CORROSION OF STEEL WALL TIES WITHIN BRICK MASONRY CAVITY AND VENEER WALLS

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ABSTRACT

In masonry construction, the steel connectors, or fitments, are important structural components connecting the outer masonry leaf to the internal load bearing frame. Wall ties are fitments used to transfer lateral loads to the internal frame. In the event of extreme winds or earthquake, the wall ties are vital to the stability of structural wall systems. This calls for greater understanding of the corrosion of wall ties within a masonry wall cavity. This paper describes an empirical experimental program implemented to evaluate the corrosion of various wall tie types in masonry veneer and cavity walls. Field data were obtained from various sites, including at a severe marine atmospheric site, by monitoring environmental conditions and corrosion of wall ties within masonry veneer and cavity walls over a two-year period. Assessment of existing masonry wall cavities, to be conducted as part of the project, will provide further quantitative observations of the condition and deterioration of fitments.

Keywords: masonry, wall ties, cavity, corrosion

INTRODUCTION

Masonry construction has developed over the centuries, with the first uses of wall ties being wrought iron fitments between two leaves of masonry that typically make-up a cavity wall system. As the requirement for wall ties grew in masonry cavity and later into veneer construction, the necessity to ensure the durability and serviceability of wall ties increased [1]. Because of the severe adverse effects that may be caused by wall tie failure in a structure, in the event of intense earthquake shaking or high wind loads, there is a need to understand the mechanisms by which wall tie failure can come about. Failure may occur as a result of errors made during the design or construction phases, for example where incorrect spacing or lower durability and strength grade wall ties are used. In addition, it is known that over time, the wall tie is evidently subject to corrosion, particularly in mild temperate and mild tropical regions. The rate at which the wall tie deteriorates due to corrosion has been discussed in the literature and it is recognised that this aspect requires further understanding and investigation [2], particularly within the microclimate of the cavity between the masonry leaves or with other support systems. This present paper details an empirical experimental program being conducted to evaluate the corrosion of various wall ties within masonry veneer and cavity walls. An extensive literature review is provided and the results from preliminary visual inspections of existing masonry structures given. These observations have informed the development of the two-year experimental program now underway.

The next section provides an overview of the state of the art informed by an extensive literature search and discussions with technology experts. This is followed by a brief review of corrosion of steel in marine environments, followed by an outline of the developing experimental program. As the research program is on-going, only some preliminary observations can be reported. This is followed by several observations in the Discussion and by the Conclusions.

BACKGROUND FOR MASONRY TIES

In the mid-nineteenth century, the first reports of brick tie use in masonry construction were noted, where wrought iron ties were used in cavity walls in England. Over the years the necessity for wall ties grew, observing their use in brick veneer and cavity wall systems with the introduction of a variety of different wall tie types depending on the durability and serviceability requirements of the structure. Figure 1 provides an overview and comparison between a brick veneer wall system (Figure 1 (A)) and a cavity brick system (Figure 1 (B)). The metal wall ties provide the connection between the outer wythe of masonry to the internal load bearing system and are imperative to ensuring lateral stability of brick veneer and cavity wall systems [1]. The consequences of wall tie failure are severe, particularly in the event of high earthquake or wind loads, where the outer leaf of masonry has been found to detach completely from the internal frame [2]–[5]. There are several causes of wall tie failure, including their incorrect classification during design, incorrect placement during construction, and their deterioration from corrosion [6].

The steel wall ties between a veneer wythe of brick and the timber frame backing or load bearing masonry wall (depicted in Figure 1) transfer lateral loads normal to the wall and allow for in plane movement, accommodating differential displacement of a wall. A minimum 40 mm air cavity exists between the internal load bearing wall and outer masonry leaf [7]. Once the structure is built, this air cavity is often not inspected due to accessibility issues, leaving the condition of the wall tie unknown until wall collapse or failure occurs [2]. Around the world, residential brick veneer wall damage has been noted after earthquakes and strong wind events, where a high demand is placed on the tensile force and displacement capacity of the tie connections [8]. The impact of corrosion of masonry brick ties can be severe for brick veneer and cavity brick construction, as reported during the 1989 Newcastle Earthquake by Melchers and Page, most of the partial failure of structures was found as relating to masonry, including veneer and cavity walls with corroded or non-existent brick ties [3].

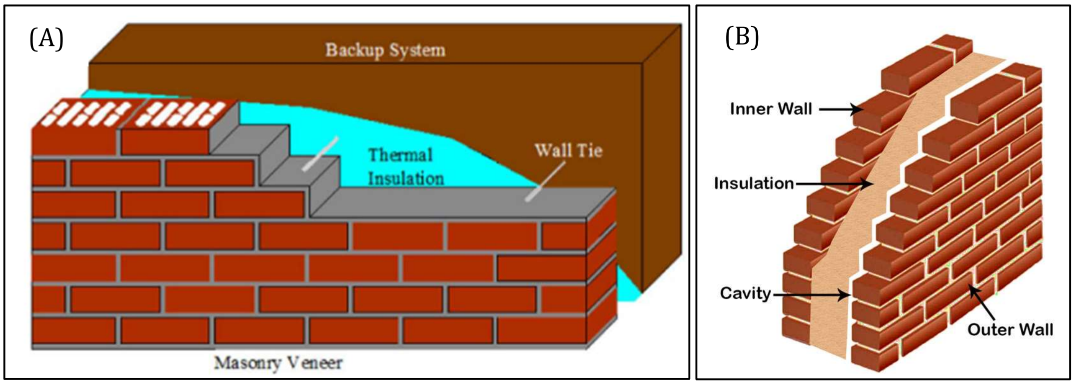

FIGURE 1: BRICK VENEER WALL WITH BACK-UP SYSTEM - COMMONLY TIMBER [5] AND (B) BRICK CAVITY WALL [9]

The masonry structures (AS3700:2018) design code provides the required placement and wall tie types necessary in brick cavity and veneer walls for durability and strength purposes [7]. However, quality in construction is difficult to regulate once the cavity is enclosed. Table 1 is an extract from AS3700 and outlines the requirements for wall tie types. In this table the durability requirements for the wall tie material selection are configured from the typical distance from either the surf or sheltered coast [7], relating directly to the corrosivity category provided in ISO 9223 [10]. From Table 1, the correct durability class must be selected for design of the masonry structure, adhering to the coating requirements reflected in AS2699.1, summarised as durability classes R1 to R4 [11]. The various wall tie types studied herein are of the sheet and wire type with variation in zinc galvanised coatings and stainless steel grade, as depicted in Figure 2.

TABLE 1: DURABILITY CLASS OF MASONRY WALL TIES BASED ON CORROSIVITY CATEGORY EXTRACTED FROM AS3700:2018 [7]

AS3700			AS4312		
Durability Class	Typical distance from		Corrosivity category	Typical distance from	
	Surf coast	Sheltered coast		Surf coast	Sheltered coast
R1 R2	> 10 km	> 1 km	C2	> 50 km	> 10 km
				10 to 50 km	1 to 10 km
R3	1 km to 10 km	100 m to 1 km	C3	1 km to 10 km	50 m to 1 km
R4	< 1 km	< 100 m	C4	200 m to 1 km	< 50 m
			C5	< 200 m	N/A

In current construction practices, heavy zinc galvanised (grade Z950) and stainless steel of marine grade 316 (SS316) are used for wall ties [1], despite their increased cost. For hot-dip-galvanised coating, the grade relates to the element (zinc) of coating denoted by 'Z' and the coating mass in grams per square metre, being Z600 (of durability class R1 or R2) or Z950 (durability class R3) [11], [12]. In stainless steel the grade relates to the chemical composition in which grade 316 contains approximately 18% chromium with the addition of 2% molybdenum for corrosion resistance [2], falling under the R4 durability class [11]. Although the higher durability coating (R3 and R4) are now standardised to ensure durability, especially for structures in close proximity to the coast, a number of heritage and greater than 40 year old masonry structures still exist with wall ties without coating or with lower durability than is specified in the current standards [7], [11]. These may include R2 ties, where grade Z600 wall ties are used, or simply mild steel without any coating. Understanding the durability and structural strength capacity of these wall tie types is also imperative for sustainability of older masonry structures and the design of future ones, hence this study draws attention to the corrosion of wall ties of grade Z600, Z950, SS314 and wall ties with no coating. An example of the wall tie types proposed can be seen in Figure 2. Notably, the wall ties with no coating are planned to be replicated by stripping the zinc coating from available Z600 or Z950 wall ties, leaving these as mild steel (MS) samples.

FIGURE 2: EXAMPLES OF WALL TIE TYPES PROPOSED IN THIS EXPERIMENTAL PROGRAM INCLUDING R2, R3 & R4 SHEET TIES AND R3 WIRE TIE

Building codes and standards specify minimum tie size and durability, as discussed. The minimum tie strength capacity is also outlined and limits for maximum tie spacing provided [1]. AS3700 classifies the mean tie strength for 'Type A' (non-seismic areas) veneer and cavity ties, from axial loading tests in accordance with AS/NZS 2699.1, outlining to the designer the tension and compression capacity of the tie based on its duty rating [7]. The current Australian Standards do not incorporate the effect of tie corrosion on the strength of the wall ties over their design life. Many studies have been conducted to experimentally quantify the strength limits of the wall tie in veneer construction. Muhit's research allowed for estimation of the failure loads of a veneer wall tie system through Monte-Carlo experimental investigations and stochastic FEA. Brick-tie-timber subassemblies with 'Type A' stainless steel grade (R4) wall ties were tested by Muhit in axial compression and tension in accordance with the test method suggested in AS2699.1 [13]. This allowed for the quantification of mean tie strength but was also used to develop probabilistic material models of the wall tie strengths and stiffnesses. An analytical model categorising the impact of corrosion of the 'Type A' light duty wall tie in a brick veneer wall was later completed. The model assumed uniform corrosion loss of the wall tie and that the same amount of corrosion occurred in each tie across the entire wall. These results showed a reduction in out of plane loading capacity of a masonry veneer wall system of over 20% for inward loading in a non-cyclonic condition [6]. Several analytical studies have also investigated brick veneer and brick cavity construction under seismic and wind loads, completing full scale experiments with walls subject to in plane and out of plane loading [5], [8], [13]. In these studies, the real behaviour of a brick veneer wall system is shown through experimental programs and results. From the available research findings, it has been identified that there is a need for further in-depth investigations to be carried out for full-scale cavity walls [5] and the impact of corrosion of wall ties within full scale wall experiments [13]. Axial compression and tension testing may also be carried out in accordance with AS2699.1 on brick veneer and cavity brick wall tie subassemblies with corroded brick ties to develop an understanding for the impact of corrosion of wall ties on their strength properties.

Existing research has identified how corrosion affects a wall tie specimen that has been subject to various exposure conditions. For instance, Chaves et al. [14] found that for the R2 wall ties exposed to artificial corrosion using electrolysis, localised corrosion was observed within a 30 mm region between the mortar embedded and atmospheric exposed section of the wall tie, known as the mortar interface region. In their study, the corroded Z600 galvanised (R2) wall ties were found to have reduced ultimate tensile strength at the mortar interface region compared to the uncorroded (control) specimens. The loss in strength was noted to potentially be a result of intergranular stress corrosion cracking making the material brittle, hence losing ductility [14]. Further justification of this can be seen in the findings from the 1989 Newcastle earthquake, where the corrosion was unparalleled just inside the outer leaf of cavity construction and within the mortar of the outer leaf of masonry [4]. In Nascimento's study, different types of wall tie samples were embedded in varying mortar mixtures in a brick couplet system and exposed to both an artificial and natural environment. The natural environment was a test site in Belmont, NSW, and is a severe marine atmospheric site, recognised as a corrosion site in AS 2728:2007. One of the many findings of this study was that after 24-months exposure in the natural environment the interface region was in good condition while the section of wall tie fully embedded in the mortar had severe rust spots. This was suggested to be caused by the moisture levels held within the mortar causing accelerated corrosion [2]. As other studies suggest the interface region to also have severe corrosion [3], [14], perhaps the conditions within the cavity are not fully represented by only exposing the wall tie to atmospheric conditions, for example, having the wall tie not enclosed in the air cavity of brick veneer or cavity wall.

Understanding the conditions within the masonry air cavity of a veneer or cavity brick wall system is therefore necessary to comprehend the causes of corrosion to brick ties and outline any patterns relating the environmental conditions to the corrosion of the wall tie. Previous studies have shown that the corrosion caused in wall ties and other steels exposed to the natural environment, or embedded in concrete or mortar, is extremely complex and many contributing factors may include the environment conditions, location, orientation and configuration of samples and type of materials [2], [15], [16].

Corrosion occurs in steel via an electrochemical process where a positive electrode (cathode) gains electrons and negative electrode (anode) loses electrons in the presence of an electrolyte (water or moisture), driven by a redox reaction. For a steel sample, or wall tie, without protective coating, this process occurs at a faster rate than that of samples that are protected [17]. The zinc protective coating is applied to steel products by a process of hot-dip-galvanising, allowing for complete formation of the coating over the sample by submersion in a molten zinc bath at 450^{0}C [18]. The zinc acts as the protective coating as it is more electrochemically active than the steel and therefore becomes the anode in the reaction; being slowly corroded. Until this protective layer is completely consumed in the presence of the electrolyte, the steel is protected against corrosion [17]. The chromium content within stainless steels continuously reacts with oxygen to form a protective coating on the steel, preventing corrosion [19].

CORROSION MODELLING

Obtaining realistic empirical data to inform subsequent corrosion modelling is the main premiss of this study. To this end, some of the more likely corrosion mechanisms taking place within wall cavities have been researched. Corrosion may occur in the form of 'approximately' uniform or through localised corrosion, such as pitting corrosion. Where corrosion loss is assumed to be uniform, the most common corrosion model is an 'average corrosion rate'. When extrapolating long-term corrosion loss from short-term artificial or natural exposures, even from field data that accurately represents in-situ conditions of a material, there is a large risk in assuming the 'average corrosion rate' model [20]. Many studies by Melchers clearly outline, through extensively calibrated real-world data, that the corrosion processes controlling the corrosion rate differ throughout the periods of exposure. This is represented in the bimodal model shown in Figure 2, where the early period (mode 1) is mainly governed by oxygen diffusion towards the metal and the longer term period (mode 2) is "*predominantly under anaerobic conditions created by the extensive corrosion products (rusts) then present over the metal surface"* [20]. It is possible to use properly calibrated parameters from actual field observations to predict longer-term corrosion using the bimodal model in the steady state shown as phase 4 in Figure 2, however, extreme care should be taken to ensure the accuracy of this prediction and the calculated parameters. This is because the mechanisms involved in each phase are different and account for different influences to the corrosion rate [20]. Although plausible considering the porous nature of mortar joints, it is unclear if wall cavity conditions are in fact continuously aerobic.

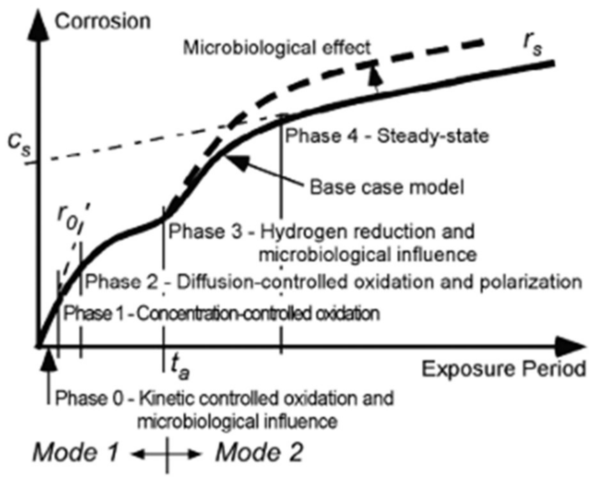

FIGURE 3: BIMODAL MODEL TAKEN FROM [20] **SHOWING THE TWO MODES, THE PHASES REPRESENTING DIFFERENT CORROSION RATE CONTROLLING MECHANISMS**

Existing studies into wall tie corrosion show the mortar embedded and mortar interface region of the wall tie is subject to localised corrosion [2], [14], [21]. Electrolytic corrosion processes occur in the presence of an electrolyte, suggesting that the moisture inside the air cavity directly impacts the corrosion of the wall tie. To represent real-world conditions and obtain accurate data, the on-going experimental program will monitor the environmental conditions, including the relative humidity and temperature variation from external to internal environments, and inspect the conditions of various wall tie types in cavity and veneer walls that are exposed to the natural environment.

EXPERIMENTAL PROGRAM

The on-going experimental program is based on findings from the existing literature and recent research observations [21]. For instance, it has been shown that a drop in pH below 9 initiates corrosion of steel in concrete and that oxygen concentration and humidity are known to facilitate electrochemical corrosion reactions [21]. That work also showed that at higher relative humidity, the mass loss and pitting depth increases, however, no trends were reported for change in temperature relative to the mass loss or pitting depths found in the wall tie samples [2]. To make progress it was postulated that a full-scale system representing a one-story enclosed brick house would allow for accurate portrayal of current construction in Australia, incorporating the wall tie into the system and enclosing it within the air cavity rather than exposing it to the atmosphere, as was done previously [2]. As corrosion is dependent upon several factors, not limited to material composition, temperature, time of wetness, pH of mortar and galvanic interactions [22], the present study aims to account for, as accurately as possible, the relevant influences on corrosion.

The preferred location for the field experimental program is at the Belmont, NSW corrosion site, previously used for atmospheric corrosion of brick tie samples by Nascimento [2]. This severe marine atmospheric site is recognised in AS 2728:2007 and its use will allow direct comparison to the results from the previous study by Nascimento [2]. Expert opinion has suggested that the brick tie corrosion in coastal regions likely is increased 24in severity by inadequate moisture drainage out of the wall cavity [5]. It follows that adequate ventilation and drainage was an important design consideration for this study. To consider this aspect, full-scale wall "samples" will be used, specifically in the form of a small one-story enclosed brick house designed and constructed in accordance with current masonry codes [7]. Figure 4 shows the cross section in plan-view and elevation of the two full-scale systems used in the on-going experimental program. It will be constructed to ensure the overall wall systems are well-ventilated and representative of current construction practices. As noted (cf. Figure 2), the use of wall tie types commercially available are in the present study to allow estimation of effectiveness of the various protective coatings currently used and recommended in efforts to limit or reduce the corrosion of wall ties [5].

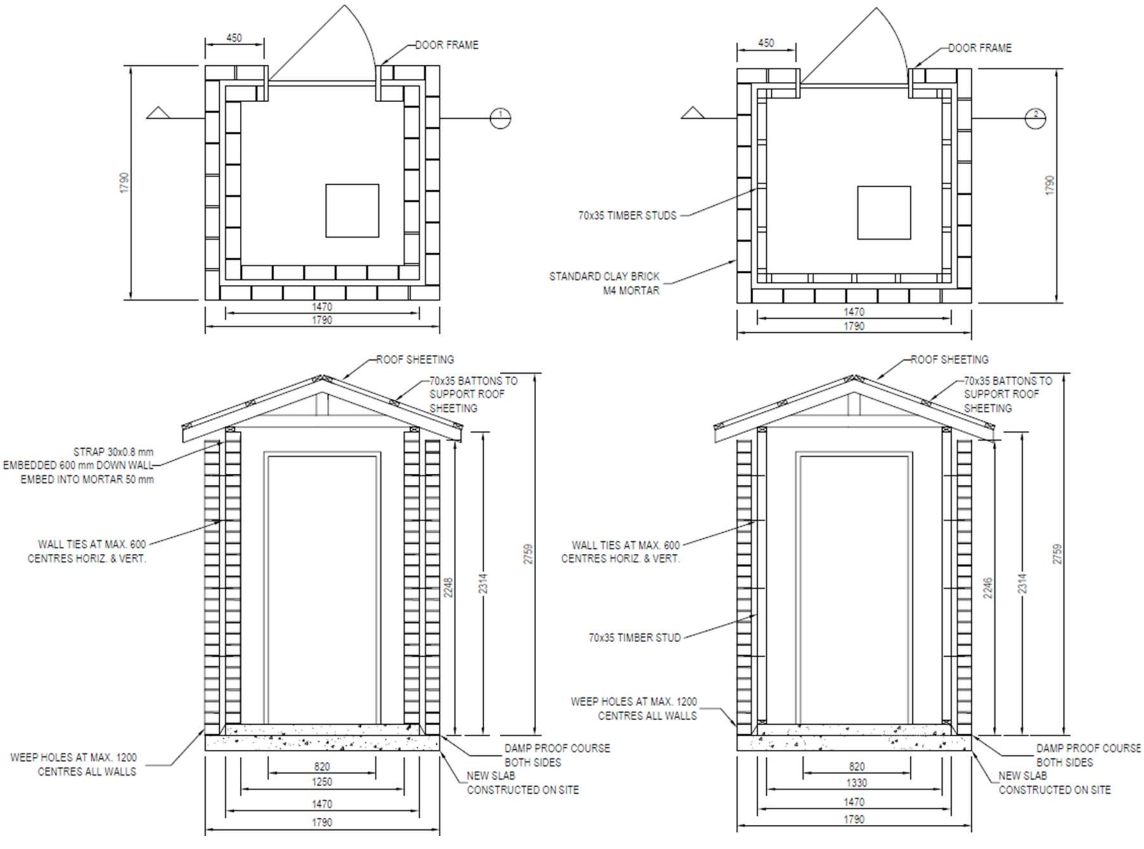

FIGURE 4: PROPOSED BRICK CAVITY 'HOUSE'CROSS SECTIONS: PLAN-VIEW (TOP LEFT), ELEVATION (BOTTOM LEFT), AND PROPOSED BRICK VENEER 'HOUSE' CROSS SECTIONS: PLAN-VIEW (TOP RIGHT), ELEVATION (BOTTOM RIGHT)

Additional aspects of the experimental program include the effects of directional impact, sample type and sample size. The effect of coupon size at the Belmont corrosion site has been reported by Melchers and Jeffrey [24], work that showed that smaller coupons had a significantly greater amount of corrosion loss compared to larger samples. This work suggested that the corrosion loss was approximately proportional to the surface area of the coupon [24]. On this basis it was expected that the wall tie samples used in the experimental program would show variability in corrosion loss as a function of their size. The observed corrosion of coupons in different directions at the Belmont site by Jeffrey and Melchers [15], showed that after 3 years, coupons facing North and West had more corrosion loss compared with those facing East and South. For the coupons tested at various angles of inclination, after three years the greatest loss occurred on coupons facing away from solar radiation. The directional variation in mass losses found may be strongly influenced by how often certain surfaces remain wet for longer periods of time, due to orientation of the sun or prevailing wind. In terms of the height of the coupons, corrosion loss was shown to increase by up to a factor of three from 0.1 m to 2.0 m in height. It was proposed that these results were influenced by wind speed, known to increase with height and also potentially to deposit more moisture and chlorides on to the higher samples [15]. These observations are directly relevant for the present project.

In view of the above observations, the experimental program was designed, as noted, to include two small enclosed 'house' samples representing both veneer and cavity wall construction, with wall ties placed at varying points over the height of the walls. Figure 5 shows the proposed layout of the two 'houses', aligned to fit the boundary of the available corrosion site while ensuring minimal shading occurs between the houses. One wall in each 'house' shall have a door, leaving the other three walls as the main sample walls for the proposed study. The three walls are labelled in Figure 5 based on the cardinal direction they are facing. The direction of the three sample walls was important, as per the findings by Jeffrey and Melchers [15], and hence Wall 1 faces the North direction, where the highest level of corrosion may be expected. This is also consistent with observations of brick-tie corrosion following the Newcastle Earthquake. Wall tie corrosion was widespread and worst in (southern) exposed walls and in buildings located close to the coast. Corrosion was also found to be worst in cavity walls within the mortar joint of the outer leaf [3]. In Australia, the most direct sunlight is in North facing walls, hence, the south facing wall (Wall 3) would have the least exposure to sunlight, making the process of 'drying' longer and potentially increasing the corrosion of wall ties in a south facing wall. Consequently, the one wall of each veneer and cavity 'house' is North facing, with the direct opposite wall being south facing. The other wall (Wall 2) is exposed to salt spray in the East direction resulting from the topography and geography of the site.

In all three walls of both the brick veneer and cavity brick walls, wall tie samples are spaced at regular intervals, of 400-600 mm vertically and horizontally, in sets of four including one each of the grade Z600, Z950, SS316 and MS wall ties. Wall tie samples are to be regularly visually inspected, and have remaining thickness measured for corrosion morphology and loss. Structurally redundant ties have been planned to allow removal for laboratory corrosion mass loss quantification for completion [23]. In addition to the findings of corrosion morphology and loss of the wall tie samples, the environmental conditions will be monitored from within the inside, the wall cavity, and the outside of both the brick veneer 'house' and cavity brick 'house'. The primary environmental conditions focussed on for this study will include temperature and relative humidity, leading to the evaluation of how these may vary through the wall cavity types, how this is opposed to or in line with the readings from internal and external wall environment and the impact this has on the corrosion losses observed.

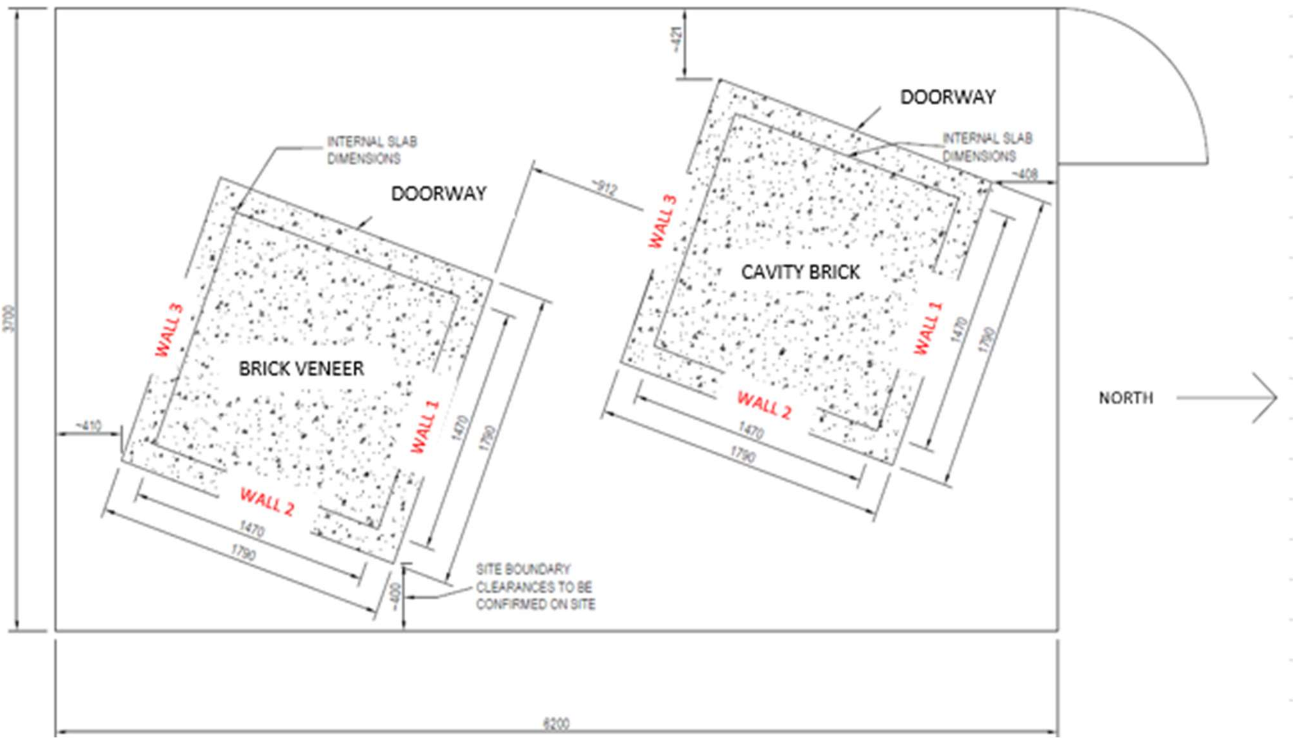

FIGURE 5: PLAN VIEW OF BELMONT CORROSION SITE SHOWING PROPOSED LAYOUT OF BASE SLAB FOR CAVITY BRICK AND BRICK VENEER 'HOUSE' AND IDENTIFYING PRIMARY WALL SAMPLES: WALL 1 (NORTH FACING), WALL 2 (EAST FACING) AND WALL 3 (SOUTH FACING)

Some Relevant Observations

During the experimental program planning, the opportunity arose for a site inspection providing relatable measurements. The site, albeit some kilometres southwest of the planned experimental location, has similar exposure conditions to the Belmont site. Visual observations of the condition of various wall tie types were found. Figure 5 shows a sample of a fractured wall tie previously embedded in mortar of a brick veneer wall shown in Figure 5 (A) and anchored to a concrete retaining wall on the other side shown as Figure 5 (B). The condition of this brick veneer retaining wall can be seen in Figure 5 (C), where ventilation and drainage blockages have occurred, causing mould growth on the outer leaf of masonry. This was suggested as one main cause of the wall tie failure in this area of the brick veneer wall. The location of this retaining wall structure was in a school in Wyoming, NSW, categorised as marine exposure environment [7] and the structure was suggested to be over 40 years old. The sample shown in Figure 5 (A) and 5 (B), clearly shows the corroded wall tie has led to failure. There were several other wall ties observed in a similar state to one shown in Figure 5. It was assumed that the wall ties used most likely had no protective coating due to the time in which it was noted to be constructed. With inadequate drainage and ventilation, high levels of moisture would have been present in the wall, as suggested by Figure 5 (C), most likely causing the complete deterioration and then fracture of the wall ties.

FIGURE 5: 40-YEAR-OLD BRICK VENEER RETAINING WALL AT SITE IN WYOMING, NSW WITH EXAMPLE OF BRICK TIE CORROSION (A) WITHIN MORTAR, (B) ACHORED TO CONCRETE WALL AND (C) THE CONDITION OF THE WALL OVERALL

DISCUSSION

The literature review showed that several conditions may affect the corrosion of brick ties within cavity walls and that these are not dissimilar to the corrosion processes previously studied for various materials, including steel samples and various wall tie types exposed artificially and naturally [2], [15], [22]. Where the wall ties are corroded to some extent, their strength may be reduced, likely increasing the risk of failure of the structure or its principal wall-system components [3], [14]. With the incorporation of 'real-world' informed wall tie corrosion data, future full-scale experiments and analytical studies will be comparable to the extensive research previously conducted for brick veneer walls. To first be able to identify how wall ties are corroding over the length and height of a full-scale cavity or veneer wall is crucial. Therefore, the proposed experimental study includes the monitoring of various wall tie types within a full-scale cavity and veneer brick 'house' exposed to a severe marine environment.

The findings presented in this paper also indicate the importance of the structural support the wall ties typically provide (if installed correctly) to the outer leaf of masonry in both cavity and veneer construction. To integrate the findings reviewed herein with the on-going experimental program it is necessary to achieve accurate results in terms of corrosion prediction and environmental monitoring that is directly applicable and relevant to corrosion in and adjacent to masonry cavity construction and to brick-veneer air cavities. In terms of the experimental program, this will be achieved as follows:

- Exposure of wall tie types Z600, Z950, 316 stainless steel and wall ties without protective coating, replicating real world design inside a small 'house' module.
- Visual inspections of all non-mortar embedded exposed sections of wall tie samples at regular intervals to understand the corrosion rate and corrosion processes impacting the wall tie.
- Removal of sufficient structurally redundant control wall tie samples after 1-year and 2-years to determine corrosion processes impacting the wall tie samples, including mass loss and pitting corrosion.
- Monitoring of environmental conditions inside the cavity, internal space of the 'house' and external environment, including the temperature and relative humidity.
- Where possible, comparing to other available field data, including visual inspections of wall ties and environmental conditions at other test site(s) to understand the impacts of corrosion in the long term.
- Determination of how corrosion impacts the durability and strength of the wall tie through strength testing of cavity brick and brick veneer subassemblies in accordance with AS2699.1 [11].
- Sharing of these results to develop future improved corrosion prediction models suitable for full scale cavity brick and brick veneer wall testing, and service-life prediction.

PREDICTED OUTCOMES

The findings of the project are expected to inform and add to the current available data for wall tie corrosion and to permit improved prediction of likely future corrosion of wall ties. The outcomes of the project are expected to allow correlation of the environmental conditions within an air cavity for masonry veneer and cavity wall construction with expected wall tie corrosion. It is expected also that trends will be found between the level of corrosion loss and the humidity within the cavity, similar to those observed by Nascimento [2]. Further, the wall ties are expected to show the 'worst' corrosion at the mortar interface region at the external leaf of masonry and most likely in the southern facing walls, as suggested by previous studies [3], [4], [14]. Due to the limitations on the two-year period of the study, it is suggested that lower levels of corrosion loss may occur than what would in a longer-term study. The wall tie corrosion is expected to vary over the height and width of the wall as well as between each wall tie type [15], [24]. Through electrochemical corrosion processes, the wall tie without protective coating is very likely to experience the highest level of corrosion loss after one-year and two-years of exposure at the Belmont corrosion site [2], [17]. As the durability class for this corrosion site is R4, the galvanised Z600 and Z950 wall ties are expected to experience greater corrosion loss than that of the 316 stainless steel samples. However, the stainless steel samples are expected to experience some localised 'pitting' corrosion, as was found by Nascimento previously [2].

In addition to the above, some research attention will be given to ascertaining to the effect of corrosion on axial compression and tension testing results for brick veneer and cavity subassemblies, with corroded wall ties to determine the effect corrosion has on the strength properties of various wall tie samples. Site inspections of in-situ wall ties in masonry veneer and cavity wall are being conducted as part of the experimental program. The visual inspections and potential samples so taken will inform the corrosion processes and losses of the wall ties within aged structures compared to the short-term corrosion found from the newly constructed veneer and cavity walls. Any field data obtained will also be used towards the end of the project for comparison to the corroded samples that are used in axial compression and tension testing.

CONCLUSIONS

The purpose of the present paper outlines the current research findings relating to wall tie corrosion and has identified the currently known key considerations for the final development of the experimental program to evaluate the corrosion of various wall tie types in brick cavity and veneer walls. It is clear from the existing literature and from field observations to date that the most accurate representation of wall tie corrosion will be achieved by exposing both veneer and cavity walls to natural environments. This will be achieved, in part, by locating three cavity and three veneer wall samples in the form of a 'house' at a severe marine corrosion site. Such exposure is likely optimal for the corrosion of the wall tie samples being considered in the experimental program. Consideration of the construction practices, orientation, materials, wall tie sample size and type, location and environmental conditions will provide a wide range of corrosion data. Experimental and logistic limitations will require such data to be limited to a two-year period of exposure. Two sets of walls are being used to form part of an enclosed 'house' structure that has wall ties with various protective coatings that, with periodic visual inspections, will permit estimation of (shorter-term) rates of corrosion loss. Correspondingly, environmental conditions are being monitored to allow for determination of the factors most affecting corrosion of the parts of the wall ties within the air cavity of veneer and cavity walls. In addition to the experimental work, site inspections are being arranged to provide observations that will are expected to provide information that will inform the development of theory for wall-tie corrosion processes and losses for in-situ situations relevant to practical masonry structures. Overall, completion of the current and on-going experimental program will provide further quantitative observations of the condition and deterioration of various wall tie types within brick veneer and cavity walls.

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