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Ventilation, Salt Ingress, Timber Moisture and Corrosion Rates in Model Coastal Subfloor Spaces

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A study of the effect of subfloor ventilation regimes on timber moisture, salt ingress and corrosion rates in artificial subfloor enclosures has enabled several conclusions to be drawn. The use of galvanised steel for subfloor connectors in coastal zones will not always result in the 50-year durability usually required for structural components under the New Zealand Building Code. Either Zincalume® or stainless steel may be alternatives to galvanised steel in severe marine environments, although stainless steel has not been investigated in this work. In addition, it is apparent that to achieve 50 years durability for galvanised steel subfloor connectors in only moderately corrosive exposed coastal areas, ventilation must be kept to a minimum, to exclude salt from the subfloor. However, the minimum allowable degree of ventilation without ground cover in NZS 3604 must be adhered to in order to prevent high timber moisture contents. As well as considering the total vented area to a subfloor, individual slot widths or gap sizes should not be greater than 20 mm where sea salt is known to increase local corrosion rates.

INTRODUCTION

The durability of subfloor connectors is an issue of concern in New Zealand. As a structural element, subfloor connectors are required by the New Zealand Building Code[1] (NZBC) to be durable for 50 years, but historically they have often been rendered unserviceable by corrosion in a lesser time. Whilst this will not normally be noticeable to building occupants, the effect could be disastrous in a large earthquake.

The connectors are usually made of hot-dip galvanised steel and come in a variety of forms. Traditionally, the subfloor connectors were galvanised wire which was stapled to timber piles and bearers (or looped through, or embedded in, concrete piles). More recently, because of increased structural requirements in modern building codes, they have tended to be proprietary nail plate systems including plates, cleats and 'wire dogs'.

Factors causing connector corrosion are: dampness of the subfloor, deposition of air-borne sea salt, and contact with damp copper-chrome-arsenic (CCA) treated timber. Increasing the ventilation to the subfloor should decrease the dampness of the subfloor and the moisture content of CCA-treated timber, but will also increase the amount of air-borne sea salt entering the subfloor. The central objective of this work was to determine what level of ventilation would be small enough to adequately screen salt ingress in a coastal subfloor, yet be large enough to prevent excessive humidity. Most cities in New Zealand are coastal, and many houses are within 5 km of the sea.

This study was carried out in experimental rather than the survey form of past studies of this topic at BRANZ[2,3], where visual inspection of subfloor connectors had given conflicting results due to the large number of parameters involved.

EXPERIMENTAL

An artificial subfloor construction was built on the south coast of Wellington at Oteranga Bay, within the Transpower facility. The construction can be seen in Figure 1 and in Photograph 1. The construction comprised eight adjacent enclosures, each with identical dimensions. The south end of each enclosure faced the sea. The eight enclosures had different forms of ventilation at their south and north ends ranging from being completely closed off to being completely open. For each enclosure, the south and north ends were identical. The ventilation to the enclosures was as in Table 1:

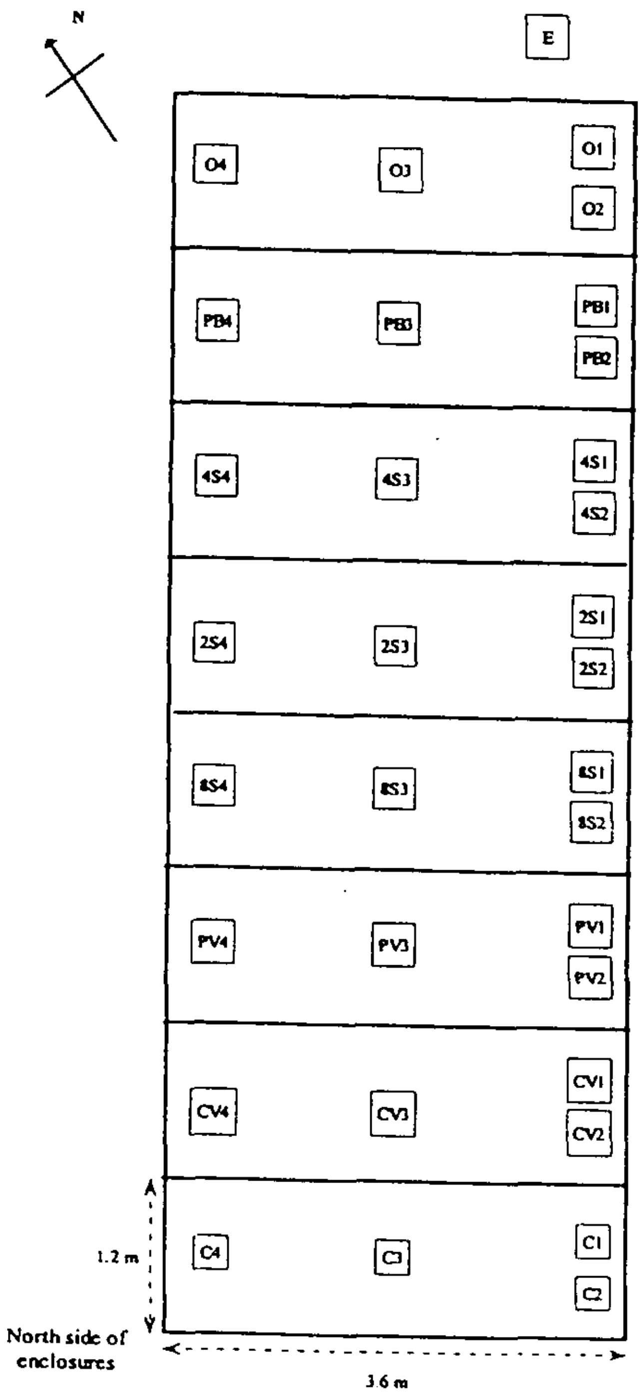
The following equipment was placed in each enclosure:

1. Four wet candle-type devices for measuring wind-blown sea salt. These are as described in ISO 9225[5]. (See Figure 1 for a depiction of their locations.) In addition, a candle was placed adjacent to the enclosures sheltered by a square plate as specified in ISO 9225. This candle was the same distance away from the sea as the candles in the enclosures.
2. An H3 CCA-treated Pinus radiata block measuring approximately 70 x 100 x 150 mm. This was placed in the middle of each enclosure on the side of the shelf holding the middle can-

Table 1

Enclosure Code.....	Vented area to each end/mm²	Description of Ventilation (enclosures same at both ends)
O........	1440000 ...	Open
2S	132000	2 slotted gaps each 1100 x 60 mm
4S	132000	4 slotted gaps each 1100 x 30 mm
8S	132000	8 slotted gaps each 1100 x 15 mm
PB.......	7800	'Post box' slot 30 x 260 mm
CV	7800	Concrete vent - each with 46 rectangular holes each measuring 27 x 6.25 mm
PV.......	7800	Plastic angled vent directing airflow upwards into enclosure - six 14 mm gaps of width 93 mm in a 2 x 3 grid
C........	0..........	Closed

Note: PB, CV and PV are all different ways of achieving the minimum NZS 3604[4] and NZBC[5] E2/AS1 requirement for subfloor ventilation to the area of the enclosures, which is 3500 mm² per m² of floor area. Each enclosure had a floor area of 4.32 m² giving a minimum required ventilation level of 7560 mm² per enclosure end.



Note: Codes within the enclosures relate to the labelling of the salt candles.

Figure 1 Layout of subfloor enclosures and salt candles at Oteranga Bay

dle, and used to monitor moisture levels in timber.

3. A vertical rack in the middle of the enclosure holding two mild steel coupons, two coil-coated galvanised steel (Z275 to AS 1650[6]) coupons, and a Zincalume® coupon. The backs of the steel and galvanised steel coupons were sealed with wax so that one of each type faced each end of the enclosure. The Zincalume® coupon was uncoated and therefore faced both directions.
4. Seven pre-weighed mild steel coupons attached horizontally to stakes in the ground, at regular intervals, from end to end of the enclosures. The bottoms of the coupons were sealed with wax, leaving the tops and edges exposed.

The experiment ran from November 1995 to November 1996, giving a whole year's data from the various methods outlined above and below. The enclosures were visited every 28 days during this period to collect data.

Data processing was carried out as follows:

1. The 33 salt candles were processed every 28 days to determine the amount of chloride from sea salt that was collected on the candle in that time period.
2. The timber blocks were analysed for moisture content every 28 days, either with a moisture meter (at the start of the year's analysis) or by weighing and comparing with oven dry weights at the end of the year's work (the majority of the data). Weighing is the most accurate way to obtain timber moisture data.
3. The metal coupons were analysed by chemical stripping to remove the corrosion products[7,8] in the laboratory after one year's exposure. The amount of metal lost to corrosion was then calculated.

RESULTS AND DISCUSSION

Salt deposition levels

The 33 salt candles used for this study were divided into three discrete groups, based on their total exposure to salt over one year (see Figure 2):

Group#1. The external candle, all the candles in the open enclosure, and the two candles at the south end of enclosures 2S, 4S, 8S and PB all received salt to the same order of magnitude.

Group#2. Approximately one order of magnitude less than the external candle (10-20%) were all the remaining candles in the slotted enclosures, and those at the south end of enclosure CV.

Group#3. The last group, with salt levels approximately two orders of magnitude less than the external candle (1-2%) were the remaining candles in enclosures PB and CV, and all the candles in enclosures PV and C. Enclosures PB, CV and PB represented different ways of achieving the minimum allowable level of ventilation set by NZS 3604.

These results indicate that to achieve a dramatic (down to approximately 1%) reduction in salt ingress from group 1 to group 3, ventilation should not be significantly above the NZS 3604 minimum requirement for this location, and even then salt levels may still be in group 2 adjacent to vents facing the sea. This may be improved by choosing a louvred vent, as seen by the reduced salt levels adjacent to vents in PV compared with CV. This is further discussed later with reference to the corrosion rates of the horizontal ground coupons.

If only a moderate reduction in salt levels is required because of a less severe coastal environment (receiving only about 10% of the salt that this location does), then either slotted or vented subfloors may be acceptable, providing that for slotted subfloors it is recognised that salt levels will not be significantly reduced adjacent to the slots in the direction from which the salt is carried. Such a less severe location might typically be found from 1 to 5 km from the sea in areas experiencing onshore winds, based on a comparison of this data with salt deposition data gathered by Duncan and Ballance[9]. The distribution of particle sizes in salt aerosol may also have an impact on the penetration of salt into the subfloor. As the relationship between particle size and penetration into a subfloor is not known, it is difficult to extrapolate these results to different locations.

Timber Moisture Content

The timber moisture content was higher during the months of May to October in all the enclosures. There was a reduction in timber moisture content in the summer months.

All enclosures apart from the closed one consistently maintained a timber moisture content below 20%. This is necessary to avoid corrosion of connectors by contact with CCA-treated timber[10]. The slotted and open enclosures provided a reduced maximum seasonal moisture content of 17-18%, whereas the vented or "NZS 3604" enclosures PB, CV and PV provided a maximum seasonal moisture content of 19%. This is very close to 20% so there is a good argument for using more ventilation in this location than the minimum NZS 3604 requirement. It might have been expected that this location would provide dry subfloor conditions because of the sandy soil. However, there may have been either a high water table or a water course close to the surface of the sand.

Corrosion Rates of Metal Coupons

Mild steel

The corrosion rates for the vertical mild steel coupons inside the enclosures, and for the ones at 45° to the horizontal situated outside the enclosures, were generally high. The rates range from 40 g/m²/year in the closed enclosure to over 1600 g/m²/year in the open enclosure.

When the average of mild steel corrosion levels in each enclosure is plotted against the salt levels at the middle salt candle in each enclosure (adjacent to where the coupons are) on a log scale, there is a reasonable correlation between the two measurements, although the highest result has a large leveraging effect. This suggests that, of the variables affecting the corrosion of the steel, salt is the most important in this experiment. Salt levels must be reduced by almost two orders of magnitude from the open enclosure level to bring steel corrosion levels down to below 100 g/m²/year.

There is no correlation between corrosion rates and timber moisture content in this experiment as the coupons were not in contact with timber. However, it would not be expected that corrosion of mild steel or galvanised steel would be caused by treated timber below 18% timber moisture content. In most cases, corrosion by contact with treated timber would not be severe unless the timber moisture was above 20% for an extended period of time.

Galvanised steel

Figure 3 shows the corrosion rates for the vertical galvanised steel coupons inside the enclosures, and for the ones at 45° to the horizontal outside the enclosures. Corrosion rates are very high in general (10-20 g/m²/year minimum), but the highest are in the open enclosure - O - where the corrosion rate of over 100 g/m²/year would reduce the lifetime of a typical hot-dip galvanised component to well below 5 years. (Hot-dip galvanised components to AS *1650*[6] made of steel less than 5 mm thick have around 400 g/m² of zinc.) In the slotted enclosures 2S, 4S, and 8S, corrosion rates were approximately 40 g/m²/year, so hot-dip galvanised components would last perhaps 10 years at the most before all the zinc was removed. In the less ventilated enclosures PB, CV, PV and C, and also outside the enclosures, the corrosion rates were around 10-20 g/m²/year which, although giving a longer life, will still only give a maximum durability of 40 years and not a minimum of 50 years as required by the NZBC'. Therefore, it is evident that for locations like Oteranga Bay, and even for less severe locations, it will be impossible to guarantee a 50-year life for hot-dip galvanised steel in the subfloor, unless it is additionally protected in some way.

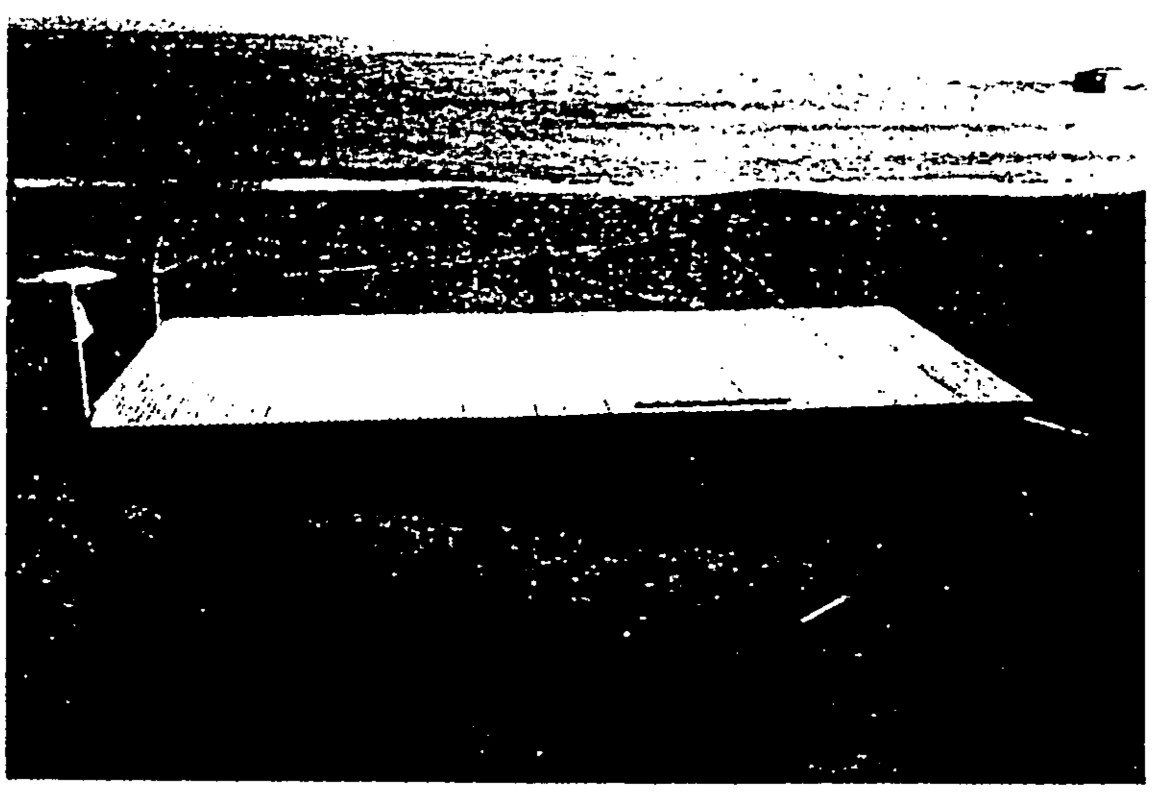


Photo 1 Eight enclosures from left to right: O, PB, 4S, 2S, 8S, PV, CV, C

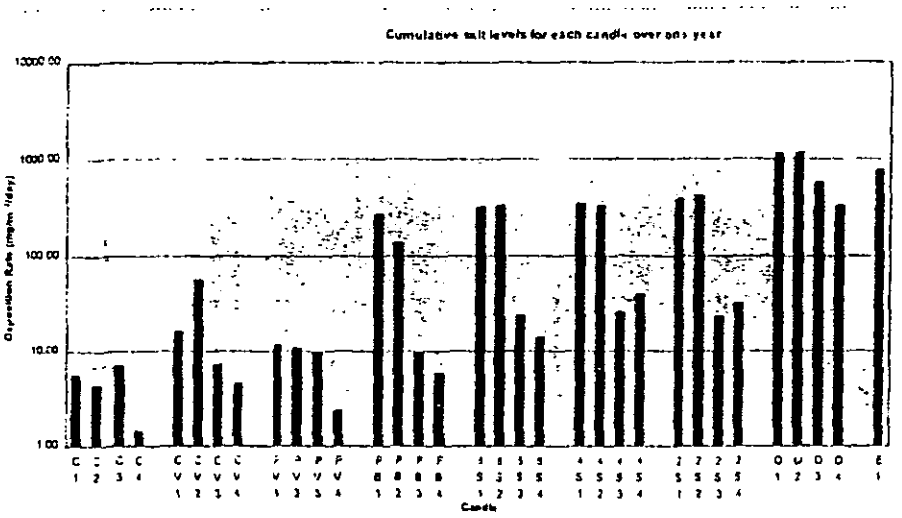
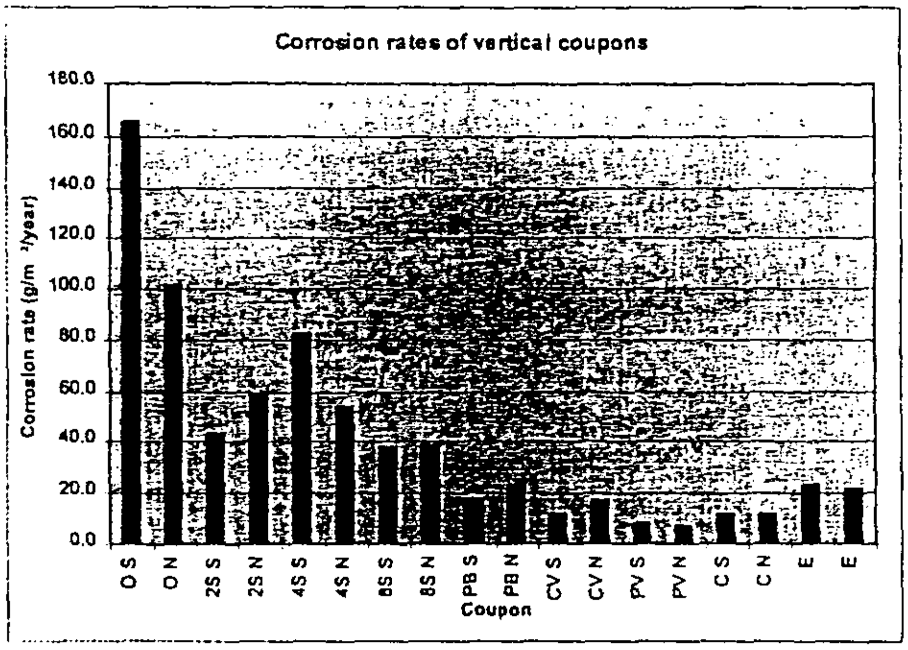
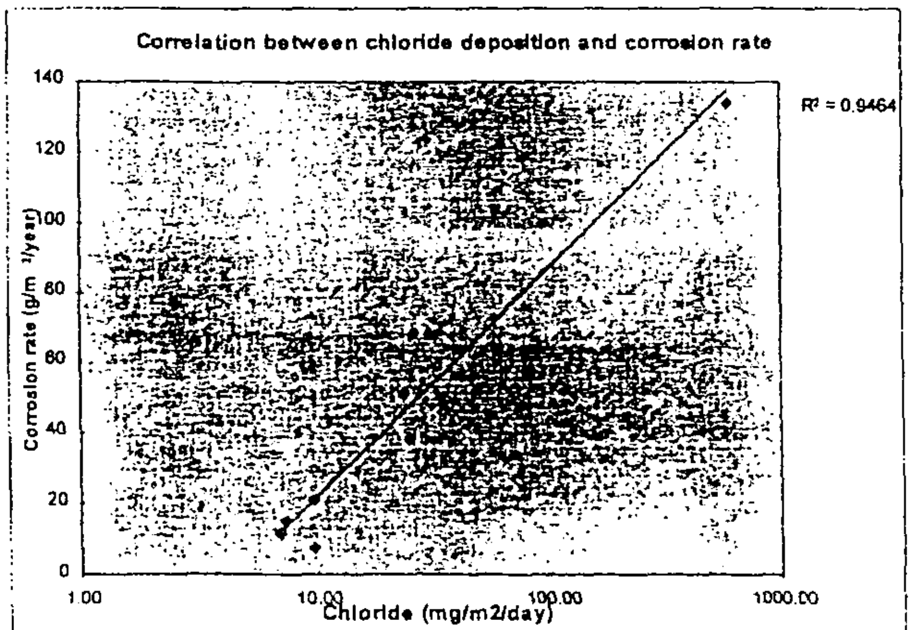


Figure 2 Cumulative salt levels for each candle (log scale)





Figures 3 & 4 Vertical galvanised steel coupon corrosion rates and correlation with salt levels recorded by candle in middle of enclosure

It follows that the use of stainless steel (type 304 or preferably 316) is worth considering as an alternative to galvanised steel for very corrosive coastal locations. If stainless steel was sufficiently durable, ventilation might be able to be increased to the subfloor in coastal locations without compromising its durability to gain the benefits of a drier subfloor space.

There is a reasonable correlation between galvanised steel corrosion levels and the log of salt levels at the middle salt candle in the enclosures although, as seen in Figure 4 and as for the corresponding mild steel correlation, the highest result has a large leveraging effect on the correlation. Some corrosion of galvanised steel will still take place with no chloride present, so for lower levels of chloride than measured in the enclosures at Oteranga Bay, the correlation shown in Figure 3 may not hold. In order to reduce the subfloor connector corrosion to acceptable levels at Oteranga Bay (below ~5 g/m²/year, if a lifetime of 50 years is to be attained), the amount of salt penetrating the subfloor must be reduced by about two orders of magnitude from the external level. This also means that even in a location with an order of magnitude less than the environmental salt of Oteranga Bay, the amount of salt penetrating the subfloor must still be reduced by a further order of magnitude for hot-dip galvanised components to be capable of lasting 50 years. Note that, in reality, there are attenuating factors which tend to reduce the environmental salt at subfloor levels. These include the presence of vegetation, other buildings and fences. Salt deposition data is often collected away from these attenuating factors, so should be considered as maximum possible local external salt levels.

Horizontal mild steel

The aim of exposing the horizontal coupons was to try and detect salt that was dropping out of the air flow just inside the enclosure vents because of air turbulence. It might be expected that the coupons closer to the ends of the enclosures would then have higher corrosion rates because of the salt deposition on them. The results showed no evidence of this effect for enclosures O, 2S (60 mm gaps), or 4S (30 mm gaps). However, the remainder of the enclosures (narrower openings) all showed some evidence of an enhanced corrosion rate for the coupons at the ends of the enclosure, especially the south or sea-facing end. This could have been due to water ingress through the ventilation openings but, if this was the case, the effect would also have been noticed in enclosures 2S and 4S. This supports the theory that vents or narrow slots induce turbulence in the air flow, causing salt "drop out". Interestingly, when comparing enclosures CV (many holes) and PB (single hole), there was no appreciable difference in the pattern of corrosion rates along the horizontal steel coupons. This suggested that the action of subdividing the ventilation opening had no effect on the amount of turbulence induced. However, when comparing 4S (30 mm gaps) with 8S (15 mm gaps), there did seem to be an increase in steel coupon corrosion rate adjacent to the ventilation openings. This suggests that a reduction from a 30 mm slot to a 15 mm slot causes salt "drop out". Salt "drop out" may not be so important away from the coast because the size distribution of salt aerosol particles is probably smaller,[11] meaning there would be relatively fewer of the larger, and therefore heavier, salt particles.

Zincalume®

The corrosion rates for the vertical Zincalume® coupons inside the enclosures range from 2 g/m²/year in enclosure PV to 35 g/m²/year in the open enclosure. The most striking aspect of these results is that the coupon corrosion rate inside the Open enclosure - 0 - is higher than all the other coupons, including the one outside, by a factor of at least 7. This indicated that rainwashing of Zincalume® vastly reduces the corrosion rate in salt-laden environments. However, even without rainwashing, reducing the level of salt dramatically reduced the corrosion of Zincalume® to below 5 g/m²/year. At this level, Zincalume® components may be capable of lasting 50 years in severe environments (depending on the coating thickness achieved), even if slotted ventilation is used.

There is no apparent linear correlation for Zincalume® between corrosion rate and salt levels at the middle salt candle. The corrosion rate is only significantly higher in the open enclosure, and not in any of the slotted enclosures. This suggests that it may not be necessary to reduce salt ingress to the same degree as required for galvanised steel in severe locations to obtain a sufficiently low corrosion rate for subfloor connectors made from Zincalume®

CONCLUSIONS

It is not possible with galvanising thicknesses of around 400 g/m² to achieve a 50 year durability as required by the NZBC[1] at Oteranga Bay and keep subfloor timber moisture content below 20% by means of ventilation, unless the zinc coating is additionally protected in some way.

Slotted type ventilation to subfloors reduces the amount of subfloor salt deposition to about 10-20% of the exterior level. Enclosed subfloors with vents near the minimum NZS 3604 level reduce subfloor salt deposition to about 1-2 % of the exterior level. At Oteranga Bay it would be necessary to reduce subfloor salt deposition to below 1% of the exterior level to give sheltered galvanised steel a life approaching 50 years.

· Even for coastal locations with only 10% of the salt deposition of Oteranga Bay, slotted subfloors would be incompatible with a standard galvanised steel connector life of 50 years. A comparison of salt levels at Oteranga Bay with levels at other New Zealand locations reveals that this may apply up to 1-5 km inland from coasts where there are onshore winds.

· The theoretical effect of turbulence-induced salt "drop out" in close proximity to the sea was tentatively confirmed for vent openings below approximately 20 mm. However, reducing individual space openings further below 20 mm does not appear to accentuate the effect. In practice, this means that it is desirable to have vent openings of 20 mm or less to encourage the turbulence that causes salt or other solid pollutants to "drop out" of the incoming air flow.

· The use of Zincalume® in subfloor connectors may be worth further investigation, as the corrosion rates in salty sheltered situations are much less than for galvanised steel. Although stainless steel was not assessed in this study, the poor performance of hot dip galvanised steel suggests wider use of stainless steel (type 304 or preferably 316) for coastal areas. There would be reasonable confidence that stainless steel fasteners would last 50 years with out any form of coating. Also, ventilation could be increased to the subfloor to gain the benefits of reduced building moisture originating from the ground.

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REFERENCES

1. Building Industry Authority, 1992. New Zealand Building Code. Wellington.
2. Holcroft, G, 1994. Report on Analysis of the 1994 BRANZ House Condition Survey Data for Subfloor Fasteners. BRANZ Unpublished Report UP 314 (confidential).
3. Holcroft, G, 1996. An investigation of 62 coastal subfloors for fastener corrosion. BRANZ Study Report 72: Judgeford.
4. Standards Association of New Zealand, 1990. Code of Practice for Light Timber Frame Buildings Not Requiring Specific Design. NZS 3604: Wellington.
5. International Organisation for Standardisation, 1992. Corrosion of metals and alloys -corrosivity of atmospheres - measurement of pollution. ISO 9225: Geneva.
6. Standards Association of Australia, 1981. Galvanised Coatings. AS 1650: Sydney.
7. American Society for Testing and Materials, 1981. Recommended practice for preparing, cleaning and evaluating corrosion test specimens, ASTM G 1 - 1981. Philadelphia.
8. Zoccola, J, Townsend, H, Borzillo, A and Horton, J, 1978. Atmospheric corrosion behaviour of aluminium-zinc alloy-coated steel. In Atmospheric factors affecting the corrosion of engineering metals, ASTM STP 646, pp165-184: Philadelphia.
9. Duncan, J and Ballance, J, 1988. Marine Salts Contribution to Atmospheric Corrosion. In ASTM STP 965 pp 316-326. American Society of Materials and Testing: Philadelphia.
10. Cox, R and Laidlaw, R, 1984. The effect of preservatives on the corrosion of galvanised metal plate fasteners in timber. Journal of the Institute of Wood Science, Vol 10 no 2 p87-90.
11. Harvey, M, 1997. Personal communication.
2. Cordner, R, 1990. Atmospheric corrosion survey of New Zealand. British Corrosion Journal. Vol 23. No 2. p115-118.
13. Duncan, J and Whitney, R, 1982. Suggested zones of steel corrosion hazard in New Zealand atmospheres. IPENZ Transactions, Vol 9. No 3. p65-75.

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