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The Structural Strengthening of a Masonry Heritage Shop House using Glass Fibre Based Materials

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Abstract. *A two-storey masonry pre-war shop house in Taiping, Malaysia was badly affected by construction being undertaken at an adjacent lot. The building was in a serious state of disrepair and on the verge of collapse at the time of the investigation and temporary propping and a stoppage of adjacent works had to be imposed. For the remedial intervention a rapid approach was critical with materials and methodologies selected to incur minimum additional impacts on the building in terms of physical works and with flexibility on site. Several innovative techniques developed for the structural intervention of masonry buildings was considered. In this case the masonry wall cracks were repaired by a stitching method using the glass fiber rod maperod g which was considered a suitable material due to the compatibility of modulus of elasticity (40,800N/mm2) to the lime mortar, having good tensile strength of 760 N/mm2 to help bridge the cracks in case of further movement and is also corrosion resistant and will remain protected in future even though it is embedded in a highly porous masonry substrate. The materials used were easily transportable, flexible (ie) could be prepared to requirements on site and could be delivered to site quickly despite this being imported. The approach taken resulted in a rapid reinstatement of the building, minimised the risk of losing heritage features and matched the client's overall objectives. The paper provides details of the approach taken and the basis for the remedial intervention.*

Keywords: *Masonry, Structural Cracking, Remedial Intervention, Glass Fibre Materials.*

1 Introduction

1.1 Project Background

A masonry shop house in Taiping, Perak in Malaysia was badly affected by construction being undertaken at an adjacent lot. There was significant evidence of settlement at the front and back of the building, leading to significant cracking of a party wall, front and rear walls and the main walkway Arch Supporting the upper floor and wall.

The building is a 2 storey pre-war shop house with an overall layout plan as shown in Figure 1. The building housed a family business until adjacent construction activity forced the owners to move from the premises due to an eviction order imposed by the local authority arising from the dangerous state of the building. The actual construction details of the adjacent building was not made available but the site visit confirmed that the original 2 storey building next door had been torn down to make way for a 3 storey structure on piled foundations with a lift at the rear.

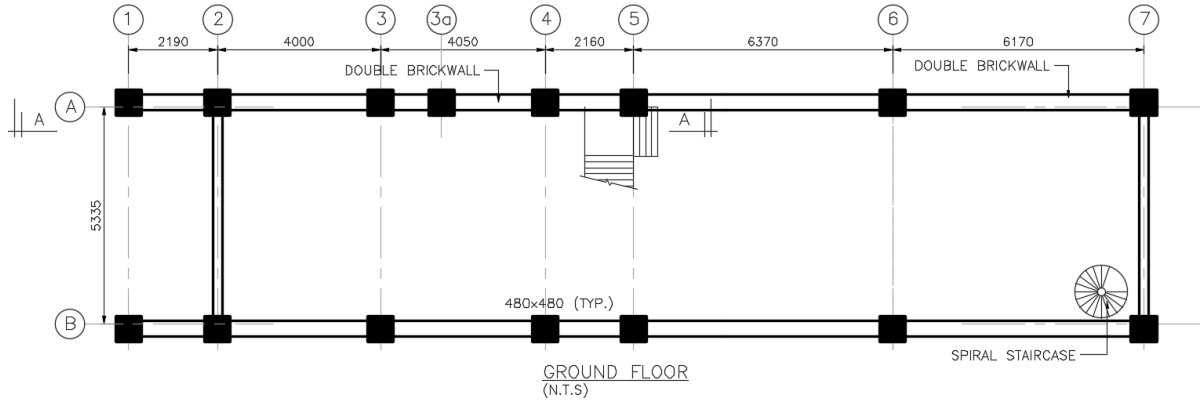

Figure 1. Plan View of Shop House.

The only precaution taken to protect the shop house was an attempt to support the common corridor arch at the front of the building with Timber Props which was totally inappropriate for a structural masonry arch and had potentially accentuated the serious damage caused by imposed stress concentrations due to the settlement and vibration. The structural Engineer who designed the new adjacent 3 storey shop house was asked by the local authority to provide a report and a basis for remedial intervention. The initial suggested approach to epoxy inject the cracks were considered wholly inadequate and not a serious measure of what was required to reinstate the shop house to its original design intent and to guard against long term settlement and cracking associated with the disturbed foundations. A site walk through was undertaken to view the condition of the structure and this is discussed below.

1.2 Condition Audit

There was considerable evidence of settlement of the columns in gridline A/1-3 as shown in Figure 2. This led to uneven loads on the masonry columns causing the characteristic structural cracking of the Arch, where cracks of up to 50 mm in width were noted. A closer examination of the party wall from the adjacent shop house confirmed that the structural cracking extended to this wall along Gridline A2- A5 where cracks of up to 30 mm were noted. In general the party wall away from the new development was structurally intact. An immediate intervention was proposed to structurally reinstate the front Arch, the common party wall along gridline A and other settlement and cracking points. It was noted that the building was not loaded with the full complement of live loads which can be expected. The cracking on the walls and the Corridor Arch were clearly to do with settlement and vibration loads associated with the adjacent construction, rendering the building unsafe to use at the time of the investigation. There was also a considerable amount of water ingress into the building particular at gridline A-B'/5-7 and also at the building corners at gridline A1 and A5 which had not been a problem previously. Based on the visual survey the key defects noted are summarised in Table1.

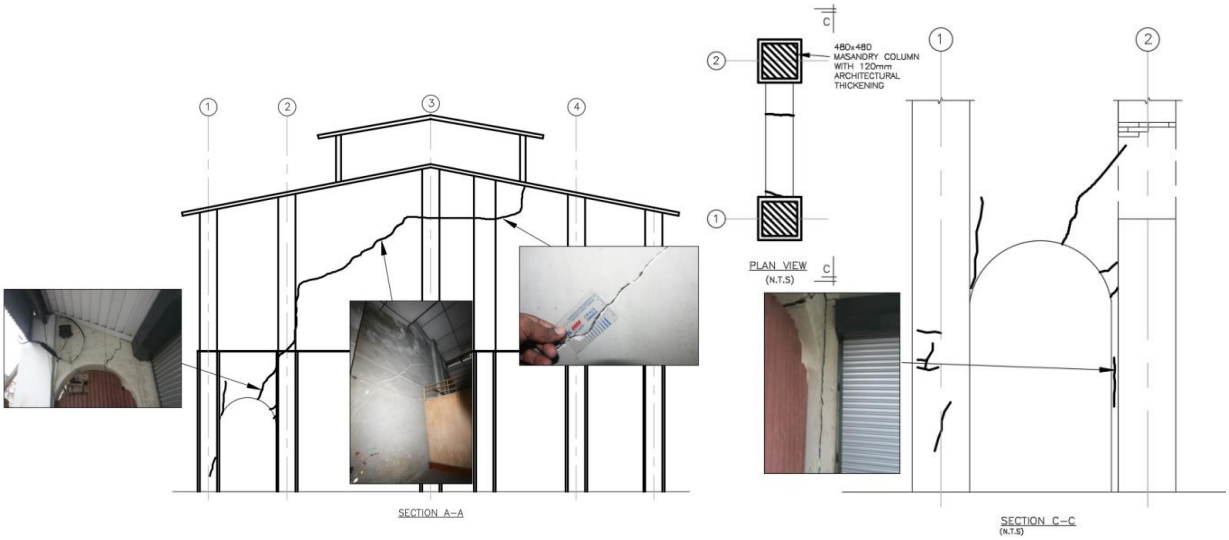

Figure 2. A Record of the defects at the Main Arch at the Shop House Front and at the Party Wall.

2 Engineering Features

2.1 Overview

Demolition of masonry shop houses and rebuilding is often considered the preferred option when such structures come into disrepair. Increasingly however repair and refurbishment is seen as a more sustainable option in terms of architectural value, materials use, neighbourhood disruption, waste disposal and overall cost. By avoiding expensive demolition and rebuild, the development of repair and refurbishment techniques retains the aesthetic and historic value of a building including its appearance and providing a sustainable structural solution. It also potentially reduces costs.

Where defects are related to settlement, it is necessary to repair or underpin the foundations before any stitching of the cracks on the brick masonry. In historic buildings, it is important to preserve as much of the original materials as possible and consider repair options which are relatively reversible and do not damage the original building fabric.

2.2 Options for Structural Reinstatement

The building was in a serious state of disrepair and on the verge of collapse. Temporary propping and a stoppage of adjacent works had to be imposed. A rapid approach was critical for the intervention, with materials and methodologies selected to incur minimum additional impacts on the building in terms of physical works and with flexibility on site.

Table 1. Summary of Condition Audit Findings.

Item	Type of Damage	Location of Damage	Options for Reinstatement
1	Damage to Footings Leading to Settlement	Party Wall between unit 150 and 152, Gridline A1-7	Compensation Grouting was done for all footings at the common Boundary between the Shop House 150 and 152 from Gridline A/1 to 7 to guard against future movement and settlement.
2	Structural Cracking of the Arch and associated Party Wall	At the Front Corridor Gridline A/1 - 3	The Arch was fully supported with a radial support structure and props to facilitate repairs. The remedial works involved reinforcing the whole span of the masonry arch across the crack with Carbon Fibre Rods and an appropriate mortar effectively introducing structural beams above the arch opening so that load shedding is directed to the columns. The remedial intervention also involved stitching of structural cracking which extended to the party wall and columns to cover the full extent of cracking
3	Wall Crack	Party wall between Gridline A/2 - 4	The remedial works consisted of stitching the cracks with Carbon Fibre Rods and a structural grade epoxy. The stitching was extended to the full extent of cracking
4	Window Lintol and wall Cracks	Gridline A-B/1	Epoxy Injection and Borehole Suspension' Grout used
5	Settlement Cracks at the Rear of Building	Gridline A-B/7	Epoxy Injection and Borehole Suspension' Grout used
6	Level 1 Cracks Leading to Water Ingress	A-B'/5-7	Flexible Acrylic Gel to Seal the Cracks with the Option of Reinjection if the problem is not resolved in the first instance
7	Other Areas of Water Ingress	A1 and A5	Further investigation was required at roof level to ascertain the source of the water leakage problems. Repair as per 6 was required and in this case replacement of damp plaster works was also necessary.
8	General		Replastering, Overall Repainting and Replacement of Internal fittings affected by moisture ingress adjacent to party wall was done.

Several innovative techniques have been developed for the structural intervention of masonry buildings. Among the key developments in this area includes the use of stainless steel helical ties and slim ties developed by Helifix (www.helifix.com). These form very strong axial ties to resist lateral forces, yet are flexible enough to accommodate natural building movement without introducing further stresses in the substrate. The associated concealed, non-disruptive installation techniques provide many outstanding benefits, from the simplicity of their design to ease of installation and their long term performance. At the time of the investigation the options for repair had been further advanced by Mapei using alternative materials with glass fibre as the base ie Maperod G and Mapewrap Foccio. Where masonry wall cracks are to be repaired by a stitching method, the glass fiber rod maperod G is a suitable material due to the compatibility of modulus of elasticity (40,800N/mm2) to the lime mortar. It also has a good tensile strength of 760 N/mm2 to help bridge the cracks in case of further movement. As glass fiber is also corrosion resistant it will be protected in future even though it is embedded in the highly porous masonry substrate. In the case of the Taiping shop house the latter approach *i.e* Mapei rod was used as the materials were easily transportable, flexible *i.e* could be prepared to requirements on site, and Mapei had the infrastructure to deliver the materials to site quickly despite this being imported.

2.3 Approach to Reinstatement

The extent of the remedial works was confirmed based on the visual examination and following hammer tapping and hacking to confirm the extent of the problem. The final remedial works undertaken between gridlines 1-5/A included the following:

a) Stabilization of six column foundations A/1, A/2, A/3, A/4, A/5 and A/6 with soil grouting using OPC and Intraplast –Z.
b) Stabilization of six column foundations A/1, A/2, A/3, A/4, A/5 and A/6 with soil grouting using OPC and Intraplast –Z.
c) Removal of wall plaster and re plastering using Mape-Antique MC a prebagged lime based plaster
d) The full reconstruction of one column at gridline A/3 by re-using the existing bricks which were carefully dismantled piece by piece.
e) The columns at gridline A/2 and A/5 were partially removed and the bricks reinstated and injected using Mape-Antique I by a low pressure injection method.
f) The Arch and wall cracks were repaired by a stitching method using Maperod G a glass fibre rod which is inert within the matrix but providing structural strength.
g) Mapewrap G Fiocco was used allowing stitching to be performed at one-side with minimum impact to the overall wall with the anchors planted deep into the masonry wall to provide the full anchorage.

In this case the stitching could only be performed at one-side and for this reason Mapewrap G Fiocco was selected as an appropriate method. Mapewrap G Fiocco is made into an L-shaped anchor using epoxy impregnator Mapewrap 31 SP and is bonded at both ends of the Maperod G.

The anchor is planted deep into the masonry wall, ie approximately to a depth of 140mm to provide the full anchorage. To structurally bond the Maperod G and Mapewrap Fiocco to the masonry wall, epoxy adhesive Adesilex PG2 TG was selected. Epoxy has high durability and good mechanical properties in terms of compressive, flexural, tensile and shear strength.

To enhance the bonding to the masonry wall, all contact surfaces of the masonry were primed with Mapewrap Primer 1 SP to consolidate the porous surface and eliminate dust. The crack lines were reinforced at every 4-5 brick intervals and inserted into the pointing layer for a minimal impact on the existing masonry wall. The full extent of the repairs is illustrated in Figure 3.

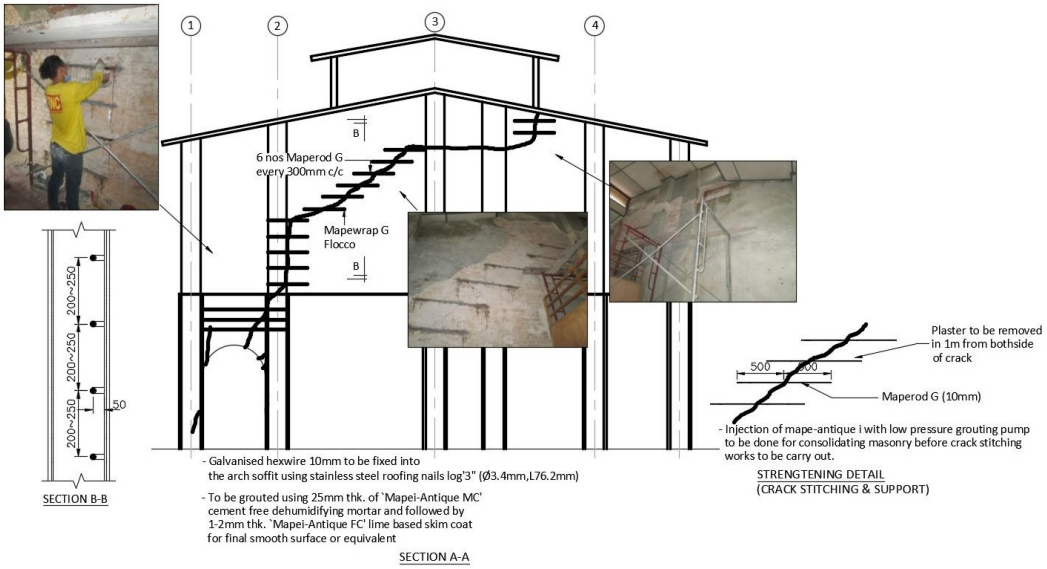

Figure 3. Significant Cracking of the Arch and Party Wall and the proposed approach to crack repair.

The remedial work was carried out by a specialist contractor and the repair materials were supplied by Mapei. The works were carried out successfully and the shop house was reinstated to its original condition within 3 weeks (see Figure 4).

Figure 4. Additional Illustrations of the Remedial works.

3 Project Accomplishment

3.1 Client Needs

The remedial works were undertaken rapidly and reduced the impact of the loss of access to the facility. The alternative which was on the cards was demolition and rebuilding. The engineering solution entailed using modern materials developed specifically for heritage upgrading which had never been used in a practical project application before for structural restoration. The work was done with little impact on the overall heritage value of the building.

3.2 Budget and Project Time Line

The project was successfully controlled with the implementation of proper documentation in the form of detailed method statements and pre-selection of materials to be used directly from a specialist supplier (Mapei). In conjunction with Mapei an off-site training was undertaken of key personnel involved in the project to minimise delay on site.

The arches and key structural components had been temporarily propped using specially designed timber props to guard against collapse and this was removed progressively. The stabilization of the foundation was undertaken within a week and as the injection works were completed in a particular area masonry strengthening works proceeded in the associated area. The crack repair works and stabilisation of the masonry walls proceeded over a 2 week period. The finishing works and painting was then undertaken by the main contractor.

The works were successfully undertaken at approximately a quarter of the cost and 1/3 of time compared to rebuilding of the structure which was the only other option. As this was the full responsibility of the adjacent works contractor as per the court order, the approach taken was a win-win for all parties (ie) in terms of time and cost. This met the client's requirements for speed and minimisation of the disruption after a lengthy delay due to the legal action.

3.3 Overview

This work demonstrated the validity of the use of modern materials for a non-invasive low maintenance reinstatement of a heritage building badly affected by settlement and structural movement with little impact on its heritage value. This was considered to be the most cost-effective solution and appropriate, where speed of reinstatement to manage structurally compromised masonry buildings are concerned. As the structural rods used in strengthening are made with glass fibre reinforcement these are not affected by corrosion which is a problem in porous Masonry structures particularly if rebars are used for strengthening. In this case life cycle issues outweighed initial capital expenditures particularly as a period building was concerned and the approach minimised the risk of any repeat intervention which would have in a rapid reinstatement of the building, minimised the risk of losing heritage features and matched the client's overall objectives.

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