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Strengthening of Historic Buildings through Structural Repair Works: Review of the Methods and Process

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ABSTRACT

This paper will focus on structural repair works process for strengthening of existing historic building. This papers will explore the several method that been used in the structural repair works and how the impact on the building structure before and after the process. The decision as to whether a given building needs to be strengthened and to what degree, must be based on calculations that show if the levels of safety demanded by present codes and recommendations are met. The method of repair and strengthening would naturally depend very largely on the structural scheme and materials used for the construction of the building.

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INTRODUCTION

The seismic behaviour of old existing buildings is affected by their original structural inadequacies, material degradation due to time, and alterations carried out during use over the years such as making new openings, addition of new parts inducing dissymmetry in plan and elevation, etc. The need to improve the ability of an existing building to withstand seismic forces arises usually from the evidence of damage and poor behaviour (Seeley, I.H., 1976). It can arise also from calculations or by comparisons with similar buildings that have been damaged in other places. The main purpose of repairs is to bring back the architectural shape of the building so that all services start working and the functioning of building is resumed quickly. English Heritage has listed ten main principles of repair, restoration and maintenance of historic buildings; which can be a basic guidance for the conservation of historic buildings and monuments in Malaysia. The principles are broad and generally applicable to the whole of the built environment. It should be recognised that each individual case must be analysed so that the principles can be applied to generate specific solutions for particular problems (Feilden, B.M., 1982).

The Purpose of Repair	Determining the primary purpose of repair is the most important principle. Its main objective is to prevent the process of decay of building materials and characters while maintaining building structures in good condition. It is also important not to alter any features that give the building its particular historical or architectural significance.
The Need for Repair	The main need for repair is to achieve a sufficiently sound structure, particularly to ensure structural safety and therefore its long-term survival and to meet certain requirements of any appropriate use. Therefore, any intervention during repair must be kept to the minimum in order to stabilise and conserve historic buildings.
Avoiding Unnecessary Damage	Any unnecessary replacement of historic fabric should be avoided even though the work is carefully carried out. This is to prevent any adverse effect on the appearance of a building which then significantly reduces its historical or architectural value or seriously diminishes its authenticity.
Analysing Historic Development	Before any repair is carried out, it is necessary to analyse thoroughly the historic development of a building. This is to ensure that any historical facts about the buildings are well documented for future work or research. Archaeological and architectural investigation, recording and interpretation of a particular structure, and its assessment in a wider historic context may be desirable. If appropriate, these processes may continue even during the course of repair.
Analysing the Causes of Defects	Any decayed fabric should be analysed prior to carrying out the work of repair and replacement. This include an analysis of causes of defects, condition and nature of existing building materials; and a survey of structural defects. The main purpose of carrying out such analyses is to avoid any repetition of building problems or to repeat previous design errors.
Adopting Proven Techniques	In order to preserve the appearance and historic integrity of a building and to ensure that repairs have an appropriate life, all repair work should match existing materials and methods of construction. Therefore, any new methods and techniques of repair should only be carried out where they have proved themselves over a long period

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	and also where traditional alternatives cannot be identified. However, the degree of damage caused to the building's appearance, historic integrity and fabric should be considered when it is decided to adopt new methods and techniques.
Truth to Materials	In carrying out repairs for building materials, it is important to execute the work honestly. There should be sincerity to the materials and also the whole building as well. However, repairs should be dated discreetly where appropriate.
Removal of Damaging Previous Alterations	In some cases, additions or alterations are of importance for the part they play in the cumulative history of a building. In fact, there will often be a strong presumption in favour of their retention. However, if they are to be removed based on the grounds of having no intrinsic value in themselves or may seriously disrupt the overall architectural interest of the building, then the implications of doing so must be carefully considered in advance.
Restoration of Lost Features	Some elements of an historic building, for example balustrades, pinnacles, cornices, festoons or window tracery, may have been broken or lost in the past. If they are of structural significance, then they should be restored or replaced in the course of repair. However, to avoid inaccurate and unnecessary replacement, sufficient evidence should be provided to support both the existence and form of the lost features.
Safeguarding the Future	Like other historical objects, buildings of architectural and historical significance should be regularly monitored and maintained. Reviews should include public safety and access, protection of historic buildings from traffic, fire and security; and preventive maintenance. Choosing an appropriate and sympathetic use for an historic building is important to secure its future and also to minimise its repair requirements and the need for structural interventions.

Repair Material and Methods:

The most common materials for damage repair works of various types are cement and steel. In many situations non-shrinking cement or an admixture like aluminium powder in the ordinary portland cement will be admissible. Steel may be required in many forms, like bolts, rods, angles, channels, expanded metal and welded wire fabric. Wood and bamboo are the most common material for providing temporary supports and scaffolding etc., and will be required in the form of rounds, sleepers, planks, etc (Construction Industry Research and Information Association (CIRIA), 1986). Besides the above, special materials and techniques are available for best results in the repair and strengthening operations. In this case, several method were apply namely, Method of Statement for Formwork Pressure Grouting Works, Method of Statement for Structure Crack Repair, Method of Statement for Structural Strengthening using Carbon Fibre Reinforced Polymer (CFRP), Method of Statement for Structural Strengthening using Carbon Fibre Reinforced Polymer (CFRP) Laminates, Method Statement for 2 Hours Cementations Fire Protection and Method of Statement for Shanghai Plaster Works.

Results and Findings:

The following results shows the process of structural repair works mostly before and after the process to justify the increase in strengths after the repair works. Details as follows:

Structural Repair Works:

A) Method of Statement for Formwork Pressure Grouting Works:

Cutting of Defective Concrete:

The areas to be repaired is indicated on site. All the defective areas were delineated and marked out before commencing of works. In this stage, no reinforcement shall be bent or cut and the depth of breakout on the edge of the repair areas to be minimum 10mm depth. The preparation shall be as such to leave a sound exposed concrete substrate free from dust, loose particles and any deleterious matter.

Reinforcement Preparation:

All exposed reinforcement was cleaned of corrosion products by wire brushing and if the area of corroded reinforcement more than 10% of the total reinforcement, new reinforcement was fixed and lapped with the existing bar with a lap length of 40xdiameter. In this case, damaged reinforcement during the removal of concrete was replaced. After cleaning but before applying the prime coat, the reinforcement was air cleaned to remove dust and other loose materials.

Reinforcement Priming:

The priming coat was applied within 2 hours after preparing and cleaning of the reinforcement and the primer coat used was MAPEFER 1K

Concrete Bonding Agent:

The bonding agent was applied to areas to be repaired. Type PLANICRETE SP with flexural strength of 5 N/mm2. In this process, the surface area to be cleaned, sound and free from contaminants and the area to be soaked with fine spray of clean water so no free surface water must be present. The bonding agent was mixed and applied to all surfaces using a suitable paint brush, using a “scrubbing” action.

Grout Mix:

The proposed dual shrinkage compensated micro concrete MAPEFILL MC 06 prebagged cementations repair material for formwork repair. In this stage, the grout shall be mixed with addition 4.0to 5.0 litres of water in a mechanical engine driven mixer to obtain homogeneous mix. Thus, the mixing should be held in agitation tank and kept in motion to prevent settlement or segregation occurring.

Fixing Formwork:

The formwork was adequately braced and rigidly constructed to withstand grouting pressure and the formwork was cleaned perfectly before fixing in place. The formwork was grout tight and minimum concrete cover to steel reinforcement of

50mm shall be ensured and grout pipe shall be filled into the formwork at internal of 1.0m to 1.5m. The grout was pumped using a pressure of not less than 50psi

Removal/Curing:

Formwork shall remain in place for a minimum of 24 to 72 hours before removal and surface was cured with potable water immediately after formwork removal.

B) Method of Statement for Structure Crack Repair:

All crack 0.2mm-0.5mm wide shall be injected. In this process, clean the surface of the crack by wire brushing and the cleaning of cracks from dust and loose particles shall be done by means of clean high pressure compressor air. Entry ports shall be propositioned along the crack line at 200mm. in addition, fix a plastic nozzle or copper tube at the entry port and seal the surface of the crack line with a temporary seal (Adesilex PG2which can be used under wet and damp conditions) to a width of between 25 to 30mm. after that, measure out each component in the volumetric ratio 1:2 (Part A: Part B) into clean, dry container for subsequent mixing. In this stage, single component injection pump shall starting at the widest crack, pressure inject (Epojet LV) into the cracks line and when the Epoxy appears at the next port lock the port by capping and proceeds with the injection until the epoxy appears from third, fourth and so on. Proceed to inject the Epoxy until a pressure of 50 psi is achieved and maintain this pressure for a few minutes to ensure full penetration of Epoxy. This procedure shall be iterated until the entire crack in the concrete filled. The injected epoxy shall be allowed to cure for twenty four (24) hours and the surface shall be left in place or removed if required

C) Method of Statement for Structural Strengthening using Carbon Fibre Reinforced Polymer (CFRP):

Surface Preparation:

The concrete surface needs to be cleaned, dry and sound. All laitance and any other surface containment need to be removed by mechanical means such as grit blasting, grinding or water blasting. All surface irregularities and defects shall be ground smooth (to less than 1mm) and all concrete angles must be rounded to no less than R=10mm. internal angles need to be smooth. Besides that, all crack and defect concrete shall be repaired before apply CFRP system.

Priming:

The Mapewrap Primer 1 SPis specifically developed for Mapewrap Sheet. In this process, mix the Primer using a slow speed drill and paddle for 3 minutes and apply by brush or roller to the concrete surface but the concrete must be dry before application.

Smoothing:

Allow Mapewrap Primer 1 SP to cure before filling any voids with Adesilex PG2. Epoxy putty with part A: part B and Map wrap C Uni-Ax300with a 0.167mm thickness application. But, ensure Adesilex PG2epoxy putty Mapewrap Primer 1 SPand are dry prior to application of Mapewrap C Uni-Ax300. After that, precut sheet to desired sizes and do not remove backing. At this stage, mix whole units of Mapewrap 31 SP only and do not apply if 5'C or below or if temperature is likely to fall 5'C during its cure period. Apply first coat of Mapewrap 31 SP by brush or roller (coverage at 400-500gm/m2) and apply Mapewrap C Uni-Ax300 and using a rubber scrapper/roller or ribbed metal roller, impregnate Mapewrap C Uni fully with the resin and extrude all air. This will means the resin has fully impregnated the sheet. After that, apply the second coat of resin by brush or roller (coverage at 100-200gm/m2) and ensure all air is extruded.

Second and Subsequent Layers:

In this process, if a second layer of Mapewrap C Uni-Ax300is required, then repeat the sequence above, ensuring that the thickness of resin application is the same and the Mapewrap C Uni-Ax300is fully impregnated and that all air is extruded. The pot life of the resin is approximately 40 minutes at 30'C therefore ensure the quantity of resin mixed at any one time is sufficient for the quantity of Mapewrap C Uni-Ax300being applied; Cure Time: within 15 hours at 30'C

D) Method of Statement for Structural Strengthening Using Carbon Fibre Reinforced Polymer (CFRP) Laminates:

In this process, all effected concrete surface shall be free from paint, cement laitance and must be sound concrete. Before apply Primer make sure concrete are in uniform or else apply 1.0mm thick layer of Adesilex PG2. Apply a layer of Epoxy Adhesive Adesilex PG 2 on the prepare area and use stiff rubber roller to roll over the Carboplate until remove the excess resin.

E) Method Statement for 2 Hours Cementations Fire Protection:

Preparation:

Prior to application of Monokote MK6-HYspray fire protection, a joint inspection shall be carried out to decide that all carbon fibre surfaces are acceptable to received fire protection. The carbon fibre to be fire proofed shall be free of oil, grease, loose mill scale and excess rolling compound, non-compatible primer and any other substrate that will impair proper adhesion. Besides, wire brush to remove loose mill

scale and detergent to remove oil, grease and excess rolling compound.

Execution of Works:

Ensure pump station are proper setup, all hoses are connected to the site requirement with access to clean water with sufficient volume and pressure and adequate electricity supply for all the pumps.

Mixing:

Monokote MK6-HY shall be mixed with a conventional, plaster-type or a continuous mixer (Sun-Continuous Mixer) specifically modified for mixing cementations fire proofing. For continuous mixer, dry Monokote MK6-HY material is first poured into the mixer hopper. The auger below the mixer hopper will force the dry material into the mixing tube. At the same time water is introduced into the mixing tube. The mixer blade inside the mixer tube mixes the fire proofing material into a creamy texture. The amount of water being introduced into the mixer tube is calibrated to blend the Monokote MK6-HY to mixer density of 640 720kg/cu.m (440-45 lb/cu.ft). in this stage, water shall be cleaned and free from impurities (consumable water). Fill up the pump hopper with water and start the pumping and discharge the wet Monokote MK6-HY, when the water in the hopper is almost empty. Then, when the water is completely flow out of the nozzle start spraying. The spraying rate is between 180 sq.m to 600 sq.m for one inch thick of Monokote MK6-HY per day depending on type of pump and site condition.

Application:

Application of Monokote MK6-HY fireproofing can be made in the following sequence:-

i. For thickness of approximately ½ inch or less, ap ply one pass.
ii. For thickness of approximately ¾ inch or grater, apply subsequent passes after the first coat has set.
iii. The second and subsequent passes can be applied 3-15 minutes after the previous application.

Protection and Cleaning:

Identify areas where protection may be required or scrap clean condition is acceptable. Above ceiling height on walls, concrete slab, or roof will not require any cleaning. Scrapping is method of cleaning up to floors and walls. Different types and sizes of scrappers are being used.

F) Method of Statement for Shanghai Plaster Works:

Surface Preparation:

The surface must be sound and free of dirt, oil, grease, laitance, curing compounds, sealers and other contaminants. The surface to receive the washed pebbles or aggregates shall be in good strength with cement and sand ratio (1: 3). Wet the surface before application for at least 2-4 hours before installation. A light acid wash is recommended and hose off with water until surface is clean. The surface should be free from any cracks.

Material Specifications:

Stone chippings for Shanghai plaster shall be granite, white stone or marble chippings. The chippings shall be free from dust and shall be graded such that 100% passes a 5 mm BS test sieve and 100% is retained on a 2.36 mm BS test sieve

Installation:

Shanghai plaster shall be applied in two coats, each 10 mm thick. The base coat shall consist of cement and sand in the proportions 1:3 by volume. The finishing coat shall consist of cement and stone chippings or marble chippings in the proportions 1:1 by volume. The chippings shall be mixed in one of the proportions stated in table below. After the finishing coat has set, the surface shall be scrubbed with an acidic liquid cleaner to expose the aggregate.

Colour of Shanghai Plaster	Cement			
		Stone chippings (Dark Grey)	Stone chippings (light Grey)	Stone chippings (White)
Dark	OPC	80		20
Medium	White	60	20	20

Hose off with water to remove the cement film. Continue the hosing until the film is no longer noticeable. Lastly, seal the chippings with one coat of sealer.

Conclusion:

Building structural repair works require sufficient supervision of a competent person to ensure that the work is carried out to a satisfactory standard and in accord with the agreed specifications. All works or repair should be recorded, photographed and documented for archival purposes and future building structural repair works.

The situation in Malaysia is such that most of the works involving building repair and maintenance unfortunately have failed to observe the principles of repair and disregard proper methods and techniques of building structural repair works. Examples given in this paper represent a general picture of common building problems and their solutions which emphasized on structural repair works. However, it is important to emphasize that each building problem should be handled individually following a thorough study of the building structures and conditions.

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