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Stabilizing Heritage Buildings Founded on Reactive Clays - Dealing with Conflicting Requirements

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Summary: The measures required for stabilizing heritage buildings founded on reactive clays often appear to create conflict among the disciplines of engineering, architecture and landscape design engaged in the conservation process. The causes of damage and the means of stabilizing or partly stabilizing the foundations are discussed, together with their parallel architectural and landscaping requirements. The authors have been associated with the conservation of many buildings in the Hunter Region and have developed techniques which may be applicable to other parts of Australia and elsewhere. Of particular note is the recommendation on choice of suitable plant species for areas near buildings which could be seen as contrary to recent practice and fashion.

1. INTRODUCTION

The Hunter Region of New South Wales was one of the first areas of white settlement in Australia and contains many historic buildings dating from the 1820's onwards. Unlike many of the earliest settled areas around Sydney, the Hunter Valley has extensive areas of clay soils which are reactive. This means that the soils change their volume as they change moisture content.

The mechanisms of this volume-changing property are beyond the scope of this paper and are well documented elsewhere(1), suffice it to say that soils formed from sedimentary rocks containing certain clay minerals, particularly montmorillonite, exhibit this property. In the Hunter Valley the soils usually range between moderately and extremely reactive when classified under the Australian Standard(2).

2. EXTENT OF PROBLEM

The awareness of building damage from reactive clay foundation movements appears to have increased, at least in the Hunter Region, since 1980. A number of reasons can be postulated for this increase:

- in our increasingly litigious society, some property owners are less inclined to patch up and forget cracks and will call in professional assistance in the hope of passing blame to someone else - road and railway authorities are favourites;
- in the lower Hunter Valley in particular, water restrictions were introduced in 1981, so limiting the amount of water applied to gardens during the drought;
- gardening practices have changed significantly since many old buildings were first erected -- lawns have replaced carefully tended (and watered!) beds of vegetables and flowers and exotic trees and shrubs have been replaced by Australian natives.

Elsewhere, particularly in Adelaide, the problem of reactive clays has been known for many years. However we believe that some of this discussion may allow a new perspective in other areas.

3. THE MECHANISM OF DAMAGE

3.1 Ground Movements

In an open field with little or no vegetation, soil moisture at the surface will vary generally in accordance with climatic conditions but with a lag depending on the properties of the soil. Variability of moisture decreases with depth which, for practical purposes, can be up to 4.0m in Adelaide or 2.0m in the Hunter Valley(1).

The wetting of the soil takes place through rainfall and irrigation with poor or defective drainage being responsible for excessive moisture build-up which can be concentrated at different points around a building. Proper grading of the ground surface surrounding a building is the most important measure in preventing excessive moisture build-up and underground drainage needs to be leak-free.

Drying of the ground during drought takes place through direct evaporation and by transpiration through plants, particularly trees. One aspect of the drying process that is often forgotten is the evaporation from ventilated under-floor areas.

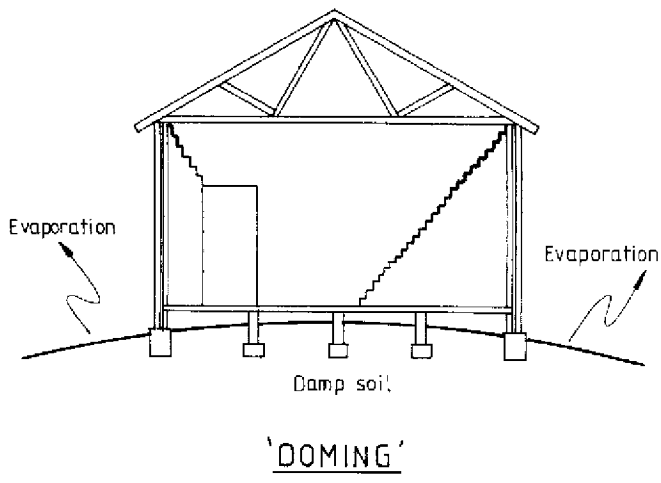

Figure 1

Figures 1 and 2 indicate the type of damage resulting from the typical "doming" and "dishing" ground movements.

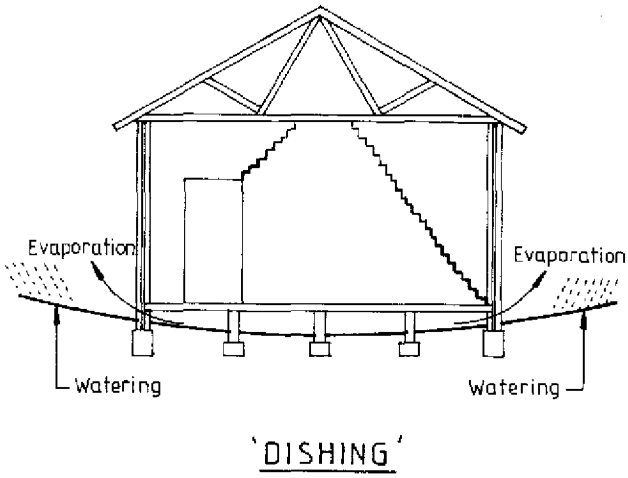

Figure 2

3.2 Effect of Trees

Trees, particularly many Australian natives, have a great ability to survive drought. Unlike many exotic deciduous trees which can lose leaves and reduce their water demand or die during severe droughts, most native species have the ability to send out roots to find remaining moisture. In and around buildings they are frequently very successful in so doing: a large eucalypt tree has been estimated to draw more than 1000 litres of water from its surrounds on a hot day. The effect of the tree is to increase soil suction which shrinks the clay

Figure 3 shows a representation of the typical damage resulting from trees.

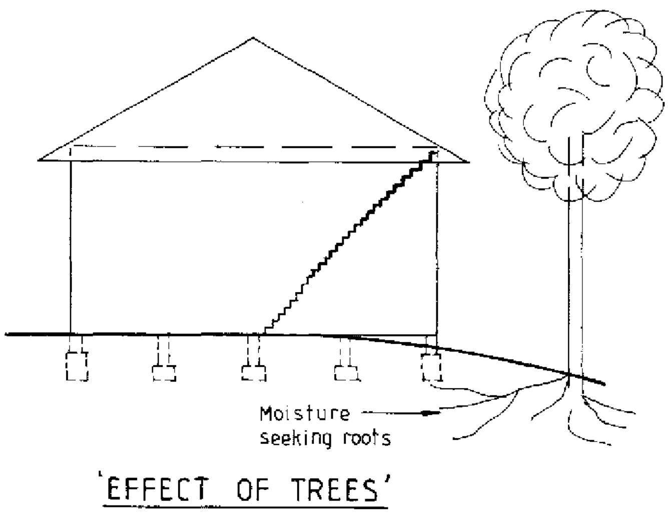

Figure 3

3.3 Drainage Practices

Various publications, including the Australian Standard(2), have detailed discussion on site grading, the need to adequately deal with stormwater and choice of materials. One aspect that is frequently overlooked occurs when a need is perceived to install subsoil drainage, particularly when there is "rising damp" present in the masonry.

As well as removing excessive moisture during wet weather, sub-soil drainage can lead to increased evaporation during dry periods. In our opinion this increased evaporation could lead to greater soil shrinkage and damage than may have occurred previously. In general, on reactive clay sites we have found it better to keep the site moist for foundation stability and deal with rising damp and excessive moisture by means other than sub-soil drainage unless it is separated from the building by a barrier.

3.4 Possible Extent of Movement

The soil classification procedure in AS2870.2-1990 classes sites in accordance with a predicted surface movement:

Class M (moderate)	20mm to 40mm
Class H (high)	40mm to 70mm
Class E (extreme)	more than 70mm

Sites are classified rather than the soils because the extent of movement will depend on the depth of soil.

In a typical example of a building with a side of dimension (say) 6m, the difference in surface movement between the centre of the building and the outside wall could be (say) 50mm on a highly reactive site and at the bottom of the footings (say) 35mm. This strain, when translated to a rotational crack in a 3m high wall, could result in a crack width of 35mm at the top of the wall. Such a crack leaves little, if any, interlock in most masonry walls and could lead to structural instability.

This example indicates the crack width resulting from a change from moist to extremely dry conditions: it is not, unfortunately, unusual in a building that has suffered some years of neglect, particularly of the garden, when a drought occurs.

4. PLANTING PRACTICES AND THE CONTRIBUTION TO BUILDING DAMAGE

Our European ancestors brought with them large numbers of exotic plants and animals, some of which have subsequently enhanced our living conditions and some of which have helped destroy the native environment. When using plants near buildings, in rural or suburban areas, they seemed to want to recreate the environments they had left behind and planted large numbers of exotic species.

There have always been people who studied and appreciated native species but until the 1960's and 1970's, the planted environment of most buildings consisted largely of exotic species. To be overly simplistic for the purpose of illustration, a typical urban or rural garden before this time probably was surrounded by a privet hedge and contained rose bushes, hydrangeas and an English oak tree if there was room.

From the point of view of maintaining stable foundation conditions, there is an essential difference between most native and most exotic species of plants, particularly the larger shrubs and trees: most exotic species are not drought resistant whilst most native species are. Practically this means that most exotic species will either die if not watered regularly or else lose their leaves and go into a form of suspended animation; on the other hand, the drought resistant Australian species will, in the first instance, send out roots to find any remaining moisture in the area and this is often from under buildings; only then will they undergo other drought survival changes.

There is a dilemma here for the environmentally aware: a European built environment has been imposed on an Australian natural environment yet, in reactive clay areas at least, an attempt to reach a compromise can jeopardise our built heritage. In fact, it might be bluntly stated that most Australian native plants are incompatible with our built environment!

We hope, in the remainder of this paper, to show what measures can be undertaken to minimize the problems that occur.

5 MEANS OF STABILIZING FOUNDATIONS

5.1 Underpinning - Why It's Often Not Successful

In the past, and all too frequently now, the first reaction of those in the building industry to foundation movement of any sort is to underpin the footings. If reactive clay rather than low bearing capacity is the cause of the movement, this can be a very expensive mistake.

As mentioned earlier reactive clay soils can be affected by moisture changes, and hence movement, to depths of up to 4m in Adelaide and 2m in the Hunter Valley. Where the problem has not been properly identified, underpinning has been taken to harder clays at depths considerably less than this and the building has suffered further damage during the next major drought. Even if the underpinning is taken deep enough to reach stable soils, damage can still be caused by shrinking or swelling soils exerting lateral pressures; in cases where the underpinning is by isolated piers swelling soils can push up on the footings between the piers.

In our experience, therefore, the preferred method of treatment is to stabilize the foundation moisture content. It is not only cheaper but it is less likely to cause damage to the building when being undertaken.

5.2 Controlling Moisture Content - important factors

If a plastic sheet is laid on the ground, even during quite dry periods, it will be moist underneath when lifted after some days:survival books suggest similar methods for collecting water in the desert. The same thing will happen under a building, so in stabilizing soil moisture it is more practicable to work towards a moist equilibrium state rather than a dry one.

The following factors, some of which have already been mentioned, should be considered in preparing a scheme for soil moisture stabilization:

- trees and shrubs likely to have an effect should be either removed or root barriers constructed;
- all drainage plumbing in the vicinity of the building should be constructed with flexible, not cemented, joints and the pipe material selected for durability and strength to resist possible damage;
- paths or other moisture barriers around the building are there primarily for the purpose of preventing evaporation during dry periods so it is just as important to have a vapour barrier covering the ground under the building if there is a foundation space (figure 4);

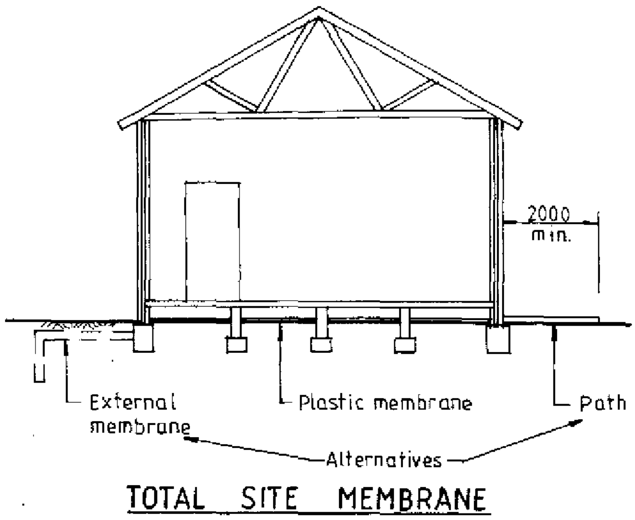

Figure 4

- unventilated timber floors can be retained as reasonably effective vapour barriers providing the timbers are given suitable treatment against fungal attack;
- sub-soil drainage near a building can increase evaporation and drying out unless installed in conjunction with a vapour barrier;
- any stabilization scheme is not going to give absolute security, particularly under an extraordinary drought event, and it should be combined with suitable articulation of the building if possible.

6 TREATMENT OF RISING DAMP

The desire to stabilize foundations in a moist condition creates an additional problem to be overcome: unfortunately, many old masonry buildings have a "rising damp" problem. This can be caused by the breakdown, bridging or absence of a damp proof course low in the wall: descriptions and treatment are well documented in many building restoration publications(4). The main practical problem in investigating damp walls is to ensure that it is not penetrating or falling moisture that is causing the dampness.

One solution to the treatment of rising damp is to install subsoil drainage around the building to lower the phreatic surface sufficiently, but on a reactive clay site where a moist equilibrium is being sought, this is not possible.

There appears to be no alternative to the traditional methods of installing a new damp-proof course or repairing the existing one. Considerable success has also been achieved with chemical injection for which there is a number of proprietary processes in the marketplace. For many years the "Sovereign" process developed in the U.K. was considered the most suitable for heritage buildings, but of late local licensees for this process have reduced the guarantee from 20 years to 10 years. A newer formulation based on the chemical alkoxysiloxane has now been used on many important heritage buildings

7 BUILDING ARTICULATION

7.1 The Need for Articulation

Despite what has been stated above, it is possible to design an underpinning system to stabilize buildings founded on reactive clays. Such a system will invariably be very expensive as it will need to completely isolate the building from the moving soil, including laterally, or be suitably reinforced to resist the strains. Such a footing can be readily designed and built for a new building, but it is much more difficult and costly for an existing building.

A more cost-effective approach is to make provision in the building for minor movements to take place without destabilizing it or causing noticeable "damage".

7.2 Engineering Considerations

The engineering considerations can be summarized as follows:

- allowance must be made in the building structure to accommodate the likely range of movement without causing structural instability - if joints are required in walls, yet the walls need structural continuity to resist wind loads, then tied joints such as those detailed in Figure 5 should be constructed;

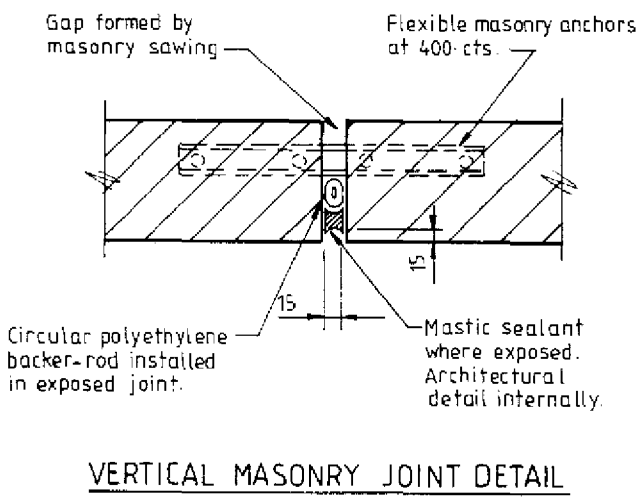

Figure 5

- with foundation moisture stabilization, the range of movement will be less than in the past, but some articulation is desirable, particularly in the vicinity of old cracks to cater for a reduced movement;

- a programme of repairs often has to be carried over a short time period which does not allow sufficient time to achieve moisture equilibrium (often more than a year) - articulation would still be desirable;

7.3 Architectural Considerations

The main architectural considerations with regard to the introduction of articulation in historic masonry buildings can be outlined as follows:

- Assessment of existing details and conditions i.e. footing type additions and alterations, masonry materials, bonds and jointing details, lintel details, special details for example earlier opening now closed and finally applied finishes.

- Assessment of articulation methods details and their proposed locations.

- The effect of articulation on visual appearance and the final detailing of joints.

7.3.1 Existing Detail

Many early Australian Buildings have been built with inadequate footings either through a lack of appreciation of the instability of many Australian soils or through cheap unskilled construction. As time passed alterations and additions occurred to buildings which can be identified by vertical cracking caused by differences in footing type and heavier or lighter constructions. Openings in masonry buildings introduce inherent weak points in the overall construction and openings that have been filled in are usually accompanied by cracking particularly if the infill has not been bonded to the surrounding masonry.

It is desirable to ensure that the masonry type is clearly identified (ie stone masonry or brickwork) and that the form is also appreciated, (eg ashlar, regular or rubble cored stonework, solid brick or cavity brick. This must be carefully considered with regard to lateral stability of wall panels after articulation joints are cut in. Lintel details above window, door and fireplace openings must be carefully investigated to ensure that the right location is chosen for the positioning of articulation joints.

While locating joints to coincide with openings is desirable it is often not possible, due to lintel details. Where masonry above openings has been arched to span the opening, the joint must be located away from the zone of influence of the arch. Where timber iron, or stone lintels have been used the joints coincide with the opening in combination with horizontal slip joints to allow for movement. Figure 6 indicates a method of "stepping" a joint vertically by means of a horizontal slip joint.

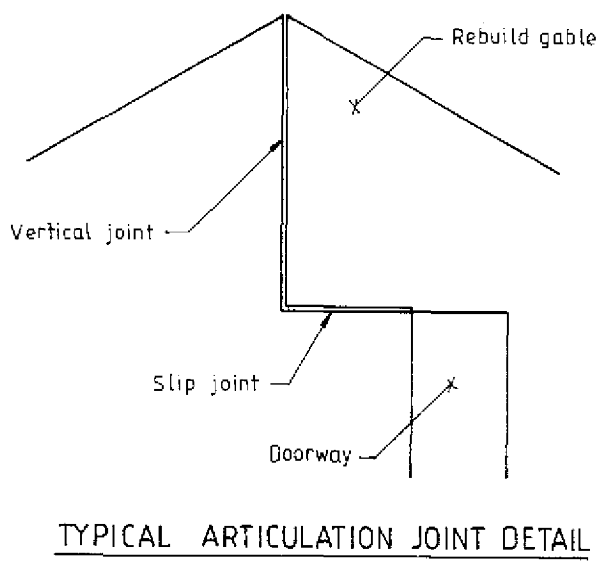

Figure 6

Applied finishes must be analysed and protected when inserting articulation joints so that minimal damage is caused to the finishes. This is of particular concern for internal finishes which tend to be more fragile and decorative in their nature.

7.3.2 Articulation Historically

Articulation is not unknown in historic buildings in Australia and many examples have been documented such as timber nogged brickwork and in specifically located vertical joints sometimes incorporating vertical timber members. Allowance for movement can also be seen in the construction and jointing methods used in many early timber roofs.

While incorporation of articulation joints using authentic construction methods is an admirable goal, the utmost priority must be given to the least intrusive method. This means that the method that requires the least amount of intervention in the existing fabric is desirable. This principle also allows for locations to be determined more easily, both from a visual point of view and a physical point of view. The methods for incorporating articulation joints in existing masonry are categorized as follows from the least intrusive to the most:

i) modification of existing cracks by handwork to create joints;

ii) cutting in new joints by hand or by use of circular or chain saws or by use of diamond embedded wire or cord with pulleys and drive motor;

iii) the removal and rebuilding of masonry to provide vertical or horizontal joints.

The selection of locations for joints also affects the choice of method to be used. If method iii) is used location is generally not restrictive. Method ii) is only limited by access for the machinery and method i) by the area required to perform the physical labour.

All joints should then be sealed using appropriate sealants and backing rods.

7.3.3 Visual Appearance and Joint Detailing

Location of joints can affect the visual appearance of historic masonry and care should be taken to minimise visual impact. Ideally they should be located to coincide with openings: if this is not possible due to existing lintel details then the joints should be located at internal angles of wall junctions. If joints are still required in long walls then their visual impact can be minimised by locating them symmetrically with minimum joint width and the use of coloured sealants to match surrounding surfaces.

Ideally the width to depth ratios of sealant should be 2:1 with the minimum depth no less than 6mm, therefore giving a minimum joint width of 12mm.

It is also desirable to slightly bend or round the edges of the masonry to minimise future damage to the joint edges and it also assists in the natural cleaning of the joint.

Cover strips may be used to protect joints however they tend to be more visually intrusive than the exposed joint.

8 CASE STUDIES

8.1 Dalwood House

Dalwood House is a National Trust property situated on the banks of the Hunter River near Branxton built in local sandstone and dating from 1828. It was built by George Wyndham in a "Greek Revival" style of which it is a rare Australian example.

The building was lived in until about 30 years ago but was then abandoned until restoration commenced, first under the direction of a trust set up by Wyndham family descendants and subsequently by the National Trust of Australia. When work commenced in the early 1980's, extensive damage, including some wall collapse had occurred as a result of foundation movements.

At the beginning of the restoration process, extensive geotechnical testing was carried out which showed that the site was extremely reactive and for considerable depth: for the reasons mentioned above, underpinning was not considered suitable. A number of trees and shrubs were situated close to the house which had to be kept as part of the conservation so a root barrier was also required in many places around the periphery of the building.

The adopted external moisture barrier is shown in Figure 7. The turn-down at the edge serves as a root barrier as well as effectively increasing the length of the evaporation path compared to a similar length of barrier laid nearly parallel to the ground. Reinforcement was proportioned as for a water-retaining structure and water-stops were used at all slab joints. A flexible seal was placed between the lower walls and the slab edge.

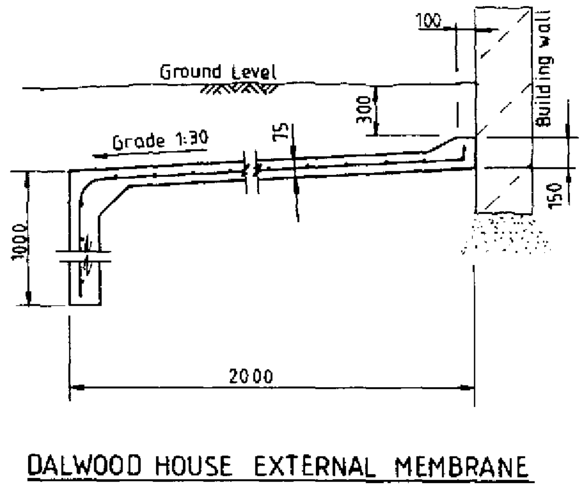

Figure 7

Internally, PVC membranes were laid on the ground and protected with a sand overlay. All paths and paved areas were repaired or sealed to provide as good a moisture seal as possible within the area bounded by the peripheral external membrane slab. Originally the underfloor areas were not ventilated and it would have been difficult to install ventilation without significant damage to the original fabric; in those areas where the timber floors have so far been replaced "Koppers" treated hardwood timber has been used for bearers and joists.

8.2 Wambo Homestead

Wambo Homestead is owned by the Wambo Mining Company and is situated at Warkworth 20 kilometres west of Singleton in the Hunter Valley. The building is one of six remaining structures on the property and of single storey construction with a sandstone foundation to floor level and then 350mm (14 inch) brickwork stucco finished above floor to roof level.

The plan form of the building is simple and symmetrical with the facades following the typical Georgian idiom of centralised door with windows symmetrically placed.

Geotechnical testing has shown that the building is founded on highly reactive clays. Severe cracking is evidenced throughout the building both internally and externally, and this cracking may have been exacerbated by underground mining below the building. Major cracks and out-of-plan movement is also associated with the location of a large Norfolk Island Hibiscus close to the north east corner of the building and a previous fireplace located in that area. Inadequate roof drainage has also concentrated water in two locations which has dramatically increased the movement at those locations.

The solution adopted for this building was to reinstate the roof drainage, install a root barrier between the hibiscus and the building, install an external fabric moisture barrier as shown in figure 8 and cut in six articulation joints to allow for movement.

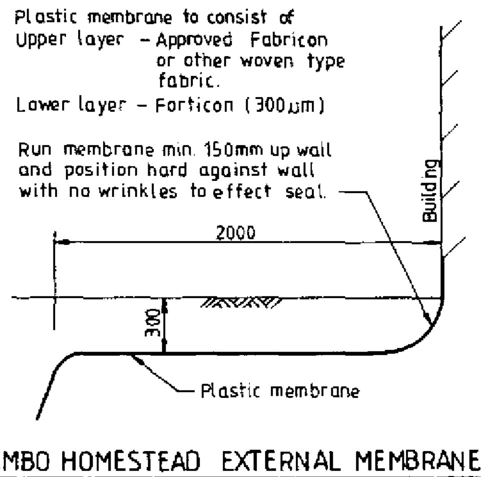

Figure 8

Additionally, PVC membranes were laid on the ground in the foundation area under the floors and protected with sand.

After completion of this work restoration of the extensive cracking and repair of finishes could then be commenced.

8.3 St Peter's Church Hall, East Maitland

St Peter's Church Hall is a brick masonry building dating from the 1840's built in Victorian Georgian architectural style. The main hall, with a stage at one end, has high solid brick walls carrying a roof supported by exposed timber trusses; at the other, street frontage, end of the hall, a two storey section includes a flat on the upper floor.

Reactive clay foundation settlements have caused cracking in some walls. The building also has extensive rising damp which continually damages the internal wall finishes and soft sandstone window sills.

At first sight, the building would not appear to be an obvious candidate for reactive clay damage: it is surrounded by a concrete path and there are no large trees nearby; it also seems to have escaped major damage for most of its life. On further inspection, however, a number of factors seems to have contributed to the conditions leading to damage:

- the building has been partly cut into the side of a hill and there is poor drainage which results in one side of the building being kept quite wet while the other dries out during extended dry periods;
- an investigation of the then less serious problems was carried out in the early 1980's without the benefit of geotechnical testing - the investigators made holes in the concrete surrounds and excavated beside the footings but did not repair the concrete later: we believe that moisture movements through these breaks in the surrounds have contributed to the additional damage now existing.

Repairs recommended to stabilize the building follow the normal guidelines, namely:

- check and repair all sewerage and stormwater drainage;
- install subsoil drainage uphill of the building to limit water intrusion under the building and assist in making the moisture conditions more even throughout the foundations;
- install a chemical damp-proof course at locations where rising damp problems exist - this may need to be extended in future, but was limited in extent at first to reduce costs;
- restore integrity of paving around building.

9 CONCLUSIONS

The budget available for work on most heritage buildings is extremely limited and engineers and architects working to conserve them must adopt approaches which keep benefits and costs in perspective. Foundation moisture stabilization is a most effective way of limiting damage to buildings on reactive clay sites and can be carried out using relatively cheap methods and materials. However, absolute stability of a building under all likely conditions cannot be guaranteed from use of these procedures and so consideration should be given to introducing articulation to allow controlled movement which does not affect the structural stability of the building.

10 REFERENCES

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