INSTALLATION AND MAINTENANCE OF EXTERNAL FAÇADE TILES ON TALL BUILDINGS

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Abstract: This paper covers general issues related to the installation and maintenance of external façade tiling systems on tall buildings.

INTRODUCTION
Tiled external building façades have been commonly used on buildings in Hong Kong for approximately the last 30 years. As time goes by taller and taller buildings are being designed and constructed with ever increasing pressure on both design and construction programmes. As buildings become taller, the popularity of tiled external facades has remained constant particularly for residential developments whereas cladding and curtain wall systems have replaced tiles to some extent on tall commercial building developments. The use of tiles on tall buildings introduces a number of issues with respect to design, installation and particularly maintenance. For the purposes of this paper tall buildings are considered as any structure of approximately 10 storeys or taller.

TILING SYSTEMS

Glossary of Common Terms

Adhesive – Refers to the material used to adhere tiles to a substrate, see tile bedding below for description.

Bond Coat – Sometimes referred to as ‘key coat’ and normally consisting of cement and a polymer additive. Applied either directly to the substrate prior to application of render or applied over the top of a spatterdash prior to application of render.

Concrete – Cement, fine aggregate, coarse aggregate and water either with or without additives. Contains steel or fiber reinforcement in the case of reinforced concrete and normally forms the parent substrate for render / tiles and the structural element.

Dubbing – Sand and cement material. The application of render at localized areas to correct significant localized surface irregularities prior to the application of the first coat of render, referred to as “dubbing out”.

Grout – Cement, fine aggregate and water either with or without additives used as a pointing material in the gap between tiles. May be applied as part of the bedding during the application of ‘pre grouted’ mosaic sheets.
**Intermediate substrate** - Sand and cement material either with or without additives applied to the substrate as an intermediate layer to level irregularities and provide desired profile. Often referred to as ‘render’ for external application, the terms plaster and render have the same meaning.

**Mortar** – Cement and fine aggregates either with or without an additive, refers primarily to mortar bedding for tiles although renders and tile grouts may also be mortars.

**Plaster** – See intermediate substrate above.

**Render** – See intermediate substrate above.

**Slurry** – Cement and water either with or without additives that is sometimes used as a tile bedding material.

**Spatterdash** – Mixture in varying proportions of sand, cement, water and possibly additive splattered onto the substrate prior to the application of the render intermediate substrate.

**Substrate** – The building structure to which finishes are applied, normally either concrete or brick / block-work.

**Tile** – Used as a decorative and protective finish to the exterior of buildings, normally either ceramic, porcelain, glass, homogenous or natural stone and either glazed or unglazed.

**Tile Bedding** – A thick or thin bed tile adhesive (often proprietary product) or mortar system used to adhere tiles to the substrate or intermediate substrate.

**Commonly Used Tiling Systems**
The majority of tall buildings in Hong Kong with external façade tiling systems are constructed using reinforced concrete, where the reinforced concrete or sometimes blockwork acts as the substrate onto which the tiles are applied normally with the use of a render intermediate substrate.

Tile system defects causing problems can be conveniently broken down into two categories; design and workmanship. For the purposes of this paper design is taken to include all aspects of material selection, specification, design, detailing and provision of resources. Workmanship covers all aspects of construction under the control of the site tradesmen such as surface preparation, mixing, application timing, correct use of materials, etc.

**Design**
Design guidelines for external wall tiles are given in British Standards (BS). The following BS are currently available to provide the necessary design guidance and for historical reasons the standards must commonly referred to in Hong Kong:

- BS 5262: 1991 Code of practice for external renderings
The majority of Hong Kong specifications are based on these BS or the older versions that have been withdrawn and superseded.

Reinforced concrete (including the majority of tiles substrate) is normally designed in accordance with BS 8110 Part 1: 1997 Structural use of concrete. Code of practice for design and construction.

Specifications and standards relevant to external wall tiles have been reviewed. The key clauses reviewed vary somewhat in detail but essentially synthesise to a two-fold structure:

- direct application of tile/tile bedding to a parent concrete substrate or the use of an intermediate render stratum to smooth irregularities in the parent substrate.
- the application of alternative tile/tile bedding systems directly or indirectly (via the render intermediate) to the parent concrete substrate.

Overview of Standards for External Wall Tiles
The following discussion reviews the tiling system substrata in turn with reference to some standard specifications. All mix ratios presented refer to batching by volume.

The Parent Substrate
Normally concrete or block-work, must satisfy certain requirements for cleanliness, soundness/integrity and dimensional flatness. Such requirements are stated in most specifications and standards in broad terms with particular flatness/smoothness criteria. Failure to achieve the latter necessitates the use of an intermediate render substrate.

BS 5385 Pt 2 :1991 recommends the concrete substrate is allowed to dry for 6 weeks before render or tile bedding application. The intention is to reduce shrinkage and the risk of debonding.

Spatterdash
Spatterdash is used at the concrete/render interface to improve mechanical bond, and is applied to partially cover the concrete surface. It is common in local specifications but tends to be optional in international specifications and could be replaced by or used in conjunction with a bond coat. Typically a 1:2 cement:granite fines mix is used in Hong Kong.

Bond Coat
The bond coat is normally applied to the cleaned concrete/spatterdash (if used) surface just prior to render application. Typically specifications insist “apply the render whilst the bond coat is still tacky”. The bond coat is normally a mix of cement and water. An additive may also be used (particularly if used in the render); compatible additives are supplied by the materials manufacturer.

The “bond coat application” is one of the most critical in achieving acceptable adhesion bond strength for the tiling system, because the common failure position is at the concrete substrate to render interface.

Render
Render forms the intermediate substrate and is normally a 1:3 cement:sand mix applied to a maximum thickness not exceeding 20mm, but more commonly to 15mm or less.
Pre-packaged or ready mix “mortars” are commonly used to form the intermediate substrate. These are not to be confused with “tile bedding mortars”.

The current Singaporean specification contains adhesion strength performance criteria for external plasters combined with paint systems (these are not applied to plasters with tiling since Singapore generally does not use external tiling). These external adhesion strength requirements for plaster range from 0.25 to 0.4 MPa depending on the application criterion concerned.

Typically plasters are required to air dry for 2-3 weeks before tiling application under British Standards. Consequently tiling should not be applied until a minimum period of 8-9 weeks has elapsed to accommodate shrinkage of the concrete and plaster substrates.

Tile Bedding
Tile bedding is perhaps the most confusing application in terms of diversity and terminology. Two principal forms of tile bedding exist:

- Thick and Thin Bed “Adhesives”
- Cement and Sand Mortar Bedding

The type of tile bedding applied depends on the nature of the tile and that of the substrate. Normally two basic classifications of tile are provided: ceramic tiles and mosaic tiles. The relationship of each to the different bedding systems are discussed below.

Mosaic Tile Bedding Systems
BS 5385 strongly recommends that adhesives (thick and thin-bed) are used for external tiling. The only exception is the option to use cement:sand mortar bed for mosaic tiles. Both systems are applied as float coats to the background. The cement:sand mortar bed is applied to a depth not exceeding 10mm and has to stiffen slightly before tile application. A 1:1 cement sand “grout” mix should be used to pre-grout paper-backed mosaics or should be floated on the mortar bed in the case of synthetic strip or mesh back mosaics.

Some local specifications are very similar to each other but differ from the British Standard with respect to the application of mosaic tiling.

Ceramic Tiling Systems
As discussed above BS 5385 Pt 2, 1991 recommends thick and thin-bed proprietary adhesive systems be used for ceramic tiles since there is greater quality control in the production of proprietary products. It no longer recommends or describes cement:sand mortar bedding systems for ceramic tiles since they are not considered strong enough.

Because of the wide ranging types of proprietary adhesives available, specifications stipulate a “catch-all” that they should be used in accordance with manufacturer recommendations. This is particularly important when manufacturer guarantees are provided. Unlike cement:sand mortar systems, laboratory performance criteria are specified to classify and test the five different types of adhesives. These stipulate shear and adhesion test criteria, among others. Since the three local standards refer to BS 5385 by default they must also infer that BS EN 12004:2001 applies with its attendant requirements. BS EN 12004:2001 stipulates laboratory adhesion strength testing requirements with a minimum of 0.5MPa. This is greater than the values used in the Singaporean Specification for pull-off testing (0.18MPa).
However, it should be noted that laboratory test and insitu test performance seldom match (e.g. laboratory adhesion strength test data for pre-bagged renders cannot be achieved in situ). Consequently it cannot be assumed that laboratory test criteria are applicable to site.

The term “slurry”, as used in local standards, refers to cement and water (with or without admixtures) applied to “thick-bed cement:sand mortar bed system”. It is not defined or termed an adhesive. Consequently no performance or QC criteria are applied to its use since it is not classified as part of an “adhesive” system.

**Local Ceramic Tiling Specification**

Local specifications provide thin-bed adhesive options for ceramic tiling. These basically require compliance with the manufacturer’s recommendations, grouting up afterwards and forming joint widths to respective tile sizes.

There are no thick-bed adhesive systems in local specifications. The only thick bed systems specified involve cement: sand mortar bedding systems and/or slurry.

It is interesting to observe that the cement and sand mortar bedding is not classified in BS 5385 as being either thick or thin bedded but by definition (up to 10mm thick) falls into the thick bed category which refers to all bedding applications exceeding 3mm.

Cement and sand mortar systems that are applied using the “buttering” method directly to the back of ceramic tiles without a floating coat should comprise 1:3-4 mortars and are only specified in BS5385 Pt 1 for internal tiling (not external tiling).

**Homogenous Tiles**

The issue of tiling specification is further complicated by the use of homogenous tiles, which require special precautions during installation. Homogenous tiles have a very low moisture absorption value and therefore can not be confidently fixed using cement slurries or hydraulically hardening mortars which require some penetration into the surface of the tile. Homogenous tiles require the use of tile adhesives as their bedding system in order to avoid delamination failure at the tile to tile bedding interface.

**Render Specification and Design**

Rendering for external wall applications should comply with BS 5262: 1991 whether or not tiles are to be installed on the rendering. Where tiles are to be installed on the rendering there are additional requirements contained in BS 5385 Part 2: 1991 principally with respect to the positioning of movement joints which must pass through the full depth of both the tile bedding and render.

Where tiles are to be applied, render is normally used to provide an acceptably level surface prior to the application of tiles or render may be used as a finish on its own (not common in Hong Kong). As a component of this level surface is it often necessary to “dub out” significant localized irregularities prior to the application of the general rendering. Dubbing is most frequently required at joints between formwork panels where movement of the panel during concreting has caused a significant level difference between the two sides of the joint. Dubbing out should be completed prior to the general application of render in layers not exceeding 8mm thick to a maximum permissible thickness of 20mm (BS 5262).
Render for external use is a blend of appropriately graded fine aggregate (either sand or crushed rock fines) mixed with cement or a proprietary external rendering product that may contain other additives in addition to fine aggregate and cement. The render material should be mixed by volume with approximately 1 part of cement to 3 parts of fine aggregate. The grading of the aggregate is important as too fine an aggregate will require excessive water in order to produce a workable material which in turn will cause excessive drying shrinkage and potential for cracking and debonding.

Movement Joints
During the life of a building it can be reasonably anticipated that certain movements within the structure will occur and it is important that relatively inflexible finishes such as tiles/render are isolated from the movement. Movement can be caused by shortening of the building over time (inevitable in high rise concrete structures), thermal effects (surface temperatures can reach 70°C compared with internal air conditioned temperatures that may be 20°C), deflections from structural loadings, earthquake, wind load and other environmental factors. These factors that will cause movement of the building are reasonably predictable and the design should therefore be sufficient to accommodate them without significant failure of the tiles.

Provision for these movements is conventionally accommodated by the use of movement joints. In order for movement joints to be effective they must be correctly placed and properly detailed. Design guidance on the use of movement joints is given in relevant BS codes of practice.

Section 20 of BS 5385 Part 2 covers movement joints in external tiling. Movement joints are required to be as follows:

- Formed to coincide with existing structural movement joints
- Junctions between dissimilar backgrounds
- Around the perimeter of tiled areas
- At storey heights horizontally
- Vertical movement joints to be spaced at approximately 3 – 4.5 meters
- At external angles of the building

Workmanship

These standards describe the recommended practices to be followed by site workers when engaged in rendering and tiling activities.

QUALITY CONTROL AND TESTING
A systematic approach is required to all aspects of quality control whereby the contractor is required to clearly state what methods and materials will be used to ensure the specification requirements are met and what checks/tests will be employed to demonstrate achievement of requirements. Quality control and testing for external façade tiling will vary little between different applications and tall buildings are no exception to this rule. However, the
consequence of failure and the cost/nuisance of rectification works will be much greater for tall buildings and hence the need to concentrate additional energy and resources into the quality control and testing aspects

Method Statements
Method statements are the basic documents used by the contractor to clearly state how he will go about his works and what materials will be used to achieve the specification requirements. The method statement will be used by both the contractor to instruct his staff and workers and by the Consultant to supervise and inspect the works. The method statement will state the exact materials to be used and will be the final written confirmation and acceptance by all parties of the materials submission and approval process. This is of particular importance for tall buildings where the investment cost in the building is enormous compared to the unit cost of the tiling system and consequently consideration should be given to using higher cost materials if a performance or durability advantage will be achieved. The method statement will also clearly state things such as staff requirements in terms of skill levels, equipment and tools to be used, exact installation methods including timing and material open times together with quality control checks/tests including acceptance limits and performance requirements. The method statement should also clearly state what action will be taken in the event that tests fall below the minimum acceptance limits including exact details of rectification works.

Inspection and Test Plan
Another commonly used tool that can either be part of the method statement or a separate document, but one that will compliment the method statement is an inspection and test plan, commonly referred to as an ITP. The ITP will state the testing to be completed together with timing, any hold points in the installation process where inspections are required by the Contractors own staff or by third party supervision staff and will state the next step after either successful or unsuccessful checks/tests.

Site Monitoring and Testing
The contractor will always be responsible for the quality of his works and will therefore be required to monitor and test the works to his own satisfaction to ensure acceptable quality installation. In addition to the contractors self checking it is prudent for a developer to engage a third party (normally either the project consultant or another testing authority) to independently monitor and test the contractors work in order to further reduce the possibility of defects or non compliant works that may cause durability or safety concerns during the service life of the building. Typical tests/checks required to be performed during the installation of tiling systems include the following which are in addition to normal visual inspections on a random sample of works in progress:

- Checks on mixing/ batching of all materials including spatterdash, bond coat, render, tile bedding material and tile grout.
- Testing/inspection of spatterdash or bond coat after installation noting timing issues with many bond coat materials.
- Inspection of completed rendering for material thickness, installation of steel mesh (if required), cracks, delaminations and adhesion strength.
- Inspections of all surfaces for cleanliness and suitability to receive proceeding materials.
- Inspection of tiling during installation including removal of a number of tiles after placement to check for voids in the bedding system behind the tiles.
• Checking of movement joint details and position prior to application of backer rod and
  sealant (position can be checked at rendering stage).
• Testing of completed tile façade system for adhesion strength and delamination

Qualification of Workers and Staff
To give confidence in completed tiling work it is important to ensure that all involved in the
tile installation process are appropriately qualified and experienced for the job they perform.
Installation workers should preferably have appropriate formal trade qualifications or at least
demonstrate sufficient trade specialization and experience. Design, specification and
supervision staff should also be able to demonstrate appropriate qualifications and experience
for the works to which they are responsible.

Mock-up Site Trials
Prior to full scale installation works on site it is advisable to have a reasonably large scale
mock up sample prepared by the contractor ensuring that the mock up covers all the various
elements of the structure such as flat wall, A/c platforms, window surrounds, architectural
features and fins, movement joints, etc. This trial should be carefully supervised, checked
and tested to ensure it is completed in accordance with the agreed method statement and that
the finished result is acceptable to all parties. The sample should remain intact until
completion of the final tiling and would be used as an acceptance standard for the final
finished product.

In the event that the mock up trial is found to be unacceptable, the root cause should be
investigated, adjustments made to the method statement as necessary and a fresh mock up
trial completed until the final result is considered acceptable by all parties. The mock up
sample is the final step in the design verification process prior to approval to proceed with
full scale construction.

COMMON DEFECTS AND TYPICAL CAUSATION
This section covers some of the common defects often identified with external tile systems
and their typical causes. These defects often result from failures to follow international
standards covering installation methods, workmanship, materials and recommendations on
provision for movement (which are a particularly important consideration on tall buildings).
As identified in the previous section the issues that lead to defects should have been
identified at the pre-construction stage and ironed out before acceptance of the final mock up
sample.

Bulging – Where materials have physically detached from their substrate and a gap has
formed between the backing material and the delaminated materials. Typically caused by
one or a combination of; self-weight for large delaminations, wind suction or water
movement, insufficient provision for movement and corrosion of embedded steel. This type
of defect is often associated with cracking and is the normal precursor to materials spalling
from a building as such, any bulging areas in a tile system should be rectified as a priority.

Cracking – Cracks are the result of stresses relieving themselves where no other outlet (such
as a movement joint) exists to accommodate them. Cracks can vary from hairline shrinkage
cracks in the various system materials which may be of little consequence to significantly
wide structural cracks reflected through from the substrate. Typical causes include
structural movement, corrosion of embedded steel, inadequate provision for movement and material shrinkage.

**Delamination** – Probably the most common defect with tiling systems characterized by a “hollow” sound when tapped with a hard object. Delaminations can result from voids beneath the tiles, corrosion of embedded steel, workmanship deficiencies, relief of stresses exceeding the bond strength of the various materials, mechanical damage, etc.

**Spalling and Falling of Tiles and Render** – The ultimate defect resulting from delamination, cracking and bulging defects where materials fall off a building and free fall off the building. The consequence of this type of defect on a tall building is likely to be serious and may be fatal. Every effort should be used to prevent this type of defect from occurring or to safely control any materials that could possibly spall from a tall building.

**Efflorescence and Staining** – This type of defect does not in itself present a hazard to the building but may be considered aesthetically unacceptable and may also be a visible indication of other potentially serious problems. Rust stains/water marks may indicate delaminations where water is being held, cracks and corrosion of buried steel (possibly substrate reinforcement). Efflorescence is an indication of moisture movement through a cementitious material where calcium hydroxide is transported to the surface by the moisture and deposited with evaporation of the moisture. The calcium hydroxide then reacts with atmospheric carbon dioxide to form unsightly white colour crystalline calcium carbonate on the surface of the tiles.

**MAINTENANCE**

Once a building is constructed it is the responsibility of the owners to maintain it in a safe condition for the occupants, users and passers by. There are three major aspects related to the maintenance of a building in safe condition including the way it is used, inspections to identify defects/deterioration and the completion of appropriate repairs in a timely fashion.

The majority of the general population probably view the apparently ‘non-moving parts’ of their property (e.g. walls, roof, foundations and including tiles) as relatively inert and not subject to change or deterioration. Such an assumption would be incorrect but may not be without basis. A properly designed, constructed and maintained external wall tile system should provide trouble free service throughout the life of the building.

However, poorly designed, specified or constructed external wall tiles are more likely to deteriorate with the consequent need for increased maintenance and repair. These potential deficiencies at the time of construction will lead to a greater maintenance requirement throughout the operational life of the building.

The various aspects of repair and maintenance are discussed in this section.

**Inspection**

Inspection and checking of the condition of external wall tiles is the essential first step to maintain them in a safe condition. Without inspection, defects are likely to go un-noticed and un-repaired which in turn exposes them to the possibility of further deterioration and ultimately spall or collapse from the building.
It is appropriate to engage a third party such as the building manager or construction professional on say an annual basis to visually inspect the external wall tiles and to engage a construction professional to complete a more detailed investigation say every five years with investigation findings and repair recommendations.

Annual inspections would be expected to identify the following potential problems for either repair or more detailed investigation:

- Spalled tiles, render and concrete
- Stains (rust, water, efflorescence)
- Significant cracks
- Bulging tiles / render
- UBW
- Major sealant defects
- Discoloration, mould growth, etc.

More thorough investigations on say a five yearly basis would identify all of the above together with:

- Extent of tile, render or concrete delamination
- Condition of the concrete including reinforcement
- Adhesion strength of applied tiles / render
- Construction system of external wall tiles
- Provision of repair and other recommendations

** Provision of Access**

Internal decoration of residential properties is relatively easy from an access point of view, with no specialized or expensive access arrangements normally being necessary. Walls, floors and even ceilings can be accessed either from standing on the floor or using a small step ladder or similar. The same ease of access is normally not the case for external wall tiles. This is particularly the case on tall buildings (constructed prior to the issue of PNAP 218 in April 1998 which gives advise on the provision of equipment to facilitate the external maintenance of buildings) where building maintenance units (BMU’s) commonly referred to as gondolas have not been provided to facilitate maintenance and inspections.

The installation of gondola, scaffold or other means of access (e.g. cherry picker or mast climbing platform (MCP)) is normally required. These types of access arrangements can prove prohibitively expensive to many owners consequently providing a significant deterrent to the completion of necessary inspections and maintenance.

Safety is a critical aspect with the use of all forms of temporary access both for workers using the access and for passers by who may be affected by objects or material falling from the access system or in the worst case, the access system itself collapsing. Legislative requirements and Labour Department Guidelines must be strictly complied with during the erection, use and dismantling of temporary access systems.

**Gondola (Suspended Working Platforms)**

The use of Gondola or suspended working platforms is one of the most common access options for external wall inspection, maintenance and repair. The use of suspended working
platforms is controlled under the Factories and Industrial Undertakings Ordinance Chapter 59, which covers all aspects of the gondola system.

Particular care must be taken when using gondola for external wall access to ensure that the platform itself does not collide with the external wall potentially causing consequential impact damage and spalling of materials from the external wall. Care must also be taken to avoid lowering the platform onto canopies, open windows, air conditioner units etc. which may result in these elements being dislodged and falling to the ground.

Gondola systems are often preferred to scaffolds by building occupants as they give a lower visual impact to the building, do not affect window views and provide a lower security risk.

**Temporary Scaffold**
Along with suspended working platforms, the sight of temporary scaffold being used for maintenance and repair work on the external walls of buildings in Hong Kong is a common one. Traditionally bamboo materials have been used (and are still extensively used) although there is now a trend towards using either steel or aluminium scaffolds that are perceived by some to be better looking, more modern, more high tech., etc.

Irrespective of the material used, bamboo, metal or a combination of the two all scaffolds are essentially a series of poles that are clamped or tied together to form a temporary framework around the outer wall from which work can be completed. Scaffolds may stand on the ground or on suspended podium slabs or alternatively off the ground on temporary steel brackets bolted to the outer wall. Scaffolds will also be required to tie back or be connected to the wall at intermediate positions throughout their height in order to prevent toppling over in high winds or as a result of live loads, etc. It is important to make sure that these scaffold wall ties are correctly installed (and removed during demolition of the scaffold) so as not to cause unnecessary damage to the external wall tiles that may lead to water ingress and/or spalling.

The safe use of scaffolding is also covered under the Factories and Industrial Undertakings Ordinance Chapter 59 and its subsidiary legislation including the use of safety features as per Labour Department guidelines such as foot boards, toe boards, hand rails, access ladders, safety netting, etc.

**Other Access Systems**
In addition to the two most common temporary access systems used in Hong Kong (scaffold and gondola) other more specialized systems exist including the following:

- **Mast Climbing Platforms (MCP)** – similar to a suspended working platform but without the suspension system. A platform that climbs up either one or two fixed masts, normally larger than gondolas and with a greater load capacity.
- **Cherry Picker** – normally a wheeled vehicle with a platform attached to the end of an articulated arm that can provide access normally to a maximum height of approximately 20 meters.
- **Scissor lifts** – a platform that rises vertically above a wheeled vehicle, normally to a maximum height of approximately 10 meters.

The advantage of cherry pickers and scissor lifts (although of limited use on tall buildings) over other temporary access arrangements for low rise applications is that they have a very
short set up time and require no attachment to the buildings external wall thus avoiding the risk of consequential damage from improper fixings.

Improper Cleaning of External Wall Tiles
Cleaning of external wall tiles is normally a simple operation requiring only the use of a brush and water or high pressure water jet possibly with the use of a mild detergent to remove oily deposits. Specialist products are available specifically intended for the cleaning of external wall tiles that the manufacturers claim improve cleaning performance or reduce the effort required for the cleaning.

Cleaning products that can initially appear very effective, but which should be avoided, are those aggressive cleaners that contain either acidic or caustic solutions. Unless these solutions are thoroughly removed as soon as possible they may cause damage to the tiles, tile grout, movement joint sealant or render and depending on how carefully they have been applied may damage window glazing and frames, vehicles parked within range of wind driven spray, etc.

Water is the preferred cleaning medium with the possible addition of a mild detergent applied using a cloth or a soft brush.

REPAIRS
It is important that a contactor with the required technical competence is engaged to complete the works and it would be prudent to engage an independent organisation (again with the necessary technical competence in repair works) to supervise the repair contractor including the completion of appropriate quality control testing.

The quality (and consequently price) of materials used for concrete repair, render, tile bedding and tile grout can vary considerably. At one end of the scale site mixing of simple sand and cement can be used to create repair mortars, render, tile bedding and tile grout with extreme variability likely in both the raw materials and the mixing ratios to give a similar variability in the finished results. At the other end of the scale are pre-bagged proprietary dry powder materials that only require the addition of water on site. These materials are specifically blended for particular applications (e.g. concrete repair, tile adhesive, render, etc.), are less workmanship sensitive and are designed to give consistent results. These materials also include workability additives that prevent the incorrect addition of water on site, if either too much or too little water is added, the materials will simply be unusable in terms of workability.

A key step that is often omitted in repair specifications (particularly if a consultant is not engaged to supervise repair works) is quality control testing. Once a repair has been completed it should be subject to quality control testing to ensure that it actually complies with the specification requirement. Appropriate quality control testing for external wall tile repairs may include the following:

- Bond adhesion strength testing for tiles and render
- Delamination checking for concrete patch repairs, tiles and render
- Tile removal during tile installation works to check fullness of tile bedding on back of tile
- Cube compression strength test for concrete repair mortar
**External Wall Tile Repair Systems**

There are a number of different repair systems that can be selected for the repair of defective external wall tile systems and the choice of repair system will depend on a number of factors including: condition of the existing installation, intended building life, cost and owners preference. It is possible that more than one repair system could be used in combination to achieve the required results in the most efficient manner e.g. a combination of breakout and pinning repairs with either an over coating or over cladding solution.

The selected repair works will be significantly influenced by the thickness of render at each delamination and the delamination size; in particular mechanical pinning can only be carried out with a minimum render thickness of say 15 to 20mm and subject to render quality.

The following repair options are available:

- No repair. This option is normally not possible due to the potential safety hazard from free falling tiles / render
- Mechanical Pinning of Defective Areas
- Epoxy Injection of Defective Areas
- Mechanical Pinning with Epoxy Injection
- Mechanical Pinning of Bonded Areas
- Replacement of Delaminated Areas
- Remove and reapply all exterior tiles and reapply new tile finish
- Overcoat the external wall
- Overclad the external wall

**Inferior Repair**

In the event that repair work to spalled concrete or external wall tiles is completed to an inferior standard, there is a possibility of repeat failure of the repaired area together with additional and consequential failure of adjacent areas.

Repair of external wall tiles must be completed in accordance with appropriate specifications. Materials should be used in accordance with the recommendations of BS 5385 Part 2 as appropriate or preferably using proprietary products.

A critical aspect with repair work is quality control testing, a sufficiently large sample of the completed works needs to be subject to quality control testing to verify the quality of the works. Quality control testing would normally include visual inspection, delamination survey and adhesion strength testing as a minimum with any defective works being removed and replaced.

**CONCLUSIONS**

Although this paper can not be exhaustive, we have covered some of the areas where questions often arise with the installation and maintenance of external façade tiling on tall buildings. Methods, materials and specifications for tiled external facades whether on tall buildings or other structures vary little. The additional demands on a tiling system for a tall building in terms of movement, access difficulties, consequence of failure, cost of failure, negative impressions created, etc. are significantly different to low rise construction. Consequently the level of care and attention applied to external tiling on a tall building must be commensurate with these factors in order to avoid negative or undesirable outcomes. We
also hope that this paper has demonstrated the relationship between decisions made during the design phase and the tile installation phase with consequent problems that may arise during the operational phase of a building's life. Generally, if appropriate attention and effort is given to the external tiling during the design and installation phases on a tall building, significant problems can be avoided during the operational phase of the building.