1.0 INTRODUCTION

A ceramic tiling finish is a system comprising no less than substrate, adhesive, stone, grout and movement joints. All components are equally important and intimately related to one another. Adequate compatibility must exist among the components as they could only function collectively. The system could only be as strong as the weakest component, if not worse.

Therefore, design, preparation works, installation, protection and maintenance must take into consideration the performance characteristics of each individual component as well as the in-situ environmental conditions that prevail during the installation process. These considerations are similar for new technologies and materials in Design for Manufacturing and Assembly (DfMA) such as Prefabricated Prefinished Volumetric Construction (PPVC) and Prefabricated Bathroom Unit (PBU). It is recommended to refer to the respective guides for ceramic tiling installation in these technologies.

Due to the volume constraint, this guide will focus on the interior installation of ceramic tiling.

2.0 DESIGN

To achieve good tiling works, it is critical to take into account the material selection besides proper installation and quality control. It is important to understand the characteristics of the selected materials as well as their compatibility with one another to achieve optimal performance.

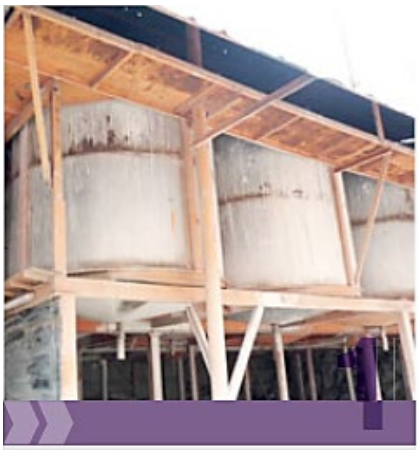
The following design details should be considered:

- Tiles selection
- Adhesives
- Grout joints
- Movement joints
- Waterproofing

2.1. TILE SELECTION

Ceramic tile is a mixture of clay, quartz ferrous sand materials and water. The clays are mined from earth, shaped and then coloured. The clays are then dried and subsequently fired at very high temperature in kilns. Ceramic tile comes in two forms: glazed and unglazed. The primary portion of the tile, known as bisque, can be naturally coloured with highly designed surfaces which can be glazed either in a high gloss or matte finish. Glaze is a liquid glass that is baked onto the bisque. Most ceramic tiles have either a white or red body colouration underneath the glazed finish.

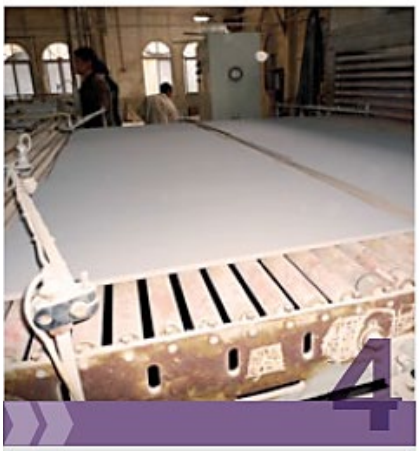
Figure 2.1a illustrates the manufacturing process of ceramic tile extracted from “Design and Material Selection for Quality – Vol 2”.



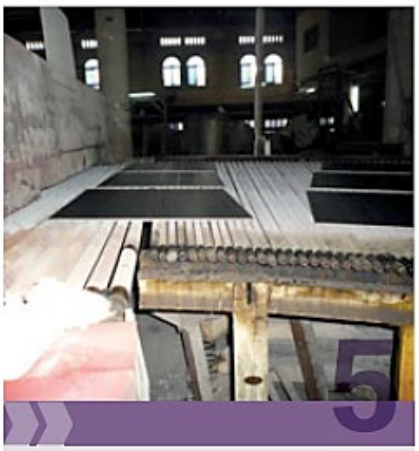
Mix ingredients.

Dry press to make bisques.

1st firing.



Colouring/glazing.



2nd firing.

Mechanical cutting.

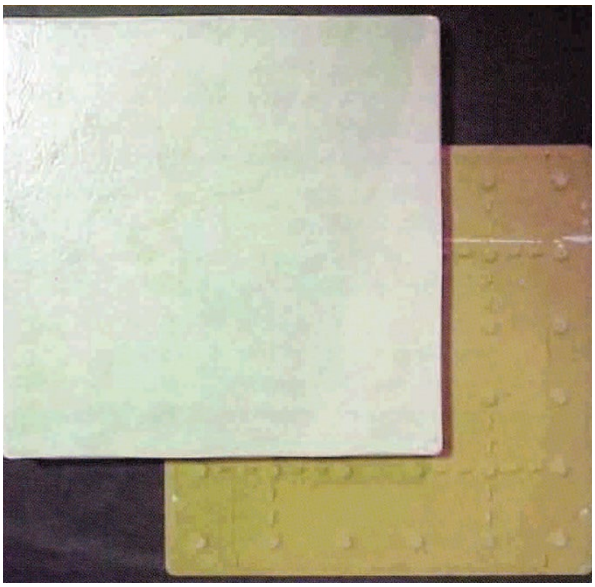
QC Check.

Packing.

Manufacturing process of ceramic tiles
Figure 2.1.a

Fine cracks could appear on the glazed surface when the bisque and glaze expand and contract at different rates. When the cracks show on the surfaces of glazed tiles, it is called crazing. This is a phenomenon caused by tensile stress between the glaze and bisque. In the kiln, if the tiles are fired up to high temperature too quickly or cooled too quickly, it can also result in crazing as a result of thermal shock.

Table 1 (under 2.1.5 - Selection Criteria) of SS 483 shows the classification of ceramic tiles with respect to water absorption and shaping. Dry pressing and extrusion are two common methods in the forming process for tile manufacturing. Dry pressed and extruded tiles can be distinguished from the mechanical keys at the back of the tile as shown in Figure 2.1.b and 2.1.c.



Mechanical key at the back of dry pressed tile
Figure 2.1.b

Mechanical key at the back of extruded tile
Figure 2.1.c

Once the ceramic tile is produced, it will be cut according to the required dimension. Proper equipment are required to cut ceramic tiles.

2.1.1. TYPES OF TILE

The choice of tile depends on the location, functional use of the area and, increasingly in recent year, environmental friendliness. Environmental friendly tiles are certified under the following schemes:

- Singapore Green Labelling Scheme (SGLS), administered by Singapore Environment Council (SEC).
- Singapore Green Building Product (SGBP) labelling scheme, administered by Singapore Green Building Council (SGBC).

The various types of tiles include ceramic tile, porcelain tile, rectified tile, quarry (unglazed) tile, etc.

2.1.2. Porcelain tiles, a type of Homogeneous tiles, are composed of fine porcelain clays and fired at a much higher temperature. This makes the porcelain tiles hardier, less porous and thus more resistant to moisture and stains as compared to ceramic tiles. Porcelain tiles have a consistent colouration and property throughout the entire section of the tile. They are suitable for use in both indoor and outdoor conditions. Porcelain tiles are harder to cut due to their density and hardness.

2.1.3. Rectified tile is defined as a tile that has had all edges mechanically finished to achieve a more precise facial dimension. Unlike a typical factory-edged tile, rectified tile is cut to size after the firing process. This process creates a precise, 90 degree angle smooth edge; as a result, the tiles can be laid with consistent grout joints. Most tiles (both homogeneous and ceramic) may vary in size, after being fired, up to 1.0 % of its size. But the size variations can be substantially minimised through the process of sawing or grinding after the tile is fired.

2.1.4. In recent years, **large format ceramic tiles** were introduced into the market. While ceramic tile is defined as having a surface area not more than 3,600cm^2 with tile edge less than 600mm, large format ceramic tile can be defined as having a surface area of more than 3,600cm^2 and tile edge of less than 1.2m. The thickness of these tiles depend on the type and area of usage. They come in wide varieties of styles and lookalike designs on the surface ranging from concrete, stones to high-polished porcelain. Large format ceramic tiles are available in any style and color that regular tiles come in.

There is another type of large format ceramic tile known as the **large ceramic panel** (Figure 2.1.4). A ceramic panel tile has a surface area of more than 1m^2 with tile edge of more than 1.2m. Thin large format panel can be supplied in 3m length by 1.5m width. They can also be fiberglass reinforced, mechanically cladded and bent.

The constraint of large format ceramic tile is that the wall and floor must be even and level. Therefore, the use of appropriate adhesive and bedding is important. It is recommended to consult an adhesive supplier when choosing adhesive for large format panels. The width of the grout joints must also be compatible with the tile dimension.

Large format panel tile - Size can be as large as 3.6m length 1.5m width and only 6mm thick

Figure 2.1.4

2.1.5. SELECTION CRITERIA

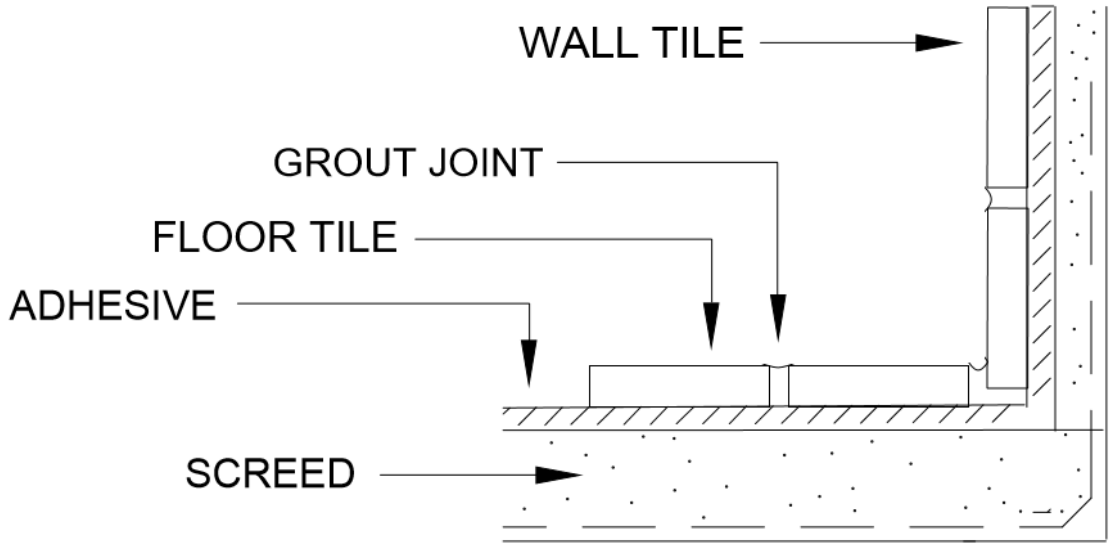
Prior to starting any tiling works, it is important to ensure that the selected tiles are able to meet the project specifications. Table 2.1.5 provides guidance on the selection criteria.

Table 2.1.5: Ceramic tile selection criteria

Ceramic tile selection criteria	Requirements
1. Water absorption	- Water absorption in tiles provide a measure of porosity. A high water absorption value indicates a porous tile body while a low value indicates a compact tile body. - In wet area, tiles with low water absorption should be used.
2. Modulus of rupture and breaking strength	- Modulus of rupture and breaking strength of ceramic tiles give an indication on where the tiles can be used. (Refer to SS 483). - Light loading areas are those where normal low-density pedestrian traffic e.g. domestic and office locations, are likely to occur. - Heavy loading areas are those where high density pedestrian traffic, and/or heavy load, are likely to occur, e.g. in industrial and engineering premises. - Tiles that withstand the required loading need to be selected accordingly.
3. Abrasion resistance	- Resistance to deep abrasion of unglazed tiles for floor should refer to ISO 10545-6. - Resistance to surface abrasion of glazed tiles for floor should refer to ISO 10545-7.
4. Slip resistance	- For safety reason, the slip resistance classification needs to be established based on usage of the location. Reference can be made to SS 485:2011.
5. Crazing resistance	- If soaking of tiles are required, glazed tiles should be tested to confirm that soaking would not lead to crazing should refer to ISO 10545-11.
6. Dimensions and surface quality	- Tiles used should have adequate dimensional characteristics (length, width, thickness, straightness or sides, rectangularity, surface flatness) and surface quality to match the design expectation, e.g. joint width, uniformity and alignment.
7. Thickness	- Generally, thin tiles are more vulnerable to impact damage. - Such floor tiles should have a minimum thickness of 8mm for better functional usage. - Ratio of tile thickness to size should be controlled. Thickness of tile should increase following the increase in tile size to avoid cracks. - Nowadays, bigger tiles with thin thickness are being fabricated with greater breaking strength or impact resistance. - Tiles can be tested for impact resistance in accordance to ISO 10545-5.
8. Special requirements	- Stain resistance should be considered for kitchen and supermarket and should refer to ISO 10545-14. - Chemical resistance should be considered for laboratories, industrial kitchen and chemical processing plant and should refer to ISO 10545-13.

2.2. ADHESIVE BEDDING

Bedding refers to the mortar, or in general terms ‘thin-bed” adhesive, thick bed mortar or levelling bed which is the screed or render (Figure 2.2). The lower and upper limits of the thickness of the adhesive should be specified by the manufacturer. Site personnel should follow the manufacturer’s instructions and apply adhesive only to the specified thickness.



Adhesive bedding
Figure 2.2

2.2.1. TYPES OF ADHESIVE

In accordance to EN 12004/12002 and ISO 13007-1, tile adhesives fall into 3 major categories:

- Cementitious (Type C): Mixture of hydraulic binding agents, aggregates and additives; to be mixed with water or other liquid before use.
- Dispersion (Type D): Mixture of binding agent in the form of polymer dispersion, additives and other mineral fillers which is ready for use.
- Reaction-resin (Type R): Mixture of synthetic resins, mineral fillers and additives in which hardening occurs by chemical reaction.

2.2.2. ADHESIVES SELECTION

Some ceramic tiles are highly absorbent. It is important to select the correct adhesive to ensure its performance, i.e. to limit water absorption from adhesive to the tiles.

There is no single formula of adhesive that is compatible with all types of tiles and substrates. It is important to note that, depending on the formulator’s technical competence and marketing strategy, products belonging to the same type of adhesive could perform significantly differently. Table 2.2.2.a and 2.2.2.b provides suggestions on the selection of adhesives.

Table 2.2.2.a: Adhesive selection criteria

Adhesive selection criteria	Requirements
1. Types of tile	- The adhesive materials should be compatible with the tiles used.
2. Types of substrate	- Different substrate types and their characteristics affect significantly the adhesive selection of the tile finish system. - Table 2.2.4 provides a general guide on different types of substrate.
3. Application properties of adhesive	- The requirement of open time (maximum interval after application at which tiles can be embedded in the applied adhesive) should cater for the site application needs, considering the differences between the site conditions and that of a standard laboratory.
4. Final properties of adhesive	- The requirement of tensile adhesion strengths should suit the worst combination of site conditions and workmanship, considering the tensile strengths after water immersion and after heat ageing as robustness and durability checks.

Table 2.2.2.b: Types of substrate

Types of substrate	Requirements
1. Floor	
1.1 Reinforced concrete floor	- Screeding required. The screed may be bonded or unbonded depending on the flexibility and condition of the substrate. - Pipes and ducts should not be laid within the thickness of a screed.
1.2 Screed thickness	- Nominal thickness of site-batched bonded screed should be 40mm & not < 25mm at any isolated point. - Nominal thickness of site-batched unbonded screed should be 75mm & not < 50mm at any isolated point. Otherwise, the screed should be reinforced with non-oxidising mesh of 100mm centre and 2mm diameter. - For proprietory screed, follow thickness recommended by manufacturer.
2. Wall	
2.1 Masonry walls	- Rendering required.
2.2 Reinforced concrete walls	- If plump satisfies the conditions specified, they may be able to receive tile installation directly. Otherwise, rendering would be required. - A splash coat (typically comprises cement, dry sand and latex in the ratio of 1:1:1 by weight) may be applied before rendering to enhance bonding.
2.3 Aerated precision concrete wall	- If plump satisfies the conditions specified, only suitable primer may be needed. Otherwise, rendering would be required. - If in doubt, it is a good practice to seek the recommendations of the manufacturers to ensure the compatibility of the render/plaster mix with the APC blocks.
2.4 Proprietary partition walls	- Manufacturers should certify the suitability of uses for these proprietary partition walls. - Installation to be in accordance with the manufacturers' instructions.
2.5 Render thickness	- For site-batched render, its total thickness should not be > 20mm, otherwise, strips of non-oxidising ribbed metal lathing should be anchored onto the substrate prior to plastering. - For proprietary render, follow thickness recommended by manufacturer.

2.3. SPECIFICATION OF GROUTS

The joint width of tiles is not just a matter of design preference. The manufacturing tolerance of the tiles should also be considered. For example, when using more dimensionally accurate tiles (e.g. dry pressed tiles), the joint width could be smaller than using dimensionally less accurate tiles (e.g. extruded tiles).

In accordance to BS 5385-3:2014, the width of the grout joint should not exceed the tile thickness. There is a provision for wider joints if wider joints are required to accommodate dimensional irregularities in the tiles, maintain modular control or provide a decorative effect. The depth of the grout joints should be at least 2/3 of the tile thickness.

While the minimum joint widths may be different between the wall and floor tiles, it is a good practice to adopt a uniform joint width for both tiles. This will enable the joints to be consistent and straight throughout the wall and floor tiles.

Grout is the material that is used to fill up the gap between tiles and support the tiles. It is classified into cementitious and reaction-resin types. They should have suitable fineness and consistency that are compatible with the designed joint width, such that grout can fill the joints successfully. Selecting the right type of grout is as important as selecting the right tile and adhesive. Before proceeding, it is advisable to test its compatibility with the tile. Table 2.3 provides guidance on the selection criteria in accordance to BS EN 13888 and ISO 13007-3.

Table 2.3: Grout selection criteria

Grout selection criteria	Requirements
1. Application properties	- Cleaning time (time interval between filling the joints and start cleaning the tiles). - Service time (time interval after which the tiling can be put into service). - Pot life.
2. Shrinkage resistance	- Should be able to prevent cracking. - Any cracking, either in the grout line itself or between the grout and tile, should be considered as failure.
3. Abrasion resistance	- Abrasion resistance is important for floor applications.
4. Compressive strength	- Compressive strength is important for applications.
5. Water absorption	- Water absorption is pertinent to stain cleaning considerations.
6. Chemical resistance	- Chemical resistance can be a key property to certain applications such as industrial kitchen and chemical processing plant.

2.3.1. CLASSIFICATIONS OF GROUT

There are 2 types and classifications of grout in accordance to EN 13888 and ISO 13007-3:-

- Cement-based grout (CG) : available in Sanded Grouts or Non-sanded Grout
  - ❖ Normal Performance (CG1)
  - ❖ Improved Performance (CG2)

- Epoxy-based grout (RG)

Grout is visible and can be water-resistant. However, in most Portland cement based grouts, water or other liquids can still be absorbed into the joints due to its capillary pores. Table 2.3.1 describes different types of grout and applications.

Table 2.3.1: Different types of grout and applications

Types of grout	Description	Application
Cement grout (CG) – Sanded	Consists of fine graded aggregates, Portland cement, synthetic resins and coloured pigments added with water retentive additive. The water retentive additive allows the grout to stay moist until the cement cured.	- Used for larger grout joint - 3mm or larger. - Excellent alternative for natural stone and heavier tiles
Cement grout (CG) – Non-sanded	Consists of very fine filler, synthetic resins, coloured pigment and water retentive additive. The water retentive additive allows the grout to stay moist until the cement cured.	- Used for smaller grout joint - 3mm or smaller. - Easier to apply on dry or vertical surfaces.
Epoxy grout (RG)	Consists epoxy resin, silica fillers, pigments and a hardener. Epoxy grout is waterless mix formed by mixing a base material (part A) and a hardener (part B).	- Ideal for porous and moisture sensitive stones. - Have very low water absorption, higher compressive strength, are resistant to staining and easy to maintain.

2.3.2. GROUT PERFORMANCE CRITERIA

Table 2.3.2.a: Guide on grout performance for CG based on EN 13888 and ISO 13007-3

Fundamental characteristics	Requirement
1. Abrasion resistance	≤ 2000 mm^3
2. Flexural strength	≥ 2.5 N/mm^2
3. Compressive strength	≥ 15 N/mm^2
4. Shrinkage	≤ 3 mm/m
5. Water absorption after 30 minutes	≤ 5 g
6. Water absorption after 240 minutes	≤ 10 g
Additional characteristics	**Requirement**
7. High abrasion resistance	≤ 1000 mm^3
8. Water absorption after 30 minutes	≤ 2 g
9. Water absorption after 240 minutes	≤ 5 g

Table 2.3.2.b: Guide on grout performance for RG based on EN 13888 and ISO 13007-3

Grout performance	Requirements
1. Abrasion resistance	≤ 250 mm^3
2. Flexural strength	≥ 30 N/mm^2
3. Compressive strength	≥ 45 N/mm^2
4. Shrinkage	≤ 1.5 mm/m
5. Water absorption after 240 minutes	≤ 0.1 g

2.3.3. JOINTS AT DOOR AREA

The joints of door frame to floor and wall should be neat, gap-free and consistent (Figure 2.3.1.a). When closed, the gap between the door and floor should be neat and consistent. The joint at floor divider area (Figure 2.3.1.b) should also be neat and uniform throughout.

Neatly cut tile at door frame
Figure 2.3.1.a

Neat joints at floor divider of completed unit
Figure 2.3.1.b

2.4. MOVEMENT JOINTS

Movement joints are provided to accommodate movement in large continuous finished areas, or between adjacent building components (e.g. brick wall and concrete column) and dissimilar substrates. These can be:

- In-situ joints which are formed during construction or sawn cut afterwards, filled with filler board and backer rod, and sealed with a suitable sealant or;
- Pre-fabricated movement joints which are installed prior to the laying of tiles.

The backer-rod material in the movement joint should be compatible with the sealant used. It should be flexible, compressible without forcing sealant out.

The sealant should be capable of accommodating the anticipated amount of movement without loss of adhesion to the sides of the joints and be able to withstand the normal service conditions affecting the installation, e.g. resistance to water and, where applicable, ultraviolet light.

The designer, in consultation with the supplier/manufacturer, are encouraged to specify movement joints and show locations and details on drawings and specifications. Table 2.4 provides guidance on the locations of movement joints and their appropriate joint widths.

Table 2.4: Location of movement joints and their appropriate joint widths

Location of joints	Minimum joint width
1. Structural movement joints should be carried through screed/render, bedding and tile layer. If the joints in the base structure are not straight and parallel, or if their layout does not coincide with that of the floor tiles, guidance should be sought from the designer.	Not less than the existing structural joint widths
2. Where tilework abuts restraining surfaces, such as columns, beams, perimeter walls, curbs, pipes and ceiling.	Interior walls - 3 ~ 5mm Interior floors – min. 5mm
3. At junctions where the substrate changes alignments, such as concave wall corners, or where the substrate changes materials, such as between conventional clay bricks and aerated precision blocks.	
4. At perimeters and to divide floor and wall tiling into bays at the following intervals: • Interior walls at interval of 5 to 6m • Interior floors at the interval of 5 to 7m • Interior floors and walls exposed to direct sunlight at the interval of 3.6 to 7m	

2.5. PLANNING OF TILE LAYOUTS

The designer should prepare tile layouts which take into consideration the minimum joint width and the tolerance of selected tiles.

Tile layout planning should consider the size of tiles used and shape of the area to be tiled. Care should be taken to minimise the number of tiles that need to be cut for satisfactory visual effect. Cut tiles should be placed at less visible corners. They should be of width greater than half of the tile size.

V-Box is used to check tile squareness and size variation before laying, in order to minimise inconsistent joints during installation. While handling the tiles, there should also be visual check for tile defects, damages, stain marks and inconsistent tonality. V-Box can be customized according to the size of the tiles. Figure 2.5 shows the use of V-Box to check tiles squareness and size variations.

V-Box to check tiles squareness and size variations
Figure 2.5

Before commencing any pre-tiling work, it is important to check that all the services are well incorporated and coordinated in the approved shop drawings.

To ensure that the owner's requirements particularly on a project's acceptable tolerances are fully understood, the contractor should construct a mock-up unit for owner's approval before carrying out the actual tiling works. This arrangement enables the main contractor and sub-contractors involved to know the exact level of quality which they are expected to deliver. A mock-up unit will also enable all parties to confirm the layout, detailing and the compatibility of the different materials.

2.6. WET AREAS

Wet areas are areas within a building that are exposed to water splashing or direct wetting. The areas are commonly installed with discharge outlets and provided with water inlet supply. It is important to seek the recommendations of the suppliers when selecting tiles in wet areas.

Gradient in wet areas should be laid to fall in accordance to specification and towards the discharge outlet. Gradient may vary depending on whether the area is enclosed or exposed to weather condition, and space usage. The direction and gradient of the fall must also be planned and indicated in drawings. Insufficient gradient, uneven laying of tiles and lippage in wet area may lead to ponding of water on the tiles.

2.7. WATERPROOFING

Waterproofing refers to the normal protection of the tiles from damages due to both rising damp and direct contact with water, such as in a shower compartment.

Continuous rising damp due to capillary action should be prevented by a proper vapor barrier below floor slab and/or of any damp-proof-course in wall.

A tile finish, even when its joints are filled with impervious grout, cannot stop water from passing through. In wet areas, a waterproofing membrane should always be installed to prevent water penetrating to the neighboring areas and below. The water trapped between the waterproof membrane and the tile layer can only evaporate by passing through the tile layer.

The type of waterproofing material used for wet area has evolved over the years with cementitious waterproofing being used most commonly in recent years. It is easy to mix and apply, and readily available from suppliers. Please follow the manufacturers' instructions to ensure an accurate mix of materials.

For more details on waterproofing in wet areas, refer to Good Industry Practices Guide – Waterproofing for Internal Wet Area, CONQUAS® Enhancement Series.

Waterproofing membrane at wet areas
Figure 2.7