Conservation of Tecton Buildings at Dudley Zoo, West Midlands

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The 12 listed Lubetkin-designed concrete structures at Dudley Zoo, built between 1936 and 1937, are the greatest collection of surviving Tecton buildings in the world and some of the most important Modern Movement buildings in the UK. As time has moved on and zoological practices have changed, some of the Tecton structures have become unused and left to serve only as monuments. The lack of use has led to poor upkeep and deterioration. All were in a poor condition, mainly due to corrosion of the reinforcement, with works to enhance the structure required in a few locations.

Four of the structures have recently been repaired with the help of the Heritage Lottery Fund. A conservation-based approach was adopted, with traditional concrete used for the majority of the repairs and carbon fibre added locally to stiffen a large cantilevered viewing platform. The repair of the structures was the first part of the conservation work and was followed by the reinterpretation of the structures to provide a programme which would sustain their future use. An area of the Bear Ravine is being used for long term testing by Historic England to monitor the performance of the different methods of repair.

Introduction

Proposals for a zoo below the ruins of Dudley Castle began in 1935 (Fig 1). The site was owned by the Earl of Dudley and together with Ernest Marsh, a local businessman, and Captain Frank Cooper they formed the first board of directors of the Dudley Zoological Society Limited. The animals came from Captain Cooper, now best known for Cooper’s Marmalade, who owned Oxford Zoo. Dr Geoffrey Vevers, the Superintendent at London Zoo was appointed as their advisor. Vevers had recently worked with Tecton Architects, led by the Tbilisi-born Berthold Lubetkin, at London where they had designed the Gorilla House and Penguin Pool. The success of these projects led to Tecton’s appointment at Dudley. Following this Lubetkin contacted the engineer Ove Arup who he had worked with at London Zoo, initially for Christiani and Neilsen and since 1934 for JL Kier and Co Ltd as the director responsible for designs and tenders.

The directors set a timetable for the zoo to open in spring 1937 and the design and construction had to proceed at a rapid pace, from design to completion in 18 months. In addition to the tight programme there were further pressures from dealing with the Ancient Monuments Department of the Office of Works, which was concerned about the setting and integrity of the castle. There were also unexpected engineering challenges from the unrecorded tunnels and mines below the site for the extraction of limestone and coal. The consequence of all this was that it appears that much of the final design was developed on site by Kier’s resident engineer, Ronald Sheldrake, and the project architect Francis Skinner. The design changes are most evident on the Bear Ravine structure where an almost complete circular stepped form had to be redesigned to a level viewing platform and a less than semi-circular plan.

The zoo opened to the public on 6 May 1937 and two weeks later the front page of the Dudley Herald reported, ‘Bewildering Bank Holiday Traffic Scenes on Castle Hill. Estimated 150,000 visitors – 50,000 admitted’. By the end of that first summer the zoo had seen nearly 700,000 visitors. The main interest was to see the animals but for many it was likely to have been their first experience of modern architecture. All but one remain of the 13 buildings constructed for either the animals or visitors, and they are now listed either Grade II or II*. Together they form arguably the most complete set of buildings of the Modern Movement in the UK. The national and international importance of these buildings led to them being placed on the World Monuments Fund’s watch list in 2009.
The design team of BPN Architects and Stand Consulting Engineers was appointed in 2011 to prepare an application to the Heritage Lottery Fund (HLF) for the repair and refurbishment of four of the structures. These were the Grade II* entrance, Bear Ravine, and a nearby kiosk, together with the Grade II listed shop, originally known as the Station Café. The design team brought together a vast expertise in 20th century buildings and an overview on conservation issues, as well as Stuart Tappin from Stand Consulting Engineers’ involvement on the casework committee of the Twentieth Century Society and the ICOMOS International Scientific Committee on Twentieth Century Heritage.

The four structures were generally in a poor condition although some parts of the Bear Ravine were in a very poor state with extensive areas of spalled concrete due to corrosion of the reinforcement. A number of previous repairs had been carried out, including some using polymer modified mortars. None of the repairs had addressed the underlying issues or prevented further damage and some of these had also failed. A number of reports written before our involvement had concluded that a combination of major repairs and partial rebuilding was required.

None of the structures was being used as originally designed. Both the Bear Ravine and kiosk were abandoned. The entrance was used occasionally, but three of the five ticket kiosks were boarded up. The Station Café had seen much change over the years and was at the time being used as an entrance to the zoo and gift shop. Much of the building was closed off and used for storage.

**Appraisal and Investigation Stage**

From the outset the approach was the same as for any pre-20th century listed buildings. This was to gain an understanding of the form and condition of the structures and use this to target repairs based on the principles of using compatible materials with the minimum amount of intervention into the
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We began with a review of the historic documents held within Dudley and the zoo’s archives. This vast amount of information allowed us to build up a detailed picture of the structures intended use, original forms and even colours. The original Tecton drawings clearly outlined the structures’ intended form. Photos taken post-completion allowed us to see materials and finishes and even though they were black and white these would help to inform later decisions on colours. These pictures also allowed us to identify alterations to elements of the buildings. For example, the ‘ZOO’ lettering on the front of the entrance kiosks was thought to be original (Fig 2). After reviewing the historic images, we identified that the ‘Z’ had a slightly different shape on the corners, telling us that they had been replaced at a later date. Within the archive we also found zoo programmes from every year dating back to its opening. On the programme from 1937 a hand painted image of the entrance clearly showed red lettering with a white border.

The next stage was a visual assessment of the structures. We posed questions such as how would they have been designed, how did they build with reinforced concrete in the 1930s, what was the quality of the construction and how had they been altered or repaired? From this we were able to get a general ‘feel’ for the structures, assess if the defects were generic or specific and identify where there were particular structural issues.

The undulating entrance structure was now used only at peak times. Several of the kiosks had been historic fabric wherever possible. A key part of this approach was not to repair unless there were clear signs of damage. For example, the poorly formed construction joints and local irregularities in the surface from poor compaction would be preserved as a record of how the structures were built.
shut off from use and wrapped with half-round timber cladding. Every element of the structure had been painted in a variety of colours through its history. The internal turnstiles had been removed and in one area a large industrial sliding gate had been installed. The proposed design for the entrance was to strip away all of the added items and to reanimate the original structure. All of the kiosks were to be reopened and put back to their original design in both form and material.

The neglected structures of the Bear Ravine and kiosk were the most unchanged due to the fact they had been left unused for many years. As with the other structures both had many years of different paint finishes. The design approach for these two structures was much the same as the entrance, to reinstate the original design intent but it was clear that the Bear Ravine would need a detailed structural appraisal due to its ambitious form and obvious poor condition.

The Station Café was the most changed from its original construction (Fig 3). Through the years the building had been carved-up, adapted, sub-divided and put back together again. It had been used for a fish and chip shop, nightclub and various other purposes which would never have crossed Lubetkin’s mind. The original open, windowless pavilion style of the building had been infilled and the existing zoo shop bore very little resemblance to the original Station Café (Fig 4). A large portion of the building had been closed off and used for overflow storage. The intention was to open up the building once more and to remove all of the later additions to leave only the original structure. A wider zoo master plan sought to relocate and improve the main entrance to the zoo, the culmination of which would now be the Station Café. It would also house an interpretation space to explain the history of the zoo and the Tecton structures.
The structural assessment found the majority of the problems were due to corrosion of the reinforcement. In many areas the cover to the reinforcement was much less than the one inch (25mm) cover for main bars and half-inch (12mm) cover for secondary reinforcement which was recommended at that time in the 1933 'Report of the Reinforced Concrete Structures Committee of the Building Research Board with recommendations for a Code of Practice of the use of reinforced concrete in buildings'. There were, however, some areas where the damage appeared to be as a result of structural problems. At the entrance building we noted there were transverse cracks in similar locations on the top face of each of the five curved slabs. We also had concerns about the integrity of the connection between the top of the solid steel columns and the slabs. At the Bear Ravine there were cracks in the side walls of the cantilevered viewing platform, a longitudinal crack in the slab above the downstand beam and a distinct ‘bounce’ at the outside edge of the platform from a heel-drop test.

Concurrent with our appraisal was a series of investigations and tests carried out by Rowan Technologies Limited. Schmidt hammer tests found the compressive strength to be mostly in the range of 40N/mm² to 55N/mm² with only a few readings between 30 and 40N/mm². All the readings were greater than the minimum cube strengths for the four categories of ‘Ordinary Grade Concrete’ in the 1933 BRB report. This, combined with our own assessment, confirmed that the strength of these structures was generally not a concern.

Tests on samples of the concrete found the chloride and sulphate levels to be within acceptable levels. The main issue was the widespread inadequate concrete cover to the steel reinforcement and carbonation depths of up to 40mm from the face of the concrete. The curved slabs to the entrance generally had a cover on the top face of between 13mm and 65mm and there were only occasional signs of corroding bars. On the underside the cover meter survey was hardly required as large areas of reinforcement were clearly visible through the many layers of paint (Fig 5). So why was the concrete cover so poor?

There is little information from the 1930s of how reinforcement was to be supported during concreting. We found one contemporary reference, Cassell’s Reinforced Concrete of 1920, which mentions the use of notched timber templates which ‘can be removed shortly after the concreting has begun, quite a small quantity of concrete sufficing to hold the rods in place’. If this was the method used at Dudley, then the undulating shape of the slabs meant it was almost inevitable that the bars would slump towards the bottom of the wet concrete. We can only surmise that the pressure to open the zoo to the public led to a ‘make do’ approach with a render coat and paint to hide the reinforcement.

There were also areas of exposed reinforcement and spalled concrete to the shop and kiosk but the greatest damage was to the Bear Ravine. On the cantilevered viewing platform there were large areas of the parapet where the whole of the face of the concrete had fallen away and exposed the corroded reinforcement behind. We were also sufficiently concerned about the extent of corrosion to some of the circular hollow steel columns around a stairwell to ask the zoo to immediately install temporary props.

At the end of this initial stage our report to the HLF was able to place the structural defects into
two broad categories; those due to poor quality construction and subsequent deterioration, and locations where there appeared to be structural issues that required more extensive works. As the finishes were removed and our knowledge of the structures improved over the course of the project we found that some of the structural concerns we had originally identified were less significant and the number of areas in this second category gradually reduced.

Our initial appraisal also confirmed that the proposal to use 'traditional' concrete for the repairs and to avoid modern polymer-modified materials wherever possible was feasible. Using compatible materials reduces the risk of future differential movements due to thermal expansion and contraction or changes in the moisture content. In addition, for listed structures with exposed concrete like these, a 'traditional' concrete mix will provide a closer visual match to the original fabric. Since 2009 we have been advocating this approach alongside the Twentieth Century Society at the annual course on concrete conservation at West Dean. The tendering of the project at Dudley coincided with the publication of an English Heritage book on the conservation of concrete, which proposes a similar approach.

The next step, during early 2013, was to undertake trials on part of the entrance to ascertain the best method of cleaning the concrete to remove the layers of paint while maintaining the surface texture and board marks. It was believed that blast cleaning was the most appropriate technique. Varying types of blast medium and air pressures were trialled until the best balance of effective paint removal and damage to existing surface was found. We also specified a trial repair to an area of spalled concrete on the shop to explore methods of how best to remove the damaged concrete, how to deal with the limited concrete cover to the bars, the best proportions for the cement/aggregate repair mix and how to match the surface finish.

Concurrent with the cleaning and repair samples on the structures, a paint survey was undertaken to analyse the layers of paint present on the different surfaces. This microscopic analysis took samples of the surface and set these into resin. These were then cut and when viewed under a microscope told us the colour history of the structures and also and more importantly the original finishes and colours.

**How the Structures Work**

The entrance to the zoo is formed of five undulating reinforced concrete slabs that appear like a wave above individual ticket kiosks which are built of brickwork and timber. Each roof slab is 175mm thick and approximately 7m x 7m on plan. The slabs have a projecting edge beam on three sides. The slabs are supported on nine 90mm diameter solid steel posts on a 3m square grid. These posts bear onto shallow concrete pad foundations. The two layers of 1/2 inch (12mm) plain round bars that we could see close to the soffit of each slab indicated that they were designed as two-way spanning slabs. Overall stability is provided by a moment connection at the column heads. The entrance is on a slope and the design cleverly exploits this by having the end of one slab overlapping the next. At each overlap the three edge columns pass through the lower slab and into the slab above; a detail that provides an additional restraint against lateral movement.

The shop is a more conventional structure with 100mm thick reinforced concrete walls and three lines of circular reinforced concrete columns. These columns support the roof which is formed by a 125mm thick slab and upstand beams. Three of the internal columns had been removed and replaced with steel beams and columns. We found out during the works that these alterations frame a lowered floor slab which was the dance floor when the building had a brief life in the 1970s as Bentleys Night Club.

The two levels of walkways to the Bear Ravine are formed by flat slabs with the upper level supported on mushroom-head columns with thin reinforced concrete walls and hollow steel columns around the stairwell. The cantilevered viewing platform is a more complex structure. The 130mm thick slab is supported at the rear by the concrete walls to the bear pens below and propped at mid-span by a 350m deep x 200mm wide downstand beam. The outside edge of the slab is connected to the concrete parapet wall that acts as a deep beam which is anchored back to the main structure at each end. The structural action of the parapet as a tie beam was confirmed when we saw lines of twisted reinforcing bars close to the top of the beam. These are Isteg bars, a patented reinforcement system which was developed in Germany and introduced to the UK in the early 1930s. The system used pairs of plain steel bars twisted together so that the cold working
increased the yield point of the steel by about 50 per cent. Spandrel panels below the parapet at each end act as a prop to the parapet walls and also provide a support to each end of the downstand beam. Both faces of all the parapets have a ribbed finish formed during the casting stage by corrugated shuttering.

The small kiosk near to the Bear Ravine uses a combination of reinforced concrete walls and hollow steel posts to support the 150mm thick elliptical roof slab.

Phasing and Procurement
A strategy for phasing the works was adopted to suit the running of the zoo, beginning with the entrance and the shop. These are the first two buildings which visitors see, so carrying out the initial works here would give an immediate impression that the zoo was improving as an attraction and caring for its building stock. Another consideration was to use these two buildings as a learning exercise for the project team and contractor before embarking on the more extensive works that were needed on the Bear Ravine. There were also concerns that the scale and extent of repairs needed on the Bear Ravine could take a sizable slice of the funds to the detriment of the entrance and shop.

The work to the entrance was also phased to maintain the visitor entrance to the zoo while the shop was being refurbished. To facilitate this the work was carried out on three kiosks first, allowing visitors to enter via the remaining two. Following this first phase the three refurbished kiosks were opened and the remaining two were then refurbished.

The majority of the works to the entrance were related to the concrete repairs, but the shop was a more general refurbishment with the concrete repairs as just one part of the overall scope of works. Based on this, it was decided to have separate tenders for a principal contractor and for the concrete repairs. In this second group were contractors who only deal with concrete repair and specialist stone masons with experience of concrete repairs. A local contractor from this second category was appointed.

The grant from the HLF included the cost of a clerk of works and two apprentices who would study part-time and gain practical experience by working alongside the contractor. The longer-term aim was for the apprentices to remain at the zoo to deal with ongoing repairs and maintenance to the other structures. Finding a clerk of works proved to be more difficult than envisaged and although candidates were interviewed, no one suitable had been found by the time the work started on site. However, the eventual outcome proved to be very beneficial, as described later.

Tender Information
Within the tender pack was a full strip out specification. Informed by our research into historic documents and site investigations we prepared detailed drawings that identified areas to be removed and more importantly areas and items to remain untouched. This was a key document and one that would be referred back to throughout the project. There were many unknowns at this stage due to the fact the structures had not been fully stripped out or cleaned. These were identified in the tender together with an approach to cover the investigations and appraisal needed to prepare final details.

The core of the tender documents was made up of detailed specifications that outlined the treatment and finish of the materials. Items which we knew were to be replaced, such as one of the shop front glazed timber screens, were detailed to match the existing profile. The middle screen was covered and assumed to be in a salvageable condition, although it turned out that this too needed replacing. The end screens were to be repaired in situ with well-seasoned timber to match the existing. The client's desire was to introduce double glazed panes but this would have been detrimental to the aesthetics of the building and it was agreed to use single glazed panes. The front screens were originally open and without glass but had been glazed for a long time. To maintain their delicate look and to emphasise the slender section size of the timber the single glazed panel had to be maintained, as the double glazed panel would have appeared far too heavy.

The opening between the roof slab and wall had been infilled with masonry. This was removed to expose the true form of the building. These areas were filled with bespoke, single gazed panels set into a slim aluminium profile.

As noted above we were not entirely sure what we would find on the internal concrete surfaces, or indeed to some extent the external ones either. Reading through previously carried out reports, it
was noted that vivid colours were discussed. None was evident but a specification for a painted finish was prepared at tender stage in the hope that cleaning would give some clue to colour and its location. A mineral paint and breathable silane were specified to enable the structure to breathe. Reports were received to the effect that when an impervious silane was used moisture was becoming trapped inside the structure causing deterioration. We wanted to stop water ingress but allow the concrete to breathe naturally.

The findings from the various tests, trials and investigations were incorporated into the tender package. For the structural works this included drawings of the existing structure which recorded the areas of damage we had seen and those areas which were still covered with finishes where we expected there to be defects. This included most of the inside of the shop, which continued to trade until the start of the works. Plans and details showing the proposed works noted the known areas of defects and indicated allowances for repairs which would be confirmed once the structure was exposed. The repairs were cross-referenced to our specification which gave details and methodologies for a number of types of repair. These were referenced to locations (on the top, side or soffit) and to the anticipated depth of the repair. This allowed the contractor to cost the scope of works and identify which repair to use for each location.

The standard repair for use on the top of level surfaces and vertical faces was a 1:2:4 cement:sand:aggregate mix to match the original concrete. Shallower repairs used a 1:4 mix of cement and graded aggregate up to 5mm in size. Up to 20mm aggregate was used in the mix for larger areas of work where the concrete was re-cast. The procedure was to cut out the edges of the damaged concrete using a small disc cutter, taking care not to cut the reinforcement. The arrises needed to be undercut slightly to improve the mechanical adhesion of the repair material. Once all the loose and damaged concrete was removed to expose all of the surface of the reinforcement the bars were cleaned back to a bright, shiny finish. They were then given an anti-corrosion coating and covered with a cement slurry immediately before placing the concrete. In general, the concrete had a plain finish but the shuttering did need to match the existing finishes including joints between boards (Fig 6).

There were some locations, mostly to the soffit of the slabs and beams, where a repair using a
traditional concrete mix was not possible without significant implications for the historic fabric. Either the concrete would need to be entirely removed to re-cast around retained reinforcement, thus losing significant amounts of historic fabric, or the thickness of the slab would have to increase to place concrete from below that would provide an acceptable cover to the bars. Both of these options were rejected and a 4mm thick proprietary render was applied to the cleaned and primed surface, which was then manually worked on the surface to match the surrounding board marks. For the entrance slabs our tender drawings showed an allowance to provide this render coating to all of the soffits (Fig 7).

The soffit within the shop was hidden by a suspended ceiling. The area within the store room showed a considerable amount of exposed reinforcement. It was believed that the rest of the soffit would be in similar condition and it was agreed that instead of repairing this, which would have considerably stretched the project, the contractor would carry out minor repairs and install a new ceiling below. This would leave the repairs for future refurbishment. This approach also gave the advantage being able to hide the new services such as cabling to new lighting and safety systems. A design was developed to stop this new ceiling finish inside the new glazing around the perimeter of the shop to help identify the ceiling as a new element.

Entrance and Shop Repairs
The contract for the entrance and shop started in September 2013. When work began the strip-out and cleaning processes happened concurrently. When the trial cleaning was carried out on the underside of the soffit a blue colour was visible. When the entire soffit was cleaned it was seen that this blue was on the entirety of the underside. The edges, however, showed no sign of colour. The microscopic analysis backed this up by showing a layer of dirt on the concrete edges before the first layer of paint was applied, indicating it had been left untreated for some time. The stripped soffits revealed extensive areas of exposed, corroded reinforcement and spalling...
concrete. It was clear that our tender allowance to treat all the soffits was indeed what was required.

Another tender-stage allowance was to break out the concrete around a number of the column heads, install additional bars and re-cast with new concrete. A trial investigation was carried out to the column head which had the greatest amount of damage to the concrete. After the slab had been temporarily supported and the concrete locally removed we saw that the reinforcement around the column was in a poor condition. We also saw that the column had a 180mm x 180mm x 20mm thick welded head plate which showed no significant signs of damage. Our tender detail for this area had been to clean all the steelwork, provide additional steel bars around the steel post and install a cementitious grout, poured from above through holes drilled through the concrete slab. For the trial location, where a hole had been formed through the slab a new section of concrete was cast. Elsewhere the contractor was able to repair these areas from below, either with a traditional concrete repair placed by a letterbox shutter, or with a render repair mix.

As mentioned earlier, there were cracks on the top surface of each canopy which were on the hogging curve of the slab. There were no obvious structural reasons for this and the most likely cause was small scale folding of the slab from thermal movements. As it is not possible to stop these movements our initial suggestion was to fill these cracks with a soft lime mortar and accept that this was an area that would need a higher level of ongoing maintenance. However, it was decided that water ingress into the slab had to be prevented across its entirety to prevent future damage to the newly repaired soffit and paint finishes. The canopies had never been waterproofed on the top surface and instead relied on a shallow fall to a small drain that ran down internally through the kiosks below. Remaining rainwater simply runs over the edge of the roof slabs. The concrete was, unsurprisingly, damp and a temporary covering was placed over each section to allow the structure to dry out before the new finishes were applied. We had planned to treat the top surface with a silane mortar and accept that this was an area that would need a higher level of ongoing maintenance. However, it was decided that water ingress into the slab had to be prevented across its entirety to prevent future damage to the newly repaired soffit and paint finishes.

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At the shop, the initial work involved the stripping out of all the internal fixtures and fittings and the removal of the external roof finishes. Once stripped, the concrete roof structure was in a better-than-expected condition and only required a few local patch repairs. A single-ply membrane was installed over new insulation. The existing roof lights were opened up and combined with the removal of the high-level brick infill this completely changed the feeling of the internal space, flooding it with natural light as was originally intended. We had seen a part of the underside of the roof slab within the storeroom and once all the finishes and the black paint – another reminder of the nightclub – had been removed we were able to complete our investigations and finalise the scope of repairs. On the underside of the slab the main issue was the poor concrete cover to the bars and a number of areas with exposed reinforcing bars needed to be repaired. As most of the soffit was to be hidden behind a new suspended ceiling a different approach was adopted for isolated exposed bars and hairline cracks. To make best use of the available funds it was

reversible and to be able to accommodate thermal movements. It also needed to be visually acceptable as the top of the entrance can be seen from the top of Castle Hill and when journeying down the chair lift. No flashings or mechanical fixings could be evident as this would destroy the slender edge detail of the wave forms. With the exposed location of the entrance the new covering would also be subject to uplift pressures. Through various discussions with the local conservation officer and English Heritage, it was agreed that a permanent solution was best to safeguard the future maintenance of the structure while providing little visual impact. The solution was a liquid applied membrane that, when dry, formed a single covering fully adhered to the concrete surface. This system allowed the waterproofing to extend right up to the edge of the slab, leaving only a 3mm thick visible profile. The resulting surface will also accommodate any thermal movement experienced by the curved concrete surfaces. To match the surface colour and texture with the existing concrete a resin-set quartz was applied to the top. The aggregate for the quartz was sourced from a local quarry to best match the tone and consistency of the concrete. The resulting view from the chair lift is of five seemingly untreated concrete canopies (Fig 8).
agreed that if the current damage was not structural and was not likely to deteriorate in the future it was left untouched.

The initial strip-out process proved to be fascinating and delivered a few surprises. One such surprise was that when the existing screed was broken out the original stone flag paved floor was found underneath. In some areas it was in remarkably good condition and after trialling some cleaning methods it looked almost new. However, due to the changing use of the building through the years the paved floor had been removed in some areas and other areas were in very poor condition. The floor had been laid onto compacted ash and it would need to be removed and re-laid over a new slab, a damp proof membrane and insulation. This, coupled with the large areas that would need replacing, led to the decision to lay new floor finishes over the slabs and leave them for a future renovation. The new timber floor floats above the existing and allowed insulation and underfloor heating to be installed. This provided the same benefit as the new ceiling, the ability to hide services. This was especially important for the underfloor heating, which avoided other, more visible methods of heating. The flooring finish was a textured vinyl tile that mimicked the finish of the existing concrete slabs. The pattern of the original floor was recorded and used to inform the layout and detail of the new flooring above.

The non-original steel beams and columns that had replaced the concrete columns were removed and new steel columns installed onto new concrete pads placed around the original damaged foundations. Steelwork was chosen in place of re-forming the columns in concrete because of the speed, ease of installation and the significantly lower cost. It was also a concern that new casting techniques would look too good next to the existing columns. Instead, a mould was taken from one of the existing columns and used to create GRP claddings which were installed in two half-sections with the joints mimicking the cast lines in the original shuttering (Fig 9).

The most significant structural alteration was the result of changes to the way visitors now arrive at the zoo. Rather than arriving by public transport at Castle Hill, the majority of visitors now arrive by car and park some distance from the original entrance. As part of a bigger site-wide development the new entrance would now come through the Station Cafe. To facilitate this, a new opening had to be made through the external reinforced concrete wall. A new steel angle was added to support the structure above the new opening and the mechanism for the sliding glass doors.

Fig 8 The completed entrance
Throughout the strip-out process, as years of paint finishes were stripped away from the concrete vivid colours started to emerge. Colour was found externally during the test cleaning but was not expected internally within the Station Café. The use of colour internally transformed the proposed interpretation of the space. It was interesting when reviewing the original black and white pictures as the different tones could now be identified as different colours. Bright red and blue were used on the internal walls, those running parallel to the entrance were red and those running perpendicular in blue. This along with the continuous gap between wall and roof served to identify the walls not as connected surfaces but as a collection of planes. Different methods were trialled to expose these coloured surfaces while causing as little damage as possible. After several attempts it was decided the best method was to strip the surface with blast cleaning and then reinstate the colours with a mineral based paint. Samples were taken and analysed and then compared against the paint remnants on site as well as reports from interviews with Lubetkin himself. A sample wall was created on the back of the toilet block to test the paint types and colours on the concrete surface. After a few trials a Keim Lasur (semi-transparent) paint was chosen for external walls. A colour matched to the existing tone was diluted at a ratio of 4:1, not to cover the repairs and surface inconsistencies but to provide an evening tone so as to not detract from the overall building form. Internally a Keim Soldalit (solid paint) was used to recreate the vibrant blue and red colours. Internal surfaces originally left fair-faced concrete were treated with the Lasur. External surfaces were treated with a breathable silane prior to colour being applied, to provide a water resistant surface while still allowing moisture to escape from within the structure.

The most significant repair works were to the attached toilet block. A section of the cantilevered roof slab above one of the entrances was so friable that the concrete could be unpicked by hand. The rebuilt section was considered as a piece of new construction and designed for imposed loads from modern codes. This required some additional reinforcement alongside the original bars before the section was re-cast to the original profile. To the rear of this building were two high-level windows which ran the full length of the building. These six-metre long openings each had a slender 130mm x 130mm reinforced concrete mullion at mid-span. Once the damaged concrete had been removed the reinforcement to one mullion was found to be in a reasonable condition. After cleaning and coating the bars the mullion was re-cast with new
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Concrete. The bars on the second mullion had lost a significant amount of their cross-section and we prepared two repair options: re-casting with additional bars or replacing with a steel hollow section. After discussions within the project team and English Heritage the option for a steel post was agreed and installed.

Paint analysis of the existing timber showed a crème enamel paint finish. A colour code was produced from this analysis and used to create a match finish. The same analysis showed the steel columns to the entrance to be bright silver. The colours, which appeared very extreme in isolation, come together as a nice composition.

Bear Ravine and Kiosk Repairs

The works to the entrance and shop were substantially complete on programme and both buildings were opened in time for Easter 2014, to much acclaim. The zoo now knew how much money was left for the works to the Bear Ravine and kiosk. More importantly the design team had tested the process of repair and could develop the best strategy to tackle the extensive works required at the Bear Ravine.

Unfortunately, the performance and general level of management by the contractor who had carried out the concrete repairs to the entrance and shop had deteriorated during the works. One consequence of this was that during the works one of their foremen applied for the position of clerk of works. The expertise in concrete and stone repair held by this person and obvious enthusiasm for the project presented a new possibility of employing someone who could be much more than just clerk of works. Subsequently hired by the zoo to lead the concrete repairs, with one assistant and two apprentices, the zoo now had direct control over the costs and quality of work. The same general contractor who had worked on the Station Café and entrance was used to provide the site mobilisation and scaffold. The concrete cleaning, painting and waterproofing were procured as a separate package through the main contractor.

In contrast to the previous structures, much of the Bear Ravine’s concrete surface is covered with a delicate corrugated finish. When it came to removing the various finishes that were present, a number of different techniques were trialled on a damaged area of concrete. It was decided that a two-stage approach was needed. Firstly, a ThermaTech super-heated steam system would be used to remove all organic contaminants and modern paints without affecting the surface finish or texture. This process cleaned the majority of the structure back to concrete but left some mineral paints and slurry coats. These more stubborn areas were inspected and further assessments carried out. Some areas were treated with chemical strippers and removed by hand. The curved wall of the kiosk reacted very well to this treatment. These chemicals were carefully chosen due to the nature of the zoo environment. Areas that did not react to this treatment were cleaned using a very light blasting programme utilising both wet and dry blasting.

The initial feasibility-stage review of the Bear Ravine had identified significant structural issues with the cantilevered viewing platform (Fig 10). Based on this we had made an allowance in the cost plan to remove all the concrete to the parapet and place additional reinforcement alongside the existing bars before the new concrete was placed. We had also made an allowance for stiffening the cantilevered slab with a layer of mesh reinforcement within a high strength cementitious render on the top and bottom faces.

With the slab propped by a support scaffold, the layers of paint were removed by the cleaning process along with loose and damaged areas of concrete. This showed that the underlying concrete was in a much better condition than we had previously anticipated. As a result, we now looked to repair rather than rebuild the parapet and explored an alternative to the addition of mesh reinforcement, which would have increased the dead load and changed the appearance of the platform (Fig 11).

Where the reinforcement was not already visible we specified local opening up to confirm the size and spacing of the bars. These were transverse layers of 9.5mm (3/8”) diameter bars at 100mm centres near the bottom of the slab. The downstand beam had six Isteg bars at the bottom and 9.5mm links at 200mm centres. There are no records of the original calculations and there was, unsurprisingly, no specific guide for the imposed loads to be used in the design of a structure like this. The 1933 HMSO publication has a category for ‘churches, schools, reading rooms, art galleries and the like’ that gives an imposed load of 80lbs per sq ft (4kN/m²). The zoo does plan to allow controlled use of the viewing platform for
Fig 10 The Bear Ravine before the works

Fig 11 The Bear Ravine during the repair works
Fig 12 The upper walkway of the Bear Ravine after the repair works

Fig 13 The viewing platform of the Bear Ravine after the repair works
visitors but 4kN/m² seemed excessive. A notional imposed load of 3kN/m² seemed more reasonable on the basis that visitors could congregate along the prow of the platform. We also wanted to provide a structure that was stiffer than before to reduce the risk of deflection-induced cracks and provide a platform that felt more secure so as not to cause undue concern to visitors.

We used this value to calculate the bending moments, shear forces and span:depth ratios for the slab and beam. This found that the slab would, theoretically, be able to support this imposed load but the beam would, again theoretically, fail in bending and shear. From our review of the calculations and the signs of damage seen on site we concluded that remedial work should be targeted to address the general lack of stiffness, the lack of top reinforcement as indicated by the crack above the downstand beam and the poor connection between the ends of the downstand beam and the spandrel panels.

This led us to propose remedial works that used carbon fibre bonded to the concrete. Once the principle of this approach was agreed with all parties we discussed the works with Fibrewrap, a carbon fibre specialist, and visited one of their projects in London to see how carbon fibre sheets were fixed onto reinforced concrete. We then provided them with values of the existing and proposed bending moments and shear forces which they then used to develop their design. Two layers of 1mm thick carbon fibre sheets were applied locally to the slab to enhance the hogging and sagging bending moments. A single layer of sheeting was applied to the downstand beam and carbon fibre cables were installed through two small holes in each spandrel panel and then splayed out to link both sides of the beam with the outside face of the spandrels. Another unscientific heel-drop test found significantly less bounce in the platform than before the repairs.

The kiosk, in comparison, needed minor structural repairs. The hollow steel columns were corroded just above ground level and a low-key repair of new steel sleeves, that were welded to sound metal, was used.

The concrete repairs were on a much larger scale than those previously carried out but followed the same philosophy, cement – sand mixes for all vertical and horizontal surfaces and a proprietary blended repair mortar for the underside of the walkways. The quality of the repairs to the corrugated finish of the parapet walls was a significant achievement by the on-site team. A series of tools was developed for this that ranged from a float profiled by a latex mould taken from an original section of corrugation to a bespoke timber profiled float. However, the most useful tool turned out to be a long round timber dowel that was used to line the profiles through.

When breaking out the necessary areas of concrete any sound pieces of concrete were left no matter how small. These small areas ensured that the rhythm of the corrugation was retained in the repairs in relation to the existing. The finished work is truly impressive and a credit to the site team (Figs 12 and 13).

Another aspect of the Bear Ravine was the steelwork present in the stair balustrade and the remains of the infill bars to protect the viewers against the bears. The latter was in extremely poor condition with only a few pieces remaining. These were removed and a blacksmith used the few pieces left to recreate the pattern and reinstate this element. This was important to the overall composition as it tells the story of the dangerous former residents. The balustrades were also removed, stripped of all paint finishes and elements rebuilt where necessary making sure to retain as much of the existing fabric as possible. These were re-galvanised, finished in bright silver and reinstalled.

The paint research here again found a thin layer of pollution between the face of the concrete and the first layer of blue paint. This indicated that the Bear Ravine was unpainted when first opened to the public. However, the layer of dirt present was much smaller than others found on unfinished areas of the Station Café leading to the conclusion that it was not left unfinished for long. We decided to put the structure back to its form following completion and an unfinished appearance by using the Keim Lasur coating. When the concrete surfaces were being blasted some very stubborn finishes remained. It was agreed that to remove these would need such an aggressive medium that it would damage the surface of the concrete. Therefore, these small flecks were left and instead the dilution ratio for the Lasur was lowered to 1:2 to provide adequate coverage. As elsewhere all external surfaces were first treated with silane.

The kiosk was, like the Station Café, coloured with bright reds and blues. As with the entrance the
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underside of the canopy was blue, with the lower wall wrapping around the counter being red. These colours were reinstated using the Keim Soldalit with the rear of the kiosk using the Lasur.

The original timber screen within the kiosk had been removed, so the original drawings and pictures were reviewed from which a pattern was developed and new screen installed. The paint analysis on the entrance and Station Café revealed that all timber was painted crème and the steel columns were finished in a bright silver. The surfaces of the walkways and viewing platform and the top of the kiosk canopy were treated with the liquid membrane and quartz layer to match the underlying surface.

The works were completed early in 2015. Following this the on-site team has worked on the sea lion pool and is currently repairing the former reptillary, now home to meerkats. This will prove a demanding challenge as this is the only enclosure never to be painted. The work will also need to be carried out in stages so that the meerkats remain in place as moving a colony is known to disrupt breeding by up to five years.

Conclusion

The approach and implementation of repairs to historic concrete is still at an early stage. To help develop the understanding of best practice a programme of monitoring and testing has been established in conjunction with English Heritage (now Historic England) to gauge the effectiveness of the recent works. This will include a photographic assessment at 1, 3, 5, and 10 year intervals and corrosion rate mapping pre- and post-repair to assess changes in the corrosion rates of the adjacent reinforcement. Concrete hardness tests using a Schmidt hammer will be undertaken on repaired and surrounding concrete, and samples will be tested to assess changes in the alkalinity at various depths across the depth of the concrete and at distances away from the repair. Historic England is hopeful that the tests will confirm that the high alkalinity of the new concrete repairs will migrate into the adjacent original concrete.

These repairs form an important part of the history of these buildings. To explain and promote this and the rich history of their inception a portion of the Station Café now houses an interpretive display telling the story of the zoo and its Tecton buildings. The display uses historic images of the zoo, presents information on its architectural significance and describes the works that have been undertaken. The surviving section of the original concrete counter to the café forms part of the exhibit. This has been finished to its original form with a polished concrete top, timber edging and a white tiled face. A portion of the counter was re-cast, with a section of the previously exposed reinforcement retained to show visitors how these buildings were formed. A large section of the counter has been rebuilt in timber and finished completely in white so as not to detract from the existing section but to better show the original sinuous form.

A key part of the success of the project has been the very close collaboration between the client, architect, engineer and contractor, alongside regular reviews with English Heritage and the Twentieth Century Society. This is especially important where the ‘light touch’ approach for listed buildings is applied. The project has been fortunate to have a client who has a long-term commitment to the buildings and understands that it is not possible to ‘solve once and for all’ the issues with these buildings and structures. The evolution of the relationship with the contractor moving into the works on the Bear Ravine and kiosk allowed for an evaluative approach without cost-pressure from a main contractor. This avoided the ‘tender and leave us alone’ approach under which a main contractor would have looked to penalise later changes. This was especially beneficial to the Bear Ravine where the approach changed significantly from tender stage. It is hoped that the approach taken here can act as an exemplar in the repair of other historic reinforced concrete structures, in the UK and elsewhere.

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Further information on the Tectons and repairs can be found on www.dudleyzoo.org/around-dzg.