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RE-STRENGTHENING 20th CENTURY ARCHITECTURAL HERITAGE: A CASE STUDY OF BRISBANE CITY HALL RESTORATION

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Abstract: *Restoring old buildings to conform the current building policies and standards is a great challenge to engineers and architects. The restoration of the Brisbane City Hall, a heritage building listed by the State of Queensland in Australia, developed an innovative approach to upgrade the building using the method called 'concrete overlay' following the guidelines of both the International Council on Monuments and Sites and the Burra Charter of Australia. Concrete overlay is a new method of structural strengthening by drilling new reinforcement and placing new concrete on top of the existing structure, akin to a bone transplant or bone grafting in the case of a human being. This method is popularly used for newer bridges which have suffered load stresses. However, this method had never been used on any heritage buildings which were built on different conditions and standards. The compatibility of this method is currently being monitored.*

Most of the modern historic buildings are rapidly deteriorating and require immediate interventions in order to be saved. As most of these heritage buildings are on the stage of advanced deterioration, significant attempts are being made and several innovations are being applied to upgrade these structures to conform with the current building requirements. To date, the knowledge and literature in regarding 'concrete cancer' in relation to rehabilitating these reinforced concrete heritage structures is significantly lacking. It is hoped that the method of concrete overlay and the case study of Brisbane City Hall restoration will contribute to the development of restoration techniques and policies for Modern Heritage Buildings.

1. INTRODUCTION


Figure 1 Photograph of St Mark's Campanile (L) & Brisbane City Hall (R) (Source: A. Cruz & BCC)

The Brisbane City Hall, situated in the heart of Brisbane's Central Business District at the corners of Ann Street, Adelaide Street, and Albert Street, is one of the most noteworthy heritage buildings in Queensland. The City Hall served as a centre for significant events for over 80 years and has continued to be a hub for both civic and community functions. It was built over a period of ten years between 1920 and 1930 and was designed by local architects Hall & Prentice [1].

The classical stone façade conceals a reinforced concrete structure in the main section, as well as a steel frame construction in the bell tower and dome. The neoclassical inspired design of the Brisbane City Hall is reminiscent of the buildings constructed during the Italian Renaissance, and is based on ancient rule of symmetry. The building is axially configured around the central concert hall with its main architectural features located centrally on each of the three facades. The clock tower is similar to the design of Venice's St. Mark's Campanile (See Figure 1).

The facade was inspired by Palladian Architecture which featured Corinthian columns at the portico and Ionic columns on the three facades. Externally the building is clad with ashlars stone façades on Ann Street, Adelaide Street and King George Square. The ground floor and exposed basement are clad with locally sourced Enoggera granite, the upper storey is clad with Helidon freestone, local timber for internal joinery and local Darra cement [2]. The rear elevation was a rendered brick wall that appeared to have been a late change to the design, possibly as a cost saving measure.

2. THE CALL FOR RESTORATION

The Brisbane City Hall was closed to the public from 2009 to April 2013 in order to accommodate the investigation and the re-strengthening of the building. The need for restoration arose when it was suspected that the building was subsiding and was on the verge of collapse if no immediate rectification were to be undertaken. Extensive testing and analysis was performed in order to determine the structural capacity and status of the building.

Several problems and their related causes were identified and documented. One major problem was the ingress of water to the basement of the building due to the leak coming from the roof. It was claimed that there was a subsequent differential settlement of the foundation where the water was ponding[3]. A photograph taken a year after Brisbane City Hall opened in 1930, shows the original flat roof (See Figure 2). That physical condition of being flat where water

Figure 2 Photograph showing the original condition of the concrete flat roof (Source: Brisbane City Council)

could easily be trapped would be susceptible to maintenance problems. It was recently discovered that the roof was leaking badly due to the limitations of the waterproofing system. The major contractor's (ABI Group) project manager, Rod Boxall, explained that they had a problem installing a watertight seal on the surface of the flat roof. The floor surface of the rooftop was exposed and it revealed that bitumen membrane was used in the past to protect the floors below from water ingress. The bitumen membrane that was used for waterproofing was originally from Northern Europe where they have a cooler climate. This technology was used 60 to 70 years ago and was not tested against the Queensland climate. Once the membrane was subjected to the harsh climate of Queensland, it became relatively brittle.

Cracks also appeared in the concrete as structural movement occurred. From the weakest point, the water found its way below the barrier until it reached the steel reinforcement of the structure. It was quite evident that previous repairs were just cosmetic and lacked thorough problem analysis that could have led to a substantial solution. As a result, the structure that was added to the roof was demolished because of the leak that was causing serious damage.

Another issue was that the Brisbane City Hall was sinking caused by an underground stream below the foundation [3]. Media opinion indicated that the cause of this problem was the building's location on a swampy site. In reality, much of the excess moisture has already been removed and the neighbouring buildings helped divert the water away and after analysis it was found that the subsidence was restricted to a limited area of the basement floor slab where leaking drains had washed away the sub-base [1].

In addition to these circumstances, the major challenge of the Brisbane City Hall restoration lies on finding a strenghtening solution that will not only be compliant with the current building codes but will also not compromise the City Hall's historical aesthetics following the guidance of the Burra Charter and the Australia ICOMOS principles. The Burra Charter and the Australia ICOMOS charter for places of cultural significance advocate a cautious approach to change: "do as much as necessary to care for the place and make it usable, but otherwise change it as little as possible so that its cultural significance is retained" [4, p 1].

3. STRUCTURAL MAKE-UP OFTHE CITY HALL

The structure of the City Hall is an in-situ reinforced concrete frame that was a relatively new and versatile material during the time of construction (1920-1930). It was also believed to be a more economical option based on the relatively low construction and maintenance [5]. The

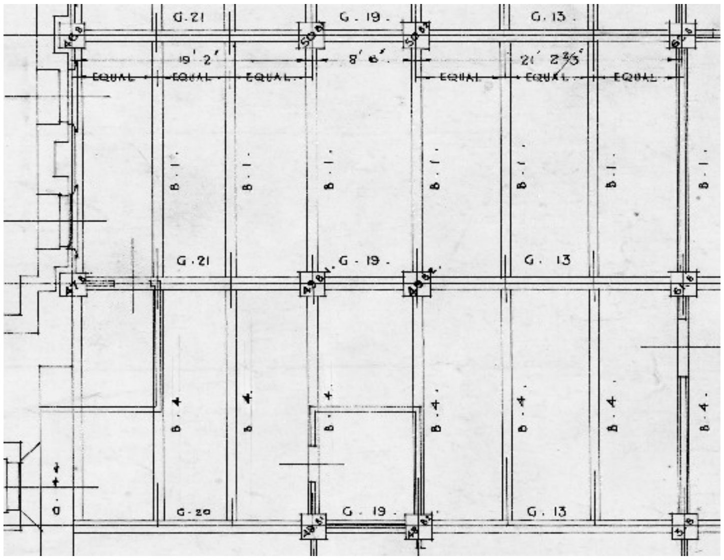

Figure 3 Brisbane City Hall typical floor beam layout (Source: Brisbane City Council, Cartwright & Belperio 2012)

layout of the structure consisted of one way spanning slabs that were supported by a series of secondary beams at 2.2 metre centres and spans at 6.6 metres from the primary beams (See Figure 3 and Table 1).

The concrete columns were supported by a series of large pier foundations, typically 1500 mm x 1500 mm, which were founded on the underlying weathered rock some 10 to 12 metres below ground level.

While the stonework was engaged with the concrete frame, it was supported by a reinforced concrete ground beam spanning between the pier footings around the perimeter. The lateral stability of the building was provided by the concrete floor slabs which act as diaphragms to distribute lateral loads to both the façade and the walls around the auditorium, transferring these loads into the foundations. The concrete walls around the various lifts also acted as stability cores.

Table 1 Typical member sizes and reinforcement [1]

	Primary beam in mm	**Secondary beam** in mm	**Column in mm**
Size	355 wide x 660 deep	280 wide x 585 deep	660 square at ground level reducing to 500 square at the roof
Reinforcement	8 x 28 diameter bars at the bottom and 3 x 12 diameter bars at the top, 10 diameter ligatures	8 x 19 diameter bars at the bottom and 3 x 12 diameter bars at the top, 10 diameter ligatures	12 x 28 diameter bars at ground level reducing to 8 x 28 diameter bars at the roof

Although the majority of the structure was a concrete frame designed for gravity loads, two of the most distinctive architectural elements were steel constructions. The first is the copper-clad dome over the auditorium that consisted of a series of lattice trusses with a plate girder compression ring at the crown. The second is the clock tower on the front elevation, facing King George Square. Although clad in sandstone, the structural frame consists of concrete-encased steel plate girders, with diagonal bracing to each face [1].

The structural design of Brisbane City Hall was constructed using a scientifically-based structural engineering method. While precedent classical (and some early neo-classical) buildings were constructed primarily using the empirical load bearing method of construction, based on traditions and proven observations, most neo-classical buildings progressively took advantage of the advancement in scientific and mathematical innovations that introduced the power of computation into structural analysis.

4. THE PROBLEM

Figure 4 Photograph showing the roof with items that were added over the years (Source: Brisbane City Council)

As mentioned earlier the failure of the original waterproofing membrane on the roof allowed water to seep into the building. The concrete was porous in places so the water was able to penetrate through the concrete roof. It came into contact with the reinforcement which eventually corroded. As the steel expanded it caused chunks of concrete to spall and break away, exposing the full surface of the reinforcement and eventually undermined its strength and integrity as a structural material.

Over the years several items in the roof such as the kindergarten school, air-conditioning systems and equipment were added that eventually led to further maintenance problems (See Figure 4).

To mitigate the cause of the problem, it was decided to completely strip back the concrete and apply a new liquid membrane to make sure that there would be no chance of any future water leakage; the roof would be covered by another layer of waterproofing membrane for additional protection [3].

4.1 The problem of reinforced concrete

The Brisbane City Hall was constructed using a reinforced concrete structural system (See Figure 5). Australian buildings were mostly made of reinforced concrete as it was one of the widely used materials in the 20th century [6]. Contrary to earlier beliefs, reinforced concrete is similar to other exposed construction materials in the way that it eventually corrodes and deteriorates. When exposed, a reinforced concrete structure is very vulnerable to different forces of nature and other internal stresses. Its resilience is also compromised especially with ever-changing construction techniques and methodologies, as in the case of the Brisbane City Hall where its original condition soon lagged behind technology and building standards. Therefore,

Figure 5 Reinforced concrete framing construction of Brisbane City Hall in the 1920's (Source: brisbanetimes.com.au)

the Brisbane City Hall, given the age of the building, was very susceptible to advanced concrete deterioration because the problems described previously had not been properly mitigated.

However, it was not until the 1970's that the best practice of minimum concrete requirements for reinforced concrete (i.e. concrete cover, length of dowel) was standardised [7]. Given this situation and the relative absence of specific research on the topic of concrete repairs in heritage buildings, it is more difficult to update such heritage structures as there is not yet a proven and universally accepted technique to resolve strength issues. Existing building standards also posed a significant hindrance to the process of renovating outdated buildings such as the Brisbane City Hall due to the variations between the reinforced concrete materials used then and what is required to be used now.

With the urgent necessity of maintenance work to the Brisbane City Hall, it has been assumed that the aged reinforced concrete shared the same characteristics as the new concrete structures. It was calculated that both old and new building structures will respond similarly to the modern techniques such as structural simulations and standards that the builders were trying to apply during the restoration process. These procedures may still need to be further verified, enhanced and developed for heritage building repairs, as most of the modern techniques have only been used in more recent reinforced concrete structures. This issue is the major focus of this study.

5. STRENGTHENING METHOD

The preparation of the comprehensive conservation plan for Brisbane City Hall, which had required investigations by several preservation consultants, exposed serious problems in the Brisbane City Hall's concrete structure. The strength and consistency of the hand-batched concrete used in the structural frame of the building when it was constructed was highly variable. Recent testing performed by D. Beal and Associates revealed that the characteristic compressive strength was only at 3.4 MPa which is significantly lower than the current minimum standard of 25 MPa required for structural concrete. As a result of this testing, the experts were compelled to further assess the main concrete element of the structure. They further discovered that the steel reinforcement of the concrete would eventually collapse under the prevailing severe stresses. Although the girders that are most susceptible to tension are heavily over-reinforced, this just shifts the mode of failure to over-stressing the concrete in the compressive zone of the beam, which would gradually lead to a catastrophic downfall.

Since the results of the tests proved the building to be significantly below the current concrete structure requirements, it was imperative that strengthening work should be integrated into the renovation strategy for the building. The Aurecon group devised a design methodology to strengthen the floor structure by increasing its capacity with additional reinforcement on the concrete overlays along the weakened areas. The reinforcement was drilled and was held in place vertically by the beams of the structure. This method was subjected to an assessment test done using the prescribed method in AS 3600 (Concrete Structures).

However the non-existence of specific guidance on how to resolve the issue of the existing low-grade structure that falls more than 20 MPa below the Australian Standard prompted Aurecon to involve Civil Engineering Professor Peter Dux from the University of Queensland to verify and validate their proposed strengthening methodology.

5.1 Re-strengthening Beams and Girders using Overlays

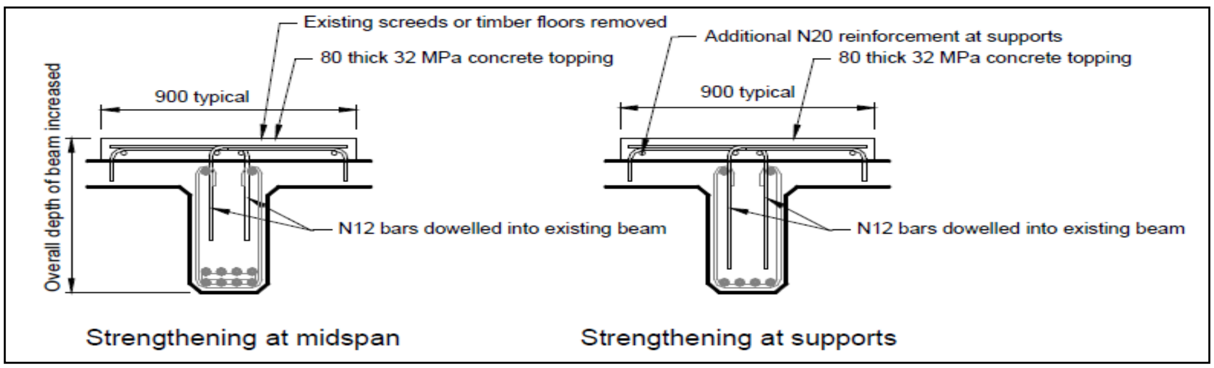

Figure 6 Overlay strengthening details (Source: Cartwright, 2011)

Figure 7 Photograph showing reinforcement drilled and epoxied vertically into the existing beams underneath (Source: The Soul of Brisbane)

The Aurecon Group devised two methods of strengthening. The first one, an innovative approach, was the provision of an overlay on top of the existing beams and girders. The idea was to increase the strength of the beams by adding additional bending and shear reinforcement in a concrete overlay along the affected length of the beam. The additional steel reinforcement is drilled and epoxied vertically into the existing beams underneath (See Figure 6 & 7).

This technique increases the effective depth of the beam at mid-span resulting in a greater rigidity of member that would furthermore decrease the deflection. The vertical dowel bars were drilled into the beams to resist the horizontal shear force between the new and old concrete.

A second method for beam and girder re-strengthening was undertaken by means of installing a series of new steel beams situated beneath, and connected to, the under-strength members.

5.2 Strengthening of Columns

For the strengthening of the columns, two solutions were proposed. The first was simply to provide a high strength concrete jacket around the existing profile. This solution is faster, however, in line with the Burra Charter guidelines, was unacceptable as it would increase the overall size of the columns.

The second solution was to remove the outer skin of the column and replace it with a high strength concrete, thus preserving the original size. This option is suitable in the columns along corridors and function rooms, where the increase in original dimensions would be unacceptable.

A suggestion to insert a steel column into the middle of the existing concrete column was not economically feasible at the current stage of technology.

5.3 Earthquake Strengthening

Figure 8 New steel structures designed to restrain the existing high stone parapets (Source: A. Cruz)

When the City Hall was constructed, earthquake loads were not considered as significant for buildings in Brisbane. Recent expert analysis indicated that the frame on its own lacked sufficient bracing strength. Currently there is a building requirement contained in Structural design actions [8] and Strengthening existing buildings for earthquake [10] . The latter code recommends that the horizontal seismic load applied to the existing structure is reduced to 33% of that used in the design of the new structures. This reduction is an allowance for a building's age and the economic considerations arising from the refurbishment and strengthening of existing structures. However there is no special consideration or any additional criteria in AS 3826 specified for heritage buildings.

It is important to note that when using concrete overlays as a strengthening solution, the mass of the building will relatively increase and this makes it more vulnerable to earthquakes and overloading in direct proportion. Considering all these factors, the structural engineers, Aurecon, ruled that it was not considered appropriate to upgrade all aspects of the structure in accordance with AS 3826. This decision was in consideration of the heritage impacts and the seismicity of the Brisbane area, among other factors. Hence to overcome this issue it was decided only to restrain the high risk elements of the structure. The strengthening work eventually undertaken, took the form of new concrete walls cast immediately against the face of the existing brickwork. These concrete walls are located adjacent to the foyers and light wells.

At roof level, the use of a steel structure for the new Museum of Brisbane is intended to restrain the existing high stone parapets (See Figure 8). It was also indicated that additional works would be carried out on the clock tower to ensure that the balustrades and finials are adequately restrained [3].

5.4 Testing and Results

Figure 9 Water tank filled with water to test beam deflection when subjected to load (Source: The Soul of Brisbane)

Full scale load testing (as shown in Figure 9) was carried out to check if the strengthening had been done correctly between the 26th May and the 8th June 2011. The test was carried out on level one in the north quadrant of the building (the Balmoral and Oak Table rooms). The objective was to test the typical strengthening works installed on the beams and girders. The soffit of the girders and beams were inspected for existing cracks. The contractor prepared a marked-up plan of the existing cracks in the concrete girders, showing crack width, orientation, location and length.

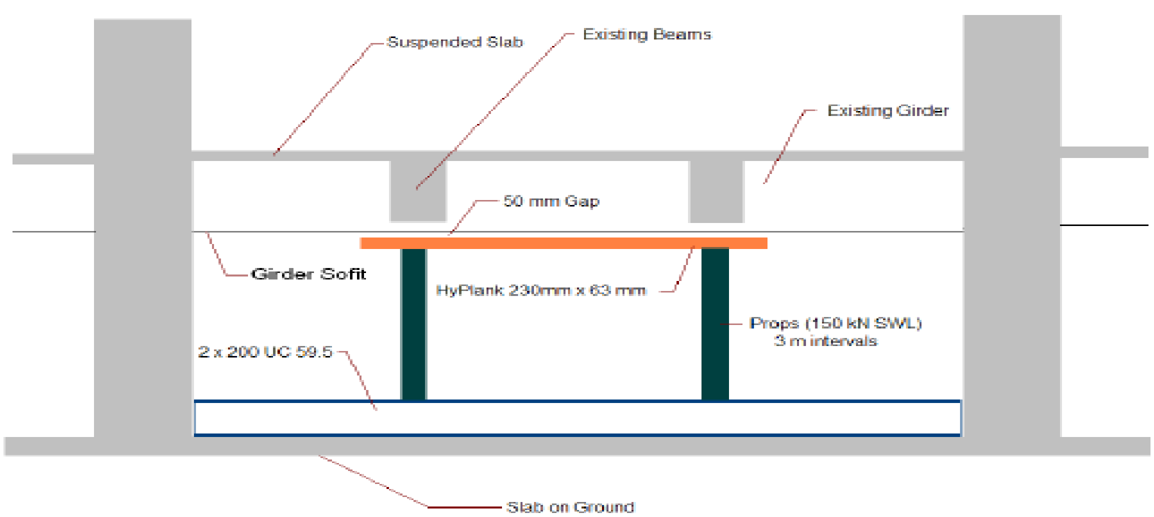

Figure 10 Propping set up devised by Aurecon to check the deflection of beams and girders under loads (Cartwright, 2011)

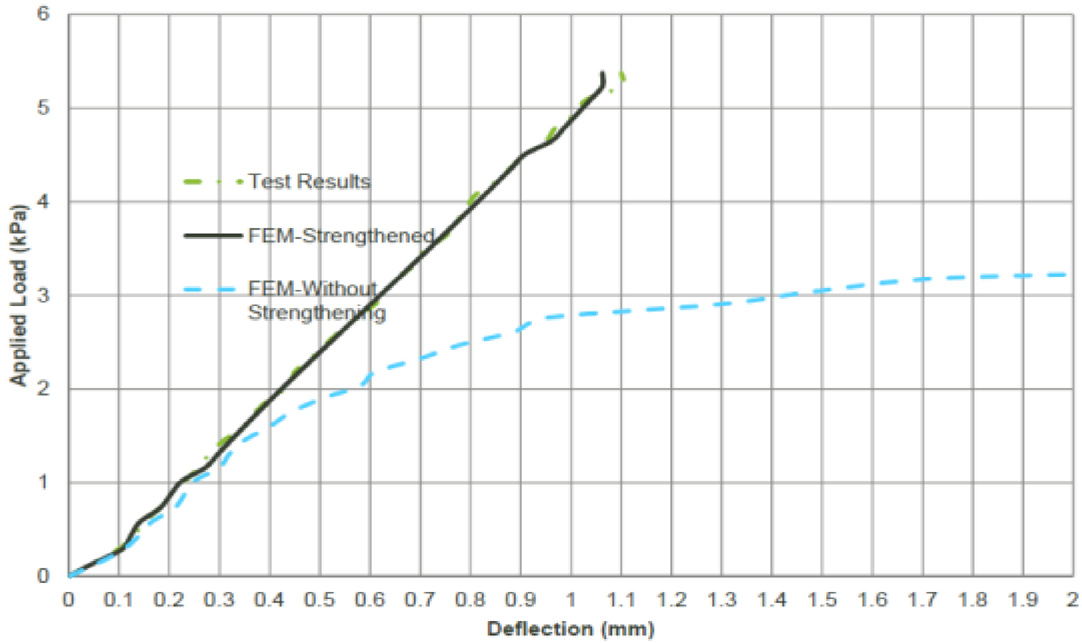

Figure 11 Comparison of the load test with the theoretical analysis (Source: Aurecon)

The beams and girders in the location where the test was to be executed have heavy duty back propping placed under them. A gap of 50 mm was provided between the top surface of the Hyplank and the soffit of the beams and girders in the loading zone. No gap was provided between the top surface of the Hyplank and the soffit of the girders located at the perimeter of the loading zone. Figures 10 illustrates the testing method that Aurecon devised to ensure the strengthening method was correct.

The results of the load test are summarised in Figure 11, which shows the deflection against the applied load for the onsite strengthened girders, along with the theoretical results for both strengthened and un-strengthened girders (both modelled using finite-element analysis).

With a 3.0 kPa imposed floor load, the deflection of the strengthened girder was similar (approximately 0.6 mm) for both the theoretical analysis and the load test. This was a significant improvement over the theoretical analysis of the un-strengthened girder, which had a higher rate of deflection, and which had failed at approximately 3.2 kPa. The measured deflections were well within the generally accepted limiting value of span / 500 (for beams where the line of sight is along the soffit).

Figure 12 Completed overlays of beams and girders (Source: A Cruz)

A visual inspection of the beams and girders after the tests revealed only fine cracking in the tension zones. This is to be expected in reinforced concrete members where the cement structure has to crack in order for the reinforcement to be effective in tension. As a result of the load test a permanent deflection in the girders of approximately 0.05 mm was recorded.

The full-scale load test demonstrated that the strengthened girders performed in the manner predicted in the theoretical analysis. Based on the results of the full scale load test it was considered that the overlay strengthening strategy has been validated for the agreed 3 kPa imposed floor load. This testing results means that the structural restrengthening upgraded the structural capacity of the beams and girders of Brisbane City Hall. The concrete overlays (see Figure 12) enable the structures to comply with the current building legislative requirements stated on AS 1170 and AS 3600 for building occupancy with an important condition that it will not allow any physical activities such as rhythmic dancing in the function rooms. The dynamic effects of those activities would increase the stresses in the floor structures. This condition was approved by the Brisbane City Council and the structural designer [1].

6. CONCLUSION

Many buildings constructed at the turn of the 20th century are challenged to meet the demands of current usage while progressively deteriorating. We are continuously learning new ways to solve the problems of these modern buildings whether technologically or systematically (while waiting for the proper solution). A better understanding of this type of building will help to align the provisions of the current policy and standards. Further monitoring, investigations and analysis would ensure to enhance the approaches of how to restore this type of building such as the Brisbane City Hall, a modern heritage building of the 20th century.

There are several state-of-the-art techniques, both in theory and in practice, in building assessment and strengthening; however the approach for historic structures requires very meticulous and comparatively conservative methods. It is not often that a reinforced concrete structure is considered a historic building, compared to masonry, cast/wrought iron and timber structures. Due to the concrete decay seen, several techniques for strengthening and repair have been developed. The case study of the Brisbane City Hall assessment and restoration will contribute to the opportunity to further explore the restoration of early reinforced concrete.

The World Heritage List has 34 ‘modern heritage’ buildings as compared to 759 overall cultural heritage properties [12] and continually growing. Modern heritage structures constitute the bulk of the heritage buildings in Oceania and The Pacific. Most of these buildings are at the stage of advanced deterioration and require immediate interventions in order to be saved. However, the restoration requirements for the restoration of ‘modern heritage’ buildings is different from that of the ‘ancient heritage’ buildings while the policy guidelines are on the early stage of development for ratification. It is hoped that the content of this case study will contribute to the debate for enhancing the approaches for the conservation of the 20th century architectural heritage.

7. RECOMMENDATION

Further investigations such as mathematical simulation, monitoring and inspection, experiment and exploration by comparison with other buildings should be done to ensure the future of the Brisbane City Hall heritage building. The ultimate integrity of the innovative methods that will come out in the post-restoration phase will provide more sources of relevant data and information. This will guarantee that this research project will not only document the important aspects of restoration projects but it will also contribute to the new knowledge regarding the restoration of 20th century modern heritage buildings such as Brisbane City Hall.

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