of design is a good place to start.

2 DESIGN AS A RESPONSE TO CONSTRAINTS

2.1 *Site constraints*

Firstly one must define the factors outside the building that will affect the structural design. There may be planning constraints regarding the external appearance of the building, especially around aspects of heritage preservation. Heritage preservation in itself provides a good principle for the approach to all buildings, in that it asks you to respect the quality features of the existing, therefore suggesting other areas which may be more flexible about being replaced.

To define the building one must have defined the site: for many older buildings each structure is not necessarily independent of its neighbour. Regardless of the legal standing of the property, the building will want to act like a unified structure. To achieve the structural ideal, ownership boundaries will need to be crossed and the building or buildings tied together to act as a structural whole. However, this may be affected by ownership constraints and local law. Tying multiple buildings together where the seismic gap between them is insufficient is a structurally efficient approach, but it may be difficult to convince multiple owners to cooperate.

Figure 1 illustrates a current project where a seven- and eight-storey building are strengthened and tied together, minimising the intervention in each, and obviating the need to create a very large, unsightly seismic gap between them.

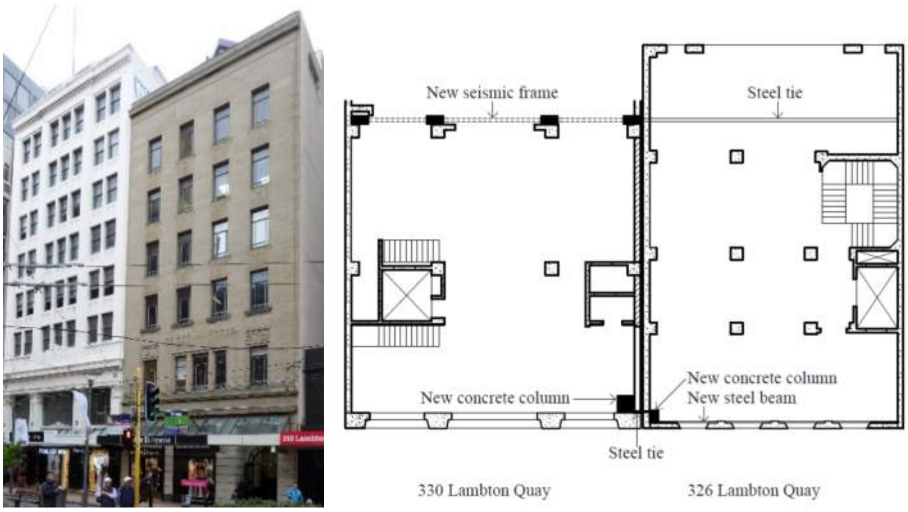

Figure 1: 326 and 330 Lambton Quay: tied together as part of the strengthening strategy

The underlying geotechnical conditions may also provide a site constraint. Should the supporting soils change at a certain level of shaking, strengthening above this level will require measures to mitigate the actions of liquefaction, lateral spreading, landslip or the like. Two options of retrofit could be considered: a shorter life option strengthening only to this lower level, or a major retrofit to a higher level of strength including augmentation of all foundations.

Regardless of the technical constraints on a site, its location may have an effect on the approach: there is always a maximum economic potential for any site, and the level of strengthening may need to reflect this. Where intensive strengthening makes little economic sense, strategic options include prioritising the highest-risk issues (e.g. weak parapets falling onto the public outside); or a staged approach, where the most critical issues are addressed during the first stage of strengthening, allowing later stages which further augment the building without the need to re-examine the work done previously.

2.2 *Durability of existing structure*

The lifespan of a building will be dictated by the fabric that you are intending to retrofit. It is important that the remaining design life of the building is understood when considering the strengthening level: a degrading building with only 20 years useful life left in it may well justify a lower strengthening level.

Degradation, especially for older structures, may be mechanical, through erosion of the external fabric and potentially the foundations. All reinforced concrete structures should have their level of carbonation and chloride attack examined, as repair of degradation can be costly and potentially should be part of a seismic retrofit scheme. Preliminary, approximate testing can be easily carried out eg. using phenolphthalein for carbonation to determine whether more specialist testing should follow. Timber and steel structures exhibit their degradation more visibly, but often the most critical areas of degradation are those hidden from view in areas where moisture or condensation can accumulate. Similarly, foundations of any of the above materials must be understood in terms of their durability for both vertical and lateral support of the structure. These examinations should be carried out in conjunction with the geotechnical aspects described above.

2.3 *External fabric*

Though not primarily of structural concern, external fabric can pose a constraint on the design life of a building especially if it is structural. Alternatively if the external fabric is to be refurbished or replaced it can be an opportunity to integrate strengthening structure, weaving them through the new skin.

2.4 *Interior*

A simple approximate metric is that less than half of the cost of a strengthening will stem from the new structure, and more than half for the "make good" and disruption. Therefore the areas of the building which are high quality and have a longer remaining design life should be identified and avoided if possible. Areas where finishes have degraded, especially around circulation paths, are often zones of opportunity that required non-structural maintenance anyway. Similarly, areas with significant building services will be very expensive to disrupt if those services are to be put back after the retrofit. Targeting sections of the building where maintenance/upgrades were inevitable in the near future will lead to more economic solutions.

The seismic restraint of building services should also be considered. For a building with a reasonable existing strength, proper restraint of the building services may provide a greater risk mitigation for the occupants in the short term, allowing time to plan an appropriate primary structural upgrade when the interior of the building is next to be retrofit as a whole.

2.5 *Level of strengthening*

Once the constraints that the solution must work within are defined, the performance of the retrofit should be agreed. This may be limited by the constraints described above, or be set by tenant or insurance requirements. Compliance is often defined as a percentage of a new building standards, but it is more holistic to understand the building's performance over a spectrum of earthquake shaking.

Priorities should be set around who is affected by damage. It may be the owner, in terms of preservation of the building's fabric and its repairability. It may be the tenant, from a purely life-safety point of view. The tenant may be more interested in avoiding disruption during small earthquakes than they are concerned about life safety. In an urban setting, the effect on the public outside the building may be the greatest life-safety concern.

These affected parties may have conflicting views: the ability of a designer to articulate what various levels of strengthening mean will help the client reach agreement/conclusion. Performance should be defined as a combination of what structural damage occurs, what non-structural damage occurs and the robustness of the building should its designed level of strengthening be exceeded. A simple number is insufficient to describe all of this: a more qualitative and holistic agreement is required.

3 **INTERACTIVE DESIGN PROCESS**

Now the constraints are defined, the design process begins. Collaboration is essential. Ideally this would be with a trained design professional (architect or architectural designer) who can provide a creative sounding board for ideas and help orientate the positioning of elements around the key planning features of levels and circulation in the building's grid. It is important that a number of options are identified. It is the process of sorting through these options which helps lead to their refinement or their combination or the stimulation for innovative new ideas. This kind of creative process is common in the architecture and design professions, but less so in traditional hard engineering. Sometimes the craziest ideas, although not appropriate in themselves, lead to the consideration of new alternatives that produce excellent outcomes.

4 **RE-USE OF STRUCTURE**

In this paper I am advocating the re-use of structure for two reasons. Firstly, mobilising all of the existing strength of a building means less additional capacity that needs to be put in to reach target performance. Secondly, and more importantly from a design point of view, sympathy to the existing strength and stiffness of the building often ends up with structural proportions that are more in harmony with the existing. The foundations as well as the superstructure should be thought about. If the foundations are poor, or the supporting ground suffers from liquefaction, the strengthening intervention will need to be spread throughout the structure so as to not concentrate loads. Should the supporting foundation/soils be strong, there is greater opportunity to concentrate new interventions in plan and so cause less disruption to the existing fabric.

4.1 *Strength and stiffness*

Older structures are typically more rigid and more brittle than new buildings. Their performance under increasing levels of acceleration may be similar to the first graph below, with little energy absorbed past the onset of damage.

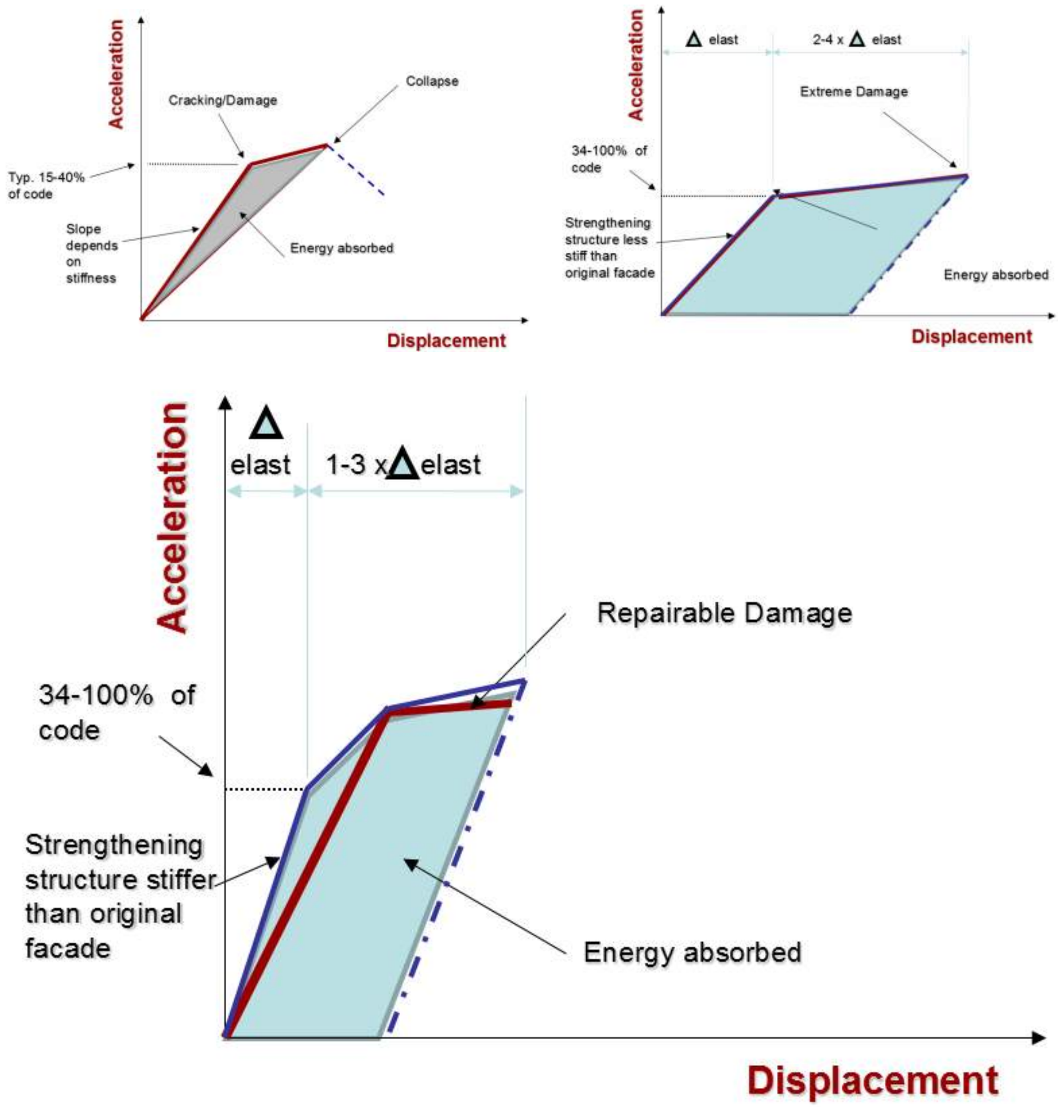

Figure 2: Graphical idealisation of Typical brittle building behaviour, Modern ductile building behaviour, and a balanced approach

A more typical new building may conversely have a performance as shown in the next graph, with greater flexibility and energy absorption. However, the second cannot be imposed over the first, or the existing elements become highly damaged and degraded before all of the new elements kick in. A better solution usually includes a delicate balance of stiffness and strength to match or improve on the existing structure, allowing some energy absorption within the combined system so that force levels can be reduced. This is idealised in the final graph.

Achieving appropriate behaviour requires decisions at the structural form level. Squat walls are stiffer than diagonal braces, which are in turn stiffer than rectangular frames. The same goes for materials, with concrete typically stiffer than steel, which is stiffer than timber. The intent is to create a harmony between the new and existing from a structural point of view, which I believe also translates to a visual harmony that a layperson can understand. Looking at Figure 3below, even a layperson could guess that the steel will have little effect on the seismic performance of the brick due to the gross incompatibility of proportion and stiffness.

Figure 3: Stiffness incompatibility between strengthening and existing elements

4.2 *Heritage buildings*

The selection of designs and details for heritage buildings often requires a more rigorous process regarding the consideration of options, effects on the building, and seismic performance. The ICOMOS principles define appropriate interventions as those which are transparent in their intention, reversible, and in keeping with the value of the existing structure. Reversibility is a good discipline to ensure that new structures are read clearly relative to the existing fabric, rather than a literal concept that the structures can be removed at a future date. If the intervention is reversible, its form and detailing allows it to be understood by a layperson as discrete and separate from the original.

A heritage building will often have an existing commentary (conservation management plan, heritage reports, or similar research) which describes the building's inherent original style. Important aspects to understand are the grid of the structure, the proportion of spaces that most define the building (major rooms and circulation routes, for example), and the most important or best features from a heritage point of view.

Precedent examples from the era of original construction are useful for inspiration on the style of detailing from the period. Design through precedent is uncommon in the engineering field (where calculations are most often done through first principles), but is common in the practice of architecture. As seismic engineering develops, the world is also developing a portfolio of retrofit options for various eras of structure, which can provide inspiration.

Although heritage buildings require far more care in the consideration of how they are strengthened, the control/planning process is intended to ensure the best parts of the building remain and that the new structure is in harmony with the existing. I therefore suggest these processes can similarly be applied to less important structures to ensure high-quality outcomes.

5 EXAMPLE PROJECTS

5.1 *Shed 13*

Shed 13 is a single-storey un-reinforced masonry warehouse structure, built circa 1903 on the Wellington waterfront. The building is approximately 50m in length, 6.5m in height and 10m in width respectively. An un-reinforced perimeter load-bearing wall encloses the building and supports the timber framed roof structure.

The initial response was to add transverse frames to the flexible centre of the structure. However the heritage architect pointed that the most important views were up to the wood of the roof, up through the mass and texture of the heavy brick walls. These walls already cantilevered up off the foundation beam, so the idea was inverted an instead u-frames were used also cantilevering out of a new foundation beam. The frames were made from precast prestressed concrete to be sufficiently stiff, topped with a ductile steel plate connection to the trusses. The side walls were vertically prestressed to augment both their face load and cantilever capacity, and capped with a steel truss hidden at the top of the wall.

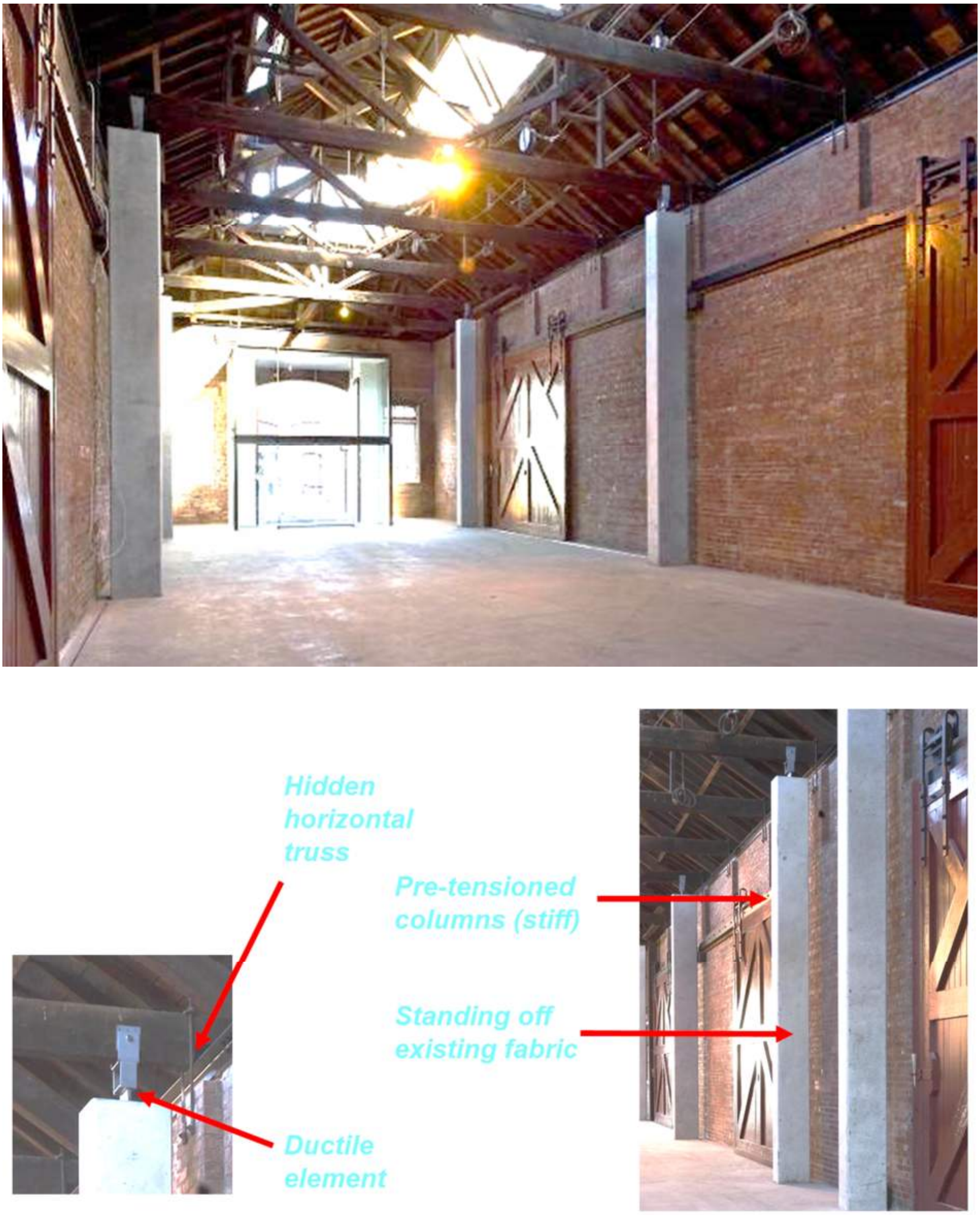

Figure 4: Shed 13 - View of refurbished interior and detail of new structure

5.2 *Harbour City Centre*

179-193 Lambton Quay, Harbour City Centre was originally built for the Drapery and General Importing Company (DIC) in 1928, comprising a structural steel frame, concrete encased with reinforced concrete floors and core walls. Identified as having a low seismic resistance in the 1970's, concentric braces were added to the steel frames. To upgrade to modern code levels, rather than replace these stiff but non-ductile braces with new, the braces were cut and new hysteretic damping devices were added. These comprised round flexural pins put into pure bending between the plated flanges of the braces.

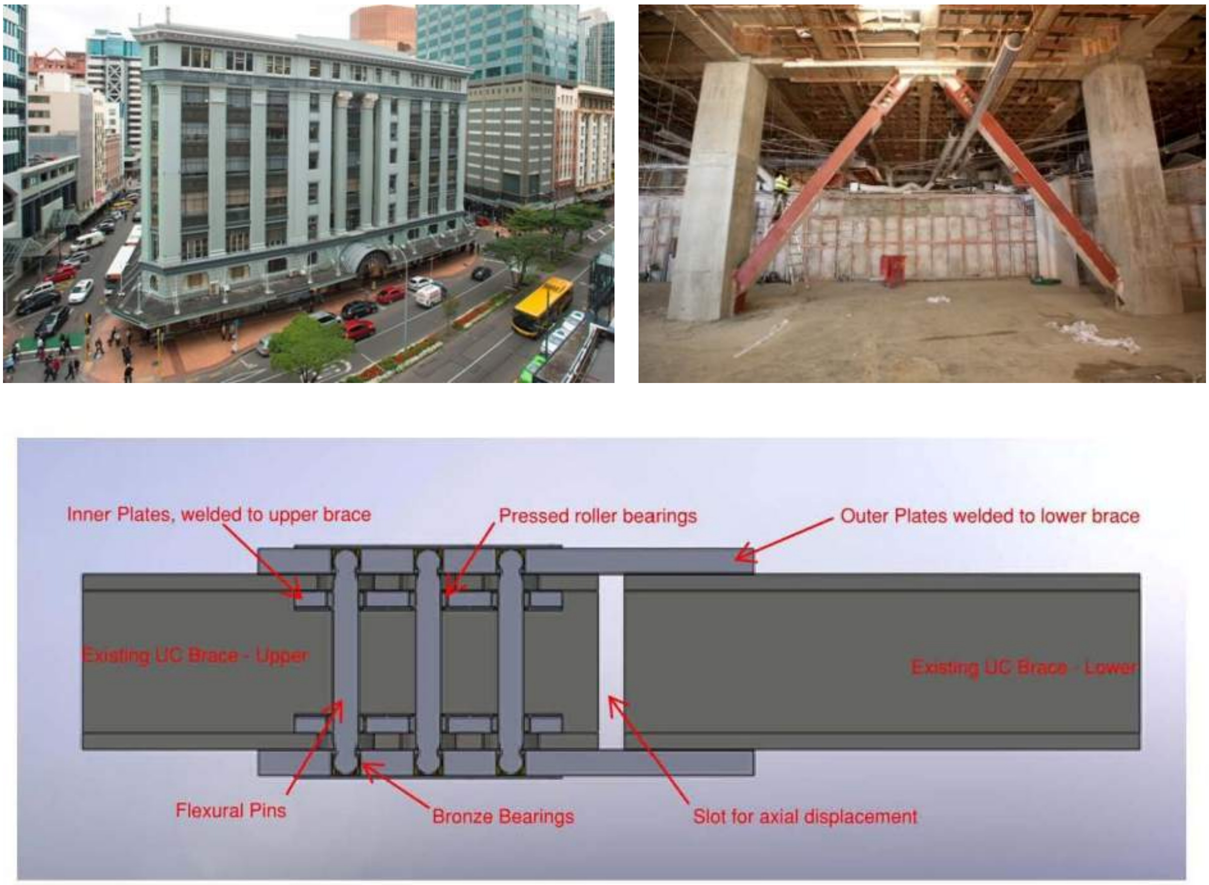

Figure 5: The Harbour City Centre Building, The first modified braces, and a schematic detail of the device

5.3 *The Woolstore*

258 – 262 Thorndon Quay, also known as The Woolstore, is a 1908 brick encased steel frame structure with timber floors. The strengthening system comprises three major interventions:

- K-Braced frames on each of the internal beam lines to give longitudinal resistance, tuned to be compatible with the stiffness of the "frame action" of the brick encased façades.
- De-stiffened end walls, with two bays augmented with sprayed concrete. The de-stiffening into 6 vertical strips allows rocking of the brick panels without shear failure. Damping was included between the augmented sprayed concrete panels and the boundary column elements.
- Strengthen floor and roof diaphragms. These were left flexible to not attract additional seismic forces, but given enough strength to ensure loads were distributed as assumed.

A 3D of the overall structural model is shown in Figure 6below.

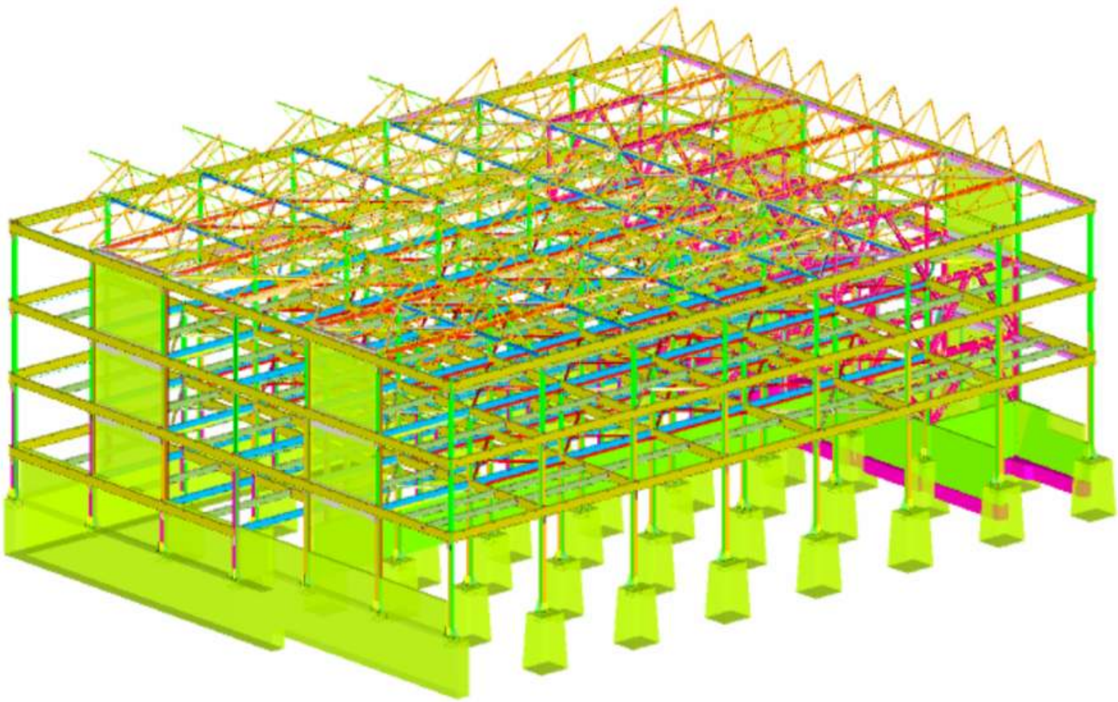

Figure 6: 3D model of the strengthened building (Brick facades not shown).

Detailing drew inspiration from the original Victorian steel frame connections, and discussions with the contractor regarding access, tolerances, and areas where it was safe to weld.

Figure 7:The Woolstore's masonry facade, and examples of the new steelwork detailing

5.4 *Newtown Park Flats*

Newtown Park is a large social housing complex, with five structures housing over 250 units. Though all five blocks were designed by the same Architect and Engineer, the depth to rock, piling method, era of construction and refurbishment philosophy required different engineering responses to each. Existing stiff walls were cut above door locations, and steel plates added as coupling beams to allow a more ductile response.

Figure 8: Steel plates forming coupling beams between walls over the existing doorways.

Architectural re-planning required connections to be formed between pairs of units. This opportunity was exploited to provide a new ductile "slot" in the existing brittle (hard-drawn wire reinforced) walls. Slots were formed in all walls whether units required connection or not, giving future architectural flexibility and a unified structural scheme.

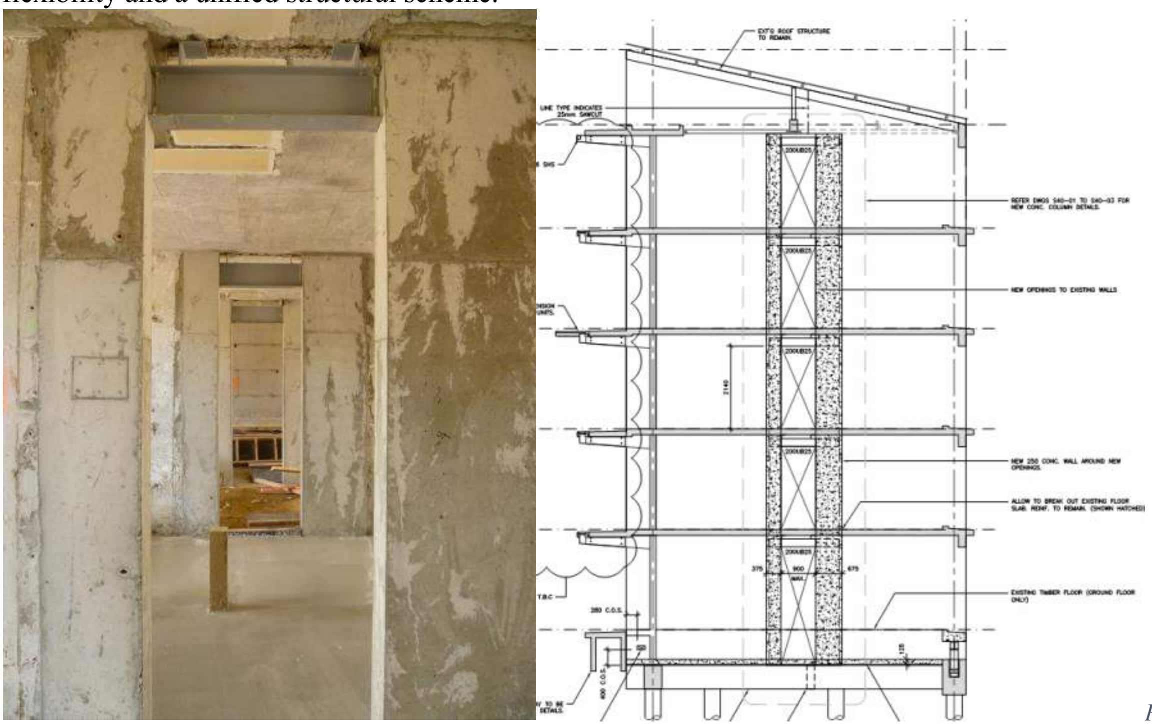

Figure 9: New ductile seismic "slots" allowing additional damping and Architectural flexibility.

5.5 *Chews Lane: National Mutual and Ballinger*

Two buildings from the heritage Chews Lane precinct redevelopment provide good contrast in the appraisal of the quality of the existing fabric. The 1960's National Mutual building, comprising reinforced concrete frames in one direction and shear walls in the other was considered a good structure in Architectural planning terms; able to be adapted to modern office needs. However it was rated as approximately 40% of modern code loadings as soft-storey behaviour was a risk. This was upgraded to 90%+ by the insertion of one narrow wall in the staircase, and the composite fibre wrapping of a number of "short columns" in the facades. The "pagoda wall" acts like the central column in a Japanese pagoda, pinned at its base but stiff and strong enough to ensure ductility demand was shared up the whole height of the concrete frames.

Figure 10: National Mutual building, and illustration of the "Pagoda Column" concept

The Ballinger building, although having an attractive masonry façade in good condition, has a small-grid internal structure which was in poor condition at the lower levels. The redevelopment therefore involved a façade retention only; allowing significant re-planning in the new building behind.

Figure 11: Ballinger Building with temporary facade retention

5.6 *Fever Hospital*

The Fever hospital was originally designed as a Tuberculosis Treatment hospital, designed in the 1920's. Healing was through the patient being exposed to significant fresh cold air while confined to bed: the ward wings therefore being very open and having large clerestory windows. With little lateral strength in these wings, inserting bracing structure would go against the large open Architectural style of the building.

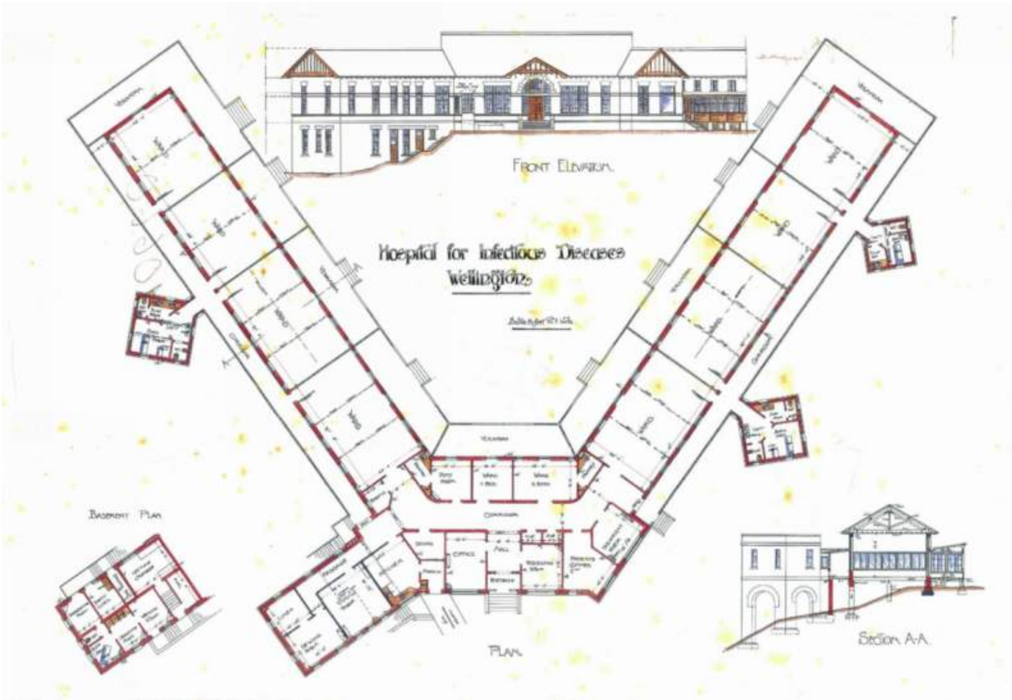

Figure 12: Original plan form of the Fever Hospital

Instead, the toilet/ancillary annexes, used to support the building from the original planning point of view, were re-used as buttresses to support the wards along their length. A ductile link between the annexes and the main structure was used to prevent dynamic overload of either structure. Masonry in both parts of the building was prestressed to increase both in-plane and out-of-plane strength.

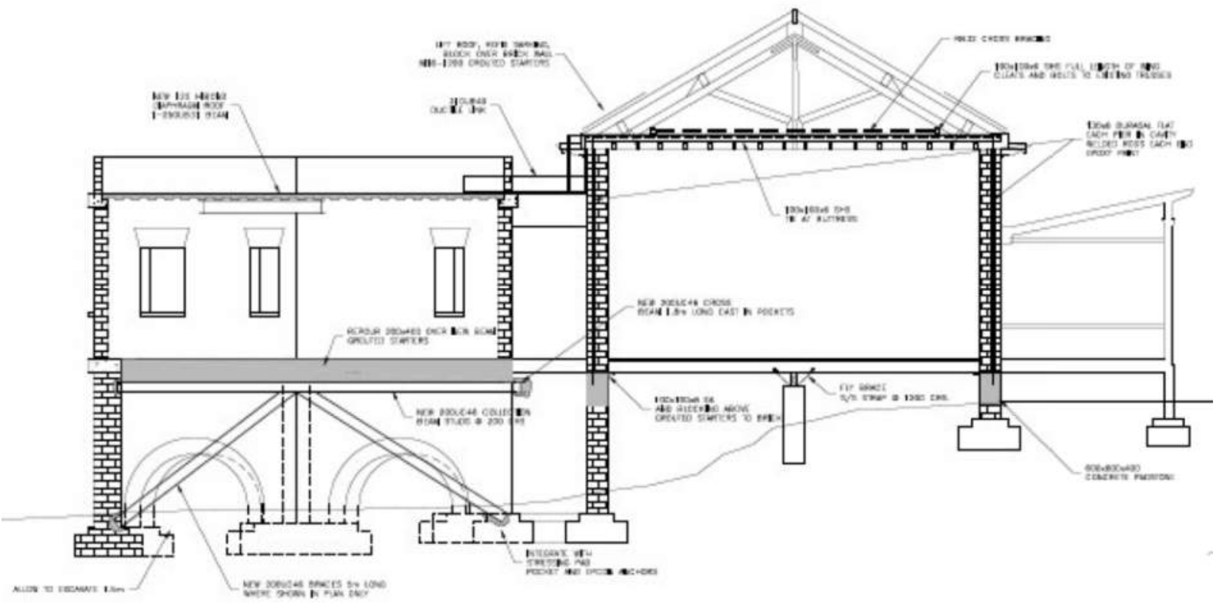

Figure 13: Cross-section through Ward wing and buttressing Annex

5.7 *Old Public Trust*

This five-storey 1908 building comprised solid masonry reinforced with a partial steel frame. Though strengthened in 1983 to the then-minimum levels, the building required extensive additional retrofit to get near to modern seismic resistance. Transversely, stiff new steel-coupled concrete shear walls were added to provide the majority of seismic resistance. Longitudinally however, the well-proportioned masonry facades were shown to exhibit good strong-spandrel rocking-pier action, providing limited ductility. Short concrete "pagoda" walls were provided in parallel behind two of the piers to ensure the rocking was shared evenly up the height of the building.

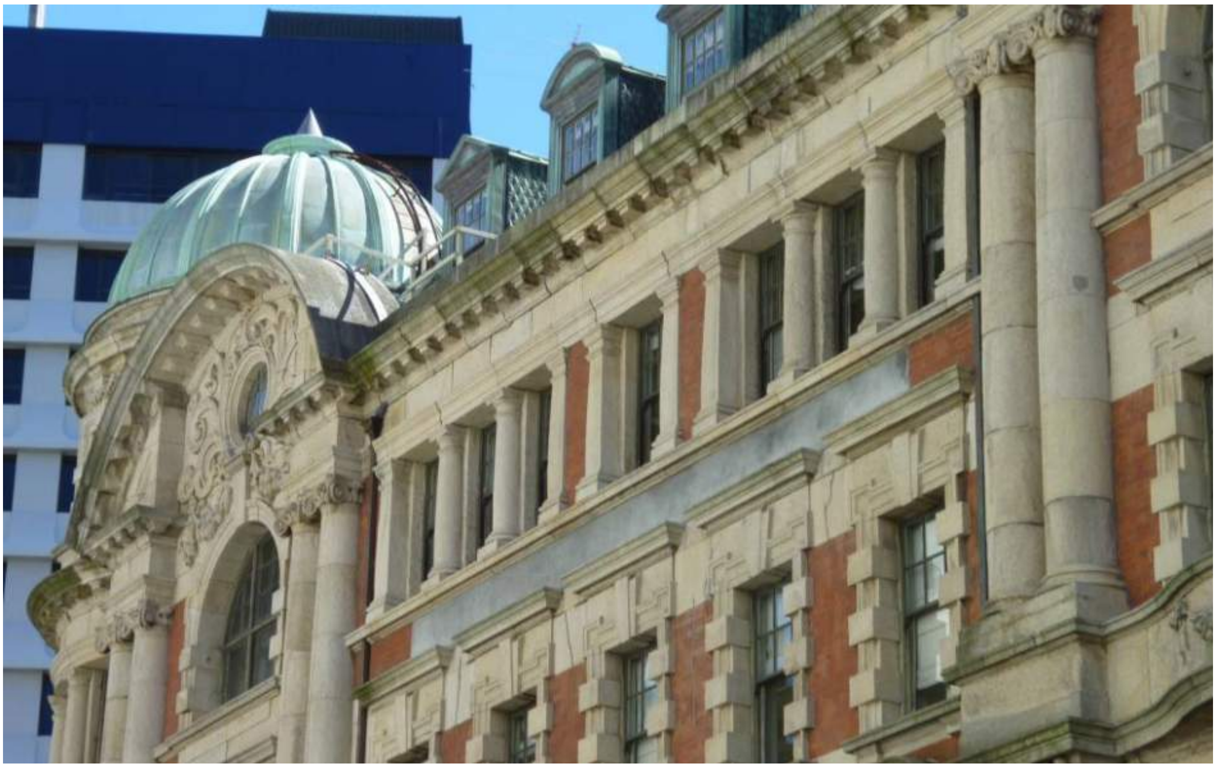

Figure 14: Old Public Trust front facade

6 **EVALUATION FRAMEWORKS**

6.1 *Self-Assessment Criteria*

In order to justify our strengthening designs under the planning rules for New Zealand (Resource Management Act Consent), we have developed a framework to appraise alternative designs and summarise why the selected option was considered the most appropriate for the building. Each option's strengths and weaknesses are qualitatively appraised under the following criteria:

- Minimum intervention: ensuring no more structure is provided than that required to achieve a defined set of performance criteria.
- Existing beneficial strength utilised: that the new structure is tuned to match the existing, and the total performance of the building is considered as the sum of both acting in unison.
- Positioning: that options for the disposition of the primary elements throughout the building and their effect on the architectural planning has been thought through.
- Transparency/reversibility: that the interventions are legible and reversible.
- Robustness and symmetry: that sensible load paths have been employed, minimising the length of tie members. That the building retains a good resistance to torsion and, ideally, provides resilience so that brittle collapse still does not occur when design loads are exceeded.
- The best current technology: the design makes the most of innovations in material and structural forms to achieve better outcomes.
- Allows staging: For a building that has a long expected life of the primary fabric, several

iterations of seismic strengthening may be expected. In future stages, the strengthening done to date should be able to be augmented without having to be removed.

6.2 *Multi-disciplinary assessment*

A recent thesis by construction management student Matt Patterson, "An Assessment Tool for Seismic Strengthening Heritage Buildings", proposes a multi-disciplinary assessment tool considering aspects beyond just the structural and architectural. The tool involves defining a brief before the outset of design, based on engineering, heritage, feasibility, architectural, services/fire protection and buildability aspects. Ambitions are set under these criteria based on a series of qualitative ratings, to create a spider graph as shown below. This tool can then be used for reappraising various schemes' performance relative to the ambitions set by the project team at the start. Various aspects of each discipline are defined, and the specialists rate each scheme against them. This is then integrated through the filter of a client rating which apportions the score of the individual components to the final summary. While this approach is less focused on providing a synthesised architectural and structural result than the framework described previously, it is an interesting tool for considering proportioning of funds, effort and resources to the project as a whole.

HERITAGE STRENGTHENING ASSESSMENT TOOL

CLIENT'S IMPORTANCE LEVELS: HIGH, MEDIUM OR LOW
DESIGN PERFORMANCE LEVELS: GREATLY EXCEEDS, EXCEEDS, ACHIEVES MIN, OR FALLS SHORT

SEISMIC ENGINEERING	NBS % level achieved	Improvement of Occupant & Public safety	Seismic Compatibility with significant heritage fabric	Minimum Intervention: Extent proportionate to actual risk level	Rediscovery or Reinterpretation of traditional techniques	Existing beneficial strength utilized	Latest technology	Ease of post Earthquake recovery to NBS level		
DESIGN ASSESSMENT	GREATLY EXCEEDS	EXCEEDS	ACHIEVES MIN	FALLS SHORT	GREATLY EXCEEDS	EXCEEDS	EXCEEDS	FALLS SHORT		
CLIENT IMPORTANCE LEVEL	HIGH	MEDIUM	LOW	MEDIUM	HIGH	MEDIUM	MEDIUM	HIGH		
HERITAGE	Building use: Intervention maintain, enhance or discover new use for the building	Significant Heritage fabric retention	Significant Heritage ambience retention	Interventions Reversible/ Removable	Positioning of Intervention: High vs low heritage value areas	Intervention Complimentary to Heritage: Hidden/ Discrete OR Visible/ Transparent where appropriate	Respect for contents & surroundings	Surface heights and levels retained	Retention of Heritage views & sightlines	Restorative Strengthening: Repairs, maintenance or reinstatement of significant heritage items
DESIGN PERFORMANCE	GREATLY EXCEEDS	GREATLY EXCEEDS	GREATLY EXCEEDS	GREATLY EXCEEDS	GREATLY EXCEEDS	EXCEEDS	EXCEEDS	GREATLY EXCEEDS	GREATLY EXCEEDS	GREATLY EXCEEDS
CLIENT IMPORTANCE LEVEL	MEDIUM	MEDIUM	LOW	HIGH	MEDIUM	MEDIUM	LOW	MEDIUM	HIGH	LOW
FEASIBILITY	Timeliness/ Program duration of works	Value Added: opportunities for enhancement	Overall project budget acceptable	Cost Risk mitigation of proposed strengthening	Acceptable knock on costs of strengthening	Cost efficiency of strengthening vs other possible designs	Insurance premium savings	Rental income retention during construction	Acceptable cost of significant material selections	Whole life cycle cost savings. Installation, operational & replacement costs
DESIGN PERFORMANCE	EXCEEDS	EXCEEDS	GREATLY EXCEEDS	GREATLY EXCEEDS	EXCEEDS	EXCEEDS	ACHIEVES MIN	GREATLY EXCEEDS	EXCEEDS	ACHIEVES MIN
CLIENT IMPORTANCE LEVEL	HIGH	HIGH	MEDIUM	MEDIUM	HIGH	MEDIUM	HIGH	MEDIUM	MEDIUM	HIGH
ARCHITECTUAL	Consentability	Floor area & Space circulation retained/ enhanced	Natural Light retained/ enhanced	Views to & from the building retained/ enhanced	Intervention aesthetics: Appropriate Positioning of intervention	Intervention aesthetics: Appropriate Contrast or compliment of form, scale, mass & colour	Acoustic performance	Thermal Insulation	Functionality of retained or reused items	Watertightness: Deflection, drainage, drying & durability
DESIGN PERFORMANCE	ACHIEVES MIN	GREATLY EXCEEDS	ACHIEVES MIN	GREATLY EXCEEDS	ACHIEVES MIN	EXCEEDS	GREATLY EXCEEDS	ACHIEVES MIN	ACHIEVES MIN	GREATLY EXCEEDS
CLIENT IMPORTANCE LEVEL	MEDIUM	MEDIUM	HIGH	MEDIUM	MEDIUM	MEDIUM	MEDIUM	HIGH	HIGH	HIGH
SERVICES & FIRE PROTECTION	Fire Regulation compliance	Impact on existing services infrastructure reduced	Incoming services capacity compatible with design	Seismic performance of services.	Ability to integrate new services technology	Energy efficiency	Future proofing: Heating, Ventilation, Electrical, lighting, Mechanical, Fire, Comms, Security, Lift	Greenstar Benchmarking		
DESIGN PERFORMANCE	EXCEEDS	GREATLY EXCEEDS	EXCEEDS	GREATLY EXCEEDS	GREATLY EXCEEDS	GREATLY EXCEEDS	EXCEEDS	GREATLY EXCEEDS		
CLIENT IMPORTANCE LEVEL	LOW	LOW	LOW	MEDIUM	LOW	MEDIUM	LOW	LOW		
BUILDABILITY	Health and Safety: Safety by design & Fire risk minimised	Disruption to occupants minimised	Availability of Heritage Trades.	Quality expectations acheivable in Design	Simplicity of construction	Ability to prefabricate interventions	Building Access to install detailed interventions	Significant Material Availability	Sensible Sequencing possible	Reduction of Manual work
DESIGN PERFORMANCE	EXCEEDS	ACHIEVES MIN	ACHIEVES MIN	EXCEEDS	EXCEEDS	GREATLY EXCEEDS	EXCEEDS	GREATLY EXCEEDS	FALLS SHORT	GREATLY EXCEEDS
CLIENT IMPORTANCE LEVEL	MEDIUM	HIGH	MEDIUM	HIGH	MEDIUM	HIGH	HIGH	MEDIUM	HIGH	MEDIUM
SUMMARY	SEISMIC ENGINEERING	HERITAGE	FEASIBILITY	ARCHITECTURAL	SERVICES & FIRE PROTECTION	BUILDABILITY				
DESIGN PERFORMANCE	EXCEEDS	GREATLY EXCEEDS	EXCEEDS	EXCEEDS	GREATLY EXCEEDS	EXCEEDS				
CLIENT IMPORTANCE LEVEL	MEDIUM	MEDIUM	HIGH	MEDIUM	LOW	HIGH				

Figure 15: Assessment Criteria

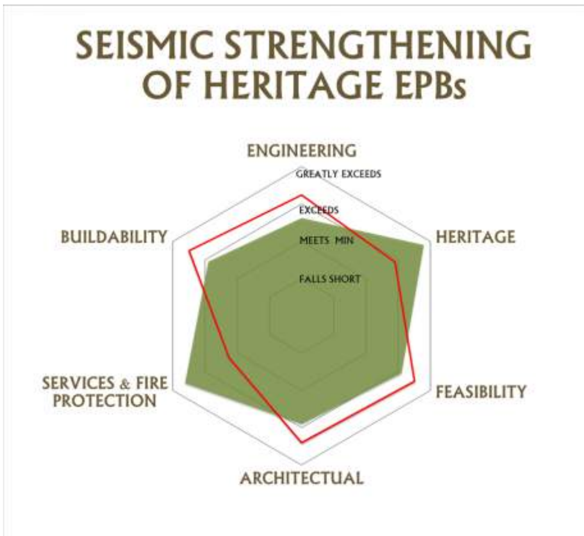

Figure 16: Visual Summary, with "Target" for the criteria being green, and "Achieved" in red.

7 CONCLUSION

Design is a skill which takes years of training and can only be touched on in a paper such as this. However, by taking a rigorous approach to informing design decisions by defining one's constraints, you end up with better solutions. A deep understanding of the existing structure can not only define mathematically the performance criteria the new structures need to match, but it also forms an empathy for the types of structural forms that may be appropriate. A designer should not be afraid to look at precedent examples, not just of retrofit solutions but structural forms in the era of the building being considered. By understanding a range of styles from this period, inspiration can be drawn for both primary bracing forms and, more commonly, connections and details that really provide character.

To end up with a great solution, one must generate a range of options from which to select the best. It may be that options that were least favourable when originally conceived end up inspiring an innovative alternative. Using a framework to consider the appropriateness of various aspects of the design can help in the selection of the best option. It can also highlight areas where the best design may be improved upon as it is detailed and implemented.

Seismic strengthening is an expensive exercise which should improve a building's safety without impacting negatively on its aesthetic and planning appeal.

A well-executed scheme, refined in its form and detail in collaboration with an architectural design professional, can add to the building's long-term appeal. It is the author's assertion that a functional-only solution is not enough.