TILING FAILURES – A CHRONIC PROBLEM RE-VISITED

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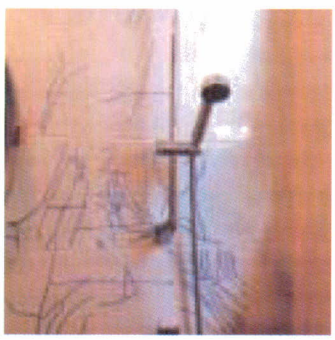
ABSTRACT

Failures of tiling systems continued to plague the building and construction trade both in Singapore and Malaysia over the last more than 10 years. Problems and shortcomings in the tile selection, installation and maintenance encountered more than 10 years ago are still occasionally encountered today. With an increase in a wide array of tiling systems and advent of newer technologies, there is no respite in the frequency of failures and controversies in tiling. On the contrary, failures seemed to be increasing. This has in part been due to a lack of understanding of materials such as their characteristics and proper use, incompatibility among the various systems, poorly developed skills, lack of appreciation of the new ISO standard for tiles and the pressing need for speed in construction. A number of today's specifiers appeared to be ill prepared to apply the new standards and thus unable to correctly or adequately prepare a proper specification for tiling works. The problems is aggravated by the lack of knowledge and guides or codes on the selection, design and use of the wide variety of tiling systems. As a result, in addition to the traditional failures such as crazing, debonding and cracking, there has been an escalation of failures of natural dimension stones, compressed marbles and glass mosaic. The failures could occur on the finished tile layer itself or often also within the bedding and underlying substrate.

This paper examines the various failures in tiling works which include cracking and debonding of internal tiles and general failures of tiling systems in swimming pools. The various causes, which are often intertwined with one another, are discussed. Broadly these factors are materials, design, workmanship and environmental factors. Suggestion is also given for the possible role of an independent tiling consultant in assisting the project team, given the myriad combination of systems in a tiling work.

Since the publicity of the several major failures of ceramic tiled facades in Singapore about 10 years ago, there had been changes in the local practices and the way both architects and owners viewed the use of ceramic tiles as envelope for the vertical external building elements. The use of adhesive bonded ceramic tiles had been discouraged by the Building Control Authority for buildings exceeding 4 storeys. This did not pose much of a problem to local professionals as there were plenty of options to consider with the advent of curtain walling using metals, natural stones and glass. These other alternatives, nevertheless have their own sets of problems with higher costs, installation difficulties, durability problems, maintenance costs and premature failures. In Singapore and under tropical climate conditions, there are a host of durability issues which such façade system will have to contend with such as spontaneous shattering of tempered glass, sealant staining, corrosion of metals, failure of coatings on the metals and breakage of the stone [1]. Though some of the issues are common in various climate conditions, others are rather unique to tropical climate like Singapore.

For buildings under 4 storeys, ceramic tiles initially continued to be used but they were few and far in between. Unfortunately, despite its reduced application, failure of such adhered façade system persisted and received no less attention from the industry and media as compared to its high rise predecessors. A detailed study had been carried out on external wall tiling in the tropical climate in Singapore [2]. The mistakes made had apparently not been learned after all these years and all these failures. This eventually led to an almost total demise of the use of bedded ceramic tiles as building façade. This is partly due to the social behaviour of the industry using unskilled workers, lack of appreciation among the professionals in the adhesive and ceramic tiles and ignorance in the interaction of the multitude of building elements. The construction industry is driven unfortunately only by cost. During the good times, profit margins were healthier and better materials and supervision could be accommodated with additional costs. In bad times, corners will somehow be inevitably cut at the expense of quality. Some factors are however, independent of the cost, such as poor design, errors and omission in design and ignorance in the behaviour of materials leading to selection of unsuitable or incompatible materials. For instance, most architects, suppliers and specifiers today are still not familiar with ISO 13006 or the local equivalent, the Singapore Standard 483. The problem is being compounded by the standards being part performance based and specifiers do not know what to stipulate or how to draft the technical performance specification.



Picture on left shows massive random fine cracks on the surface of the glazed tiles. These cracks were due mainly to shrinkage in the bedding/plaster. Picture on right shows regular pattern cracks on the glazed tiles, partly contributed by movement in the brick wall, especially along the brick mortar joints.

Failures in general in tiled facades had reduced over the years mainly because of its drastically reduced use. Most tiled façade failures of late have been confined to aged buildings, usually more than 10-15 years old. These facades were eventually cladded or finished with other systems. Though such events had dampened the popularity of tiles as façade materials, its use as internal finishes suffered little due to its ease of maintenance, cost, controlled quality etc. It is still better perceived as compared to other increasingly popular traditional materials like natural stone and compressed marble. This is attributed partly to the increasing variety of tiles finishes with superior quality such as homogeneous tiles and those with new aesthetic design such as rustic look, metallic look and marble look alike.

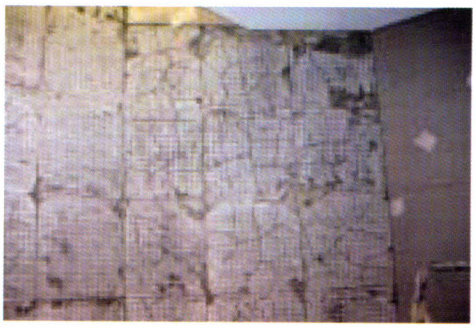
Despite its continued favourable position in the industry as a building material, failure of tiles and tiling system preserved locally but this time mostly on internal walls and floors and swimming pools. Frequent failures encountered include cracking of wall and floor tiles, debonding of wall tiles and buckling and debonding of floor tiles. Though crazing and fine cracking of wall glazed wall tiles are not new and has been reported [3,4], the regularity of its manifestation locally is surprisingly not uncommon. These usually happened on glazed tiles laid in the bathrooms and kitchens. They typically appeared on tiles with much higher water absorption and lower modulus of rupture but on tiles with lower water absorption and modulus of rupture using the same method of installation and adhesive in the same project, the defect is almost non-existent. Obviously therefore the quality of the tiles have a contributory effect. The architects and contractors will therefore inevitably put the blame onto the quality of the tiles albeit the tiles satisfy the requirements of the ISO 13006, as Classification Group BIII. The authors had investigated a large numbers of such cases and had been unable to attribute the failure solely on the so-labeled 'weak or inferior' tiles. Typically, there are, as expectedly, a combination of several mechanisms or causation. These include:

- too rich bedding adhesive used, often without the use of fillers or inadequate fillers
- shrinkage of the underlying render due to the use of again, a rich mix or drying
- too thick bedding adhesive resulting in increased shrinkage
- discontinuity in the bedding creating pockets of weakness allowing preferential cracking
- movement of the wall, which is usually of clay brick construction

When the above hypotheses or findings are put forth, howls of protests were often received from the various parties from the architects to the structural engineers. The supplier of the adhesive will insist that the bedding adhesive is 'flexible' whilst the engineers will not agree that the wall moved. It is undeniable that most building components will move, but perhaps at the micro level, due to load, shrinkage, creep etc. The degree of movement is by no means of structural concerns or implications but given the brittleness and rigidity of the tiles, they are more susceptible to cracking as compared to for instance the plaster and paint. Commonly encountered is also bedding that is too thick and without fillers. A number of adhesives supplied are not premixed, with separated packaging for cement, fillers and latex. The sand content and size would depend affect the thickness of the bedding. Sometimes, for

convenient, contractors would just use the cement with latex and frequently with thickness exceeding 6 mm for a specified thin bed system.

Here lies one of the biggest controversies: what is defined as a thin bed system? According to BS 5385: Part 1: 1990, installation of thin bed adhesive in excess of 3mm, can lead to excessive stresses possibly resulting in cracking of the tiles and/or adhesion failure. Similar recommendations have been given in AS 3958.1: 1998. In the TCA Handbook for Ceramic Tile Installation, the term 'thin-set' is used to describe the method of installing tile with a bonding material usually 3/32" to 1/8" in thickness (2.3 to 3.1 mm). A thick bed system has been defined as bedding exceeding 3 mm. To the local practitioners, a thin bed system is those with thickness typically between 3 – 6mm. For larger tiles, which are becoming more popular, thickness of thin bed up to 8mm has also been used. Bedding between 6-15mm is considered as medium bed and those exceeding 15mm as thick bed system. Some technical brochure of adhesive locally defined a thin bed system as those exceeding 3 mm with no clear indication of the maximum limit. It is also argued, obviously by the contractor, that is it not feasible to lay tiles with 3mm *thin* adhesive since it is not possible to ensure that degree of flatness of the rendered wall. According to Goldberg [5], thin bedding method is defined as an application of a layer of adhesive, ranging from a minimum of 3mm to a maximum of approximately 20 mm thick for facades. So, this begs the question as to how does one knows if the thin bed has been applied too thick and has contributed to the cracking of the tiles. Substantial amount of investigation works carried out by the author on cracked glazed wall tiles showed presence of shrinkage cracks in the bedding. These cracks are typically rectilinear and some linear and perpendicular to the bed thickness. Many of these cracks had been carried through to the tile. Most of these bedding that had cracked were very thick and without fillers.



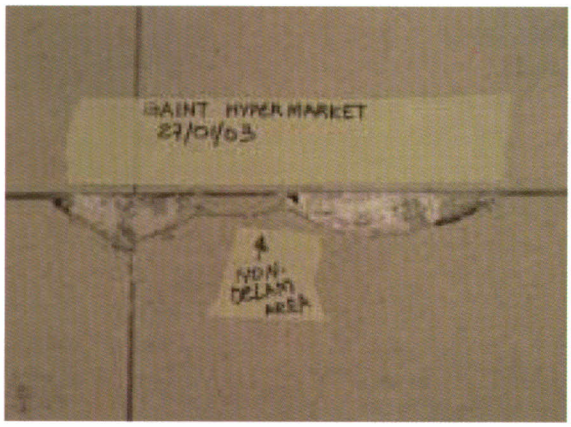
In picture, hollow sounding or debonded tiles were removed and the bedding adhesive was found to contain massive shrinkage cracks. The bedding was neat cement without any fillers with thickness up to 6-8 mm.

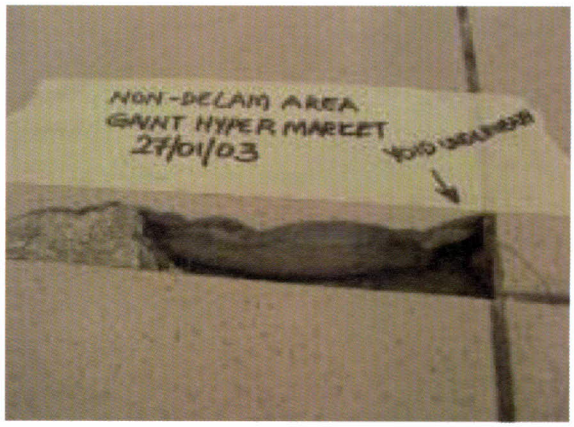
In certain cases, knowing that the tiles selected were of Class BIII, with high water absorption and low modulus of rupture and breaking strength, the contractor or architect discerningly wanted a 'flexible' adhesive. Again, this is another point of confusion; what is defined as 'flexible' adhesive? Current ISO and BS EN provide a classification of 'flexibility' but before the publication of these standards, any adhesive with polymer modification have been marketed as 'flexible'. There are nevertheless, different degree of 'flexibility' which could be inferred by the price and not any technical justification. Most of these 'flexible' adhesive also showed evidence of cracking. Through the investigation works carried out, both the tiles and adhesive satisfy their respective standards within the categories which they fall. The materials therefore, each by itself cannot be faulted. This does not help the specifier to make a selection on compatible combination of the tiles and bedding.

There is apparently, a lot of confusion in the selection of the right bedding with regards to the mix and type of adhesive. The author suggest that perhaps, tests should be carried out on the selected tiles and bedding to evaluate the compatibility and performance of the proposed system. Such practice is not new and has been performed to assess suitable adhesive for moisture sensitive stones such as green marbles and some agglomerate. The author had also showed that some adhesive will cause cracking of the tiles when the adhesive is allowed to shrink. Under laboratory trial and tests, however, the experiment may not be rigorous enough to identify potential problems as it is not possible to simulate all factors and parameters from the site. These include the environmental condition, degree of movement or shrinkage in the wall, quality of the plaster etc. Nevertheless, it can serve as a guide to mitigate potential failures.

Another problem bugging the tiling industry in Singapore is the degree of adhesion of the tiles to the bedding and sometimes, the background substrate. Generally, a bond strength of 0.15 N/mm^2 is called for by the Housing and Development Authority (HDB) for internal wall tiles. In addition, checks are being carried out by the HDB to detect presence of hollowness by tapping the surface of the laid tiles with a metallic rod to pick out tiles with inadequate contact between the tiles and bedding. Building owners consequently followed the practice and started to reject tiled walls and floors whenever "drummy" sound is obtained although the tiles may be adequately bonded. Confirmation test by pull-off adhesion can be conducted but it is destructive. The problem is the lack of adequate guide on the degree of contact required, which is understandably not a straightforward decision. It depends among others the flexibility of the adhesive, adhesion bond strength, quality of the tiles, loading etc. Whilst it can be appreciated that for floor tiles, maximum contact is essential to minimize cracking of the tiles, on internal walls, a higher degree of hollowness can be tolerated. BS 5385: Part 1: 1990 recommends an area of contact of at least 50%, spread evenly over the back of the tile. No figures had been given in the BS for floor tiles. BRE[6] meanwhile suggests full bedding, which has been defined as at least 90% of the undersides of the tiles should be in contact with the bedding or adhesive. Any voids should be widely spaced. The author had however found even 10% voids along the edge and corner of the tiles can result in severe cracking, especially for heavily trafficked areas like a hypermarket and loading/unloading bays. Such degree and location of void is not abnormal for buttered tiles, common for installation of large size tiles using thick bed system. Some of these failed floors were laid by tilers with more than 20 years experience! To address the controversies surrounding the wall tiles, the author had suggested to carry out proof load test using suction cups, similar to that recommended by the Marble Institute of America[7] for floor tiles.

Tiling of swimming pool is one of the biggest nightmare for contractors. Fortunately, we do not build swimming pools everyday! Whilst one of the primary concerns in the construction of the pool is to ensure water-tightness and hence the installation of a waterproofing membrane layer, this layer has often been attributed to tiling failure. Some waterproofing system had been found to inhibit adhesion between the render/screed and the concrete wall/floor. Proper selection should therefore be made to ensure the use of waterproofing system or membrane that is compatible with the plaster/screed or one that is able to receive the plaster/screed. In one of the cases investigated by the author, failure of the tiling occurred at the junction of the termination point of the bituminous waterproofing system, which was not carried through the whole height of the wall. More commonly however, are buckling and lifting of the tiles from the floor or wall of the pool. When the pool water is drained

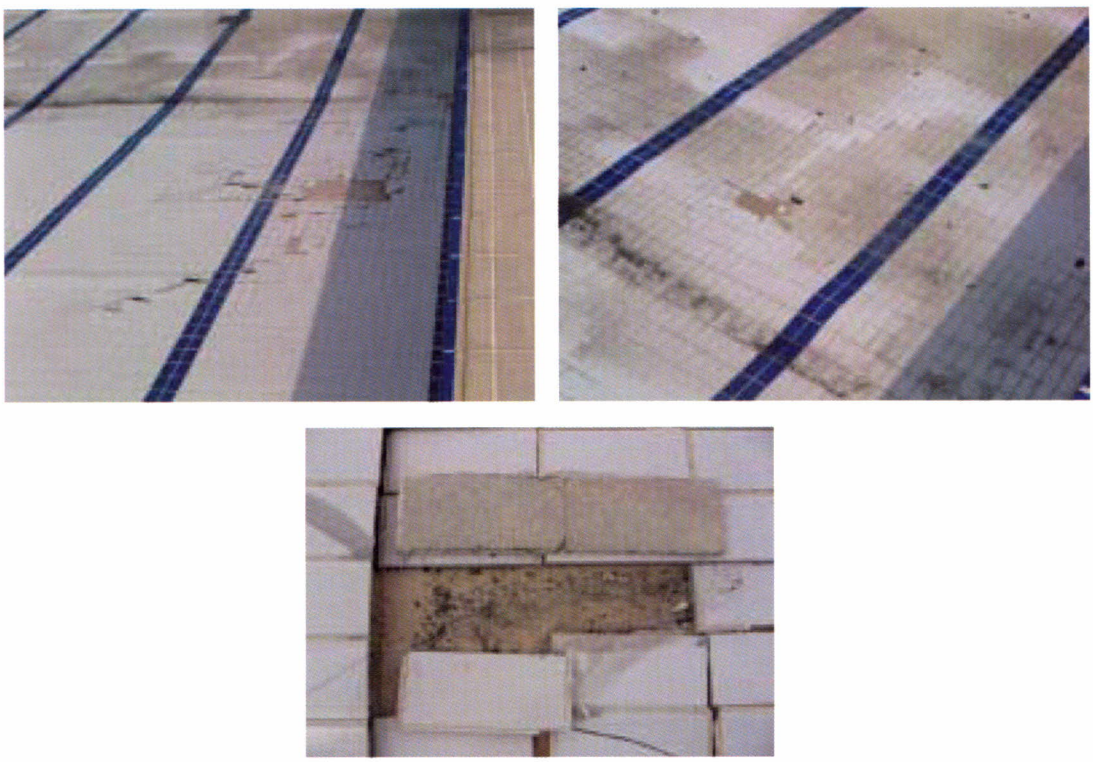




Top pictures show cracking and impact damage of floor tiles along or near the edge. These tiles were laid in heavily trafficked area. Down picture shows presence of voids below the tiles. The voids were generally found to be less than 10% of each tile surface area.

Top pictures show cracking of the tiles in a swimming pool. Down picture shows lifting up of the tiles especially around the inlet of water supply. These cases were found to be due to leaking water supply pipes.

for repair, cleaning or testing, the failure proliferated. This is due to the removal of the counter weight of the water and expansion of the tiles due to moisture and thermal once the tiles are now exposed to direct solar heat. Such failure is commonly due to badly prepared plaster/screed background. The failure mode is typically either adhesion failure between the bedding and screed or cohesive shearing of the top layer of the screed. In some cases, the tile with the bedding were lifted up and detached from the underlying waterproofing membrane. This suggests an unsuitable waterproofing membrane and poor screed quality as among the possible roots.



Top pictures show buckling and debonding failure of tiles in a swimming pool. The failure proliferated upon draining of the pool water for repair. Down picture shows a close up view of the mode of failure. Most of the tiles failed by cohesion fracture along the surface of the screed, indicating a poor screed quality

These pools clearly were not constructed with movement/expansion joints and its omission is one of the leading causes of failure in ceramic tiled pools. The exclusion is mainly because of difficulties with waterproofing and sealant installation and maintenance. There appear to be a lack of guide in the design and installation of ceramic tiled swimming pool locally. Currently, the Technical Committee for the Architectural Works of the Singapore Productivity Board, in which the author is a member, is looking at the drafting of such a guide or code.

In some cases of ceramic tiled swimming pool failure, the cause was not so much of the tiling works and materials themselves, but rather, from faulty buried mechanical services. The water supply pipes to the swimming pool would need to overcome the pressure of the water height and thus the water from the pipe is supplied under high pressure. There had been cases where the pipes embedded within the screed at the base of the pool leaked and the leaking water under the immense pressure was uplifting the screed up resulting in cracking of the tiles, especially along the pour joint in the screed. The problem with such symptom is that the initial diagnosis was thought tot be movement of the joint. Similarly, phenomenon has also been experienced in water supply pipe from the wall.

Perhaps, failure in tiling system that is brewing hot in Singapore lately is debonding of stone tiles. There are a lot of controversies and confusion in this field as to the use of water repelling sealer at the back of the stone to prevent egress of moisture and salt from the bedding and background which will mar the appearance of the stone. Such sealers have been claimed and in a number of cases had been found to have inhibited proper bonding with the bedding adhesive. This is because the sealer imparts 'non-wetting' or hydrophobic property onto the surface on which it is applied. The term sealer had been used loosely, with some describing it as a penetrating sealer, film forming sealer and impregnating sealer. Such sealers used include silane, siloxane and acrylic based. These sealers had been attempted at one time in Singapore to address tiles with 'reverse staining' problem. 'Reverse staining' here refers to the appearance of water mark as seen from the glazed surface when water is absorbed by the tile body[8]. This is similar to the water stain mark commonly encountered on granite tiles but in the case of ceramic tiles, it is due to the absence or lack of the engobe layer. Locally, there are two different schools of thoughts with one totally against the use of sealer at the back of the stone as it will lead to debonding failure while the other promulgated the use of the sealer but with only compatible adhesive. Tests and investigations conducted by the author so far have been showing conflicting results. Investigation of debonding failure of the stone tiles treated with sealer showed up other equally influencing factors such as workmanship aside from the use of the sealer as contributing to adhesion failure. Laboratory tests meanwhile did infer that some sealers may well be suitable with certain adhesive. However, as these were mostly tests under laboratory conditions, further intense studies in this matter would be required. For the moment, a number of architects and contractors are becoming increasingly aware of the danger of the sealer but an equally large if not greater numbers are still ignorant. At least, the author will still be kept busy investigating tiling problems!

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