Research Paper 6

A Survey of the Frost Resistance of Clay Brickwork in the Australian Alps

Abstract

Clay brick structures in the Australian Alps were examined to determine their resistance to exposure to frost.

It was found that brick quality, type and colour together with the design of the structures in which they were used were all significant factors influencing the bricks' performance under these conditions of exposure.

Overall, good quality pressed bricks were found to be satisfactory and many extruded bricks performed well, but with them care is required at the selection and design stages.

Several instances were seen where good quality brick suffered damage as a result of either or both poor detailing or poor construction methods.

Clay Brick and Paver Institute

PO Box 6567, Baulkham Hills BC NSW 2153, Australia

T 02 9629 4922 **F** 02 9629 7022

info@claybrick.com.au

www.claybrick.com.au (main website)

www.brickbydesign.com (design website)

Research Paper 6

A Survey of the Frost Resistance of Clay Brickwork in the Australian Alps

by Stephen Zsembery and John Macintosh

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Editor's note: The image quality of some figures reflects that of the source material. Some photographs have been substituted or deleted in the absence of the original photographs.

1.0 Introduction

Frost resistance of clay bricks had been a major concern to brick users in Europe and North America ever since it was recognised that not all bricks are capable of withstanding the destructive forces involved in the formation of ice in their pores.

This problem did not arise in Australia until the past two or three decades during which time snow skiing has become very popular and the construction of accommodation for skiers was found to be a profitable investment.

Little or no damage to clay bricks had been reported from the NSW Alps because there clay bricks have been restricted to internal uses. Cases of frost damage have been reported in the Victorian Alps where no such restrictions apply.

In spite of the concerted efforts of researchers in countries where frost damage to bricks is a real problem, no indirect test has been developed which would allow accurate prediction of the performance of bricks under these conditions. Therefore the most reasonable advice which may currently be given is to refer the user to the past performance of the proposed bricks under the given exposure conditions. Because experience with Australian bricks subjected to snow and frost exposure was very limited, a survey was undertaken by the Brick Development Research Institute to examine existing brick structures at ski resorts in Victoria and New South Wales in order to evaluate and record their performances for future reference.

2.0 Locations and conditions

On the Australian mainland the ski resorts are in North East Victoria and at the Mt. Kosciosko National Park in South East New South Wales.

The snow season is between mid June and mid September with wide temperature variations at the resorts during this time. Temperatures would normally fall below O°C during the night and be above O°C during the day. This means that water absorbed by bricks on the north and north west sides of buildings will freeze during the night and thaw during the day. On the other hand bricks on the east and south faces are much more likely to stay at a reasonably steady low temperature.

Resorts surveyed were Smiggin's Hole and Thredbo Alpine Village in NSW and Mt. Buffalo, Mt. Hotham, Falls Creek and Mt. Buller in Victoria.

Frost damage was also observed in Cooma and Jindabyne located close to Mt. Kosciosko. Towns and villages close to these resorts experience frequent overnight frosts and occasional snow which melts quickly.

3.0 Aim of the survey

The aim of this survey was to identify and record bricks used in the snow areas, to observe their performance, to formulate theories to explain the reasons for their performances and to make recommendations for types of bricks and building practices that will enhance the successful use of clay bricks in ski resorts.

In order to achieve these aims brick structures were examined for defects and where these were seen the brick type, colour and quality was noted. Photographs of each brick structure and of the failures were taken and when possible samples of the bricks were collected for laboratory tests.

4.0 Theoretical considerations on the mechanism of frost damage

This section of this report has been developed from a paper by G.G. Litvan[1].

The outcome of freezing on brick structures or bricks alone is largely dependent on the amount of water held by the system, the rate of cooling, and the pore structure of the bricks.

It is known that water may remain in a liquid-like state at sub-zero temperatures when adsorbed on porous bodies. This is probably due to the surface effect of the body.

4.1 Adsorption and retention of moisture at sub-zero temperatures

The amount of moisture that may be either adsorbed or held in a liquid state by a porous body at sub-zero temperatures is dependent on its degree of saturation prior to freezing.

4.2 Adsorption

For example, if a completely dry brick at sub-zero temperatures has water sprayed on it, it will adsorb water into the pores in such quantity as will exert a vapour pressure equal to that of ice at that temperature. No further water can be adsorbed because, in accordance with the requirements for an equilibrium condition, excess water will form ice outside the pores before it can enter the system. The significance of this phenomenon is that dry bricks that become frozen cannot then become saturated and therefore damage due to the formation of ice in fine pores is not likely. Naturally water could enter large cracks where it will form ice that could cause damage.

4.3 Retention

The situation is more serious when bricks become saturated at O°C or above and are then brought to sub-zero temperatures. In this case a non-equilibrium state exists because the bricks contain more water than they can hold under these conditions. Under ideal conditions where sub-zero temperatures develop gradually, freezing may not occur. In these circumstances nature deals with this problem by a very simple mechanism: part of the water contained in the pores migrates to, and freezes at locations where the effect of the internal surfaces is not felt. However not all the excess water has to leave the brick. Reduction of the amount of water in the pores to the fraction that will present a concave surface with an appropriate curvature reduces the free energy of the liquid and produces a corresponding reduction of its vapour pressure. Thus equilibrium is achieved between ice with a relatively low vapour pressure and the liquid with a reduced vapour pressure. Due to the loss of moisture in this process the brick will contract whilst ice accumulates in the cracks or on the external surfaces. With further cooling the above process is repeated and, as long as the moisture can leave the pores, no damage will occur.

From the above it can be seen that in spite of the lower temperatures wet bricks hold more water in the liquid state than they would if they were dry when brought to the same temperature and then had water sprayed on them.

4.4 Conditions leading to frost damage

In actual exposure, changes in temperature and humidity mostly occur in large increments rather than gradually. Under these conditions mechanical damage to the unit is possible unless:

a) the amount of water that has to be transferred is small, i.e. the porosity or the degree of saturation or both are low;

b) the cooling rate is low;

c) the permeability of the system is high, i.e. large pore diameters;

d) the unit is small, i.e. the distance from the surface to the pores containing water is short; and,

e) the mobility of water is high, i.e. low viscosity.

The presence of soluble salts has been reported as an additional factor that may increase the likelihood of frost damage.

4.5 Mechanism of frost damage

From the above, it can be seen that mechanical damage can occur to solids in non-equilibrium freeze-thaw cycles due to one or several of the following mechanisms:

1. A brick will lose water on cooling and the water will collect in cracks and on the surface as ice. On warming, water from the external surface will migrate back to the interior and it is more likely to be collected in the cracks than to be completely re-adsorbed by the pores. At the next cycle of cooling the water will freeze in the cracks and the accompanying 9 percent increase in volume will exert increased pressure on the brick. Repeated cycles enlarge the cracks until failure occurs.
2. The presence of cracks in bricks is not necessarily the main cause of frost damage. A situation may arise when on cooling a saturated brick the amount of water released by the body is in excess of that which leaves the pores. This leads to water being collected in the pores. This excess water forms a non-crystalline amorphous ice with expansive properties that cause considerable stiffening of the body which is in the process of shrinking due to the lowering of the temperature. The effect of these differential movements is revealed on thawing when mechanical damage is shown due to the permanent volume increase of the system.

3. It is well known that volume changes in porous bodies will occur due to changes in their temperatures and or their moisture content. For example, cooling causes shrinking in the body and in addition, when the body is wet, the reduction in temperature will cause further shrinkage due to moisture loss because the drop in the relative humidity of the air will encourage evaporation.

   The magnitudes of the shrinkages caused by temperature and moisture changes are different. Therefore, when cooling is rapid, significant stresses are created in the body because of these different rates of shrinkage.

   Rapid wetting or drying is known to cause cracking with damage occurring more readily when this rapid wetting or drying takes place at or just below O°C. The reason given for this phenomenon is that it is extremely difficult, if at all possible, to create by other means rates of drying of the magnitude produced during cooling in the range just under O°C.

5.0 Implications of the theory

From the above theories it is evident that few if any bricks can be labelled as entirely frost resistant. The conditions of exposure may be so severe that no porous body would survive it.

Therefore durability classes can only be assigned to bricks under given conditions of exposure; e.g. bricks found to be frost resistant under the exposure conditions of the Australian Alps may not be durable when used in New Zealand or Antarctica.

The theories put forward to explain the mechanism of frost damage all stress the importance of avoiding situations where the bricks become completely saturated.

Protection to the brickwork can be provided by sensible design. Wide roof over- hangs, membrane damp-courses and copings that will shed water from horizontal surfaces will considerably reduce the chance of frost damage. Brick with low porosity will absorb little water and their use will also contribute to increased frost resistance. Extruded bricks with visible lamination cracks in their bodies are liable to frost damage as water may collect within these cracks.

Creating conditions that reduce permeability without significantly reducing porosity is potentially dangerous as those conditions will retard the loss of water from the material without being able to prevent saturation. For this reason painting, rendering or glazing of bricks or even silicone treatment is likely to lead to extensive damage. See Figure 1 (this photograph is not available).

6.0 Assessment criteria

Bricks were assessed an the basis that any damage due to frost action was taken to be a failure of that particular colour and type of brick irrespective of the number of bricks involved or any matters of faulty detailing.

In structures where more than one colour and or type was used, or when the bricks were sold as a blend of colours, the performances of individual brick colours of the same type were recorded separately; e.g. in a case when a blend consisting of extruded browns, reds and pinks was used, the performance of each of these colours was assessed separately. However, when there was reason to believe that the colour variation within a blend of bricks was due to degree of firing, the assessment was made on the basis that the whole blend was of the one type.

The colour assigned to each observation was based on the perception of colour of those conducting the survey rather than the colour under which these bricks might have been sold. Bricks with a distinct red colour were described as red, other lighter shades as pink. It is also worth noting, that colours assigned to bricks, for example in NSW, differ from those in Victoria. Most red bricks sold in NSW, particularly the semi-dry pressed types, would be described as browns or greys in Victoria.

The observations of frost damage in Cooma and Jindabyne are not included in the table of results because the examination of buildings in these areas was not comprehensive.

7.0 Results of the survey

The survey covers 52 completed buildings, six jobs under construction plus six exposure panels erected by a brick manufacturer at Falls Creek three years ago.

The bricks used in the structures were categorised according to their mode of manufacture – extruded or pressed. Judgement was made as to whether the bricks were of first or second quality and their performance under exposure was noted.

Table 1. Summary of observations

Brick colour and manufacturing method	Number of first or second quality	Total number		Number of failures			
				According to type		According to reason	
		Passing	Failing	General	Isolated	Bad brick	Bad detail
Extruded pink	First: 6	3	3	3	0	3	0
Total: 7	Second: 1	0	1	1	0	1	0
Extruded red	First: 10	7	2	2	0	2	0
Total: 12	Second: 1	1	2	2	0	2	0
Pressed red	First: 10	9	1	1	0	1	0
Total: 11	Second: 1	0	1	1	0	1	0
Extruded cream	First: 7	3	4	3	1	3	1
Total: 9	Second: 2	0	2	2	0	2	0
Pressed cream	First: 1	1	0	0	0	0	0
Total: 1	Second: 0	0	0	0	0	0	0
Extruded grey	First: 7	5	2	0	2	0	2
Total: 10	Second: 3	0	3	2	1	2	1
Pressed grey	First: 5	5	0	0	0	0	0
Total: 5	Second: 0	0	0	0	0	0	0
Extruded brown	First: 5	4	1	1	0	1	0
Total: 7	Second: 2	1	1	1	0	1	0
Pressed brown	First: 2	2	0	0	0	0	0
Total: 2	Second: 0	0	0	0	0	0	0
TOTALS	First: 52	39	13	10	3	10	3
Total: 64	Second: 12	2	10	9	1	9	1

8.0 Survey details

The survey covered the main ski resorts of NSW and Victoria and some damage due to frost was inspected in Cooma and Jindabyne.

8.1 Cooma

a) Lawn Cemetery. Extensive frost damage was observed at the Lawn Cemetery, where locally made extruded brown bricks were used as a lawn edge around the memorial wall. See Figure 2 . The bricks appeared to have been well made, but not to be highly vitrified.

b) Common grade bricks used partly below ground level in a rendered retaining wall showed extensive damage due to frost.

During winter the bricks would become completely saturated with water and they would often freeze during the night and thaw during daylight hours. This is an extremely severe test of durability and failure could not be regarded as unexpected. Bricks identical to those used as the lawn edging suffered no damage when used as a wall at the main entrance.

Figure 2. Failure of lightly vitrified bricks in contact with the ground

8.2 Jindabyne

Light coloured extruded bricks in a poorly designed front fence showed extensive frost damage. See Figure 3.

The same bricks used in the house showed no damage. Once again failure was due to frequent cycles of freezing and thawing of saturated bricks.

Figure 3. Frost failure resulting from poor detailing

8.3 Smiggin's Hole

Only one job with exposed brickwork was found. It was a very old club house that had some painted external brick work up to first floor height. The bricks were brown dry pressed bricks and the building was around 20 years old. Some fretting was observed near ground level, not necessarily due to frost and two bricks in the chimney showed signs of wear, again not necessarily due to frost

The rest of the brickwork in the area was clad with timber or veneered with stone.

8.4 Thredbo Village

The main brick use was at the shopping centre which was paved with pressed red bricks (stiff plastic process). The paving and landscaping of the pool surround of the Alpine Hotel used the same bricks.

Appreciable wear was observed on the paving in the heavy foot traffic areas of the shopping centre. Failure was most likely to be due to wear and to frost damage to a lesser degree. In the pool surrounds (see Figure 4) little wear due to pedestrian traffic was observed, but frost damage was evident on the lighter fired bricks.

Most of those bricks were very hard fired, some showed signs of glazing and they would have been classified as good quality pressed bricks.

In this case the conditions of exposure were severe; i.e. saturated and with cycles of freezing and thawing. Considering the age of the paving, its condition must be considered acceptable.

One club house with painted brickwork was examined. The brick was identified as being a buff coloured semi-dry pressed product and no damage was observed.

Figure 4. Failure of the lighter-fired end of the range of well-made stiff-plastic pressed bricks

8.5 Falls Creek

Six panels of extruded bricks manufactured by Albury Brickwork Ltd. were examined.

These panels were built three years ago to a design similar to that given in British Standard BS 3921:1974 (see Appendix A) except that they were five courses lower and a half brick longer. No damp-proof courses were provided at the locations required by this standard. These deviations did not favourably influence the end result as the lack of a DPC should increase the severity of the exposure. The lack of height may be criticised, but the fact that some bricks in one panel deteriorated indicates that the exposure was severe enough to cause failure. See Figure 5.

Figure 5. Exposure panels at Falls Creek after three winters

An interesting feature of these bricks is that those with a relatively weak compressive strength survived the exposure, whilst the strongest (Cream Velour) did not. Table 2 highlights the difficulty of specifying bricks for frost areas from the results of indirect tests. For example, the initial rate of absorption (IRA) and cold water absorption (CWA) values of the Cream Velour and the Grey bricks are similar, the boiling water absorption (BWA) value of the Cream Velours is higher, but, from the high BWA value of the 'Saw Dust' bricks, one could mistakenly conclude that the cream bricks should perform as well as the rest of the panels.

An examination of the pores of these different bricks would probably show that there are significant differences between their structures.

The 'Saw Dust' brick with its (presumably) large pore diameters allows the free drainage of water from those pores before it freezes, whilst the pore structure of the Cream Velour must be such that a greater amount of water is retained.

Besides the exposure panels, two buildings were examined. In each case the structures consisted of bricks up to first floor and timber above. One building was built several years ago with reddish-brown extruded bricks containing three extrusion holes. They showed no signs of damage, even under the most severe exposure conditions when used in a substantial earth retaining wall leading-up to the entrance of this building. See Figure 6.

Figure 6. Extruded brown bricks surviving severe exposure (approximately 10 years)

Similar bricks made by the same manufacturer are characterised by IRA values of 0.1 to 0.2 kg/m^2, cold water absorption of 4 to 5 percent and compressive strength of 80 to 100 MPa.

The bricks in the other building were dark cream to buff in colour and were made by the stiff-plastic press process. A small addition contained some extruded cream bricks similar to those that failed in the exposure panel. No damage was observed to the brickwork.

Whilst the satisfactory performance of the pressed bricks may be explained by their pore structure, their mode of manufacture and by the general behaviour of pressed bricks when subjected to frost in those areas, the only explanation for the behaviour of the extruded creams is that the exposure at the location was not severe enough to cause damage.

Table 2. Typical properties of the bricks used in the exposure panels and the results of the exposure

Brick*	I.R.A. (kg/m^2)	C.W.A. (%)	B.W.A. (%)	Saturation coefficient	Average compressive strength (MPa)	Performance
Cream Velour	0.9	9.0	16.0	0.56	40.0	Failed
Cream (Saw Dust)	2.0	15.0	25.0	0.60	20.0	Passed
Grey (Cinnamon)	1.2	9.5	12.5	0.76	28.0	Passed
Grey† (Pearl Grey)	1.8	N/A	N/A	–	27.0	Passed
Red (Burgundy)	No data available			–	28.0	Passed

* These bricks contained 10 small round extrusion holes

† Two panels, one referred to as Texture, other as Velour.

8.6 Mt. Hotham

It was not possible to examine the Snow Bird Restaurant where the brickwork has substantially failed due to frost as it has been reclad with timber and aluminium boards. Bricks from the building were found and were identified as common grade bricks made in Melbourne. Their colour ranged from light cream to grey.

Two other ski-club houses were inspected. One built with well fired extruded bricks showed no signs of damage, whilst the other club house built with assorted pink to red bricks showed extensive frost damage to the lighter coloured bricks.

8.7 Mt. Buffalo

Well-fired pressed red bricks were used in some of the outhouses of the Chalet and in the ranger's house no damage was observed.

The workshop was built with extruded pink coloured bricks (now painted). Extensive damage was observed. See Figure 7. Whilst these bricks might not be underfired, their body showed very low vitrification.

Figure 7. Failure of (painted) light-coloured extruded bricks

8.8 Mt. Buller

In contrast to the other snow resorts large proportions of the buildings at Buller were built and are being built with clay bricks.

37 buildings were examined, some still under construction. Stiff-plastic pressed bricks were used exclusively or in part in only 15 buildings, the rest were built with extruded bricks.

The performance of the pressed bricks was impressive as no failure was observed except in one major building where approx. 500 poor quality pressed reds were used in a small landing behind the main building. These particular bricks would probably fail if used externally on or off the snow line.

The colours of pressed bricks used were red, brown and grey.

Several very large structures were found built and being built with extruded bricks. With some exceptions the bricks in these structures performed satisfactorily after many years of exposure.

Failures were observed at smaller club houses where common grade bricks of assorted colours were used.

Brickwork which has previously failed and was subsequently painted was observed to continue deteriorating. Painted common grade brick behaved similarly.

Design problems and exposure caused the failure of a protecting wall near the entrance of one lodge, the same bricks in the main building performed satisfactorily.

The Twin Towers was known from earlier reports to have suffered frost damage. These bricks are not now visible as this structure has been clad with cedar shingles and the adjoining buildings, built with similar bricks, are now being clad with cedar planks. These bricks showed no sign of damage and the cladding is believed to be being used to improve watertightness.

Two buildings were observed with damaged bricks near the exposed top of the walls. In each case the brickwork was protected from the entry of water by only a thin mortar weathering. Obviously such a practice is entirely unsatisfactory. See Figure 8.

Figure 8. Failure of otherwise durable bricks as a result of bad detail

9.0 Discussion

Whilst the total number of observations is reasonably large, the number of observations regarding the use of extruded bricks outweigh the number of observations where pressed bricks are used by a ratio of 2 to 1. At the same time entirely satisfactory performance of extruded bricks was only around 50 percent of their usage whilst satisfactory pressed brick performance was around 90 percent. These figures alone would indicate that, when no information is available on the expected performance of a given extruded brick, the use of pressed bricks is to be preferred.

This blanket recommendation for the use of pressed bricks applies only to first quality well fired units built on suitable membrane damp-proof courses to protect the brickwork from excessive dampness and soluble salt-attack.

The number of observations regarding the use of semi-dry pressed bricks is too few from which to draw satisfactory conclusions. However, from theoretical considerations, their performance should not be different from those manufactured by the stiff-plastic pressed process. These will also need to be hard fired top quality bricks.

With the expectation of the test panels at Falls Creek, all of the extruded bricks examined in this survey were of Victorian origin and, in general, can be said to have performed well in correctly detailed structures.

Compared with bricks produced in other states, data show that Victorian bricks are characterised by high compressive strength and low initial rate of absorption brought about by the high degree of fusion imparted to successfully reduce their moisture expansion.

It is likely to be quite wrong to presume from these data that high compressive strength and low IRA values are characteristics to be expected in frost resistant bricks and experience remains as the only fully reliable guide to this property.

In these circumstances the setting up of test panels of the British Standard type shown in Appendix A on a selected exposure site in the snow area is recommended as a practical way of determining the frost resistance of particular bricks.

The topic is seen as having applicability to the industry only in Victoria, NSW and Tasmania. In Tasmania, experience over some 20 years suggests that well fired red and brown pressed and extruded bricks can be successfully used. No experience can be recorded for bricks made in NSW.

Observations regarding the use of extruded bricks indicate that their quality and colour are very important factors for satisfactory performance. The use of cream. pink and light greys is not recommended. The survey did not cover any white clay bricks and a recommendation against their use is based on theoretical considerations alone.

Successful use of cream bricks was recorded in two instances. One concerned the use of special lightweight bricks built in an exposure panel and the other was one where normal production cream bricks were used in a fairly well sheltered location.. The same bricks failed in an exposure panel located near this structure. See Figure 5.

The performance of the lightweight brick is convincing as it has behaved as would be expected knowing that its pore structure would be such that water would escape to the surface before freezing occurred.

Among the exposure panels at Falls Creek were three panels built with a very light grey coloured brick. They were still performing faultlessly after three years of exposure. These bricks have a low compressive strength resulting from their highly porous body (see Table 2). Again, whilst no measurements of pore sizes were made, it is believed that the reason for their satisfactory frost resistance can be explained by pore sizes that renders them resistant to frost damage.

However, before satisfactory criteria for frost resistance has been established on the basis of pore sizes the use of such bricks could only be justified from a record of satisfactory past performance, either in exposure panels or in structures exposed for some years.

A satisfactory performance was observed in all structures where both top quality extruded bricks of darker shades and sound building techniques were used.

One failure was observed in extruded bricks that would have been sold as first quality on the basis of their appearance. However, after examination of the failed bricks it was clear that these bricks were underfired in a sense that they did not achieve the same degree of fusion during firing as the darker shades of the same consignment which did not fail. See Figure 9.

Figure 9. Low-end of the firing range of these bricks is not frost resistant

High quality hard fired grey bricks were observed to have failed when used in a free standing cavity wall built to protect the main entrance to a lodge against snow drifts. In this instance the construction details of the wall were poor and the exposure conditions were extreme. The same bricks, some 300,000 of them were used in the lodge and they performed without problems due to frost attack.

The worst performing extruded bricks were those sold as seconds or as blends of reds and pinks, where the pinks were in fact underfired reds.

It is true that not all pink coloured bricks are underfired reds and some performed well, but if this colour is to be used, it must be made certain that they receive the highest possible firing temperature in their manufacture. Well fired extruded red, brown and grey bricks showed excellent frost resistance qualities.

10.0 Conclusion

10.1 Pressed bricks

There appears to be little doubt that good quality well fired pressed bricks, regardless of their mode of manufacture, are suitable for use in walls under the conditions prevailing in the Australian Alps. White coloured pressed bricks, if available, may not be satisfactory.

The slight experience with brick paving does not suggest that even pressed bricks will give entirely trouble free service.

10. 2 Extruded bricks

Extruded bricks made in Victoria and by a manufacturer in Albury are also suitable for use above the snowline provided that:

1. Cream, white, pink and light grey coloured bricks are used only when proof has been provided of their suitability;
2. Grey, red and brown bricks are fired in their darkest colour shades;
3. When colour blends are used, the blend is made-up from well fired colours;
4. The bricks are free from visible extrusion laminations; and,
5. Only the hardest fired and most durable bricks are used for earth retaining walls or for paving. Bricks suitable for such applications will have very low cold water absorption (less than 5 percent) and IRA values less than 0.2 kg/m^2.

No experience is available to enable an opinion to be expressed about extruded bricks made by other NSW manufacturers.

11.0 Technical recommendations

Frost damage occurs when bricks become saturated and then frozen. The best resistance to damage from freezing will therefore be achieved by detailing brickwork for minimum water penetration. Whilst this should always be done, the harsh treatment of brickwork imposed by saturation and freezing will result in damage in locations where it would not occur under more temperate conditions.

11. 1 Essential requirements are:

1. Mortar. Normal mixes are adequate, but air-entraining additives should NOT be used because the honeycomb nature of the joint which results from the use of air-entraining plasticisers reduces resistance of the brickwork to saturation.
2. Joints. Raked joints should NOT be used. Even when the raked joint is properly tooled (a rare occurrence in Australian practice) the exposure created round the brick may lead to damage. Maximum protection against saturation calls for the use of properly tooled weatherstruck or ironed joints.
3. Parapets, chimney tops, retaining and courtyard walls. Clay brickwork is vulnerable to frost damage in these locations if water can penetrate the structure from the top. The use of cappings of copper, zinc, aluminium or galvanised steel is recommended. Failing this, specially selected bricks should be used and a damp-proof course should be built in near the top of the wall. A practice often observed in this survey (which had invariably resulted in failure) was that of providing a mortar weathering to brick copings. In harsh conditions this method of protecting brickwork is useless.
4. Sills. During rain windows and doors concentrate water on the sill. It is essential that the flashing below sills should be carried to the face of the wall. (See Brickwork Facts 3A). Specially selected bricks should be used for the sill, they should be laid with a steep fall with all joints filled flush and should project at least 25 mm beyond the wall-face below.

5. **Damp-proof courses and membranes.** Mortar type DPCs are inadequate. These should be metal or plastic. See Brickwork Facts 3A. In the case of retaining walls it is recommended that DPCs be used. To counteract the liability of the wall to slide on this membrane, galvanised pipe dowels should be provided in the centre of the width of the wall. The dowel perforation of the DPC should be sealed with a suitable mastic before any mortar bed is laid on it. Before backfilling against a retaining wall or a below-ground wall, the entire surface should be protected with a heavy duty plastic sheet membrane. Laps should be taped as specified by the manufacturer and the top edge should be treated in such a way as will prevent water entering between the membrane and the brickwork.

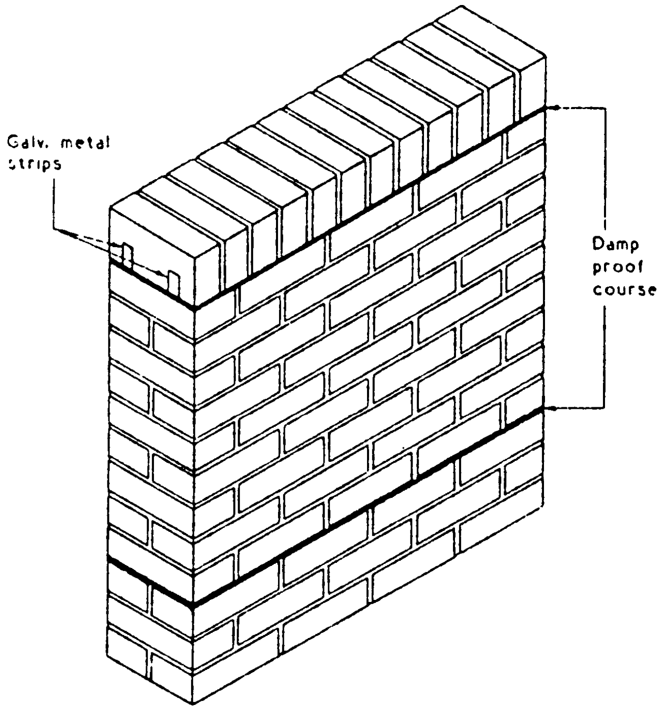
12.0 Acknowledgements

The authors are grateful to Mr A McKenzie, building surveyor of the Shire of Cooma-Monaro, Mr WS Young, building surveyor of the Shire of Bright, Mr TAK Hobson, deputy building surveyor of the Shire of Mansfield, Mr P Morey of Albury Brickworks, and Mr G Simon of Brick and Pipe Industries for their invaluable assistance during the survey.

13.0 Reference

1. Litvan, GG, *Testing the Frost Susceptibility of Bricks*. Masonry: Past and Present, ASTM STP 589, American Society for Testing and Material, 1975, pp 123-132

Appendix A



Suggested form of exposure wall (from BS 3921:1974)