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CORROSION – CONSERVATION – INSPECTION – MONITORING – CONSULTANCY

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TECTON BUILDINGS (DUDLEY ZOO)

(Long Term Monitoring of Like-for-Like Repairs - 2016)

1. Introduction and Background

A group of thirteen reinforced concrete structures were built in the period 1935 to 1937 at Dudley Zoo (DZG) by the Tecton Partnership, led by Berthold Lubetkin. The condition of the reinforced concrete had been slowly deteriorating over the past few decades. DZG was successful in being awarded an HLF grant in 2013 and the repairs and conservation started towards the end of 2013. The first building to be conserved was the shop, which was subsequently turned into an entrance hall. The second building was the original entrance which was retained to provide a ‘front’ for the zoo. Both of these buildings were successfully repaired and conserved. The third Tecton building to be repaired was the Bear Ravine. This building had been derelict for many years and was in a very poor condition with extensive decay of the reinforced concrete. This building was successfully completed in 2014. Finally, the Meerkat enclosure has only recently been repaired and conserved.

In order to monitor the long-term performance of the like-for-like concrete repairs, RTL was asked by Historic England to undertake monitoring of the repairs (and adjacent original concrete). Monitoring mainly used NDT techniques, although drill samples (for subsequent laboratory analyses) were taken in 2014. A significant amount of images have also been taken so that repaired and original concrete surfaces could be suitably identified in the future. This monitoring programme was initiated in 2014 and the testing is likely to go on for a number of years to ascertain that these like-for-like repairs provide sufficient long term life and that they do not result in decay to the adjoining (original) concrete by a process termed ‘the incipient anode effect’. Monitoring points (stainless steel connections to the embedded steel reinforcements) were made on repaired areas on both the Bear Ravine and also on the Meerkat Enclosure.

2. Site Visit (Bear Ravine)

The third annual site visit was made to Dudley Zoo on the 13th October 2016 to take measurements on both the Bear Ravine and the Meerkat enclosure. The weather was fairly cold (11°C) and wet and the preceding week had also been wet. All concrete surfaces were damp.

Corrosion Rate Measurements- Corrosion rate measurements were taken of the embedded steel reinforcements within and around four repair patches in both the new and original concrete on the Bear Ravine. Images of the four test areas are shown in Figures 1 and 2. Area 3 had reportedly been repaired using a proprietary concrete repair mortar (Renderoc) and areas 1, 2 and 4 had been repaired using a like-for-like concrete mix. The exact locations where measurements were taken for areas 3 and 4 (numbered 1 to 11) are illustrated in Figure 3. Prior to the repairs being made, stainless steel threaded bars were attached (screw fitted) to the existing steel reinforcements. This direct electrical connection enabled both potential and corrosion rate measurements to be made after the repairs had been completed. A Linear Polarisation Resistance Measurement (LPRM) electrochemical monitor was used to take the NDT corrosion rate measurements on the repaired wall at the top of the bear ravine. The results are shown in Table 1.

Table 1

Corrosion Rate Measurements (µm/yr)

Location	Area 1	Area 2
1 Repair	22.0	12.6
2 Left - original	0.27	11.9
3 Right - original	1.41	0.86

Location	Area 3	Area 4
1 back left on original	1.17	3.15
2 back centre under repair	6.06	0.16
3 back right on original	7.39	1.24
4 top left on original	20.5	20.9
5 top centre on repair	8.4	40.4
6 top right on original	9.29	17.2
7 front left on original	75.0	72.3
8 front centre on repair	24.1	73.1
9 front right on original	14.3	69.0

These results are significantly higher (approximately 5 to 10 times) than those taken in either 2014 or 2015 and this is almost certainly due to the increased moisture content in the concrete during this particular visit. Increased moisture can significantly increase corrosion rates on embedded steel if it is not protected by a passive oxide coating. As in previous reports, the higher corrosion rates were generally associated with the repaired areas, although sometimes the adjacent original concrete also showed higher levels of corrosion. During the repairs, the steel reinforcements were generally cleaned of their corrosion products (using a wire brush) and then coated using a zinc rich paint. This ‘barrier film’ might be responsible for delaying the formation of the protective oxide layer which normally forms on ‘cleaned steel’ in a highly alkaline environment. The original concrete would already have developed the protective stable oxide layer over the steel surfaces. Note – corrosion rates below 5µm/yr are generally regarded as being low and acceptable.

There does not appear to be any indication of ‘increased corrosion activity’ of the original concrete adjacent to the repairs, indicating that the ‘incipient anode effect’ may not be affecting these repaired areas of concrete. This is probably to be expected as this type of deterioration has only ever been noted where the concrete has been contaminated with chloride salts (marine or de-icing salts).

Hammer Surveys - A full hammer survey (using a small 120gm head) was carried out on many areas of the repaired and adjacent original concrete surfaces on the Bear Ravine. The 'lightweight' hammer gives a high note when it bounces off good quality concrete but gives a dull thud where it meets poor quality or delaminated concrete. All repaired and adjacent concrete areas indicated good quality concrete to be present and no signs of delamination were found.

A Schmidt hammer was next used to make concrete strength measurements of the original and repair concretes in seven specific areas. The measurements are given in Table 1.

Table 2

Concrete Strength Measurements (N/mm^2) for the Seven Test Areas

Areas	Original	Repair	Comments
1	24	32	On the fluted surface
2	22	20	On the fluted surface
3	36	26	Top of railings
4	24	20	On the fluted surface
5	40	34	On solid wall up stairs
6	22	22	Left side of Prow
7	50	34	1st Pillar to ravine

A concrete strength of 35 N/mm^2 is generally taken to differentiate between poor and average quality concrete. The readings on the fluted surfaces were affected by the surface finish which resulted in lower measurements. These particular results should be ignored. None of the repaired test areas on solid surfaces showed readings above 35 N/mm^2. This could be associated with most of the repairs being 'hand placed' as compared to using shutters which would have compacted the concrete to a greater extent.

3. Site Visit (Meerkat Enclosure)

The repairs had now been fully completed on this structure. 4mm stainless steel threaded bars were mechanically attached to four of the existing steel reinforcements so that measurements could be taken both in the repaired and original concrete, Figure 4.

Corrosion Rate Measurements- Corrosion rate measurements were taken of the embedded steel reinforcements on the top horizontal surfaces between the repairs and the parent concrete. The results are given in Table 3.

Table 3

Corrosion Rate Measurements on Meerkat Enclosure (μm/yr)

Location	(Repair)	(middle)	(original)
1 Area 1	6.05	0.04	0.03
2 Area 2	5.63	9.53	10.8
3 Area 3	4.95	2.76	3.49
4 Area 4	0.05	0.04	0.05

Again, most of the corrosion rates were significantly higher than those measured in 2015 most likely due to the higher moisture levels in the concrete due to the wetter conditions. There did not appear to be any indication of ‘increased corrosion activity’ of the original concrete adjacent to the repairs, indicating that the ‘incipient anode effect’ was also not affecting these repaired areas.

A Schmidt hammer survey was carried out on many areas of the original concrete and these generally showed values between 32 to 48 N/mm^2 indicating good quality concrete.

4. Visual Assessment of the Monitored Areas

A brief assessment was made of the repaired areas of the concrete for both structures. The four areas that were monitored on the Bear Ravine showed that one of them (area 3) now displayed cracking on both the top and front surfaces of the two year old repair, Figure 5. The other repaired areas did not appear to have been effected. The cracks appeared to be due to shrinkage as the hammer survey showed no signs of delamination or spalling which would have indicated reinforcement corrosion. This particular repair had been hand applied using the proprietary repair material – Renderoc. The other three repairs had been hand applied using like-for-like materials.

The main front pillar to the Bear Ravine showed a long vertical crack on its front face, Figure 6. This two year old repair was reportedly carried out using like-for-like materials and shutters to affect the repair. This needs more investigation. No signs of cracking were noted to the monitoring areas on the Meerkat Enclosure although these are currently less than one year old..

5. Discussion and Conclusions

The NDT monitoring results are currently difficult to interpret at this time. This may be due to the ‘cleaned steel’ having being previously coated using a ‘zinc rich’ paint which is delaying the formation of the protective oxide layer. The higher corrosion rate readings on some areas of the ‘cleaned steel’ could then have been initiated when the repaired concrete gets ‘wet’. Further monitoring is required to confirm this.

Some things that do seem to have been proven is that a) all corrosion rates seem to have increased when the concrete becomes ‘wet’ due to rainfall b) the insipient anode effect does not appear to be affecting these particular repairs. This is probably due to the low levels of chlorides in the concrete.

The next survey will be in 2017. This should include a full visual assessment of all repairs to all four structures.

Dr David Farrell
Rowan Technologies Ltd
21st October 2016

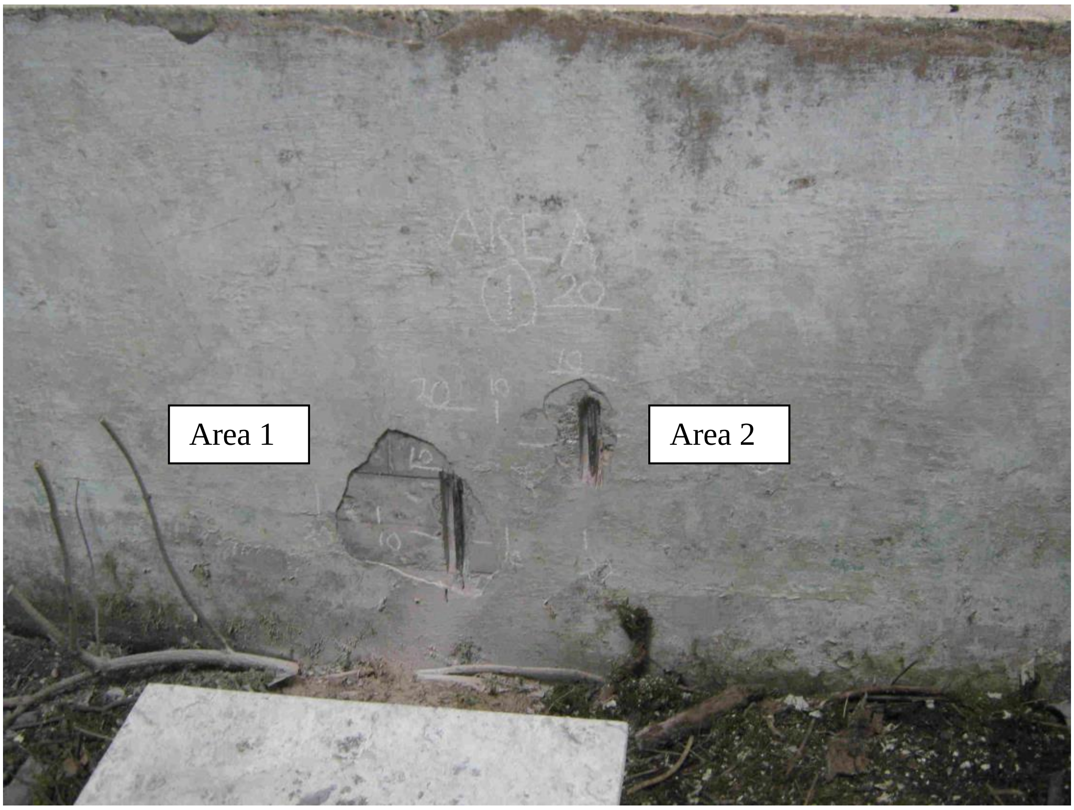

Figure 1 Test areas 1 and 2 on the Bear Ravine.

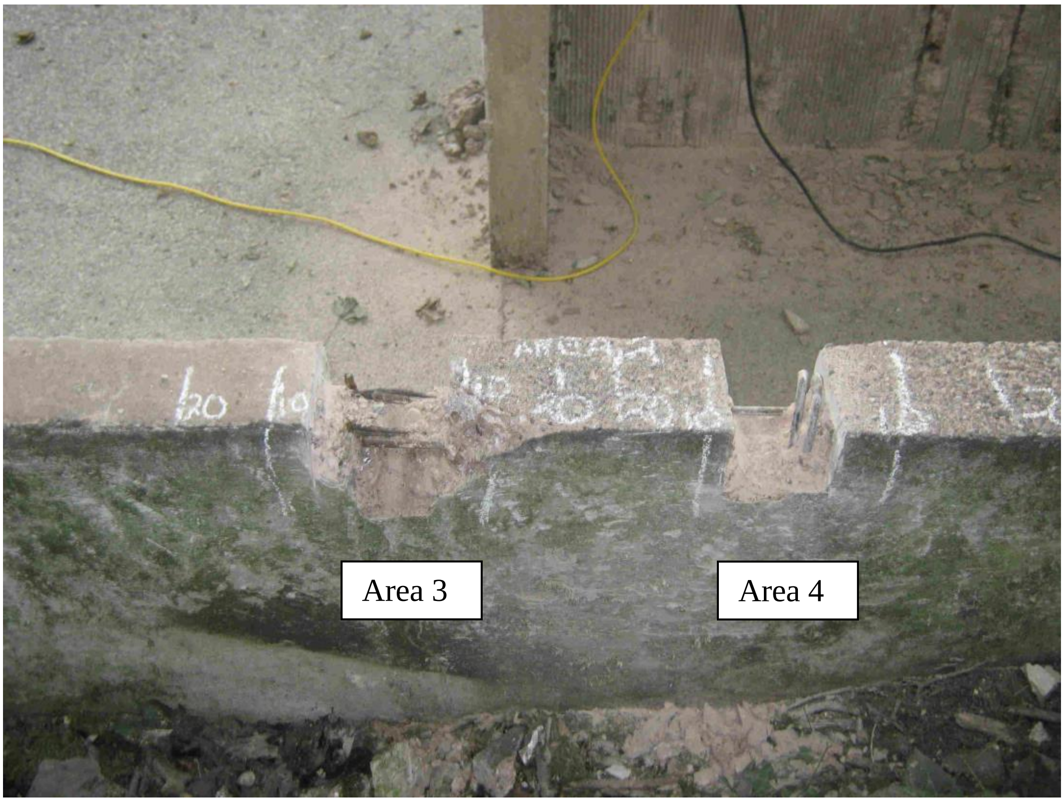

Figure 2 Test areas 3 and 4 on the Bear Ravine.

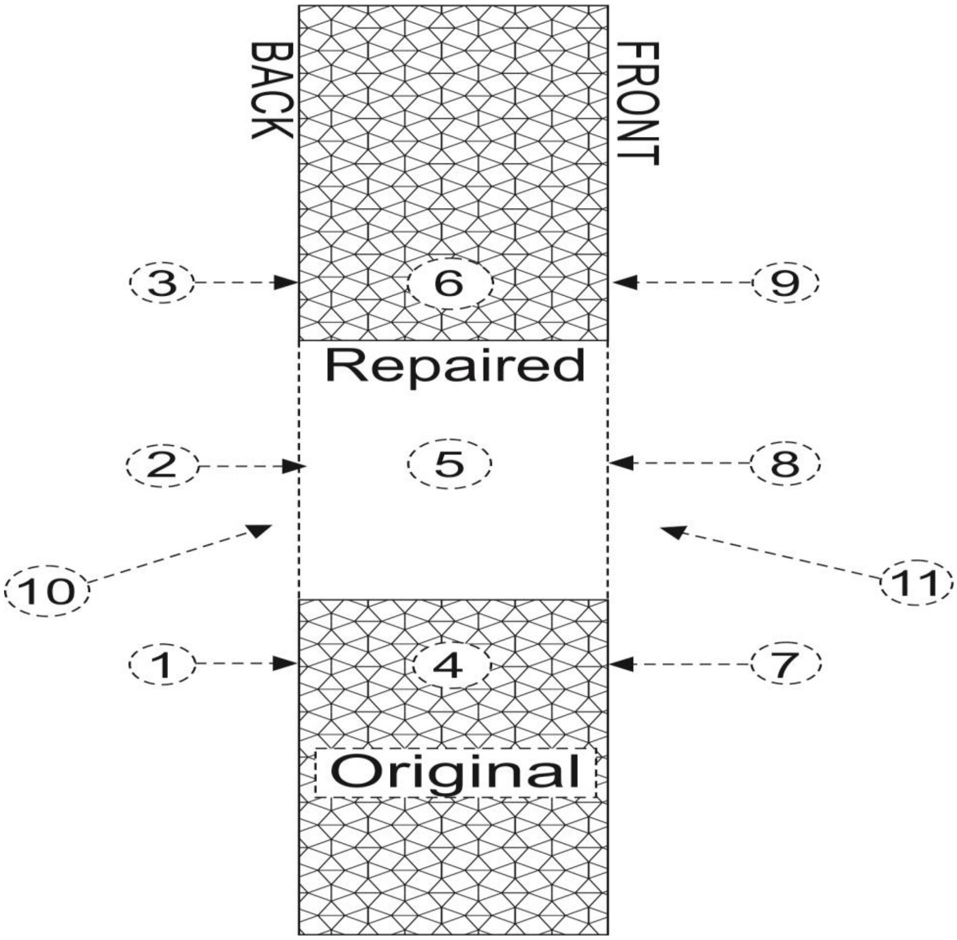

Figure 3 Locations where corrosion rate readings were taken in areas 3 and 4.

Figure 4 Broken out section at the back of the Meerkat Enclosure prior to repairs – showing the four stainless steel test points (right front and left back) attached to the rebars.

Figure 5 Visual assessment of repaired areas 3 and 4 on Bear Ravine. Note area 3 (repaired with Renderoc) showing shrinkage. Area 4 (like-for-like) OK.

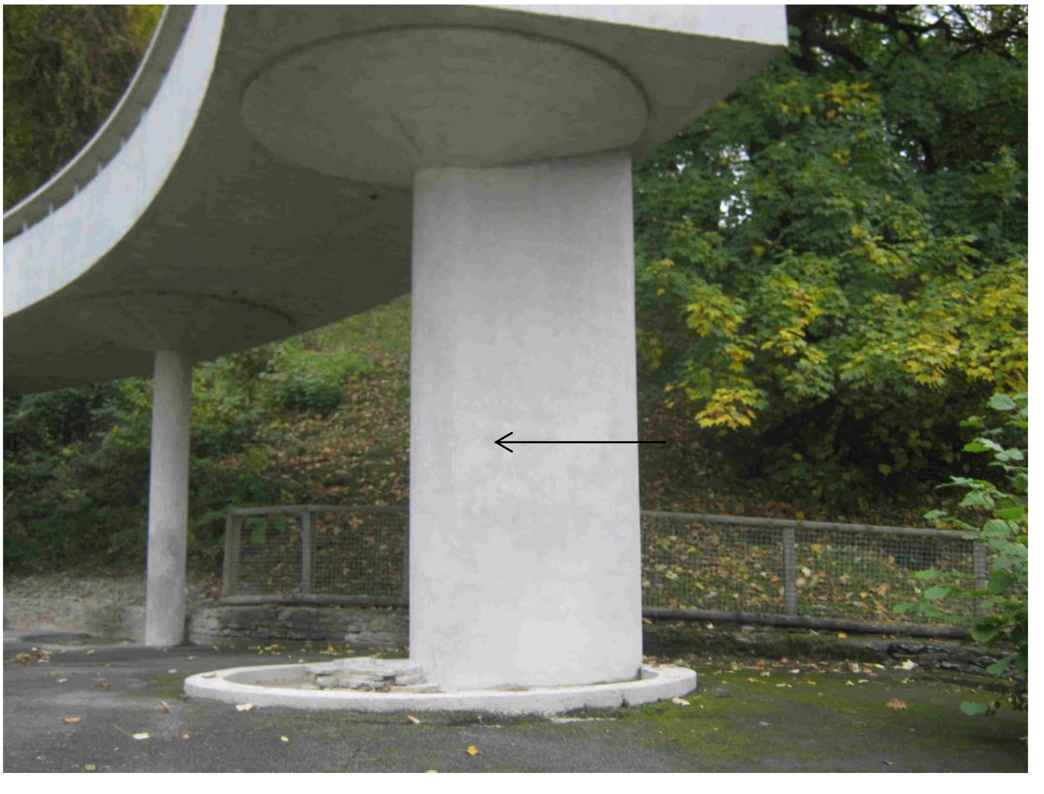

Figure 6 First pillar on Bear Ravine – showing vertical crack on repaired front face.