Positional material deterioration over the building envelope of a building in a geothermal area

BRANZ research is finding that the corrosive effects of different micro-environments around a building can differ significantly from each other and from the surrounding atmospheric environment. This Research Now reports on a building subject to Rotorua's geothermal atmosphere. Research Now: Positional corrosion #1 and #2 reported on research carried out on a test building on the BRANZ campus at Judgeford, near Porirua, while Research Now: Positional corrosion #3 covers a building very close to the marine influences of Auckland Harbour.

Gaining a better understanding of building micro-environments should ultimately produce a better understanding of how, where and why materials degrade and how building durability can be improved.

Preliminary findings at the Rotorua site show the following:

- The corrosivity of the sheltered position was significantly lower than that of the exposed position.
- The corrosion rate in a lower exposed position could be approximately 1.2-1.4 times higher than that in a higher position on the same wall. Both mild steel plates and mild steel nails embedded in timber on the southeast and northeast walls, facing the geothermal source of Sulphur Bay, had slightly higher corrosion rates than those on the southwest wall.
- The concentrations of hydrogen sulphide (H_2S) and sulphur dioxide (SO_2) during a 3-week monitoring period were uniformly distributed around the test building, with no significant difference related to wall orientation, height or position (exposed or sheltered). This result differed from other research.

The measurement of H_2S and SO_2 gas concentrations in the air around the test building was made with passive tube sensors during a 3-week period (October-November 2017).

Measurements of corrosion on the test building were made on two types of samples:

- Mild steel plates of approximately 120 × 80 × 1 mm installed horizontally (0°), vertically (90°) and at a 45° slope. The first-year corrosion rate of each plate was measured through weight loss after this 1-year monitoring period.

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Testing and the test building

The research was carried out on a rectangular concrete building approximately 13 × 7 metres in the Arawa substation close to the geothermal area of Sulphur Bay, Rotorua. Its lengthwise orientation is approximately southwest-northeast. The 1-year monitoring started in June 2017.

Monitoring positions were selected at:

- a low position approximately 1 metre from the ground and fully exposed to the weather on the northeast and southeast walls with no eaves (Figure 1a)
- a high position approximately 2.6 metres from the ground and fully exposed to the weather on the northeast and southeast walls (Figure 1a)
- an exposed position and a sheltered position approximately 2.6 metres from the ground and an exposed position approximately 1 metre from the ground on the southwest wall (Figure 1b).

Note that the northwest wall was not available for monitoring due to health and safety concerns, and sheltered positions were only available on the southwest wall of this test building.

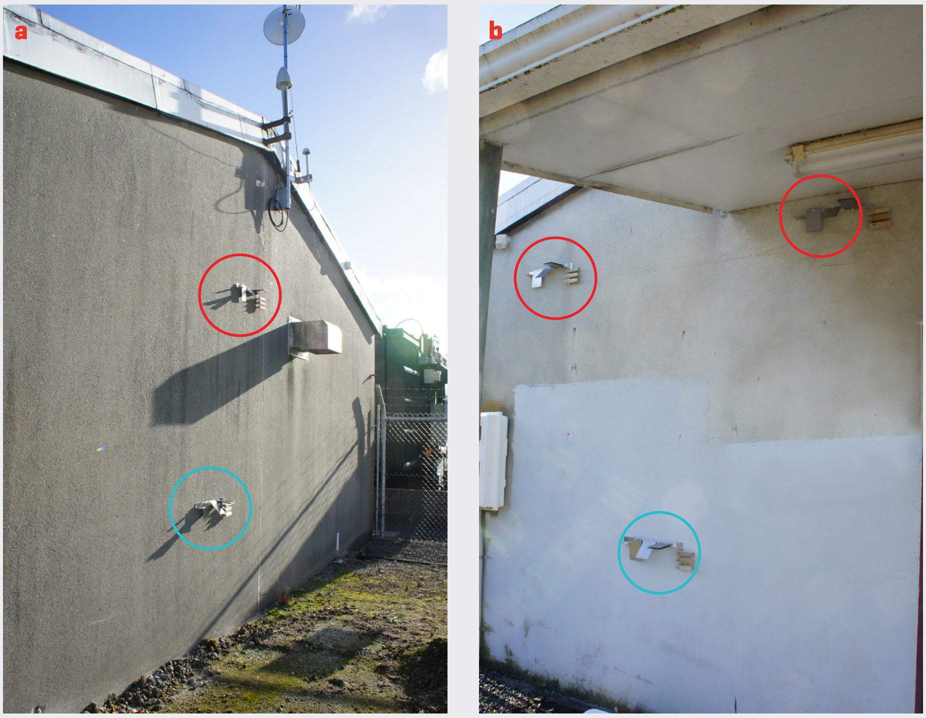

Figure 1. The monitoring positions on the Arawa substation building in Rotorua.

- Mild steel nails approximately 3.15 × 75 mm nailed into H3.2 CCA-treated timber blocks (~20 × 20 × 100 mm) to simulate fastener deterioration in timber wall cladding.

Two groups of reference samples were exposed at the test site:

- Mild steel plates identical to those on the test building were installed on four sides of a small rectangular rack (~600 × 400 mm) that had the same orientation as the test building. They were installed horizontally (0°), vertically (90°) and at 45°.
- Metal plates (~150 × 100 × 0.6-3.0 mm) of copper, mild steel and zinc were positioned to the north to classify atmospheric corrosivity of the test site according to ISO 9223:2012 *Corrosion of metals and alloys – Corrosivity of atmospheres – Classification, determination and estimation*.

Environmental conditions

- The highest hourly ambient temperature was around 28°C and the lowest around -2°C over the 1-year measurement period.
- Time of wetness was approximately 5,139 hours. (This refers to the period when environmental conditions could allow a moisture layer to form on a surface, particularly metal. RH > 80% and T > 0°C.)
- Rainfall was 1,783 mm.
- The prevailing wind was from the south-southwest and north-northeast.
- The maximum wind speed was around 13 m/s.

The first-year corrosion rates of mild steel and zinc indicate an atmospheric corrosivity category of C5 Very high in ISO 9223:2012, while the corrosion rate of copper indicates a category of CX Extreme. The test site is clearly very corrosive because of its close location to a geothermal source.

Airborne sulphur gases

Previous research has found that sulphur-containing gases such as H_2S and SO_2 can negatively affect the environmental performance of various building materials such as metals and timbers – for example, see BRANZ Study Report SR393 *Materials within geothermal environments*.

The average concentrations of H_2S and SO_2 around this test building were monitored and analysed during a 3-week period from October to November 2017 (Table 1). The results found that the gases were uniformly distributed around the test building. There was no significant concentration difference related to either wall orientation, height or position (exposed or sheltered).

The results around height-related H_2S concentrations were different from earlier measurements in Rotorua, which found the airborne H_2S concentration in an open environment at approximately 3 metres height was significantly lower than that at 1 metre height. This was explained at the time by the fact that H_2S concentration is slightly denser than air, therefore tending to concentrate closer to the ground.

An explanation for the current findings could be that the test building is just 150 metres from the very large, complex geothermal system of Sulphur Bay. H_2S could distribute in the dynamic air uniformly, particularly with a busy road running between the geothermal source and the test site.

Corrosion of mild steel on the test building

The first-year corrosion rates of the mild steel plates on the test building and the reference exposure rack are shown in Table 2.

The corrosion rate of the plates fully exposed to the weather showed no consistent orientation effect, indicating that the sulphur-containing species were distributing uniformly in the surrounding atmosphere.

In general, the steel samples installed on the test building corroded at slower rates than those fully exposed to the weather on the reference exposure rack. (This was also true of the coastal building monitored in Auckland - see Research Now: Positional corrosion #3 - and the building on the BRANZ campus - see Research Now: Positional corrosion #2.) The corrosion rates of the vertical plates exposed to the weather were approximately 2-8 times higher than those installed on the building.

The plates on the southeast and northeast walls, especially the vertical ones, had slightly higher corrosion rates than those on the southwest wall. The southeast and northeast walls face Sulphur Bay - the geothermal source. The wind from the northeast or north-northeast could carry sulphur gases, explaining why the steel on these two walls was corroding slightly faster. A consistent and significant orientation effect for sulphur-containing gas concentrations does not appear in Table 1, but this monitoring was only done once for a 3-week period from October to November 2017.

Table 2 shows a relatively weak height effect, particularly on the southeast and northeast walls of the building. The corrosion rate at a lower position could be approximately 1.2-1.4 times higher than that at a higher position on the same wall. Again, this was not supported by the gas concentration measurement done in a 3-week period (i.e. a higher concentration of sulphur gases was not revealed in a lower position on the wall).

The vastly reduced corrosion rate of the steel plates in the high sheltered position on the southwest wall clearly demonstrates the benefits of shelter. The horizontal plates (0°) had approximately 10-19 times less corrosion than the horizontal plates in other locations, while the corrosion on the 45° and vertical (90°) plates was approximately 2-3 times lower than other locations.

The steel plates in the sheltered position were protected from direct rain and had a shorter time of wetness. This drier microenvironment tended to reduce the dissolution of airborne sulphur-containing gases and make their attack on metal more difficult.

The corrosion rates of the mild steel plates on the building and test rack were vastly higher - in some cases more than 10 times higher - than those found at Judgeford (Research Now: Positional corrosion #2) and the Auckland coastal building (Research Now: Positional corrosion #3). This indicates that the geothermal environment is much more corrosive when compared with the rural (Judgeford) and marine (Auckland Harbour) environments.

Table 1. Concentration of sulphur-containing gases around the test building (ppb).

WALL	POSITION	SULPHUR-CONTAINING SPECIES	AVERAGE CONCENTRATION
Southwest	Exposed – high	H_2S	4.2
		SO_2	21.6
	Sheltered – high	H_2S	4.9
		SO_2	26.1
	Exposed – low	H_2S	3.4
		SO_2	31.4
Southeast	Exposed – high	H_2S	4.1
		SO_2	28.3
	Exposed – low	H_2S	5.1
		SO_2	27.2
Northeast	Exposed – high	H_2S	4.0
		SO_2	24.9
	Exposed – low	H_2S	4.8
		SO_2	31.7
West	Exposed – high	H_2S	5.7
		SO_2	32.6
	Exposed – low	H_2S	5.4
		SO_2	32.6

Note: Monitoring was not performed on the northwest wall.

Table 2. Corrosion rates of mild steel plates after 1 year (g/m²/year).

WALL	POSITION	PLATE ON TEST BUILDING				PLATE EXPOSED TO THE WEATHER			
		0º (S)	0º (G)	45º	90º	0º (S)	0º (G)	45º	90º
Southwest	Exposed – high	2,568	2,541	710	261	3,149	3,254	1,655	2,079
	Sheltered – high	266	134	213	127				
	Exposed – low	2,967	2,420	785	289				
Southeast	Exposed – high	3,018	1,838	722	288	3,155	2,826	1,431	1,828
	Exposed – low	3,763	2,312	1,069	410				
Northeast	Exposed – high	1,953	3,039	1,897	578	2,946	3,966	1,387	1,634
	Exposed – low	2,626	3,356	1,872	717				
Northwest	Exposed – high	-	-	-	-	2,784	3,016	1,998	1,510
	Exposed – low	-	-	-	-				

S: skyward surface, G: groundward surface.

Corrosion of mild steel nails in timber

The first-year corrosion rates of mild steel nails in H3.2 CCA-treated timber blocks are shown in Table 3.

The nails in timber blocks fully exposed to the weather on the reference exposure rack had a higher corrosion rate than those installed on the southwest wall (approximately 2.5 times) but lower than those installed on the southeast and northeast walls of the test building. This is slightly different from the measurements done on buildings in other atmospheric environments.

Orientation had an impact on the nail corrosion rates. Nails on the southeast and northeast walls corroded faster than those on the southwest wall. This is a broadly similar result to some of the steel plates on the test building.

The northeast/north-northeast winds carrying sulphur-containing gases to the test site may contribute to higher nail corrosion on the southeast and northeast walls. However, this cannot explain why nails on the southeast and northeast walls were corroding faster than those fully exposed to the weather.

Corrosion of nails in timber is dependent on the timber moisture content and how long it stays above a threshold of approximately 18-20%. In geothermal environments, sulphur-containing gases can diffuse into timber, contributing to degradation. It is expected that, when penetrating the timber block used in this study, sulphur-containing gases may have a reasonably high chance of interacting with the nail, contributing to its accelerated corrosion.

On the southwest wall, the nails installed in the sheltered position had a corrosion rate approximately three times lower than those in the exposed positions. This is very similar to the measurement of the steel plates. The exposed position, with its higher chance of rain wetting and thus higher timber moisture content, contributed to faster nail corrosion.

In addition, the corrosion rates of nails on this building and test rack were considerably higher than those found on the buildings at Judgeford (Research Now: Positional corrosion #2) and Auckland Harbour (Research Now: Positional corrosion #3.)

Table 3. Corrosion rates of mild steel nails in H3.2 CCA-treated timber blocks after 1 year (g/m2/year).

WALL	POSITION	NAIL IN TIMBER ON THE TEST BUILDING	NAIL IN TIMBER EXPOSED TO THE WEATHER
Southwest	Exposed – high	36.5±15.0	91.4±52.8
	Sheltered – high	12.3±1.4	
Southeast	Exposed – low	37.4±8.1	
	Exposed – high	56.1±20.1	
	Exposed – low	111.7±40.3	
Northeast	Exposed – high	160.0±21.7	
	Exposed – low	165.4±61.7	

Note: Test was not performed on the northwest wall.

Conclusion

- The concentrations of H_2S and SO_2 during a 3-week monitoring period were uniformly distributed around the test building, with no significant difference related to wall orientation, height or position (exposed or sheltered). This result differed from earlier research.
- The corrosion rate of mild steel plate in a lower position could be approximately 1.2-1.4 times higher than that in a higher position on the same wall.
- The horizontal (0°) steel plates in the high sheltered position had approximately 10-19 times less corrosion than the horizontal plates in other locations, while the corrosion on the 45° and vertical (90°) plates was approximately 2-3 times lower than other locations, showing the considerable protection that shelter gives.
- The plates on the southeast and northeast walls (especially the vertical plates) facing the geothermal source of Sulphur Bay had slightly higher corrosion rates than those on the southwest wall.
- The nails on the southeast and northeast walls also corroded faster than those on the southwest wall.
- In general, the micro-climates on this building were slightly less corrosive than the surrounding atmospheric environment.

Further reading

BRANZ Research Now: Positional corrosion #1 *The impacts of natural elements on different parts of the building envelope*

BRANZ Research Now: Positional corrosion #2 *How different micro-environments around a building envelope affect material corrosion*

BRANZ Research Now: Positional corrosion #3 *Positional material deterioration over the building envelope of a coastal building*

BRANZ Research Now: Geothermal corrosion #1 *Which metals are more sensitive to geothermal corrosion?*

BRANZ Research Now: Geothermal corrosion #2 *Distance effects of corrosion in geothermal environments*

BRANZ Study Report SR393 *Materials within geothermal environments* (2018)

This Research Now describes a BRANZ research project in progress. More findings will be reported in due course and may modify the findings reported here.