CONSERVATION DEPARTMENT

A DEVELOPMENT OF A NEW METHODOLOGY FOR MAPPING AND MONITORING THE CONDITION OF 3DIMENSIONAL CULTURAL HERITAGE.

CASE STUDY: The Standing Iguanodon in Crystal Palace Park. Using Photogrammetry and 3D Digitalisation to Record Condition and to Map and Monitor Deterioration. Engaging Open Access as a Means of Digital Preservation and Project Outreach.

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Plate 1 – Iguanodons 2016[1]

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[1] Carpenter, I. (2016). Iguanodons. [Unpublished Photograph].

ABSTRACT

The conservation of 3D cultural heritage requires accurate condition reporting over time in order to monitor deterioration and devise appropriate treatment. This thesis presents the development a new methodology using photogrammetry and 3D digitalisation to record the condition of a large object and to map and monitor its deterioration using computer analysis and digital data storage. The research data is being digitally preserved and made available via a range of open access digital platforms, enabling long term access to a wide audience and encouraging a diversification of knowledge through new engagement.

The thesis demonstrates the application of this methodology taking as a case study the Standing Iguanodon in Crystal Palace Park, London. The Standing Iguanodon is one of 32 concrete sculptures depicting pre-historic creatures built to accompany the Crystal Palace Exhibition after its move to South East London in the 1850's. Over the past 163 years it has been subject to numerous restorations, however deterioration specifically relating to structural issues persists. This paper explores the limitations of the current documentation process and employs the new methodology, utilising traditional methods of measuring with digital methods of recording and analysing to assess and document deterioration. The monitoring programme revealed damage caused by ground subsidence. The measurements revealed an increase in dimensions, at points, to 41% of the cracks over a 3-month monitoring period. Measures to stabilise the ground beneath the sculpture are recommended.

The study revealed some important lessons for future applications of the methodology. The most significant being the time needed to capture and process the data, as creating a high-resolution model is extremely time consuming. In addition, conservators would need to develop skills in data processing and analysis. An online open access data repository specifically for conservation projects will be necessary for the long- term preservation of digital research and reports. Opening up such research would be enormously beneficial to the cultural heritage sector in relation to collaboration and for outreach to the wider community. This may result in increased transparency and accountability for high profile conservation projects.

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1.0 INTRODUCTION

The Crystal Palace Dinosaurs are a collection of thirty-two concrete sculptures, depicting extinct and prehistoric creatures, including the world's first full scale, three dimensional constructions of dinosaurs. Built between 1850-1854 by the artist Benjamin Waterhouse Hawkins and designed with the scientific guidance of palaeontologist Sir Richard Owen, the Crystal Palace Dinosaurs (hereafter 'the dinosaurs') were commissioned to accompany the Crystal Palace after it moved from The Great Exhibition in Hyde Park, to its assumed permanent location in the landscaped park of South East London (MacDermot, 1854, McCarthy and Gilbert, 1994). Unveiled by Queen Victoria, five years before the publication of Darwin's The Origin of Species, the antediluvian beasts were enormously popular, capitalising on the scientific and public enthusiasm for palaeontology and what would later be termed the 'dino-mania' of the time. They attracted a vast number of visitors, becoming, at the time, the most viewed scientific work of any kind (Secord, 2004).

Over the past 160 years, the dinosaurs have been the subject of numerous conservation and restoration campaigns, with varying levels and limited accessibility to previous documentation. This thesis will focus on the Standing Iguanodon dinosaur and will investigate the limitations of the current documentation practice, specifically with regards to the dinosaurs ongoing deterioration. It will explore the use of 3D digitalisation, by way of photogrammetry, as a means to map and monitor deterioration, focusing on its use to document and monitor crack development. It will address issues concerning accessibility by exploring a range of digital platforms from which the documentation and research can be viewed and how the concept of open-access can be beneficially utilised for future research, digital preservation and project outreach.

1.1 The Crystal Palace Dinosaur Court and the Standing Iguanodon

Plate 2. – Dinosaurs under construction[2]

Records are unclear precisely who conceived the idea for the Dinosaurs, though It was most likely a collaborative scheme contrived by Prince Albert, Joseph Paxton- the architect of the Crystal Palace and Sir Richard Owen- the palaeontologist and later founder of the Natural History Museum (McCarthy and Gilbert, 1994). The idea was that the park and its exhibits would both entertain and educate the general public, a scheme grounded in the theories of the Swiss educational theorist Johann Heinrich Pestalozzi and his notion of 'conveying knowledge directly through the senses' (Secord 2004).

Three islands, representing the Primary, Secondary and Tertiary epochs were built on the existing lake in the park, with each landscaped island displaying the appropriate geological formations according the era (Doyle and Robinson 1993). Situated on the islands, in approximate chronological order, were the concrete sculptures including the marine reptiles, the dinosaurs and finally, the extinct mammals. See Appendix I for their location.

[2] Delamotte, P. (2017). *Models of Extinct Animals, the Iguanodon*. [Photograph] British Library, London.

Plate 3. Drawing of the Dinosaur Islands by Richard Owen[3]

Overseen by Owen, the sculptures were the work of natural history artist and sculptor Benjamin Waterhouse Hawkins and were created in a temporary studio set up at the lower end of Crystal Palace Park (McCarthy and Gilbert, 1994). Working from the fossilised bone collections of The British Museum and the Geological Society, Hawkins, employing the method of comparative anatomy[4], made preliminary sketches of the creatures. Once the drawings were refined, he constructed 6th or 12th scale models in clay and submitted them for appraisal and modification to Richard Owen (Waterhouse Hawkins, 1854). The models were then scaled to 'life size' and constructed in clay. A mould was taken from the full scale model and used to cast multiple panels in concrete, these concrete panels would later make up the external 'skin' of the creatures. In his address to the members of the Society of the Arts in 1854, Hawkins described the construction of the Standing Iguanodon –

> It is not less than building a house upon four columns, as the quantities of material of which the standing Iguanodon is composed, consist of 4 iron columns 9 feet long by 7 inches in

[3] Owen, R. (1854). Geology and inhabitants of the ancient world. 1st ed. London: Crystal Palace Library and Bradbury and Evans.

[4] 'Comparative Anatomy' was a technique employed by palaeontologists in the 18th-19th Century, where the bone structures of living animals were compared to fossilised remains in order to determine the appearance of the extinct animal, George Cuvier being a leading authority.

diameter, 600 bricks, 650 5-inch half-round drain tiles, 900 plain tiles, 38 casks of cement, 90 casks of broken stone, making a total of 640 bushels[5] of artificial stone. These, with 100 feet of iron hooping and 20 feet of cube inch bar, constitute the bones, sinews and muscles of this large model, the largest of which there is any record of any cast being made.
(Waterhouse Hawkins, 1854 p447).

When faced with a lack of fossilised evidence, a certain amount of artistic licence was taken with a number of the reconstructions, notably that of the Mosasaurus, Labyrinthodon and Dicynodon. Owen, to his credit, openly acknowledged the difficulties and admitted that such reconstructions may be 'thought, perhaps a little too bold' (Owen 1854, p7). Nevertheless, these infamous incongruities, such as the horn of the Iguanodon (later discovered to be a thumb spike) did some-what compromise the scientific authenticity of the models and by the end of the century they were not only discredited but viewed by some as an injustice to the very creatures they were mean to represent (McCarthy and Gilbert, 1994 p85).

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Plate 4. The Standing Iguanodon under construction in the Sydenham studio[6]

The vast numbers of books, articles, short films and visitors to the Dinosaurs is a testament to their enduring popularity and in 2001 they were awarded grade 1 listed heritage status. Though their educational role was short lived, their capacity to inspire curiosity and wonder has remained.

The decline in popularity of the park as an attraction, the bankruptcy of the Crystal Palace Company and the eventual destruction of the Crystal Palace by fire in 1936 saw the creatures fall into a state of disrepair (Walker, 2017). Between 1950 and 2000 there were numerous conservation/restoration campaigns to address their deteriorating condition, however, for reasons such as changing

[5] A unit of dry measure equivalent to 35.24 litres.
[6] Unknown, (1853). The Sydenham Studio. *The Illustrated London News*.

ownership, official documentation of treatments has been sparse and the majority of evidence of these historical interventions have come from archival photographs (McCarthy and Gilbert, 1994), personal anecdotes (Wyncoll 2013), and material evidence such as the multiple layers of paint, indicating various paint schemes, identified in cross section paint analysis (Hirst 2004, Siddall 2016). See plate 6.

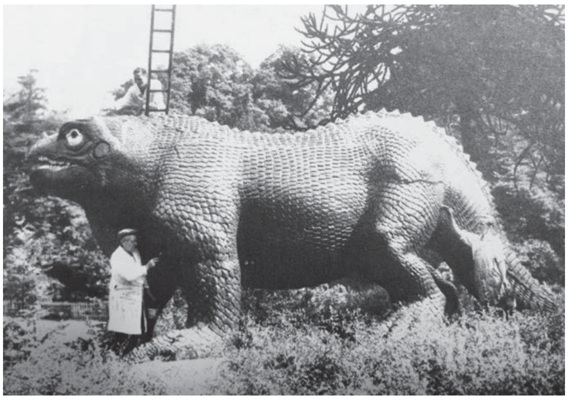


Plate 5. – Restoration in the 1950's[7]

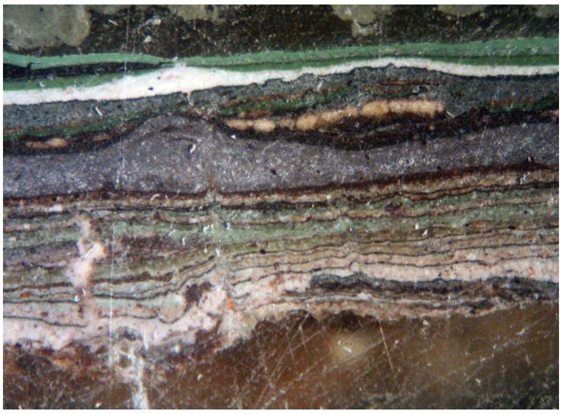
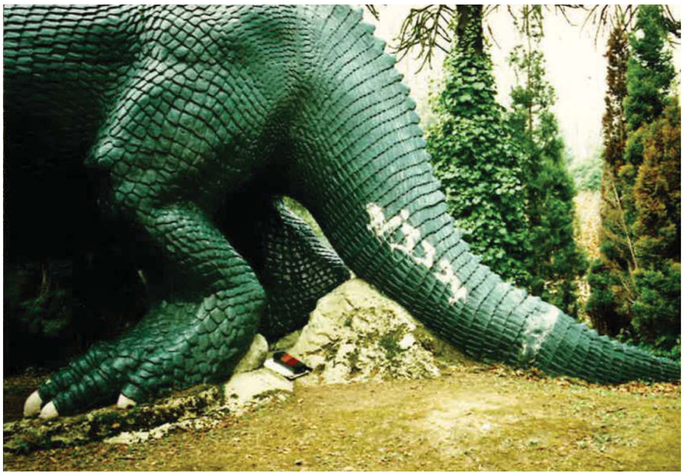


Plate 6. – Paint cross section viewed under magnification. Sample taken from a section of the Standing Iguanodon's tail by Dr Ruth Siddall[8].

[7] McCarthy, S. and Gilbert, M. (1994). The Crystal Palace dinosaurs. London: Crystal Palace Foundation.

[8] Siddall, R. (2016). #talesfromthetail (with images, tweets) · cpdinosaurs. [online] Storify. Available at: https://storify.com/cpdinosaurs/talesfromthetail [Accessed 13 Feb. 2017].



Plates 7 and 8. The Standing Iguanodon in the late 1990's. Note the green gloss paint and graffiti[9]

[9] Morton,E. (1998). The Standing Iguanodon. [Unpublished Photograph].

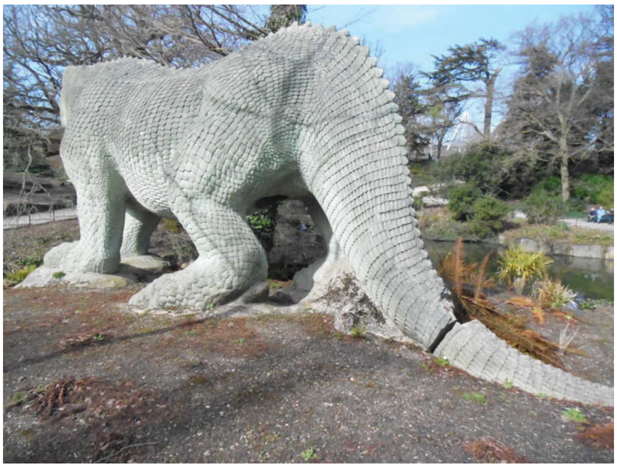
1.2

21st Century Conservation and Restorations

Towards the end of the 1990's the dinosaurs were placed on the Heritage at Risk list and between 2000-2002, the most comprehensive conservation campaign on record was undertaken (Eura 2001). Each of the 32 beasts were treated; paint was stripped, corroded internal iron removed, cracks filled, entire missing elements were replaced with fibreglass and each of the animals were repainted. Nevertheless, within a year cracks were once again developing and concerns over their rapidly deteriorating condition were being raised.

Plate 9. Corroded Iron hooping in the Iguanodon. Removed 2001[10].

Plate 10. Iguanodon pre 2015 restoration[11].



By 2015 cracks in the Standing Iguanodon had reopened (up to 100mm in width), the front feet were severely cracked, the tail had completely detached and the surface displayed extensive paint loss and biological growth (Cliveden, 2016). See plate 10. After campaigning and fundraising, the most iconic of the dinosaurs, the Standing Iguanodon was selected for re-treatment; the painted surface was cleaned, micro piles were inserted beneath the tail, cracks were again filled, losses remodelled, teeth were replaced and another paint scheme was applied. The treatment was completed in January 2016, however, by May 2016 cracks were, once again opening up along the sites of the new repairs. By August 2016 many of the cracks had re-opened, up to 5mm in width, and sections of the surface were spalling. See plate 11.

[10] Morton, E. (1998). Corroded Iron Hooping in the Standing Iguanodon. [Unpublished Photograph].
[11] Porter, M. (2015). Standing Iguanodon pre 2015 restoration. [Unpublished Photograph].

Plate 11. Back right foot of Standing Iguanodon Summer 2016.
Cracks reopening[12].

1.3

The Standing Iguanodon – Materials and DImensions

Of all the dinosaurs, the Standing Iguanodon was selected for analysis due to the fact that it was, at the time of starting the research, the only dinosaur to have undergone further restoration treatment since 2002. Any progressive deterioration such as cracking formed in the new paint layer could be ascribed to have happened post January 2016 (the end of the last restoration), therefore giving a more accurate timescale for determining the rate of deterioration. See plates 12-14 below for a summary of the Iguanodon's dimensions and materials.

[12] Carpenter, I. (2016). Cracks in the Back-Right Foot, Summer 2016. [Unpublished Photograph].

1.3.1

Exterior of Standing Iguanodon

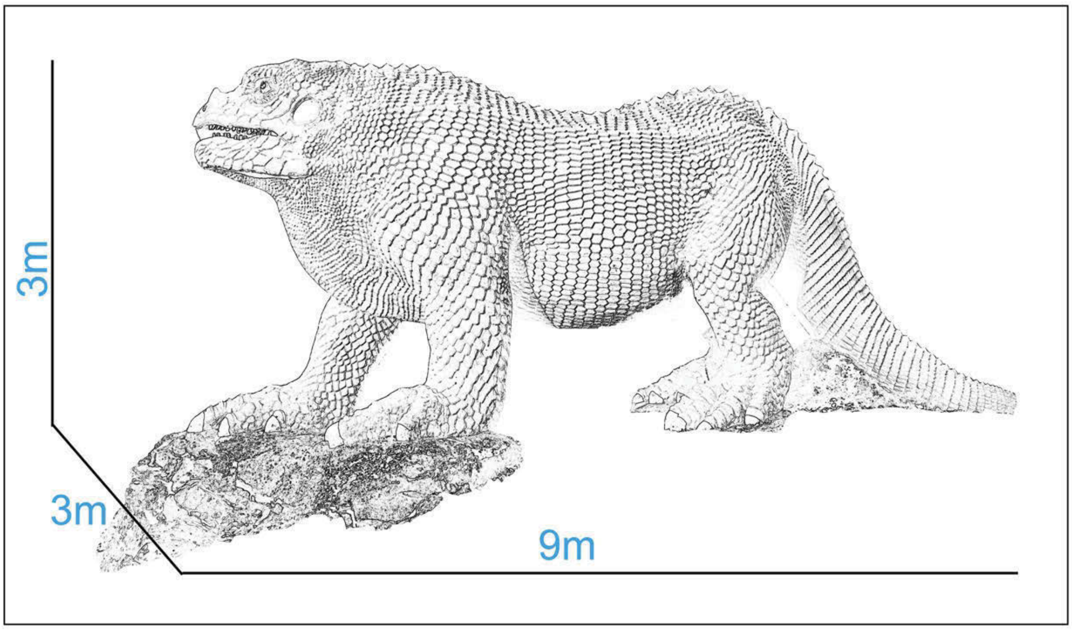


Plate 12. Dimensions Diagram

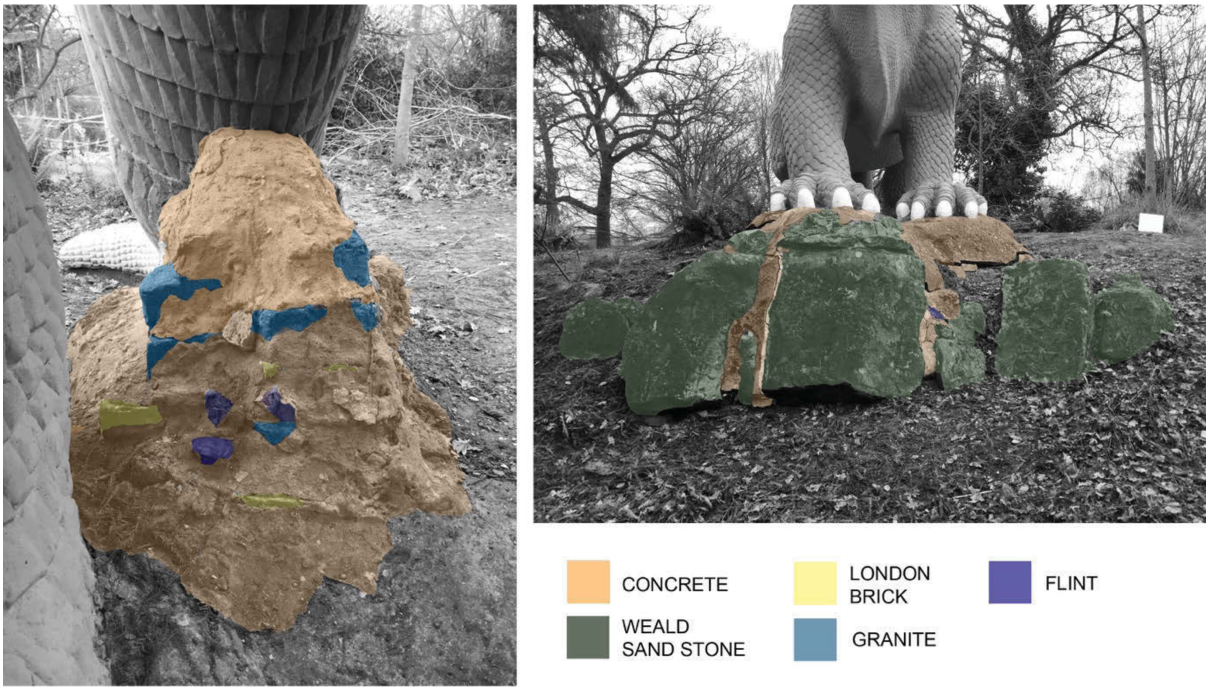


Plate 13 and 14 Plinth Materials[13].

[13] Carpenter, I. (2016) Front and Back Plinths [Unpublished Photograph].

The Iguanodon measures 3x3x9m and the exterior comprises of cast panels of coarse aggregate concrete. The numerous restorations and remodelled sections are concelled by a layer of paint applied in 2015-2016. The front plinth is constructed from Weald sandstone and concrete, see plate 14. The different aggregates in the concrete suggest that the front plinth has been subject to numerous restorations, with a variety of concretes used. The back plinth (supporting the tail) comprises of yellow london brick, granite cobbles and flint. This has been partially covered with a layer of concrete.

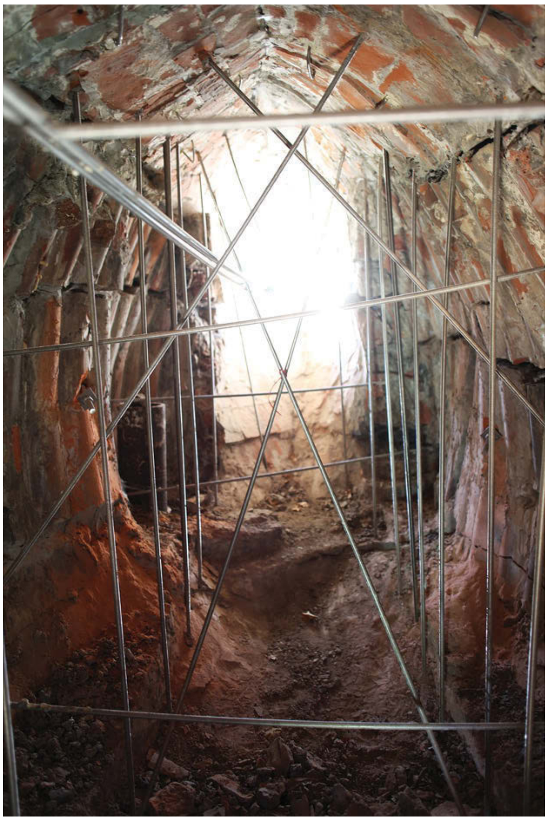


Plate 15. Interior – Front facing.

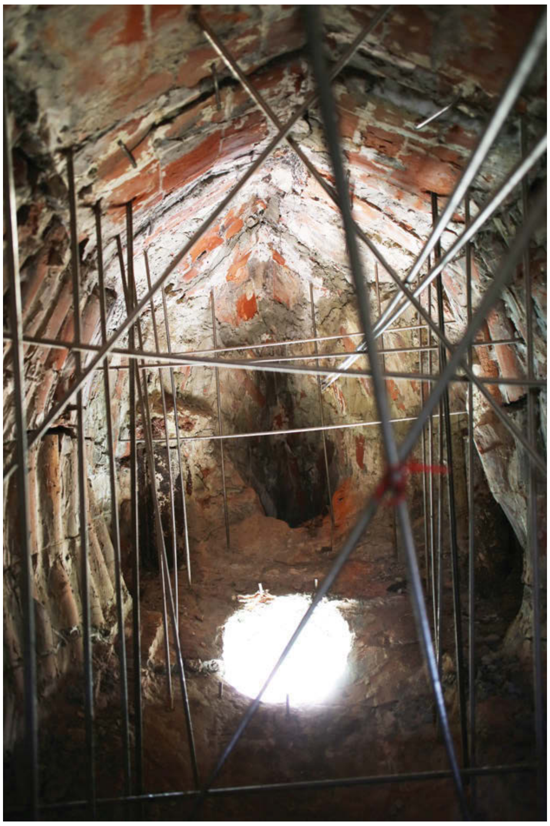


Plate 16. Interior – Rear facing.

Plate 17. Cast Iron pipe, running through each leg[14].

1.3.2

The Interior of the Standing Iguanodon

The interior is accessible through a hole towards the rear of the dinosaur. The interior comprises of brick, half round drain tiles and flat terracotta tiles, held in position with cement. Running in concentric bands around the interior are gaps where the severely corroded cast iron hooping was removed in 2001-2002. Through

[14] Plates 15-17 Carpenter, I. (2016). Interior of Iguanodon. [Unpublished Photograph].

each of the legs are 4 cast iron pipes, see plate 16. The interior is intersected by lengths of 12-15mm stainless steel studding, inserted during both 20th century restorations, presumably to structurally support the work. Numerous stainless steel wire 'staples' have been affixed on either side of filled cracks and adhered with resin. Patches of stainless steel mesh have been used to bridge large gaps before being filled with concrete, these are 2015 additions.

1.4

What is Causing the Cracks in the Standing Iguanodon?

This research thesis evolved from the deceptively simple question 'What is causing the cracks in the Standing Iguanodon?' Cracks in concrete can be caused by a number of factors including; the expansion of corroded internal armatures, ground movement, shrinkage, the use of inappropriate materials, poor application of repair materials, and can be further exacerbated by agents such as biological growth and freeze-thaw (Heritage, E. 2013, PCA 2017, CCI 2017). Whilst one or all of these may have been the cause of historical cracking, the rapidity, the location and the evidence displayed in the surrounding ground suggest that the primary cause of the cracking in the Iguanodon is due to ground subsidence and failure of the foundations. Evidence for this will be discussed later in the research. This hypothesis is neither new or unexpected, having been formally and informally diagnosed for at least 22 years (London Borough of Bromley 1994, Eura 2014). However, the instability of foundations had not been successfully addressed in either of the recent conservation campaigns (Eura 2001, Cliveden 2016) as indicated by the continued, progressive cracking of the repairs.

1.5

Existing Documentation of Cracks

Identifying the patterns and rate of cracking is essential in understanding a work's underlying structural condition and such documentation is fundamental in order to assess the necessary action needed to prevent further damage (Moore, 2001). Research into the conservation contractor's paper archive, including previous tender applications, pre-treatment condition reports and post-treatment reports from 1994 to 2016 revealed;

- No condition monitoring program, current or historical.
- No pre-treatment documentation concerning crack locations, size, depth or interrelation.

- No post-treatment documentation concerning the specific locations and the precise extent of crack-related treatments undertaken.
- No wide shot[15] photographs of the Iguanodon pre or post treatment from either 20th Century conservation campaign.
- Complete omission of the report regarding the 2000-2001 treatment of the Crystal Palace Dinosaurs, including the treatment report of the Standing Iguanodon.

Such omissions in its documentation record reveal that the rate of structural deterioration of the Standing Iguanodon has been left unchecked for at least 23 years and furthermore, the lack of documentation makes retrospective analysis, extremely difficult and potentially unreliable.

1.6

The Ethics of Documentation

Documentation is an integral part of the conservation process. Documentation is produced and is used for a vast number of reasons including; to evaluate an object's current condition, plan future treatment, evaluate previous treatments and methods, for study if the original object has been lost/destroyed, to support scholarly research and to expand appreciation and understanding of an object. Furthermore, it can be used to study the history of the conservation profession, the thought processes and rationales applied to cultural property, to serve as a record that can help avoid misunderstanding and unnecessary legal issues and when undertaken effectively, it can enhance the credibility of the conservation profession by setting a positive example for allied professionals and the public (AIC, 2016, Radin, 2012).

Since the work of conservation professionals are not covered by laws, codes of ethics have been developed to guide this work. These ethics are established by national and international bodies who concern themselves with maintaining integrity and standards within the conservation profession (ICOMOS 1964, AIC 2015, ICON 2009, CAC 2009 etc.) Conservation documentation is one of the main ethical principles stated in the guidelines of these bodies. As stated in the Institute of Conservation Code of Ethics:

[15] Photograph of the whole object.

> 4.9 i. - You must create records of the condition of objects before undertaking any conservation measures. Investigations, analyses, decisions made and measures undertaken as well as subsequent results and observations must be documented.

And in the American Institute of Conservation -

> VII. The conservation professional shall document examination, scientific investigation, and treatment by creating permanent records and reports.

In addition to producing documentation, the conservator is ethically obliged to preserve such documentation and to make it accessible to the owners of the object and, within reason, to other conservation or affiliated professionals. The principle being that there is no point in making or keeping records if they cannot be consulted.

> Documentation is an invaluable part of the history of cultural property and should be produced and maintained in as permanent a manner as practicable. Copies of reports of examination and treatment must be given to the owner, custodian, or authorized agent, who should be advised of the importance of maintaining these materials with the cultural property. Documentation is also an important part of the profession's body of knowledge. The conservation professional should strive to preserve these records and give other professionals appropriate access to them, when access does not contravene agreements regarding confidentiality (AIC, 1996-2016)

1.7
The Difficulties in Documenting Complex 3-Dimensional Cultural Heritage

Large and complex 3D objects are, by their nature, difficult to document, often encountering issues relating to accessibility and requiring complex logistics. Difficulties are compounded when the level of detail required for effective monitoring is extensive, nuanced and interconnected over a large surface area, such as that needed for the recording and mapping of cracks in a 30ft dinosaur. Traditional 2D methods of condition documentation can include large numbers of annotated photographs, diagrams, full-scale and detail images, and data in the form of graphs and tables. Analysing, interpreting and ultimately utilising such documentation often requires extensive and potentially confusing cross referencing, particularly if a monitoring program extends over a number of years. Such interpretation can be further complicated by the similarity and limitations of a 2D image, for example, multiple detail images of cracks can often look remarkably similar to one another and are unlikely to reveal information regarding depth and profile.

1.8
3D Digitalisation of Cultural Heritage

3D digitalisation is an increasingly used tool in the diagnosis, presentation, study and conservation of cultural heritage. Since the late 1990's, the heritage sector has employed the process in an ever increasing number of projects (Ikeuchi et al., 2007, Urban 2015, Hess 2015). Early examples being; The IBM Pieta Project (Taubin, 1998), The Stanford Michelangelo Project (Stanford, 1999) and The Beauvais Cathedral Project (Allen, 2001). See plate 12. Until recently, the cost of the required technologies has been a barrier to their wide spread use, however, developments in low cost digital cameras, new laser-based scanning systems and increased computational power has drastically reduced this cost (Hess, 2015). Furthermore, the establishment of various internationally funded digitalisation projects (3DICONS, 2015) and community driven online 3D publishing platforms (Sketchfab, 2017) have been key in facilitating its ease of use and accessibility.

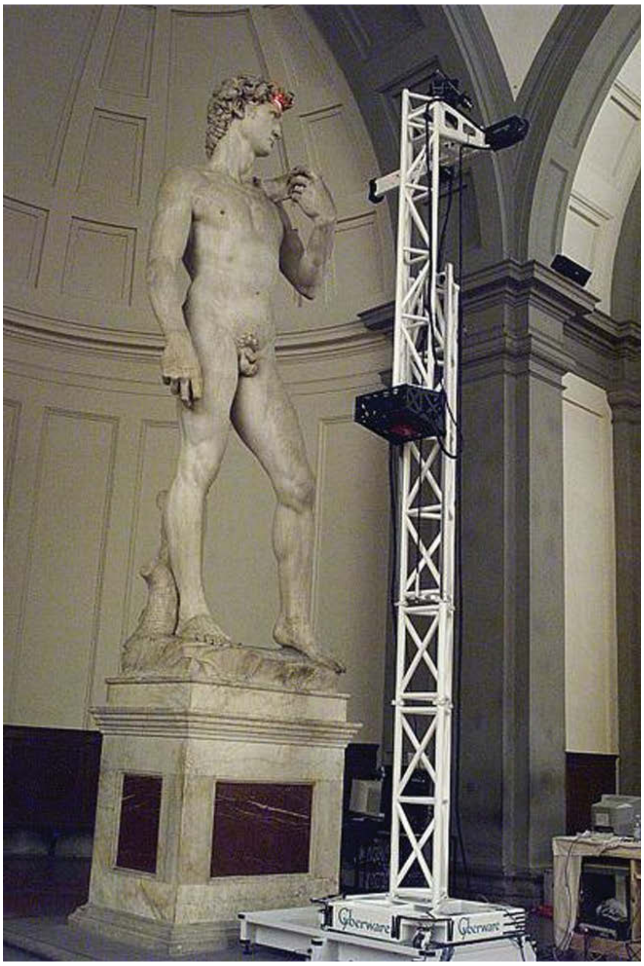


Plate 18. The Stanford Michelangelo Project 1999[16].

1.8.1.
Photogrammetry

Photogrammetry is a 3-dimensional measuring technique that uses photographs as the medium for measurement[17]. The use of photogrammetry as a means to digitally document 3D objects has seen a particular rise in popularity, as it can be undertaken with a regular digital camera and processed with

[16] Cyberware, (2017). *The Stanford Michelangelo Project*. [image] Available at: http://cyberware.com/products/scanners/lss.html [Accessed 4 Apr. 2017].
[17] The term photogrammetry was first used by the Prussian architect Albrecht Meydenbauer in 1867 who fashioned some of the earliest topographic maps and elevation drawings (Albertz, 2017)

both open source and commercially available software (Bartoš, Pukanská and Sabová, 2014, Urban 2017). Furthermore, photogrammetry is a comparatively easy to archive process, since all that is needed to generate a 3D model are a series of 2D photographs. This means that so long as the 2D photographs and relevant metadata are carefully archived, then it is possible to generate and re-generate a textured 3D model at any point from this set of images. As the computer software develops and improves, so too will the ability to create faster and more detailed iterations from the original data set of images. This versatility means that the data will not become obsolete in the manner that can befall certain hardware/software/file formats etc.

To generate the information necessary to create a 3D digitalisation, an object needs to be photographed a number of times with overlapping images from varying angles and orientations. Computer software then identifies repeating clusters of pixels and projects these into a 3Dimensional space by way of co-ordinates. These co-ordinates create a point cloud which can be refined through a series of adjusting algorithms. Further software is then used to create a dense point cloud which can be transformed into a textured 3D model (CHI, 2017). *Please see the Methodology for a detailed description of the photogrammetric process used to create the 3D digitalisation of the Standing Iguanodon.*

Plate 19. Screen shot showing the position of the camera used to create the digital image of the sculpture using photogrammetry[18].

[18] Agisoft Photoscan, (2017). *Generation of Image Using Photogrammetry*. [video] Available at: http://www.agisoft.com/community/showcase/ [Accessed 4 Apr. 2017].

1.9
Open Access to Digital Data

Many museums, such as the Smithsonian, the Natural History Museum and the British Museum have recently embarked on large scale digitisation schemes and most significantly, are making these accessible to the public, not simply to view but to download. Photogrammetry is the technique most frequently used in creating 3D digitalisations. (NHM, 2017, 3d.si.edu 2017, British Museum, 2017).

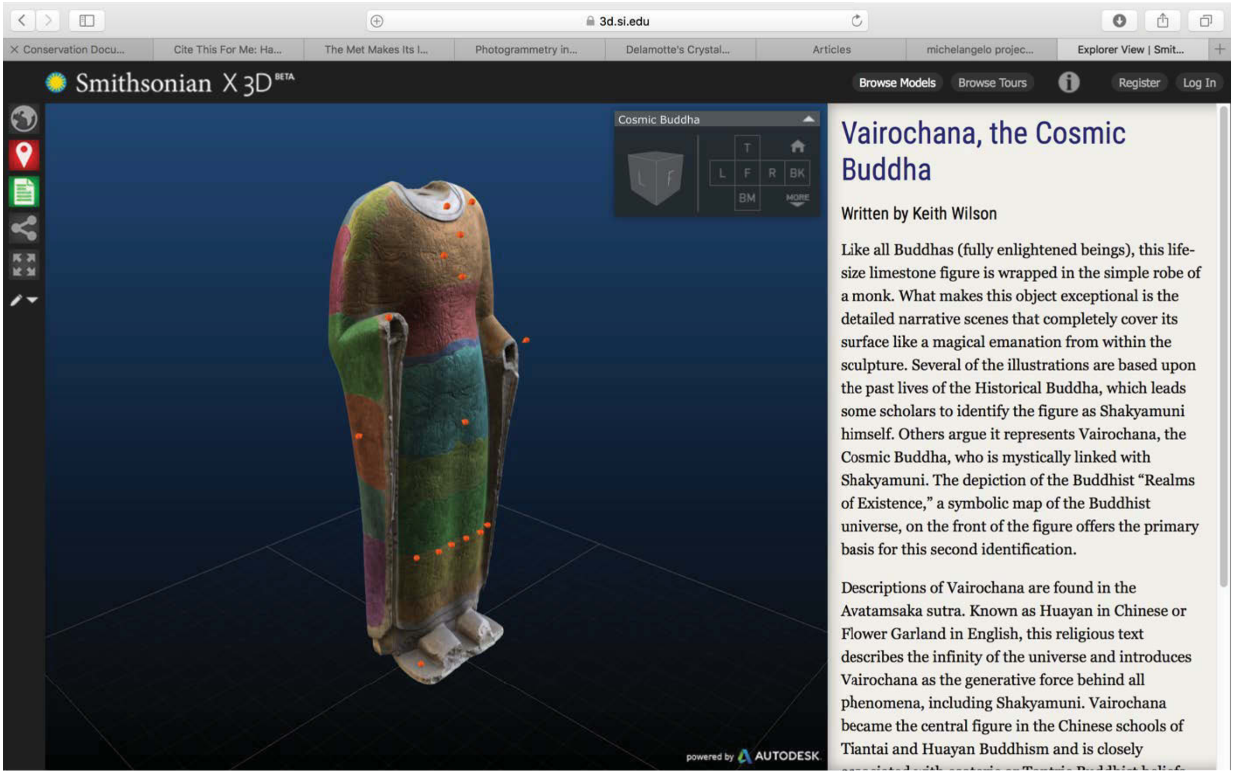


Plate 20. Screen shot of The Smithsonian X3D website showing a 3D model of the Vairochana Cosmic Buddha, created using photogrammetry[19].

Arguably, the most ambitious of these digitisation and open access schemes is that being run by The Smithsonian, whose 3D digitisation project has currently prioritised 10% of its 137million artefacts, artworks and specimens for digitisation, including the interior of the Apollo 11 command module. The 3D models are both accessible, and in most instances, downloadable through their website Smithsonian X3D (3d.si.edu). The digital program team predict that future researchers working in the field may not come back with specimens, but with 3D data documenting a site or a find. They also believe that with only 1% of their collection on display in the Smithsonian museum galleries, that digitisation creates the possibility for the remaining 99% of the collection to be viewed and studied virtually by a limitless number of researchers and interested parties across the world.

[19] Smithsonian, (2016). *3D model of the Cosmic Buddha*. [image] Available at: http://3d.si.edu/explorer?modelid=44 [Accessed 4 Apr. 2017].

Similarly, The British Museum has an online database of 2D digitisations accessible through their website and are regular contributors to the website 'Sketchfab', an online publishing platform for accessing and sharing 3D models (Boissenin, Oms and Games, 2017). There they contribute 3D models of renowned cultural artefacts, including relevant information on the item itself, but also relevant digital meta data (such as the size of the mesh, how many photographs were used to create the model etc.) The 'comments' section encourages users to engage with the model, not simply with the representation, but also on *how* the representation was realised. Furthermore, by utilising this platform, The British Museum are reaching out beyond their usual cultural heritage audience and engaging with a much wider range of users including the scientific and computer gaming communities. Their 3D model of the 'Granite Head of Amenemhat III, posted in 2015 has, for example, been viewed over 72,000 times and downloaded by over 3,600 users (British Museum, 2017).

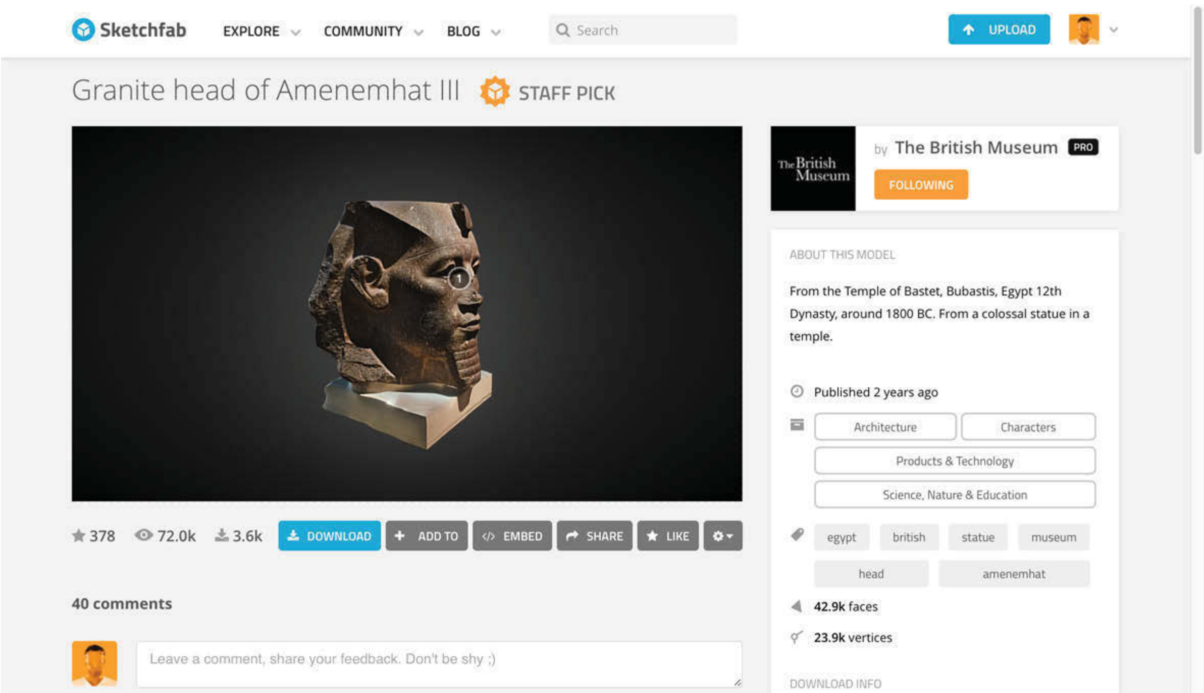


Plate 21. – Screen shot of The Granite head of Amenemhat III uploaded by The British Museum on Sketchfab[20].

[20] British Museum, T. (2017). *Granite head of Amenemhat III by The British Museum - download 3D model*. [online] Sketchfab. Available at: https://sketchfab.com/models/64d0b7662b59417986e9d693624de97a [Accessed 5 Apr. 2017].

This democratisation of access to research is an increasingly important and recurring theme in the community of scientific and cultural heritage digitisation. The Natural History Museum's online collections data portal not only includes information for researchers to download, but actively encourages researchers and interested parties to *contribute* to the database. As their website states-

> It is hoped that by opening up the collections data to the outside world the Museum's datasets will be enriched, as scientists and the public can contribute additional information about specimens. (NHM, 2017).

There is also the acknowledgement that technological problems can, and are expected to arise in creating and opening up such a huge dataset, and so they have incorporated a function in the data portal through which people can report errors. As the museum's digital portal developer Ben Scott explains -

> 'This Data Portal offers an important opportunity for citizen science, allowing people outside the Museum to contribute and help us correct these records'. (NHM, 2017).

The opening of these digital archives is viewed as an enormously significant step in the field of research, both for independent researchers, but also for the museums themselves as they encourage and promote an unprecedented opportunity for collaboration. Significant is the transparency with which they are approaching the endeavour; acknowledging that they are embarking on the unknown, expecting mistakes and encouraging comment and feedback from the users. It signals a fundamental change in the nature of research and information exchange, where user and supplier can engage to create an ongoing, evolving and mutually enriching system.

2.0
Aim

The primary research into the condition of the Standing Iguanodon revealed the necessity for;

- A detailed documentation of the dinosaur in its current state.
- Instigation of a condition monitoring program – focused on monitoring crack progression.

Due to the complexities and issues surrounding the documentation of large 3D objects in traditional 2D formats, this research project aims to create, using photogrammetry, a full scale 3D digital model of the Standing Iguanodon, a record that will accurately capture the dinosaur's condition in detail and can be used as a virtual site to map information and monitor deterioration. This will be undertaken in collaboration with Stephen Gray, University of Bristol. A manual crack measuring and monitoring program will also be undertaken over the course of the project, with the results incorporated into the digital model.

Fundamental to the project is the creation of a range of platforms from which this information can be accessed. Each platform will be interconnected, but each will fulfil a particular function;

1. An online, open access resource/research repository. This will be stored permanently with the Archaeological Data Service (temporarily with Fig-Share). This repository will include a full scale 3-Dimensional digital model of the Standing Iguanodon and all the accompanying photogrammetry data. The model will include, by way of pin-drops, identification of each of the cracks as recorded between 2016-2017. This will allow the viewer to visually identify the cracks and can be used in conjunction with the crack report included in the repository, detailing all documentation and data regarding the crack monitoring program. The digital model will be available for anyone to download and use and will be licenced under Creative Commons[21].

2. An online lower resolution 3D digitalisation of the Standing Iguanodon. This will be accessible through Sketchfab, the world's largest platform for publishing and sharing 3D content online. The Sketchfab 'community' has over 500,000 contributors spanning; the cultural heritage sector, gaming, architecture, science and education. This lighter and lower resolution model will be accessible through a regular internet browser and can be viewed on a computer, tablet and smartphone. It will include basic information about the Standing Iguanodon/The Crystal Palace Dinosaurs and include pin-drops identifying the cracks with hyperlinks to the research repository for those interested in viewing the high resolution model and learning more about the condition of the dinosaur. This platform will be a key aspect in promoting cross community access and project outreach.

[21] Creative Commons - This license lets others distribute and build upon your work, even commercially, as long as they credit you for the original creation. This is the most accommodating of licenses offered. Recommended for maximum dissemination and use of licensed materials.

3. Hard copy documentation of this report – which will include documentation and data relating to the crack monitoring program. This will not require any complex storing method, need no special equipment to view or access and can be physically stored within the existing paper archive of the Crystal Palace Dinosaurs.

4. Electronic 2D documentation of this report – Whist not including a 3D model, all information and data will be reproduced and available in a 2D format. This will be easily accessible, can be easily shared and will provide detailed photographic records.

3.0

Methodology

The surface of the Standing Iguanodon was photographed in detail using the following method in order to create a sufficiently detailed data set with which to create the 3-Dimensional model.

Please see Appendix II for Risk Assessment.

3.1

Collecting the Photographic Data

The precise method of collecting data is specific to each project and is dependent upon variables such as the location of the object, the surface characteristics and also the quality and scale of the intended model, however, there are some considerations that relate to all objects, including the camera settings and lighting etc. The following methodology relates specifically to the method used to capture the data for the Standing Iguanodon.

Equipment –

The surface of the Iguanodon was photographed using a Canon EOS 5D Mark III using the equipment and setting given below in **Methodology Table 1 (M1)**

Table M.1

<table>
<tr><th>Photography</th><th>Access</th><th>PPE</th></tr>
<tr><td>Canon EOS 5D Mark III
Canon 1.4 50mm lens
Monopod
5meter shutter release cable
Multiple 64G SDX cards</td><td>Step Ladder
2.5m Ladder
Scaffolding Tower.
Plastizote</td><td>Blankets/Knee pads</td></tr>
<tr><td colspan="3">Camera Settings
No zoom.
Auto focus predominantly used.
Manual Settings as much as possible.
Aperture/shutter speed combination maximising depth of field and adequate exposure. All images taken hand held, so relatively short shutter speed.
Over exposure avoided at all costs, under exposure favoured.
ISO kept as low as possible.
Large JPEG setting used (RAW too large).</td></tr>
</table>

Conditions –

Lighting is an essential element to factor in the collecting of data as the software algorithms that generate the 3D model rely on information gathered through colour and contrast, specifically the Scale-invariant feature transform equation (SIFT) (Barratt, 2013). Neutral and stable lighting conditions are therefore a requirement in the photography of the object. The location of the dinosaur (outside in a park) meant that it would be effected by changes in the weather conditions, specifically the changing position and intensity of the sun. To counter this, the work was photographed on dry and overcast days when stark cast-shadows and over exposure was at a minimum. If there were changes in weather (the sun coming out) then a makeshift sun-screen was used to eliminate any cast shadows.

Technique –

The principle factor in capturing the photographs was maintaining a consistent and systematic approach. See below in **Methodology Table 2 (M2)**

Table M2

Photographic Technique
• 60-80% overlap between each photo, side to side and top to bottom. • Photographs taken from no more than 60cm away from the surface. The distance did not have to be exact, but focus was essential. • Photographs taken in a systematic order. The dinosaur was portioned into distinct sections (body, tail, head etc.) and photographed in either bands circling the section or systematically up and down. • A ruler was included next to the dinosaur to give the work a scale, important for the later processing.

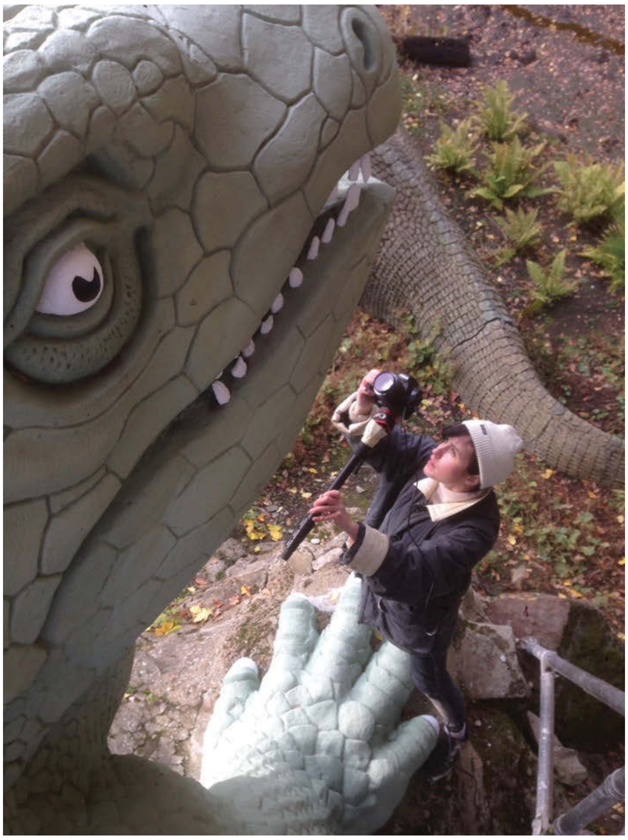


Plate 22.

Plate 23.

Plates 22 & 23. Photographing the exterior of the Iguanodon.

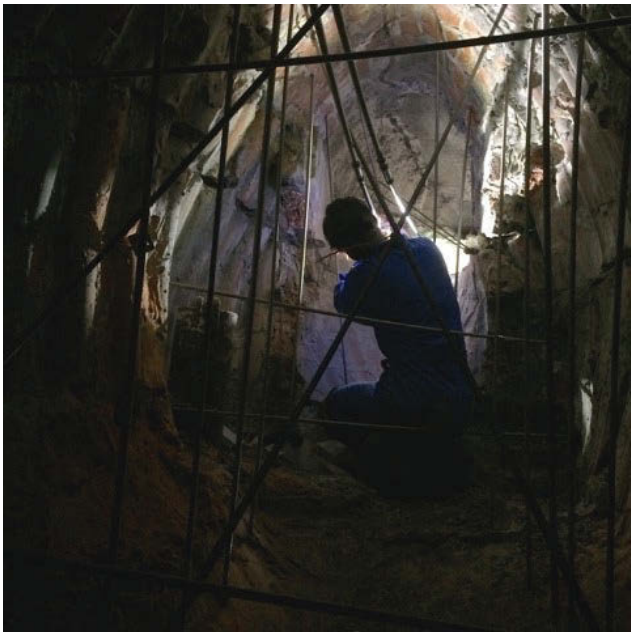


Plate 24. Photographing the interior of the Iguanodon[22].

[22] Plates 22-24 - Carpenter, I. (2016). Collecting photogrammetry data. [Unpublished Photograph].

3.2

Post Processing – Creating the 3D Model from the 2D Photographic Data.

The post processing was undertaken at Bristol University by researcher Stephen Gray using Agisoft Photoscan Pro. See **Methodology Table 3 (M3)** for the step by step method used to generate the 3D Iguanodon model from the 2D photographic data set.

Table M3

Post Processing
Software – Agisoft Photoscan Pro • Import photographs of a section[23] into software (such as the head of the Iguanodon) • Photoscan aligns photographs for each chunk • Repeat for each section (head, tail, front plinth etc.) • Photoscan aligns photographs for all sections • Build a sparse point cloud, which then needs optimising • Build a dense point cloud • Build a polygon mesh • Build a texture for the mesh • Export as hi res .obj with textures. Decimate for upload to Sketchfab or another web platform
Post Processing Step II
Software – Agisoft Photoscan Pro • Import photographs of a section into software • Align photographs for each section • Build a dense point cloud for each section • Repeat for each section • 'Align sections' (point based) • Dense point cloud may need optimising • 'Merge sections' (and 'Combine Models') • Build a polygon mesh • Build a texture for the mesh • Export as hi res .obj or .fbx file with textures. Decimate for upload to Sketchfab or another web platform

Settings
Photoscan alignment – • Accuracy set to 'high' • Pair selection 'disabled' • Keypoint limit '400000'
Optimise sparse point cloud –

[23] The sections are defined in plate 25.

• In 'gradual selection' set 'Reconstruction Uncertainty' to '10' & delete selected points • Repeat • Optimize the alignment of the cameras based only on the high-quality points by selecting 'Optimize cameras' • Select all options except '-' the last • In 'gradual selection' set 'Re-projection Error' to '1' & delete selected points • In 'gradual selection' set 'Projection Accuracy' to '10' & delete selected points • Manually remove any obviously inaccurate points
Build dense point cloud • Set quality to 'high'
Build a mesh • Set 'surface type' to Arbitrary
Build textures • Set maps at 1024/png • Export

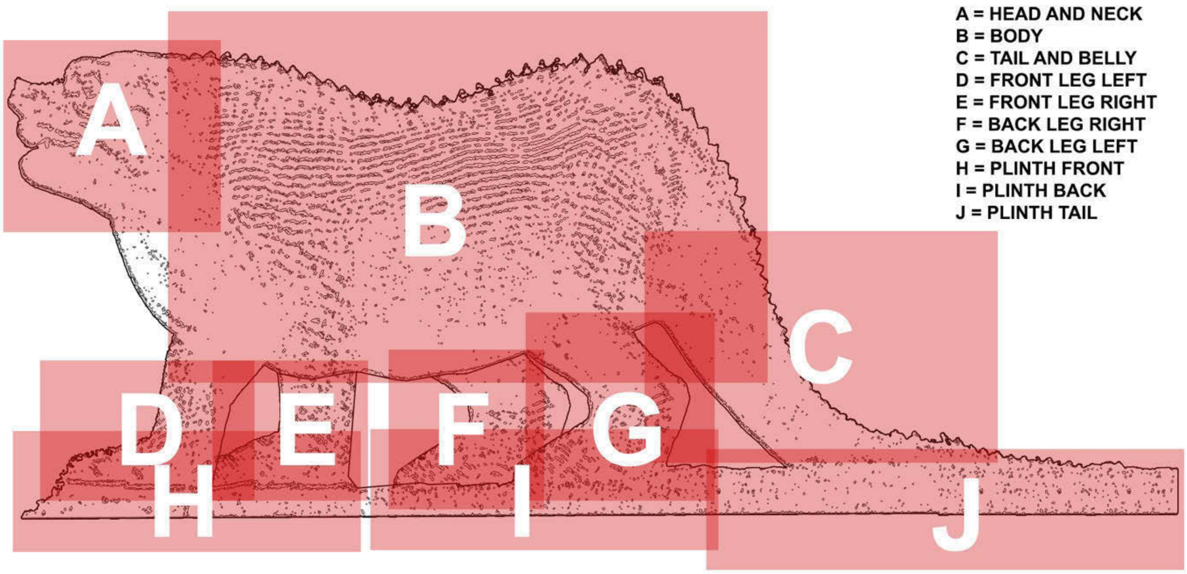


Plate 25 – Diagram depicting the sections of the Iguanodon defined for the purpose of post processing. See Table M3[24].

[24] Gray, S. (2016). Diagram depicting the sections of the Iguanodon used for post processing. [Unpublished .jpg].

Plate 26 – Examples of the stages in post processing -Sparse Cloud, Mesh and Textured Map[25]

3.3

Manual Recording, Measuring and Monitoring of Cracks

A second stage of *manually* monitoring the structural condition changes in the Iguanodon was implemented once the photogrammetry data had been gathered.

The cracks were initially identified and measured over the course of two consecutive days directly after the photogrammetry data set had been collected. These dates were – 14.12.2016 and 15.12.2016. The measurements recorded were the number, location, length, width and depth of the cracks that had developed since the 2015 restoration. The cracks were then re-recorded over two days, three months later - 10.03.2017 and 15.03.2017. These measurements were used to compare changes in crack dimensions over the three-month period.
The cracks in the Standing Iguanodon were recorded and measured with the method described in **Methodology Table 4 (M4).**

[25] Agisoft Photoscan (2015). *3D Model Reconstruction Agisoft PhotoScan*. [image] Available at: https://80.lv/vendors/agisoft/ [Accessed 13 Feb. 2017].

Please see Appendix II for Risk Assessment.

Table M4.

Equipment
Tape Measure Digital Callipers Linestorm Crack Width Gauge Silverline Crack Depth Gauge
Method
• Each crack was identified and allocated a number and the letter A. These were identified as *primary* cracks. Any 'offshoots' from these primary cracks were given the same number proceeded by the next letter in the alphabet, i.e. 1A, 1B, 1C etc. 2A, 2B, 2C etc. These were identified as *secondary* cracks. • The identified cracks were annotated onto diagrams of the Iguanodon. • An 'origin' point was identified for each crack. In the majority of cases, this was a point starting at the ground. This point was photographed and marked with the number 0 onto the surface of the dinosaur. This identified the starting point for measuring. • Working along the crack, at 10cm increments, the length, width and depth of the crack was measured and recorded, using the equipment listed above. Measurement points were marked onto the dinosaur and annotated onto photographs. • Points of interest, such as spalling, paint loss etc. were measured and recorded photographically. • This process was repeated after three months.

Limitations

- Depths <0.5mm and >100mm were capped at those figures due to the limitations of the depth gauge. The gauge was not sensitive enough to be able to accurately record measurements <0.5mm and neither was it long enough to record depths >100mm.
- Loose, but non-disassociated fragments were recorded as having a depth of 100mm as these points were too fragile to take accurate readings.

4.0
Results

The results of the research can be divided into two sections;

1. The Digital Model: Gathering the photographic data and how the digital model can be used to record, display and interpret information regarding the condition of the dinosaur.

2. Assessment of the Crack Recording and Monitoring Programme including what can be understood from the data collected manually over the course of the 3-month monitoring programme.

4.1
Collecting the photographic data and generating the full-scale model

Collecting the photographic data for the full model took four days and generated over 15,000 photographs, each around 5-7MB in size. All images will be stored permanently with the Archaeology Data Service (see chapter 4.1.3).

The digital model was generated at Bristol University by researcher Stephen Gray. The entire process taking approximately 4 months of continuous *automated* computer processing. The 'stitching' together and tidying of the model once the processing was complete took approximately 2 weeks.

Plate 26- Examples of the photographs from the head/neck data set[26]

[26] Carpenter, I. (2016) Contact sheet of the photographs from head/neck data set. [Unpublished Photograph].

4.1.1

Viewing the Full Scale Digital Model

The model and all associated metadata are currently stored at –

https://doi.org/10.6084/m9.figshare.4898921

Unless you already have 3D modelling software on your computer, you will need to install an appropriate programme. Due to the sheer size of the model, fairly powerful hardware is necessary to get the best from the model. Please see Appendix III for instructions on how to install open-source software if you would like to view the full-scale model. Alternatively, follow the link in Chapter 4.1.4 to view the lower resolution model in Sketchfab. This does not require any software installation and can be viewed on most devices including desktop computers, laptops, smartphone and tablets.

The high resolution of the model is best understood by viewing the digitisation as a wire frame model[27]. See plates 27 and 28. These detail images of the eye and foot depict the lines and vertices and how they construct the 3dimensional Image.

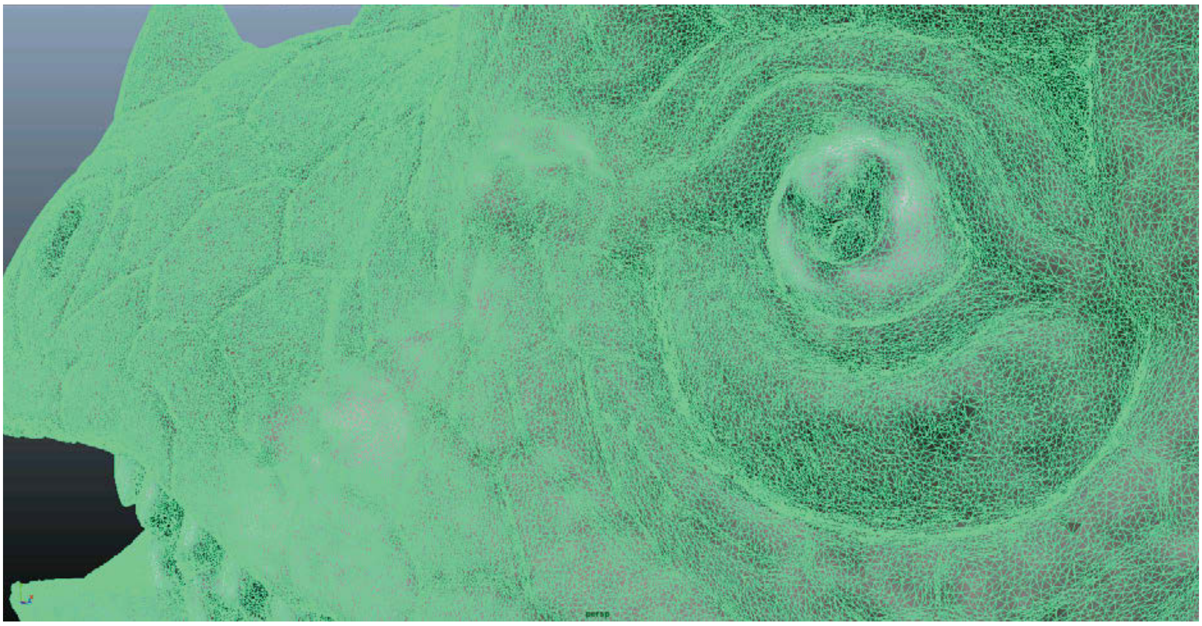
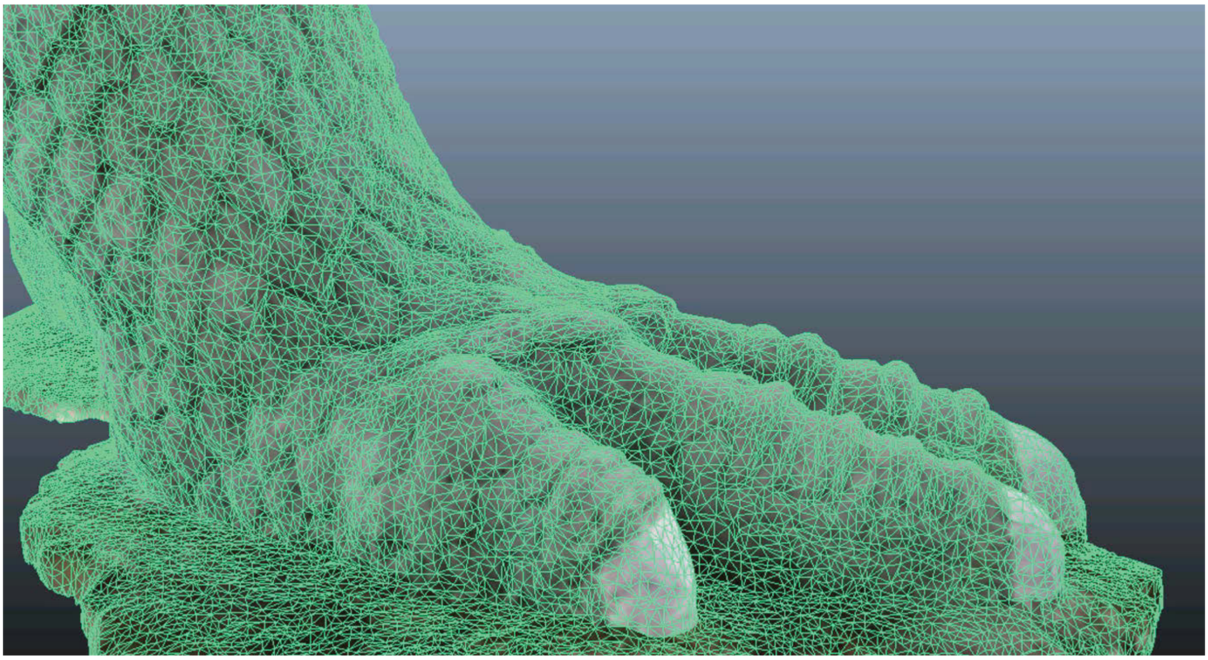


Plate 27- Detail images of full scale, high resolution Iguanodon model viewed in wire frame – Eye.

[27] Wire frame is a skeletal three-dimensional model in which only lines and vertices are represented.



Plates 27-28 – Detail images of full scale, high resolution Iguanodon model viewed in wire frame[28].

The following images (plates 29-35) depict the full-scale model with a texture map applied. The texture map is calculated from the colour information generated from the original photographs and the knowledge of how those pixels map onto the 3D geometry. The images include annotations which describe the location of each of the cracks. These numbers and letters can be used in conjunction with the crack report which is stored permanently with the 3D model.

[28] Gray, S. (2017). Detail images of full scale, high resolution Iguanodon model viewed in wire frame. [Unpublished Screen Capture].

Plate 29 – Full scale digital model with texture– front diagonal view[29]

[29] Gray, S. (2017). Full scale digital model with texture– front diagonal view. [Unpublished Screen Capture].

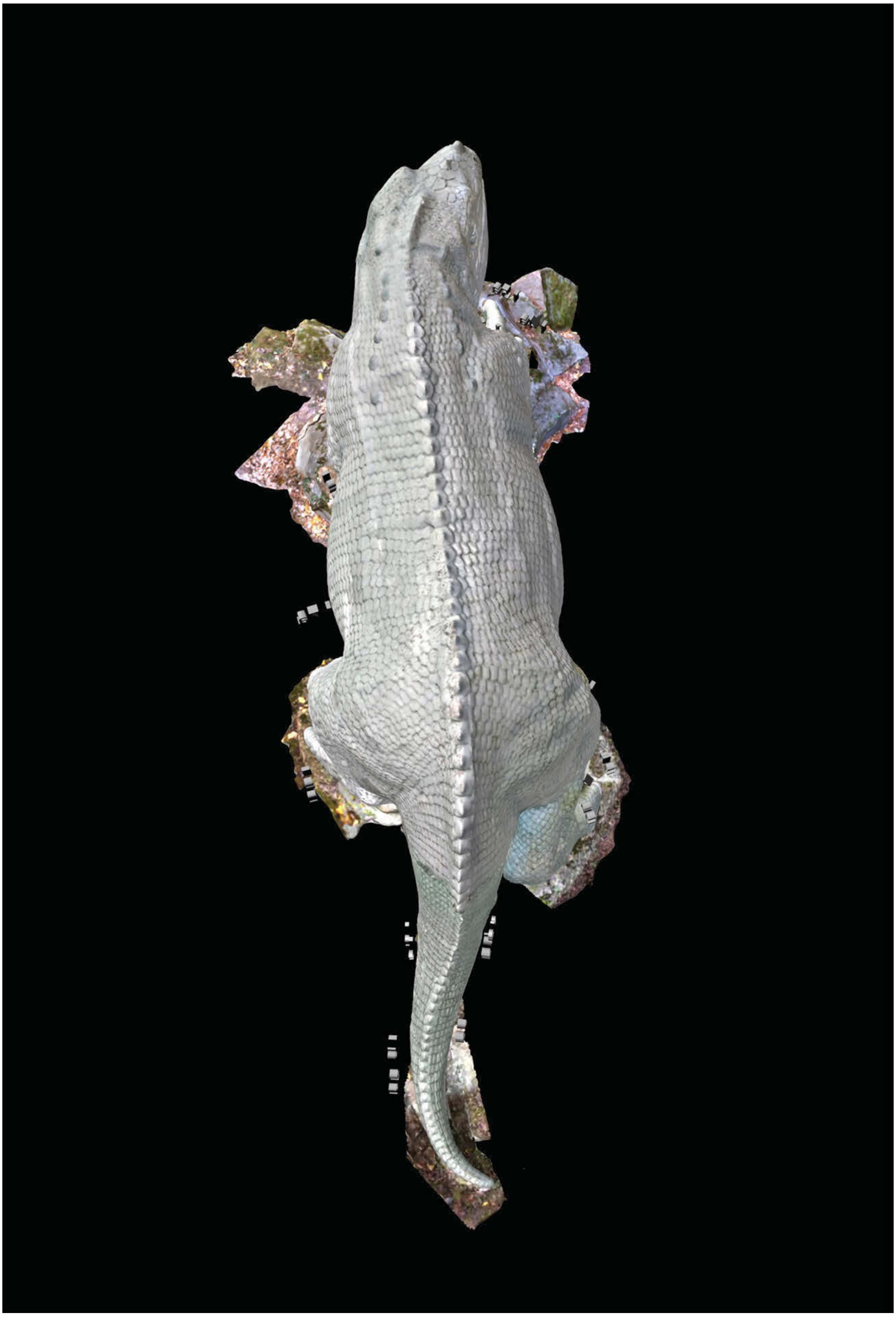


Plate 30 – Full scale digital model with texture– Top view[30]

[30] Gray, S. (2017). Full scale digital model with texture– top view. [Unpublished Screen Capture].

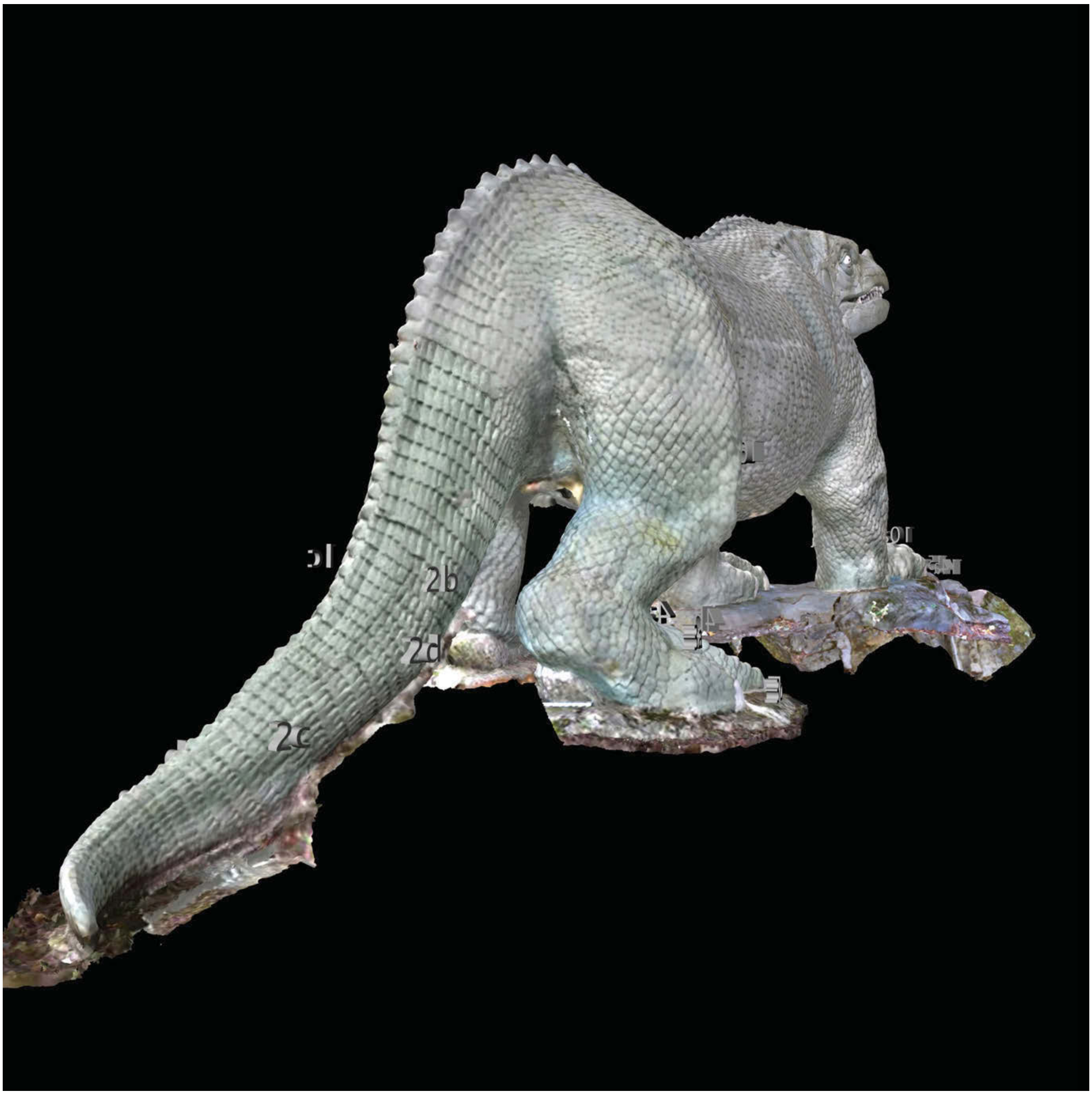


Plate 31 – Full scale digital model with texture – back right diagonal view[31]

[31] Gray, S. (2017). Full scale digital model with texture–back right diagonal view. [Unpublished Screen Capture].

Plate 32 – Full scale digital model with texture – back left diagonal view[32]

[32] Gray, S. (2017). Full scale digital model with texture–back left diagonal view. [Unpublished Screen Capture].

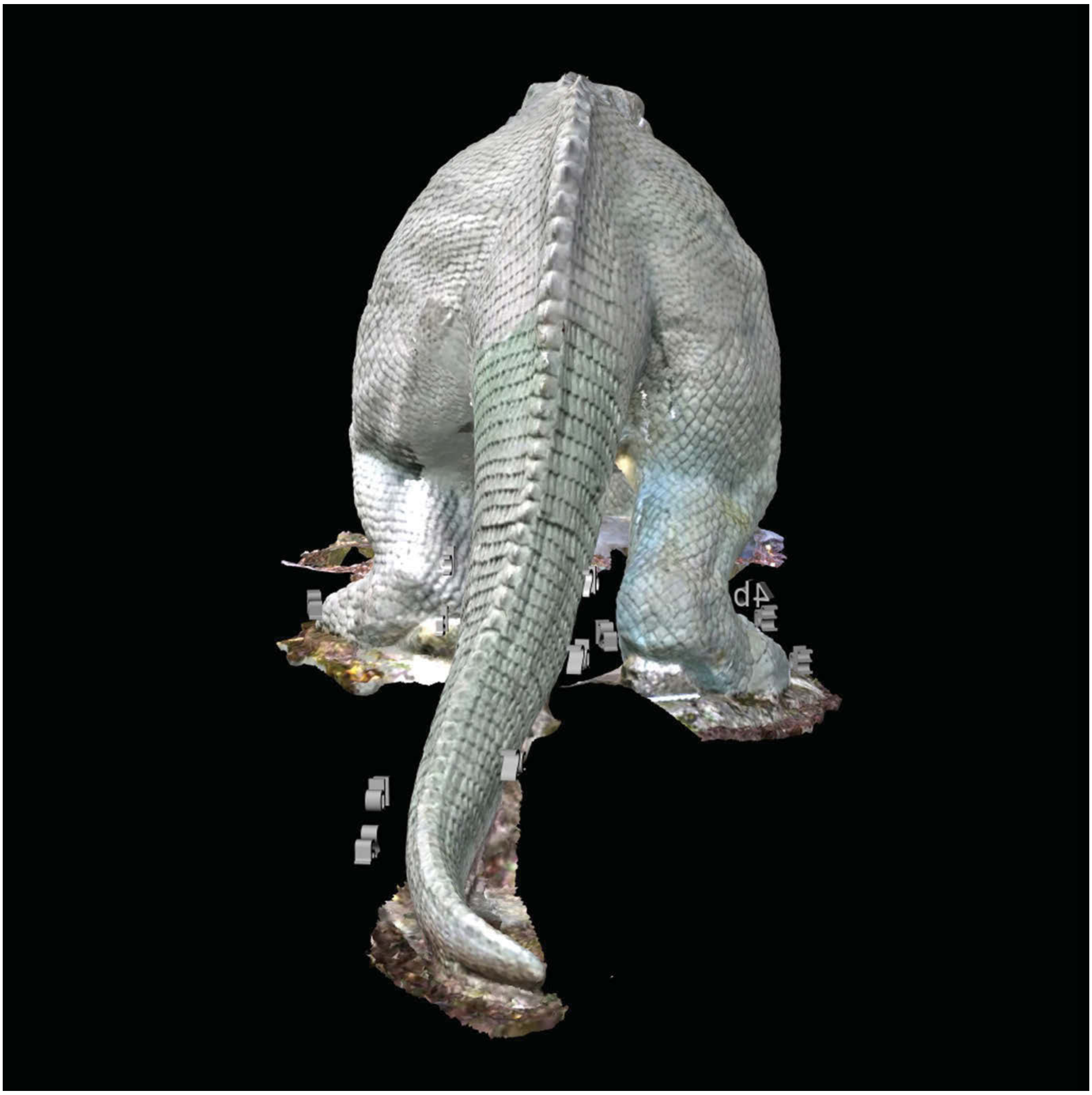


Plate 33 – Full scale digital model with texture – back view[33]

[33] Gray, S. (2017). Full scale digital model with texture–back view. [Unpublished Screen Capture].

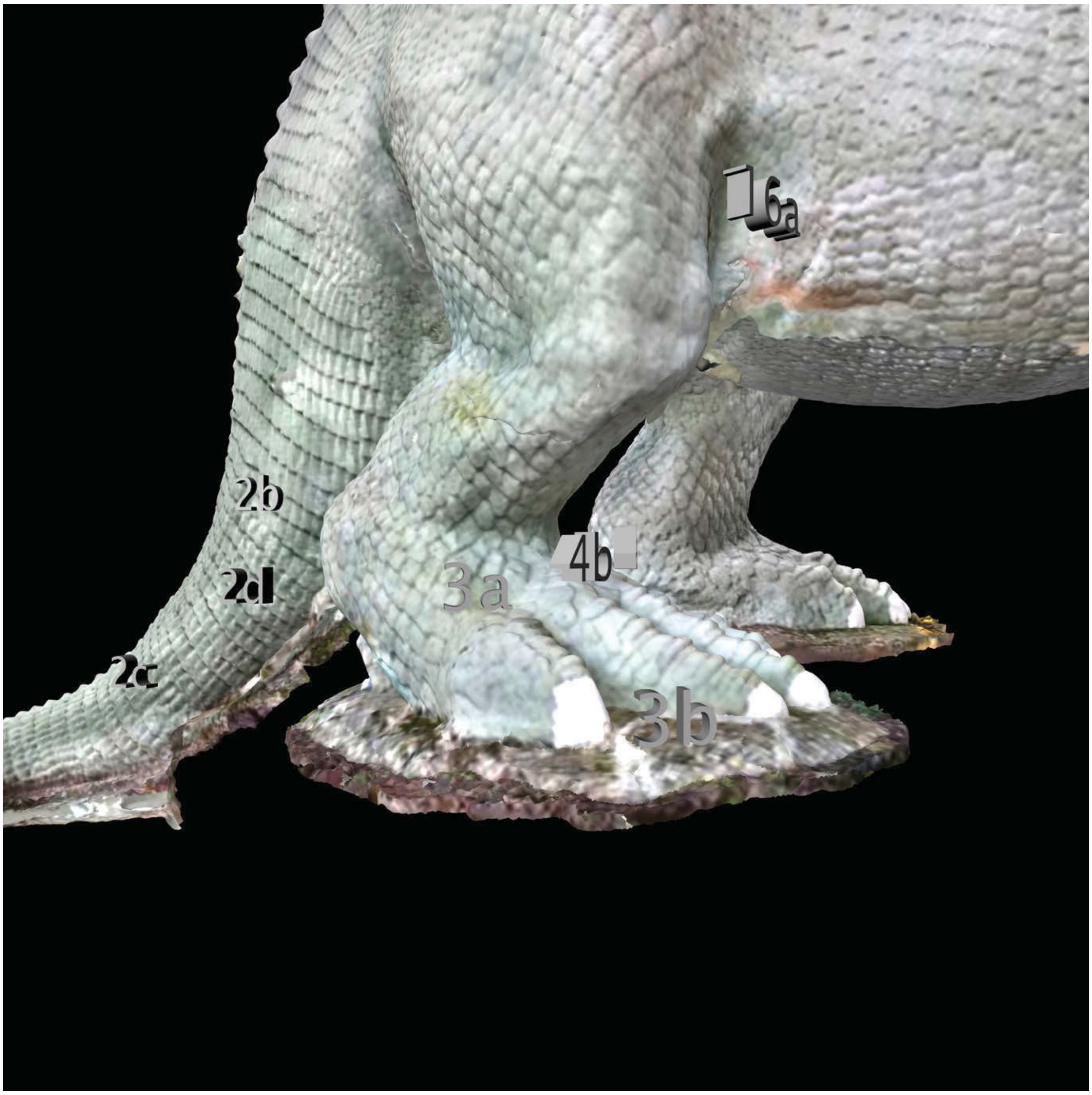


Plate 35 – Full scale digital model with texture – detail of annotations[34]

4.1.2

Using the 3D Digitisation to identify and compare changes in condition

A number of techniques can be used to identify, compare and record changes in the condition using the digital model. Most notable is the ability to navigate the whole model, including ordinarily inaccessible areas (such as the top) with ease.

[34] Gray, S. (2017). Full scale digital model with texture–detail of annotations. [Unpublished Screen Capture].

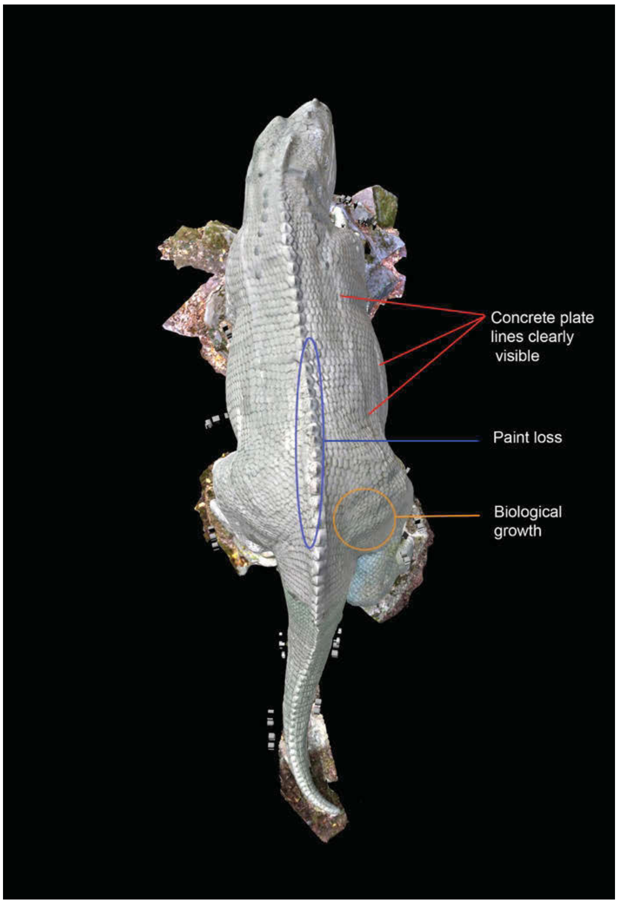


Plate 36 – Digital model viewed from the top – condition issues and structural details revealed[35].

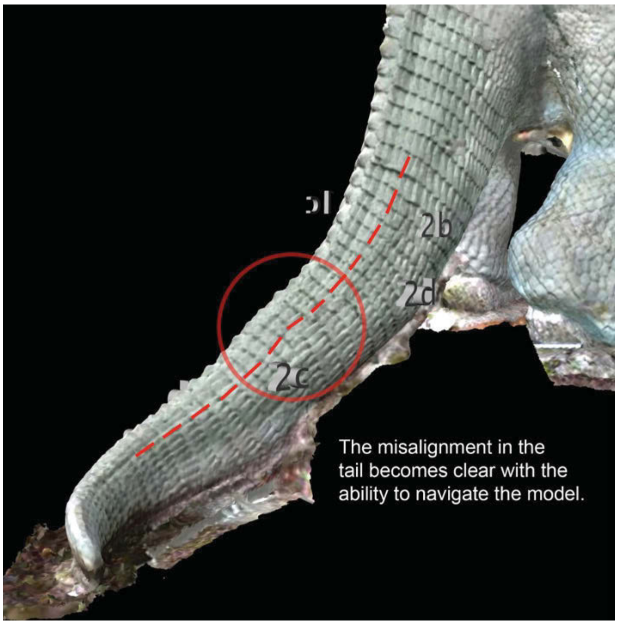
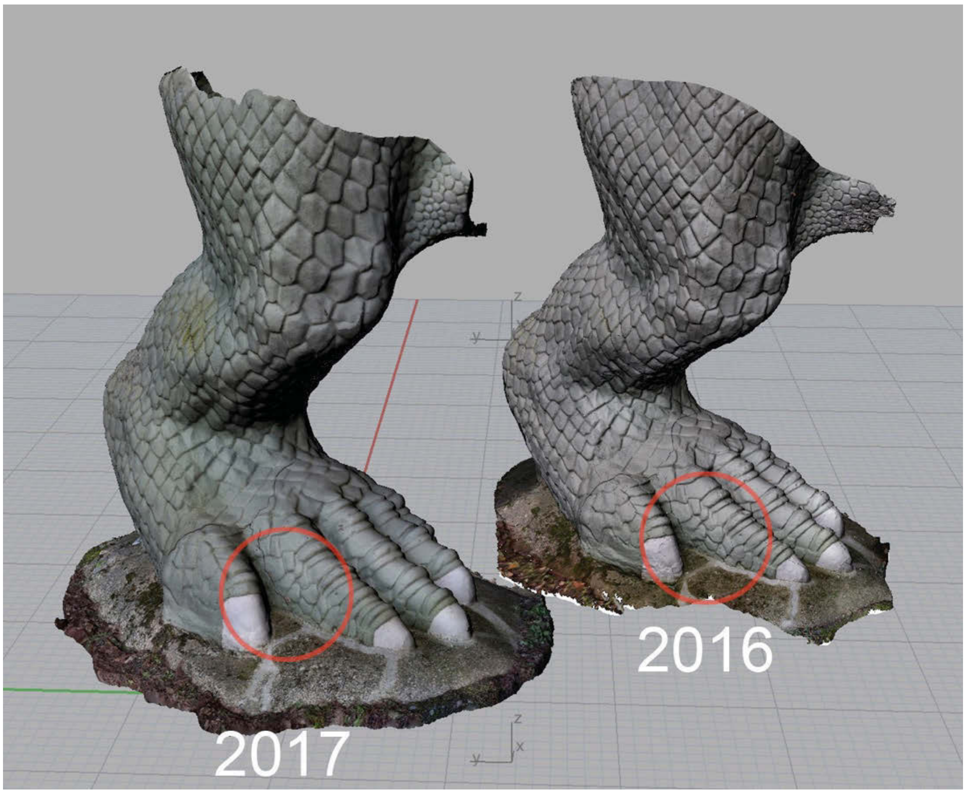


Plate 37 – Distortion of the tail revealed with the ability to navigate the tail and observe from numerous angles[36].

[35] Carpenter, I. Gray, S. (2017). Annotated Screen Capture - Top. [Unpublished Screen Capture].
[36] Carpenter, I. Gray, S. (2017). Annotated Screen Capture - Tail. [Unpublished Screen Capture].

Placing models next to one another enables the viewer to navigate and compare models simultaneously. This is demonstrated in the plates below-

The time limitations of the project meant that it would be unrealistic to return in March to make another *complete* Iguanodon digitisation for comparative purposes. As a compromise, the back-right leg was re-photographed in March 2017 at the same time that the second round of manual crack measurements were made. The following images demonstrate how a 3D digitisation can be used for comparative analytical purposes to identify and monitor changes in condition.



Plates 37,38,39 –Images of the digital model comparing data from 2016 and 2017, red circles identifying concrete loss.[37]

[37] Carpenter, I. (2016). Digital images comparing 2016 and 2017 data of back right leg [Unpublished Screen Shot].

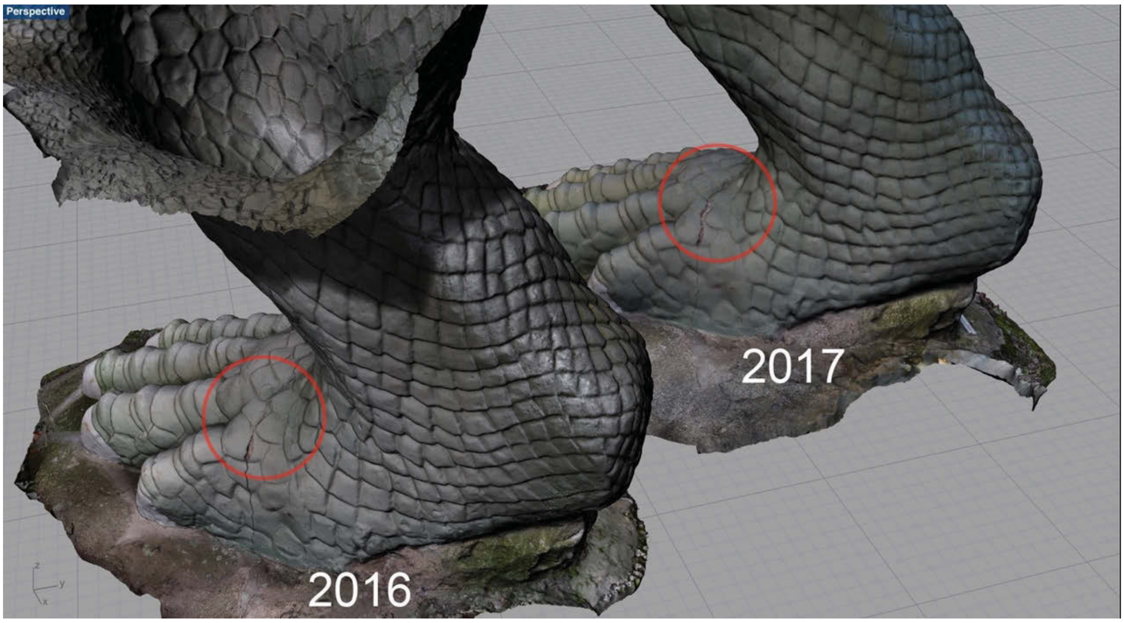


Plate 40 – View of the inside leg 2016-2017 comparison. Red circles indicate areas of paint loss (crack 4A)[38]

The models can also be used to compare other condition issues (see **plate 41**). The red circles highlight an increase in biological growth over the 3-month period and the muddy foot prints on the heel suggest that someone has tried to climb the side of the Iguanodon.

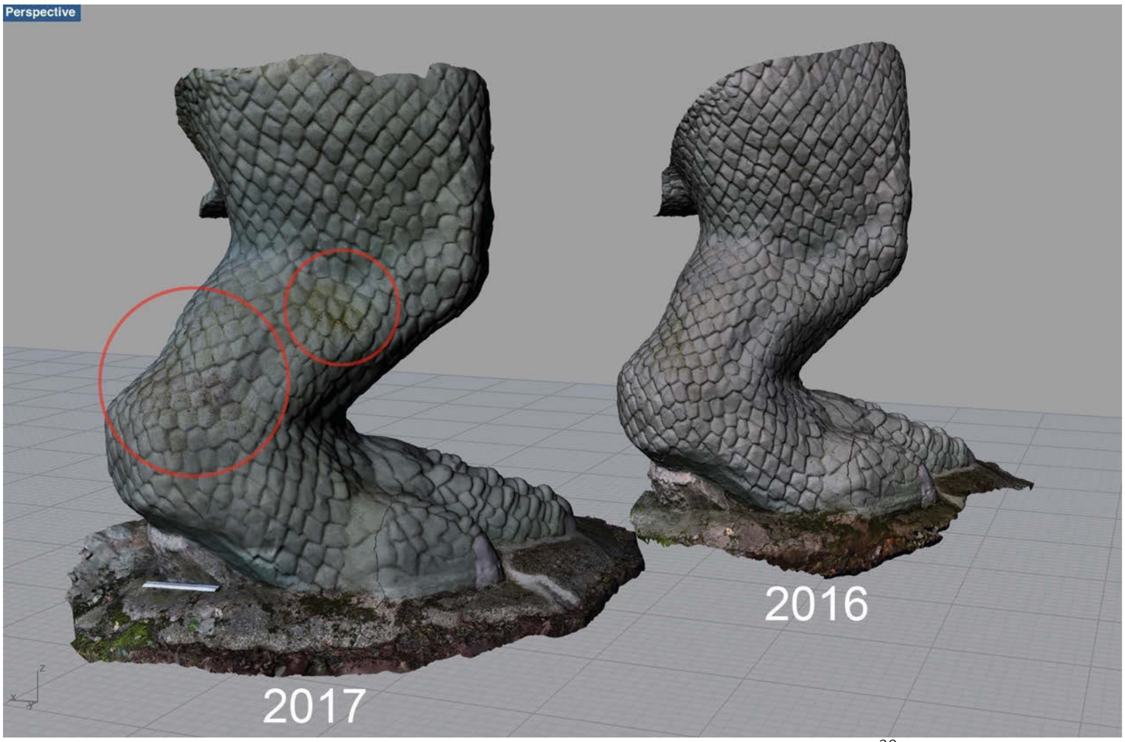


Plate 41 – Red circles indicate biological growth and dirt[39].

[38] Carpenter, I. (2016). Comparative images of the digital model – back right inside leg view - 2016 and 2017 [Unpublished Screen Capture]
[39] Carpenter, I. (2016). Comparative images of the digital model –Identifying biological growth- 2016 and 2017 [Unpublished Screen Capture]

By overlaying the two models, any distortion or the development of large cracks that may be the result of structural changes can be easily identified. This would be an excellent means to assess significant changes in the Iguanodon over a longer period of time. For example, movement in the outer concrete plates and the sinking tail could be tracked and accurately assessed. This technique is less useful for minimal or surface changes. No differences are visible in the plates below due to the minor nature of the changes.

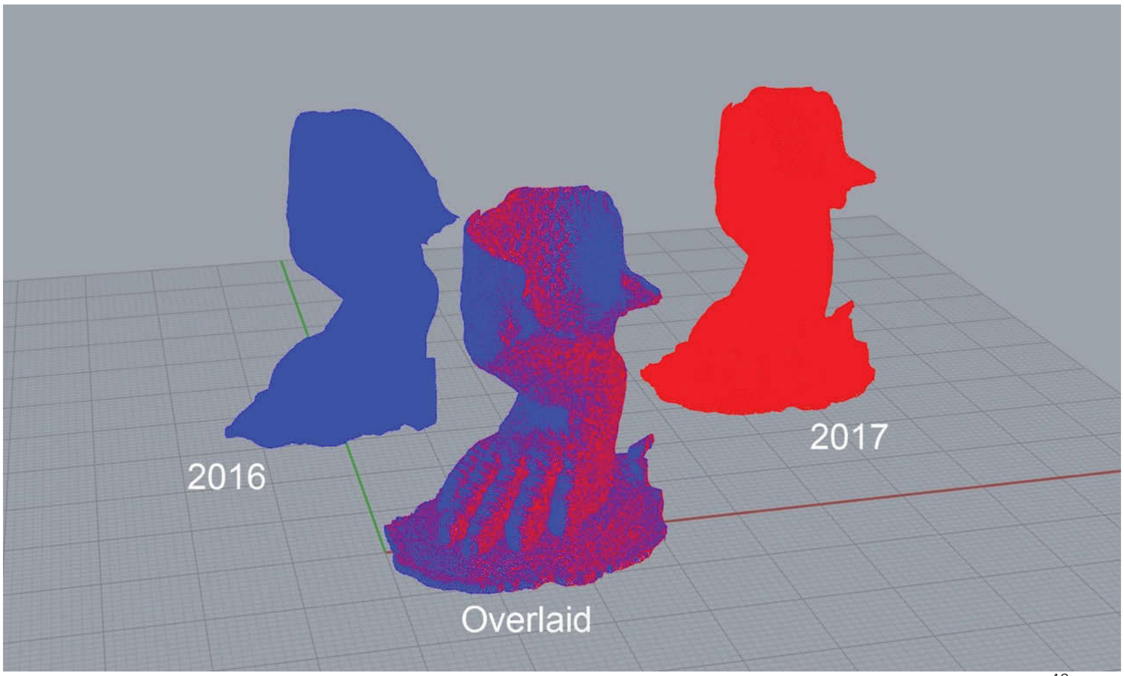


Plate 42 – 2017 and 2016 legs in wireframe view. Centre depicts two models overlaid[40].

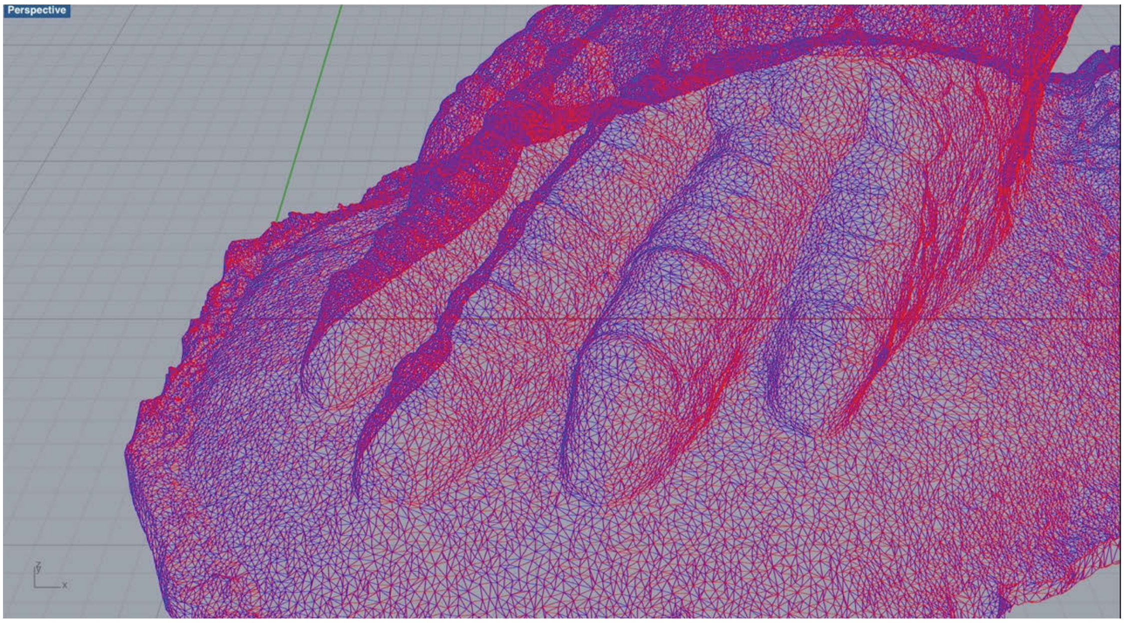


Plate 43 – Detail of overlaid models viewed in wire frame. Structural distortions would be visible due to misalignment of objects when overlaid[41].

[40] Carpenter, I. (2016). Overlaid Images in wireframe view [Unpublished Screen Capture]
[41] Carpenter, I. (2016). Overlaid Images in wireframe view - Detail [Unpublished Screen Capture]

Experimenting with the view settings of the model can facilitate in identifying areas of loss. In plate 44, by eliminating colour, the surface relief is emphasised. This area of surface loss becomes clearly identifiable.

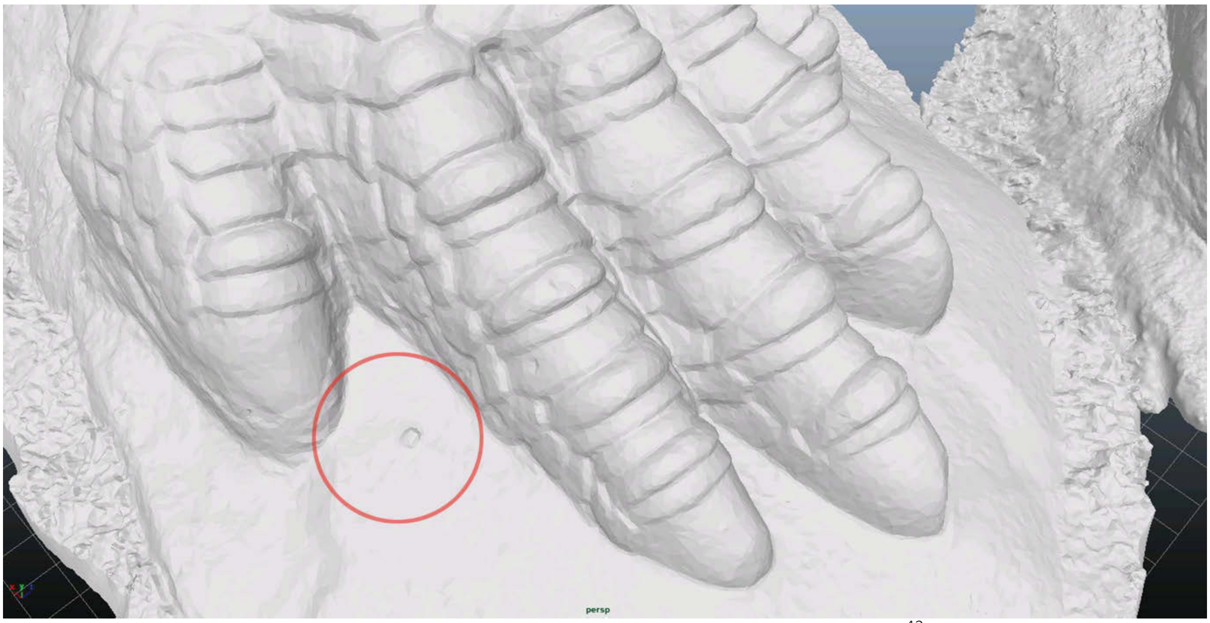


Plate 44 – Loss highlighted by change in view settings[42].

4.1.3

Long-Term Storage of The Digital Models and All Associated Data

The long-term storage of the full-scale digital model and all associated data has been accepted by the Archaeology Data Service (here on referred to as ADS). ADS is an internationally renowned digital archive and currently the only trusted digital repository in the UK that specialises in preserving historic environment data (Archaeologydataservice.ac.uk, 2017). Based at York University, ADS ensure that any data deposited will be professionally curated in the long term and will remain easily accessible for future use. They have very precise guidelines for the submission of data, particularly with regards to meta data accompanying each project. ADS is an open access resource, meaning that data is free at point of use however, each deposit is subject to a fee. ADS have generously waivered their fee for this project. See below for a link to the ADS home page – http://archaeologydataservice.ac.uk/

[42] Gray, S. (2017). Loss Identification enabled by adjustment of view settings. [Unpublished Screen Capture].

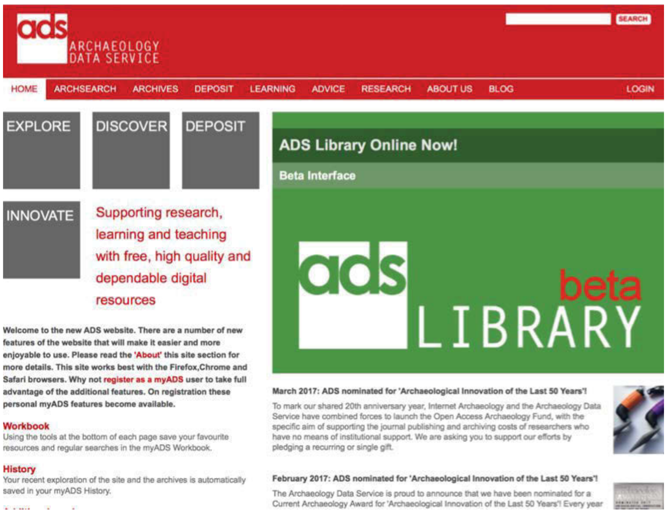


Plate 45 – Home page of the Archaeology Data Service[43]

At the time of writing, the project was waiting to be deposited with ADS and is temporarily stored with Figshare, an online and open access research repository (Figshare.com, 2017). Due to size restrictions of the repository (2GB), the photogrammetry data set cannot be included with the Figshare deposit. See below for a link to the deposit.
https://doi.org/10.6084/m9.figshare.4898921

4.1.4

Sketchfab – The User-Friendly Model

The sheer size of the full-scale high-resolution digital model severely limits its ease of use, as it requires access via a desktop computer and 3D modelling software. Its value lies in its use for future researchers who may wish to view and compare its condition in high resolution, or to further develop and improve the digitisation itself.

The ability to view the model without specialised equipment, quickly and easily and even on-site whilst inspecting the 'real' Iguanodon has been made possible by utilising the world's largest 3D viewing platform Sketchfab. Its community of users is extremely broad, including cultural heritage, gaming, science and education, design and architecture sectors etc. Sketchfab models can be viewed

[43] Archaeologydataservice.ac.uk. (2017). *Archaeology Data Service: Homepage*. [online] Available at: http://archaeologydataservice.ac.uk [Accessed 5 Feb. 2017].

on desktop computers, laptops, smartphones and tablets and the models can be embedded into webpages, Facebook, Twitter, Tumblr, LinkedIn etc.

Sketchfab pro has a size limit of 200MB for each model, so two models were made. One of the full Iguanodon and one more detailed model of the back-right leg (data collected in March 2017).
Both can be accessed here –

Sketchfab Model - Full Standing Iguanodon - https://skfb.ly/67vFS
Sketchfab Model -Back Right Leg of Standing Iguanodon - https://skfb.ly/6pxYX

Both models include reference numbers identifying the locations of the recorded cracks. By clicking on a number, the user is given a hyperlink to the research repository (currently Figshare) and the corresponding page number(s) of the Crack Report pdf. The crack report is a stand-alone document including the results detailed in chapter 3.2 (and continued in Appendix II). The report includes detailed information regarding each of the cracks, including; photographs, graphs, tables and annotated diagrams detailing the locations and dimensions of the cracks (readings taken in 2016 and 2017) along with a summary of the findings from the research.

Plates 46-53 are screen shots of the models and how the user can access the report information.

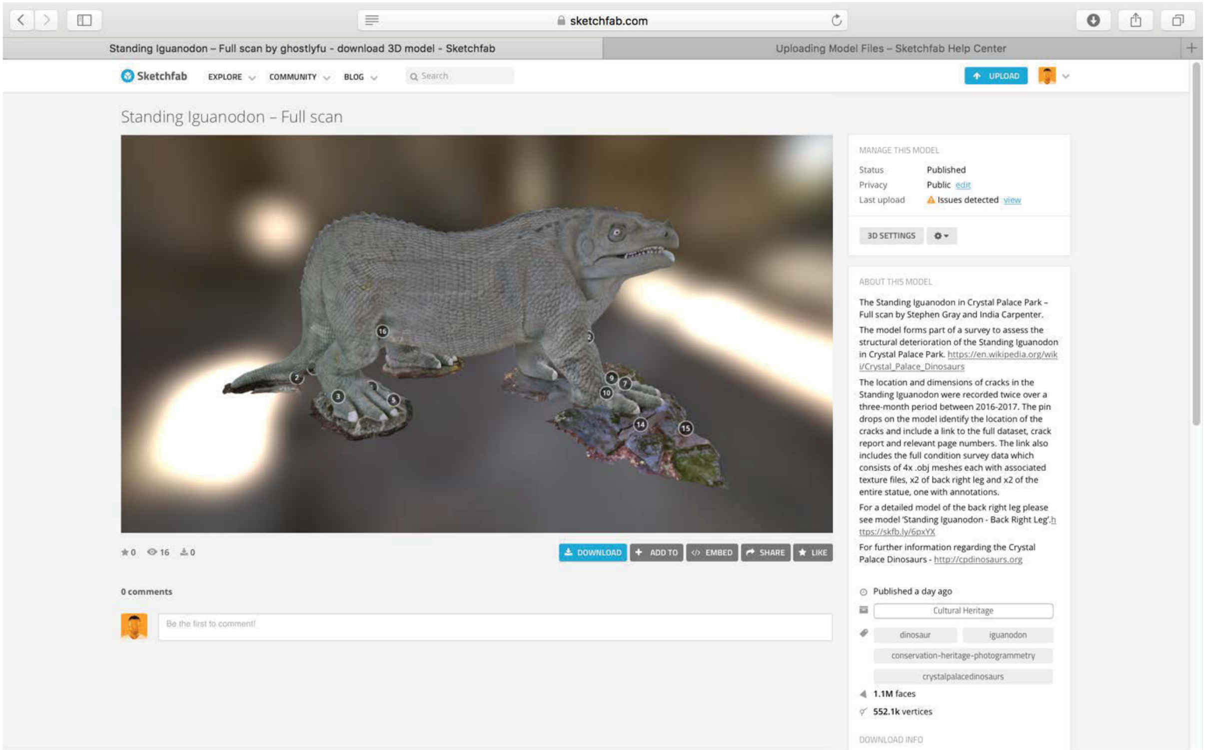


Plate 46- Screen capture of the Full Scale Standing Iguanodon Sketchfab webpage[44]

Plate 47 – Screen Capture of the Full Scale Sketchfab model with annotations[45]

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[44] Carpenter, I. and Gray, S. (2017). *Standing Iguanodon – Full scan by ghostlyfu - download 3D model*. [online] Sketchfab. Available at: https://skfb.ly/67vFS [Accessed 23 Apr. 2017]. [Screen Capture].

[45] Carpenter, I. and Gray, S. (2017). *Standing Iguanodon – Full scan by ghostlyfu - download 3D model*. [online] Sketchfab. Available at: https://skfb.ly/67vFS [Accessed 23 Apr. 2017]. [Screen Capture].

Plate 48 – Screen capture of the back-right leg Sketchfab model with annotations[46]

Plate 49 – Screen capture of the back-right leg (detail of crack 3A) Sketchfab model[47]

[46] Carpenter, I. and Gray, S. (2017). *Standing Iguanodon - Back Right Leg by ghostlyfu - download 3D model*. [online] Sketchfab. Available at: https://skfb.ly/6pxYX [Accessed 23 Apr. 2017]. [Screen Capture]
[47] Carpenter, I. and Gray, S. (2017). *Standing Iguanodon - Back Right Leg by ghostlyfu - download 3D model*. [online] Sketchfab. Available at: https://skfb.ly/6pxYX [Accessed 23 Apr. 2017]. [Screen Capture]

Plate 50 – Activated annotation linking to research repository[48]

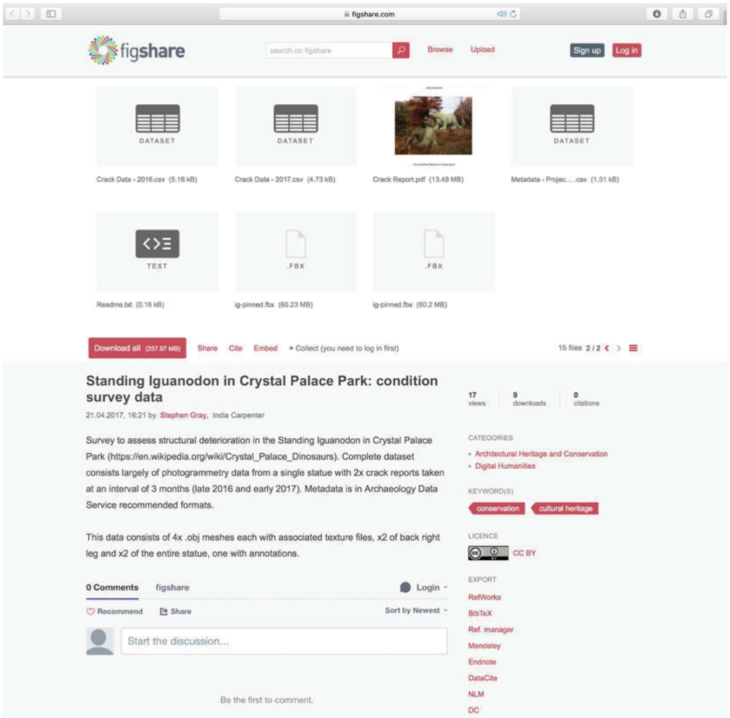
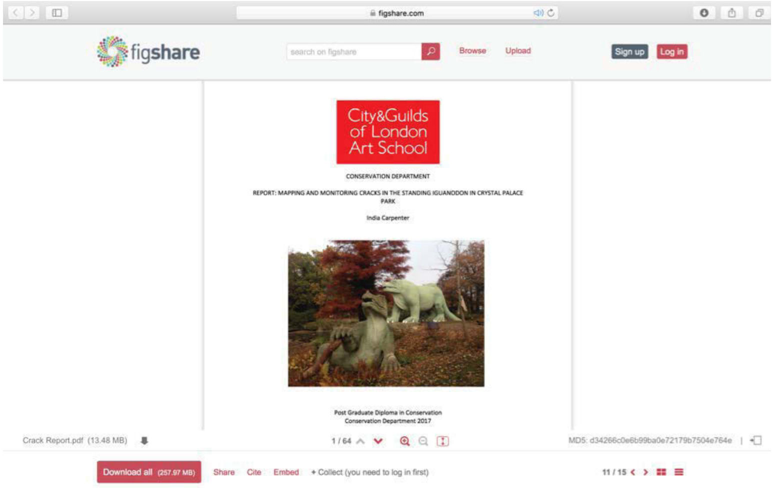


Plate 51 – Figshare research repository screen capture[49]

[48] Carpenter, I. and Gray, S. (2017). *Standing Iguanodon - Back Right Leg by ghostlyfu - download 3D model*. [online] Sketchfab. Available at: https://skfb.ly/6pxYX [Accessed 23 Apr. 2017]. [Screen Capture]
[49] Stephen, G. and India, C. (2017). *Standing Iguanodon in Crystal Palace Park: condition survey data*. [online] figshare. Available at: https://doi.org/10.6084/m9.figshare.4898921 [Accessed 23 Apr. 2017]. [Screen Capture]



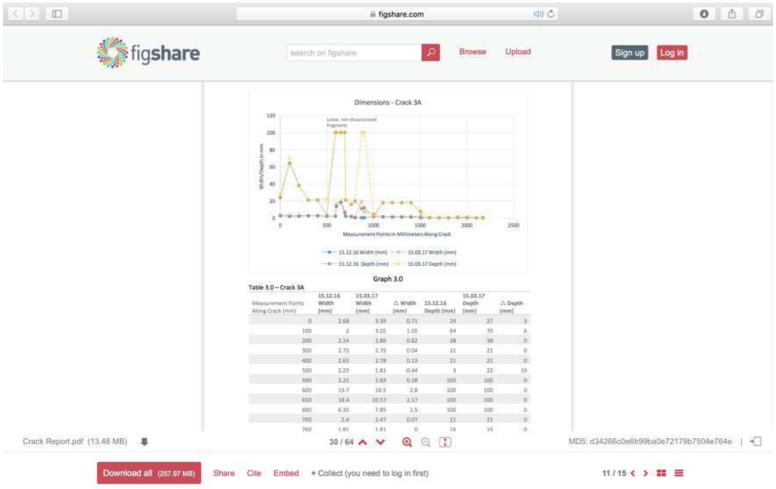


Table 3.0 – Crack 3A

Measurement Points Along Crack (mm)	15.12.16 Width (mm)	15.03.17 Width (mm)	△ Width (mm)	15.12.16 Depth (mm)	15.03.17 Depth (mm)	△ Depth (mm)
0	2.68	3.39	0.71	24	27	3
100	2	3.05	1.05	64	70	6
200	2.24	2.86	0.62	38	38	0
300	2.75	2.79	0.04	21	21	0
400	2.65	2.78	0.13	21	21	0
500	2.25	1.81	-0.44	3	22	19
590	2.25	2.83	0.58	100	100	0
600	13.7	16.5	2.8	100	100	0
650	18.4	20.57	2.17	100	100	0
690	6.35	7.85	1.5	100	100	0
700	2.4	2.47	0.07	21	21	0
760	1.81	1.81	0	16	16	0

Plate 52 and 53 – Crack Report in Figshare, title page and data[50]

[50] Stephen, G. and India, C. (2017). *Standing Iguanodon in Crystal Palace Park: condition survey data.* [online] figshare. Available at: https://doi.org/10.6084/m9.figshare.4898921 [Accessed 23 Apr. 2017]. [Screen Capture]

4.2

Results from the Manual Crack Recording and Monitoring Assessment

This chapter presents the data and results from the crack monitoring programme. The cracks were identified, mapped and measured over the course of two consecutive days – 14.12.16 and 15.12.16 and then returned to three months later and re measured on the 10.03.2017 and 15.03.2017. *Please see chapter 2.3 for the methodology.*

Due to the complexity and scale of the Iguanodon, the analysis of the results has been sectioned into categories; The Tail, Back feet, Front Feet, Front Plinth and Body with an overall conclusion of the entire Iguanodon at the end.

In order to keep the results concise, only the first section (the tail, cracks 1A-2D) has its full set of results, including data, displayed within the main body of this text. The other sections have been edited to include a crack location diagram and a summary. The *full results* including the data in the form of tables and graphs, along with annotated photographs can be found in Appendix IV. Furthermore, a full and complete report on the racks can be found in the research repository at – https://doi.org/10.6084/m9.figshare.4898921

4.2.1
TAIL –
The cracks were identified, measured and recorded on 14.12.2016. They were re-measured and recorded on 10.03.2017.

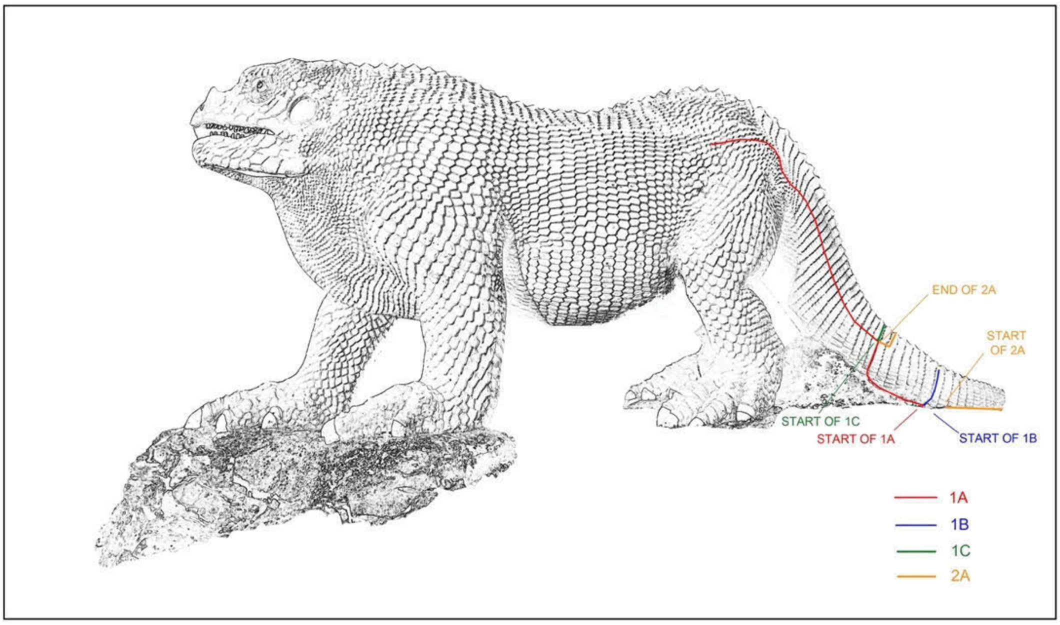


Plate 54- Diagram depicting the location of the cracks 1a,1b,1c.

PHOTOGRAPHS

Crack 1A. Detail images depicting the progressive deterioration related to cracking. Numbers refer to the measurement points along the length of the crack in millimetres.

Plate 55-. Photographed **14.12.16** – 0 identifies the origin and the first measurement point of 1A[51].

[51] Carpenter, I. (2016) Crack 1A. [Unpublished Photograph].

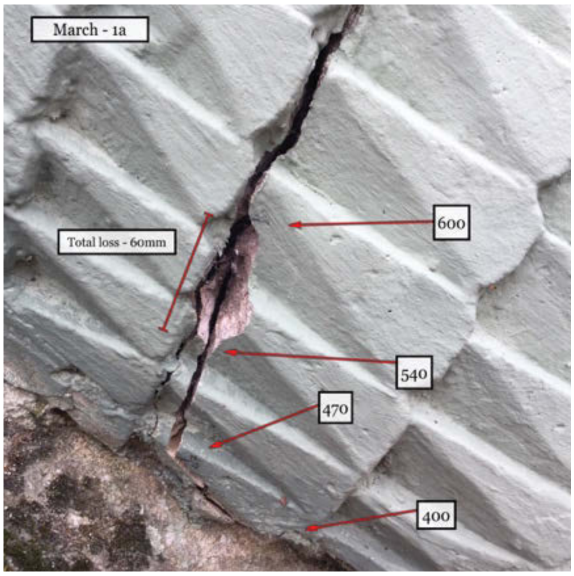


Plate 56-. Photographed **14.12.16**[52]
total

Plate 57-. Photographed **10.03.17** – Indicating loss to crack 1A[53]

DATA

The graphs display the length, width and depth measurements for each individual crack. Starting at 0mm (the crack's origin point), the measurements were recorded every 100mm along the length of the crack and at points of noticeable deterioration.

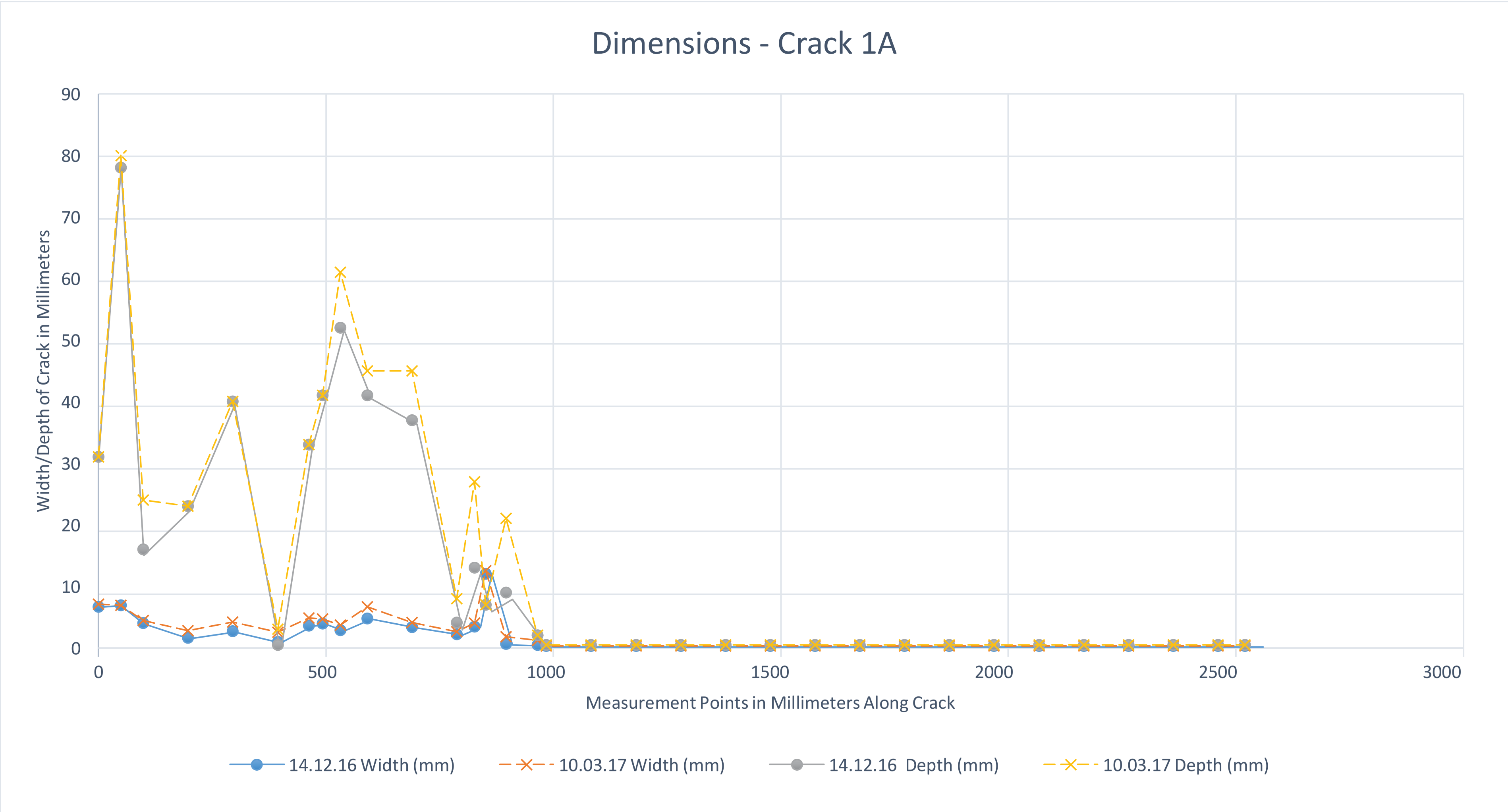
Due to the accuracy limitations of the depth gauge, depth values of 100mm indicate values 100> and depth values of 0.5 indicate values of <0.5.

Loose, but non-disassociated fragments were recorded as having a depth of 100mm as these points were too fragile to take accurate readings.

Measurements were recorded on 14.12.2016 and again on the 10.03.2017.

[52] Carpenter, I. (2016). Crack 1A [Unpublished Photograph].

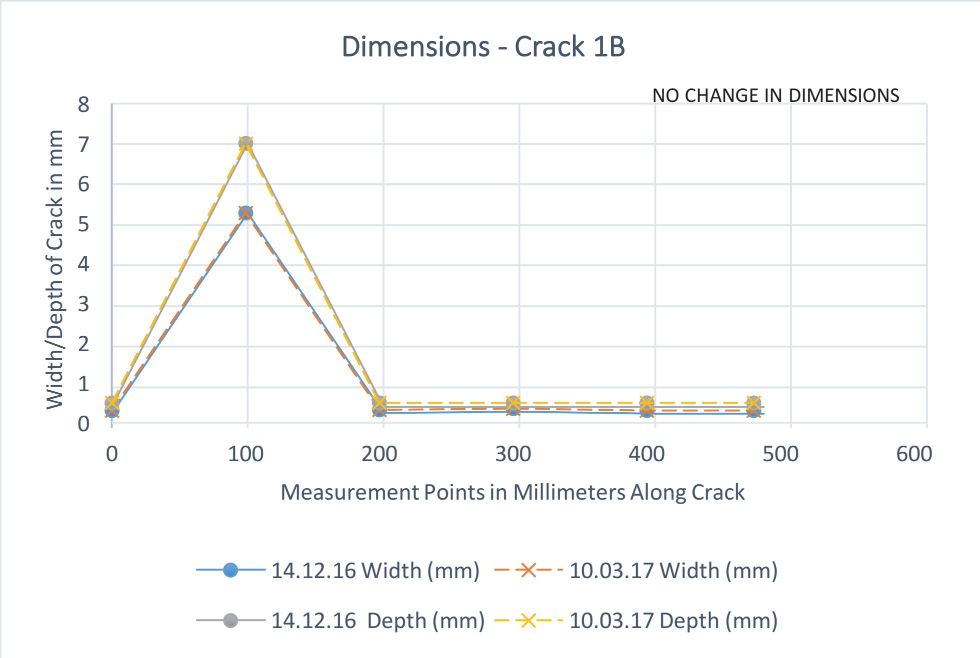
[53] Carpenter, I. (2016). Crack 1A [Unpublished Photograph].


Dimensions - Crack 1A
Width/Depth of Crack in Millimeters
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
2000
2500
3000
Measurement Points in Millimeters Along Crack
14.12.16 Width (mm)
10.03.17 Width (mm)
14.12.16 Depth (mm)
10.03.17 Depth (mm)

Graph 1.0

Table 1.0 – Crack 1A

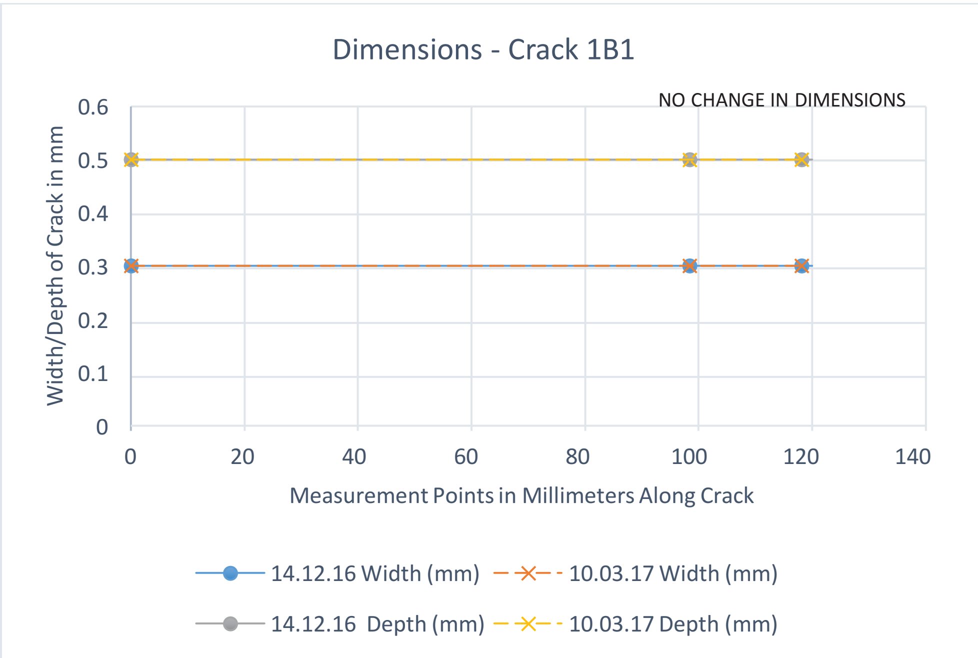
Measurement Points Along Crack (mm)	14.12.16 Width (mm)	10.03.17 Width (mm)	△ Width (mm)	14.12.16 Depth (mm)	10.03.17 Depth (mm)	△ Depth (mm)
0	6.67	7.05	0.38	31	31	0
50	6.9	6.91	0.01	78	80	2
100	4	4.4	0.4	16	24	8
200	1.6	2.79	1.19	23	23	0
300	2.7	4.15	1.45	40	40	0
400	1	2.5	1.5	0.5	3	2.5
470	3.6	4.86	1.26	33	33	0
500	3.94	4.68	0.74	41	41	0
540	2.83	3.69	0.86	52	61	9
600	4.79	6.68	1.89	41	45	4
700	3.36	4.12	0.76	37	45	8
800	2.17	2.6	0.43	4.1	8	3.9
840	3.44	4.05	0.61	13	27	14
865	12	12.56	0.56	7	7	0
910	0.64	1.8	1.16	9	21	12
980	0.45	1.2	0.75	2	2	0
1000	0.3	0.3	0	0.5	0.5	0
1100	0.3	0.3	0	0.5	0.5	0
1200	0.3	0.3	0	0.5	0.5	0
1300	0.3	0.3	0	0.5	0.5	0
1400	0.3	0.3	0	0.5	0.5	0
1500	0.3	0.3	0	0.5	0.5	0
1600	0.3	0.3	0	0.5	0.5	0
1700	0.3	0.3	0	0.5	0.5	0
1800	0.3	0.3	0	0.5	0.5	0
1900	0.3	0.3	0	0.5	0.5	0
2000	0.3	0.3	0	0.5	0.5	0
2100	0.3	0.3	0	0.5	0.5	0
2200	0.3	0.3	0	0.5	0.5	0
2300	0.3	0.3	0	0.5	0.5	0
2400	0.3	0.3	0	0.5	0.5	0
2500	0.3	0.3	0	0.5	0.5	0
2560	0.3	0.3	0	0.5	0.5	0



Graph 1.1

Table 1.1– Crack 1B

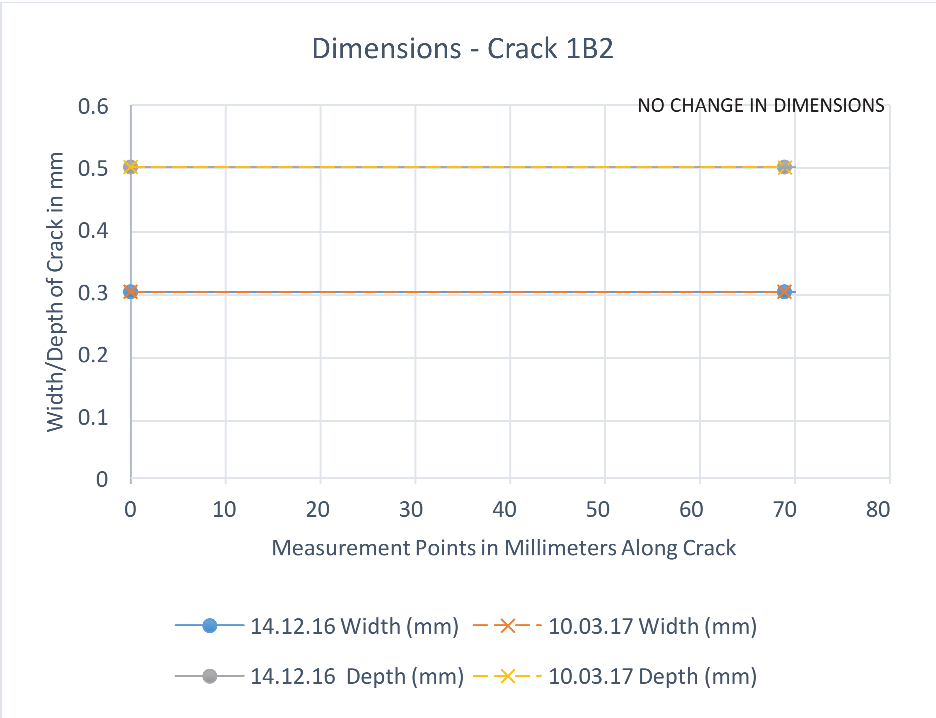
Measurement Points Along Crack (mm)	14.12.16 Width (mm)	10.03.17 Width (mm)	△ Width (mm)	14.12.16 Depth (mm)	10.03.17 Depth (mm)	△ Depth (mm)
0	0.3	0.3	0	0.5	0.5	0
100	5.26	5.26	0	7	7	0
200	0.32	0.32	0	0.5	0.5	0
300	0.35	0.35	0	0.5	0.5	0
400	0.3	0.3	0	0.5	0.5	0
480	0.3	0.3	0	0.5	0.5	0



Graph 1.2

Table R.1.2 – Crack 1B1

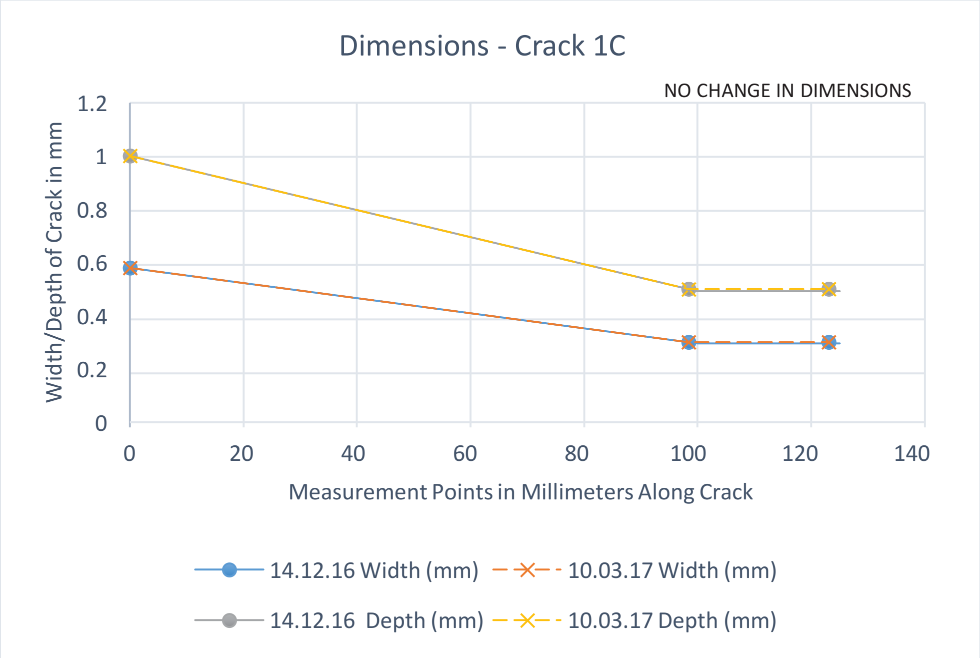
Measurement Points Along Crack (mm)	14.12.16 Width (mm)	10.03.17 Width (mm)	△ Width (mm)	14.12.16 Depth (mm)	10.03.17 Depth (mm)	△ Depth (mm)
0	0.3	0.3	0	0.5	0.5	0
100	0.3	0.3	0	0.5	0.5	0
120	0.3	0.3	0	0.5	0.5	0



Graph 1.3

Table 1.3 – Crack 1B2

Measurement Points Along Crack (mm)	14.12.16 Width (mm)	10.03.17 Width (mm)	△ Width (mm)	14.12.16 Depth (mm)	10.03.17 Depth (mm)	△ Depth (mm)
0	0.3	0.3	0	0.5	0.5	0
70	0.3	0.3	0	0.5	0.5	0



Graphs 1.4

Table 1.4 – Crack 1C

Measurement Points Along Crack (mm)	14.12.16 Width (mm)	10.03.17 Width (mm)	△ Width (mm)	14.12.16 Depth (mm)	10.03.17 Depth (mm)	△ Depth (mm)
0	0.58	0.58	0	1	1	0
100	0.3	0.3	0	0.5	0.5	0
125	0.3	0.3	0	0.5	0.5	0

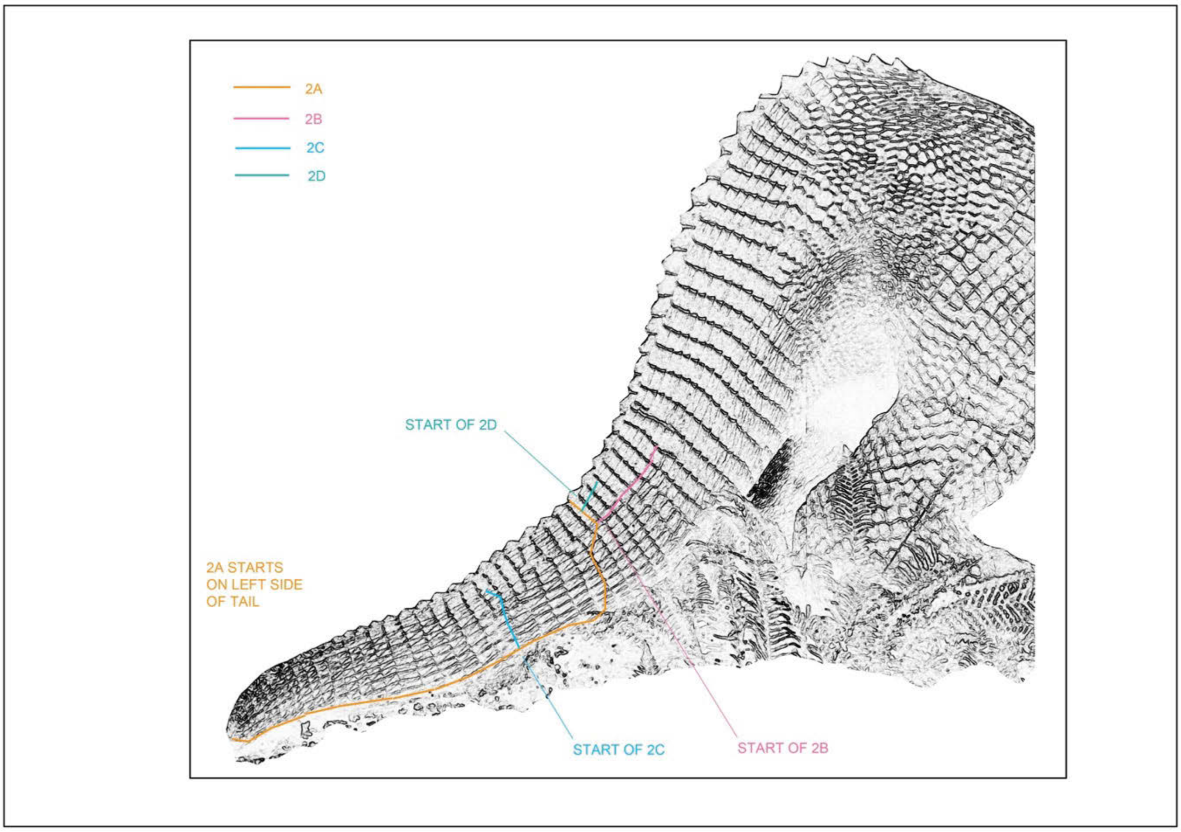


Plate 58-. Diagram depicting the location of the cracks 2A, 2B,2C,2D.

Crack 2A. Detail images depicting the progressive deterioration related to cracking. Numbers refer to the measurement points along the length of the crack in millimetres.

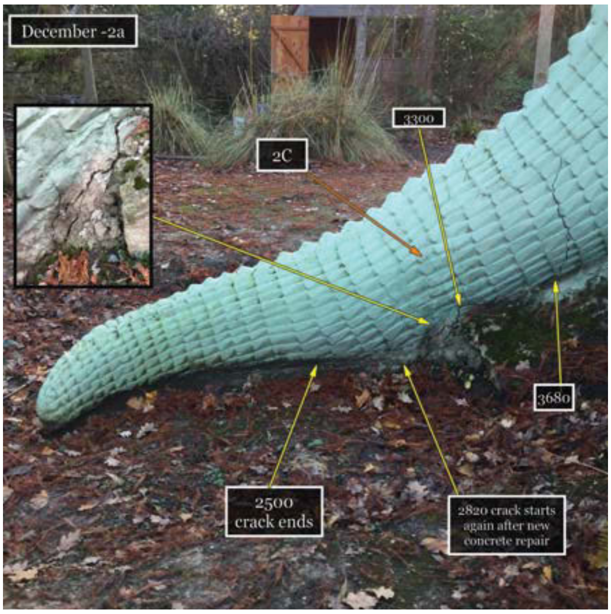


Plate 59-. Photographed **14.12.16**[54]

[54] Carpenter, I. (2016). Cracks 2A, 2B,2C. [Unpublished Photograph].

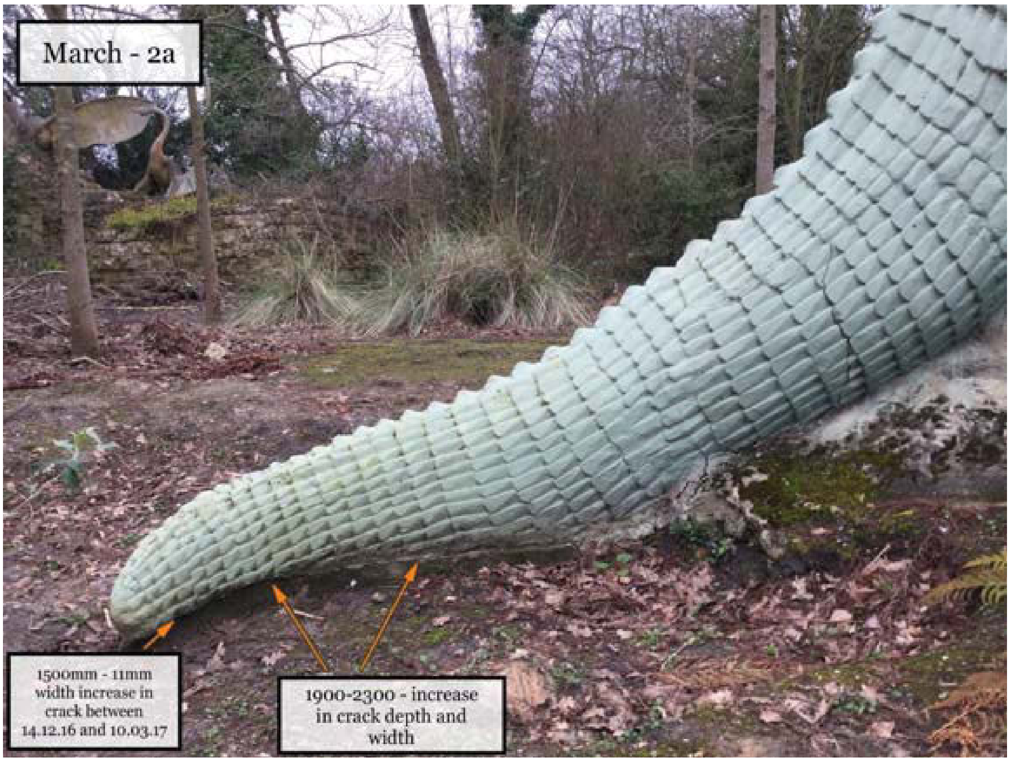


Plate 60- Photographed **10.03.17** - Locating the points of greatest crack depth and width increase[55]

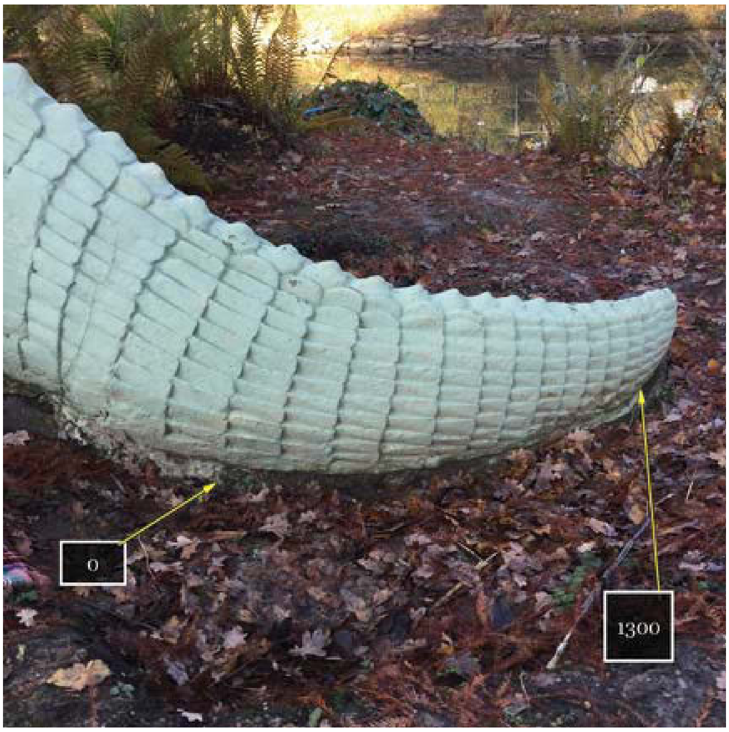
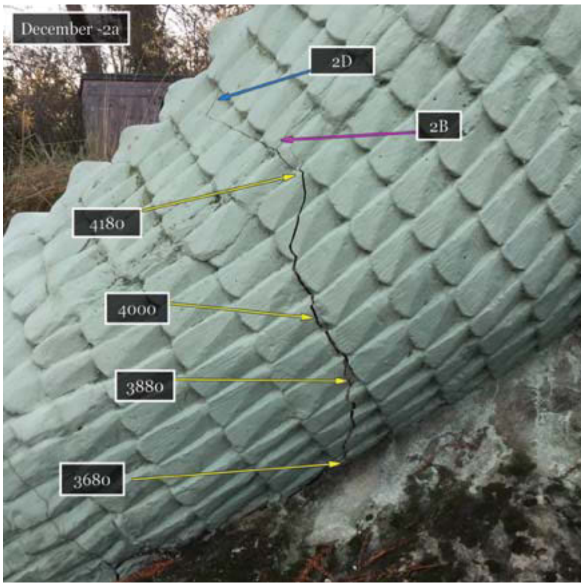


Plate 61-. Photographed **14.12.16 –** Crack 2A origin point and end of tail[56]

[55] Carpenter, I. (2016). Crack 2A [Unpublished Photograph].
[56] Carpenter, I. (2016). Crack 2A [Unpublished Photograph].



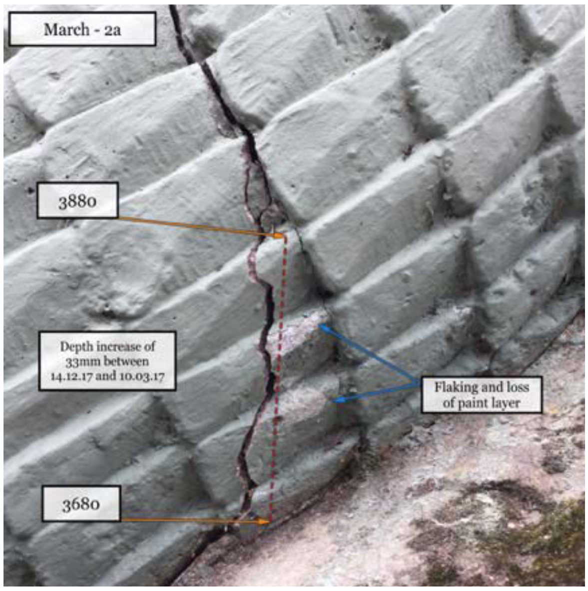
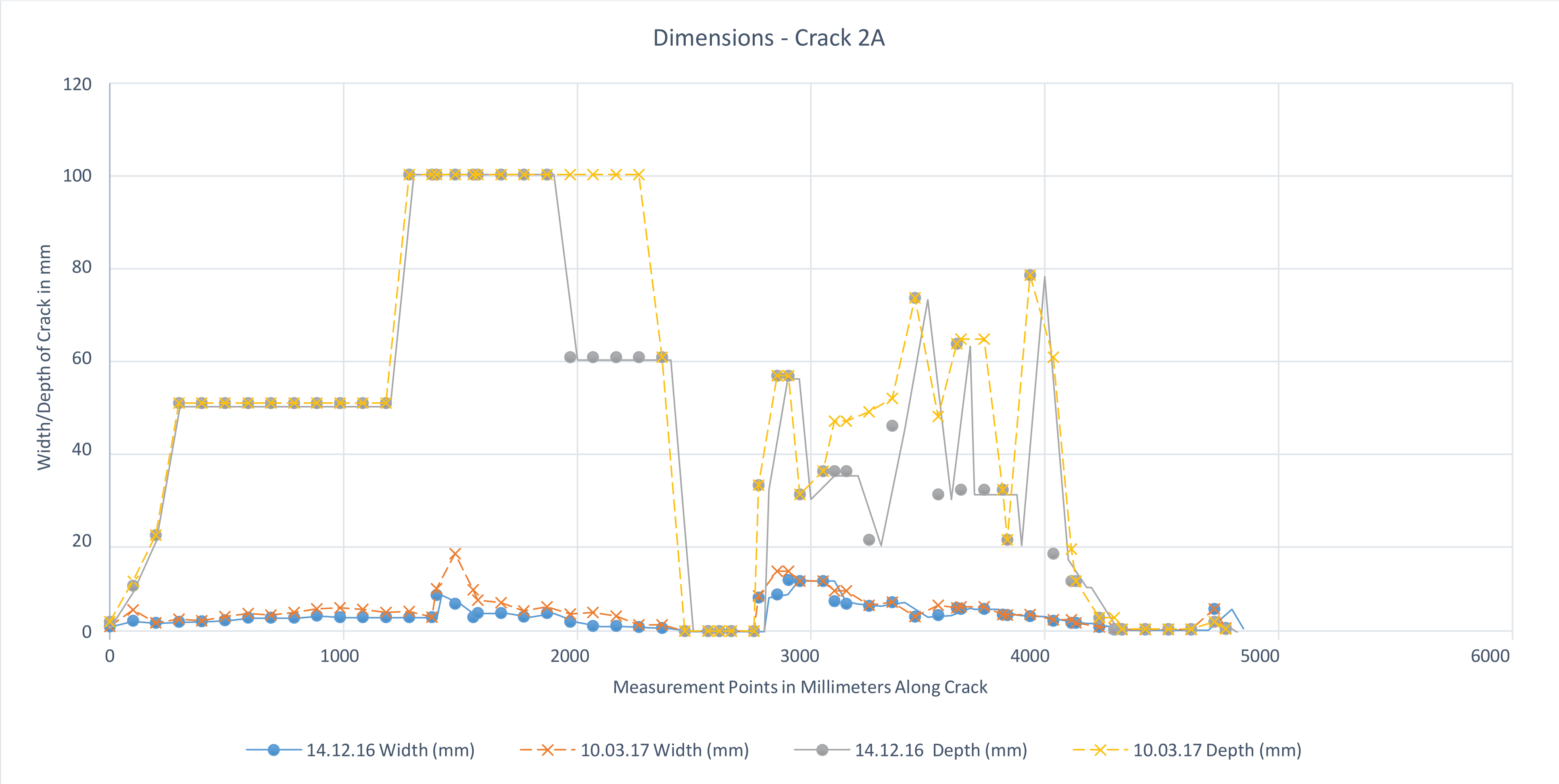


Plate 62-. Photographed **14.12.16**[57] **Plate 63-**. Photographed **10.03.17**[58]
Crack 2A continues from base and over to the left side of the tail where it meets crack 1a. Crack 2A has formed in the original concrete, not in a historical repair.

Plate 64-. Photographed **14.12.16 –** End measurement point of Crack[59]

[57] Carpenter, I. (2016). Crack 2A [Unpublished Photograph].
[58] Carpenter, I. (2016). Crack 2A [Unpublished Photograph].
[59] Carpenter, I. (2016). Crack 2A [Unpublished Photograph].

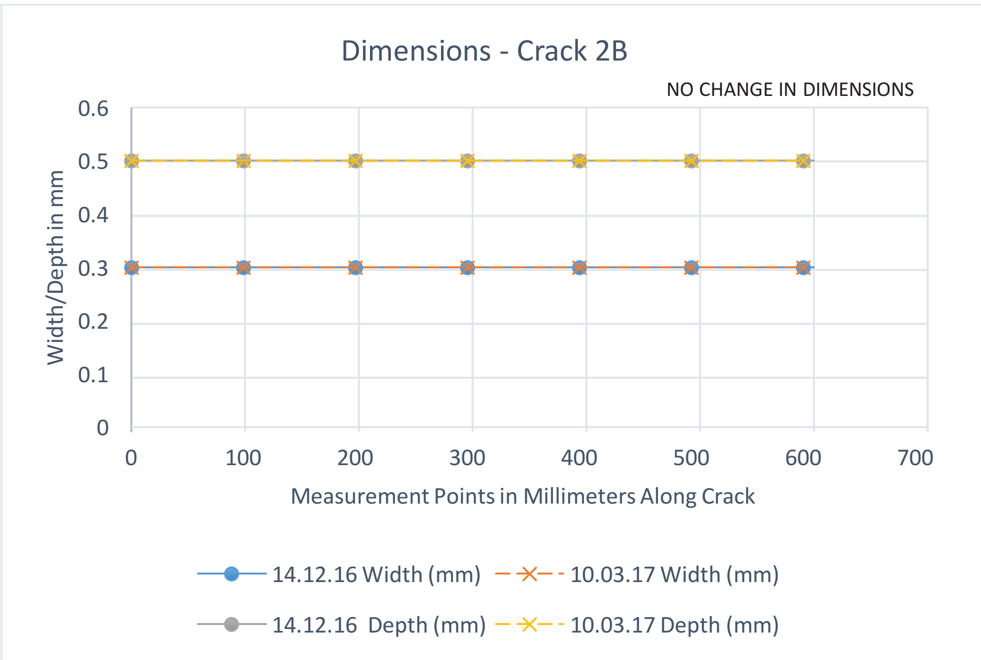

Dimensions - Crack 2A
Width/Depth of Crack in mm
0
20
40
60
80
100
120
0
1000
2000
3000
4000
5000
6000
Measurement Points in Millimeters Along Crack
14.12.16 Width (mm)
10.03.17 Width (mm)
14.12.16 Depth (mm)
10.03.17 Depth (mm)

Graph 2.0

Table 2.0 – Crack 2A

Measurement Points Along Crack (mm)	14.12.16 Width (mm)	10.03.17 Width (mm)	△ Width (mm)	14.12.16 Depth (mm)	10.03.17 Depth (mm)	△ Depth (mm)
0	1	1	0	2	2	0
100	2.3	4.7	2.4	10	11	1
200	1.8	1.8	0	21	21	0
300	2.1	2.64	0.54	50	50	0
400	2.2	2.3	0.1	50	50	0
500	2.4	3.2	0.8	50	50	0
600	2.9	3.8	0.9	50	50	0
700	2.9	3.5	0.6	50	50	0
800	2.9	4.1	1.2	50	50	0
900	3.4	4.85	1.45	50	50	0
1000	3.1	5.09	1.99	50	50	0
1100	3.1	4.8	1.7	50	50	0
1200	3.1	4.03	0.93	50	50	0
1300	3.1	4.35	1.25	100	100	0
1400	3.1	3.1	0	100	100	0
1420	7.9	9.3	1.4	100	100	0
1500	6	17	11	100	100	0
1580	3.1	9	5.9	100	100	0
1600	4	6.78	2.78	100	100	0
1700	4	6.2	2.2	100	100	0
1800	3.2	4.39	1.19	100	100	0
1900	4	5.3	1.3	100	100	0
2000	2.1	3.7	1.6	60	100	40
2100	1.09	4.03	2.94	60	100	40
2200	1.09	3.33	2.24	60	100	40
2300	0.89	1.36	0.47	60	100	40
2400	0.7	1.36	0.66	60	60	0
2500	0	0	0	0	0	0
2600	0	0	0	0	0	0
2650	0	0	0	0	0	0
2700	0	0	0	0	0	0
2800	0	0	0	0	0	0
2820	7.37	7.7	0.33	32	32	0
2900	8	13.1	5.1	56	56	0
2950	11.19	13.1	1.91	56	56	0
3000	11	11	0	30	30	0
3100	11	11	0	35	35	0
3150	6.58	8.84	2.26	35	46	11
3200	6	8.84	2.84	35	46	11
3300	5.57	5.66	0.09	20	48	28
3400	6.3	6.3	0	45	51	6

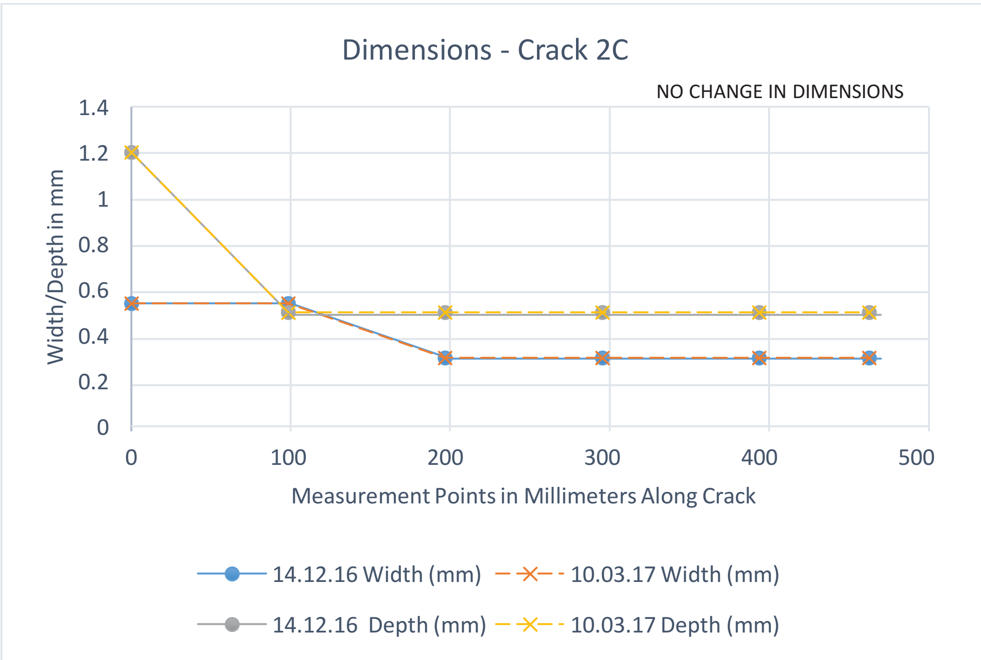
3500	3.2	3.2	0	73	73	0
3600	3.49	5.66	2.17	30	47	17
3680	5.1	5.1	0	63	63	0
3700	4.9	5.35	0.45	31	64	33
3800	4.9	5.35	0.45	31	64	33
3880	3.65	3.65	0	31	31	0
3900	3.56	3.56	0	20	20	0
4000	3.29	3.59	0.3	78	78	0
4100	2.3	2.45	0.15	17	60	43
4180	1.8	2.54	0.74	11	18	7
4200	1.8	1.8	0	11	11	0
4300	0.93	0.93	0	3	3	0
4365	0.3	0.65	0.35	0.5	3	2.5
4400	0.3	0.3	0	0.5	0.5	0
4500	0.3	0.3	0	0.5	0.5	0
4600	0.3	0.3	0	0.5	0.5	0
4700	0.3	0.3	0	0.5	0.5	0
4800	4.9	4.9	0	2	2	0
4850	0.7	0.7	0	0.5	0.5	0



Graph 2.1

Table 2.1 – 2B

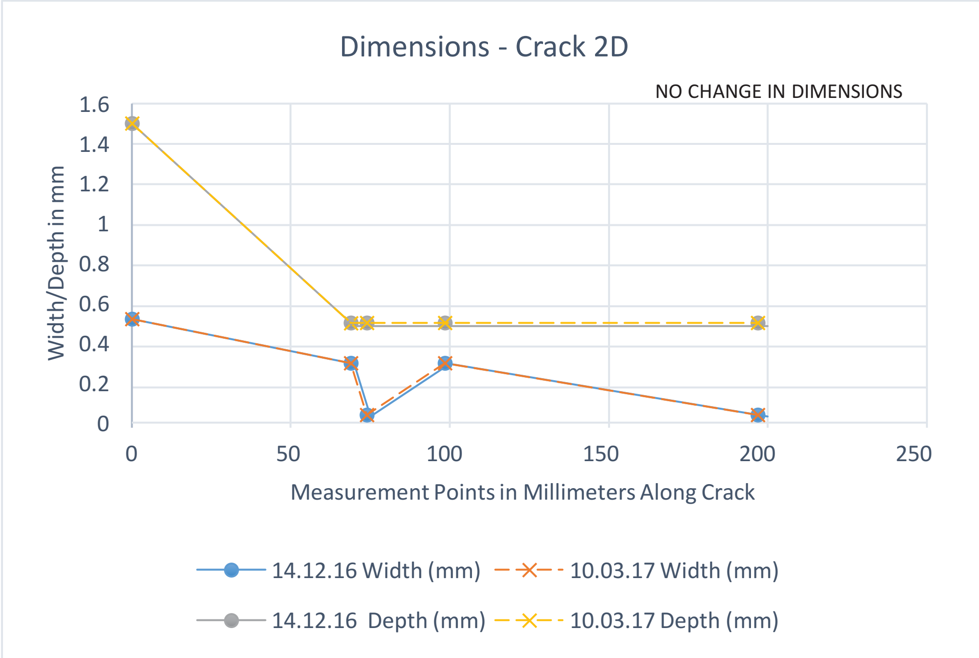
Measurement Points Along Crack (mm)	14.12.16 Width (mm)	10.03.17 Width (mm)	△ Width (mm)	14.12.16 Depth (mm)	10.03.17 Depth (mm)	△ Depth (mm)
0	0.3	0.3	0	0.5	0.5	0
100	0.3	0.3	0	0.5	0.5	0
200	0.3	0.3	0	0.5	0.5	0
300	0.3	0.3	0	0.5	0.5	0
400	0.3	0.3	0	0.5	0.5	0
500	0.3	0.3	0	0.5	0.5	0
600	0.3	0.3	0	0.5	0.5	0



Graph 2.2

Table 2.2 – 2C

Measurement Points Along Crack (mm)	14.12.16 Width (mm)	10.03.17 Width (mm)	△ Width (mm)	14.12.16 Depth (mm)	10.03.17 Depth (mm)	△ Depth (mm)
0	0.54	0.54	0	1.2	1.2	0
100	0.54	0.54	0	0.5	0.5	0
200	0.3	0.3	0	0.5	0.5	0
300	0.3	0.3	0	0.5	0.5	0
400	0.3	0.3	0	0.5	0.5	0
470	0.3	0.3	0	0.5	0.5	0



Graph 2.3

Table 2.3 – Crack 2D

Measurement Points Along Crack (mm)	**14.12.16 Width (mm)**	**10.03.17 Width (mm)**	**△ Width (mm)**	**14.12.16 Depth (mm)**	**10.03.17 Depth (mm)**	**△ Depth (mm)**
0	0.52	0.52	0	1.5	1.5	0
70	0.3	0.3	0	0.5	0.5	0
75	0.04	0.04	0	0.5	0.5	0
100	0.3	0.3	0	0.5	0.5	0
200	0.04	0.04	0	0.5	0.5	0

<u>Summary of the Tail Cracks</u>

- The tail has 2 primary cracks, identified as 1a and 2a. Emanating from these are numerous secondary cracks, identified as 1b,1b1,1b2,1c, 2b,2c,2d.
- Between 14.12.2016 and 10.03.2017, both primary cracks increased *at points* in both width and depth – see graphs/tables 1.0 and 2.0.
- Crack 1a between points 470mm-1000mm and Crack 2a between points 3680-4850mm, indicate a crack created due to shear force, see plate 65. This crack has increased in width and depth between 14.12.2016 and 10.03.2017.
- Between 14.12.2016 and 10.03.2017, Crack 1a has developed a loss at 540mm, with a disassociated fragment measuring 60x25x18mm. See plates 56,57.

- Crack 2a, between points 1300mm and 2300mm displays a complete detachment between the tail and the concrete raft on which it sits. See graph 2.0 and plate 60.
- There was no change in the dimensions of the secondary cracks; 1b,1b1,1b2,1c,2b,2c,2d.

Results from the monitoring of the tail cracks between 14.12.2016 and 10.03.2017 indicate a series of cracks formed due to shear stress as the ground beneath the lower section of the tail subsides. This is causing progressive cracking. The crack across the width of the tail has formed in the original concrete, not in the 2015 repair. The 2015 repair treatment included the insertion of a steel dowel (Cliveden 2015). It is likely that the rigidity of the steel dowels is preventing a crack forming at this point and the stress is transferring further up into the tail where the new crack has developed in the original concrete.

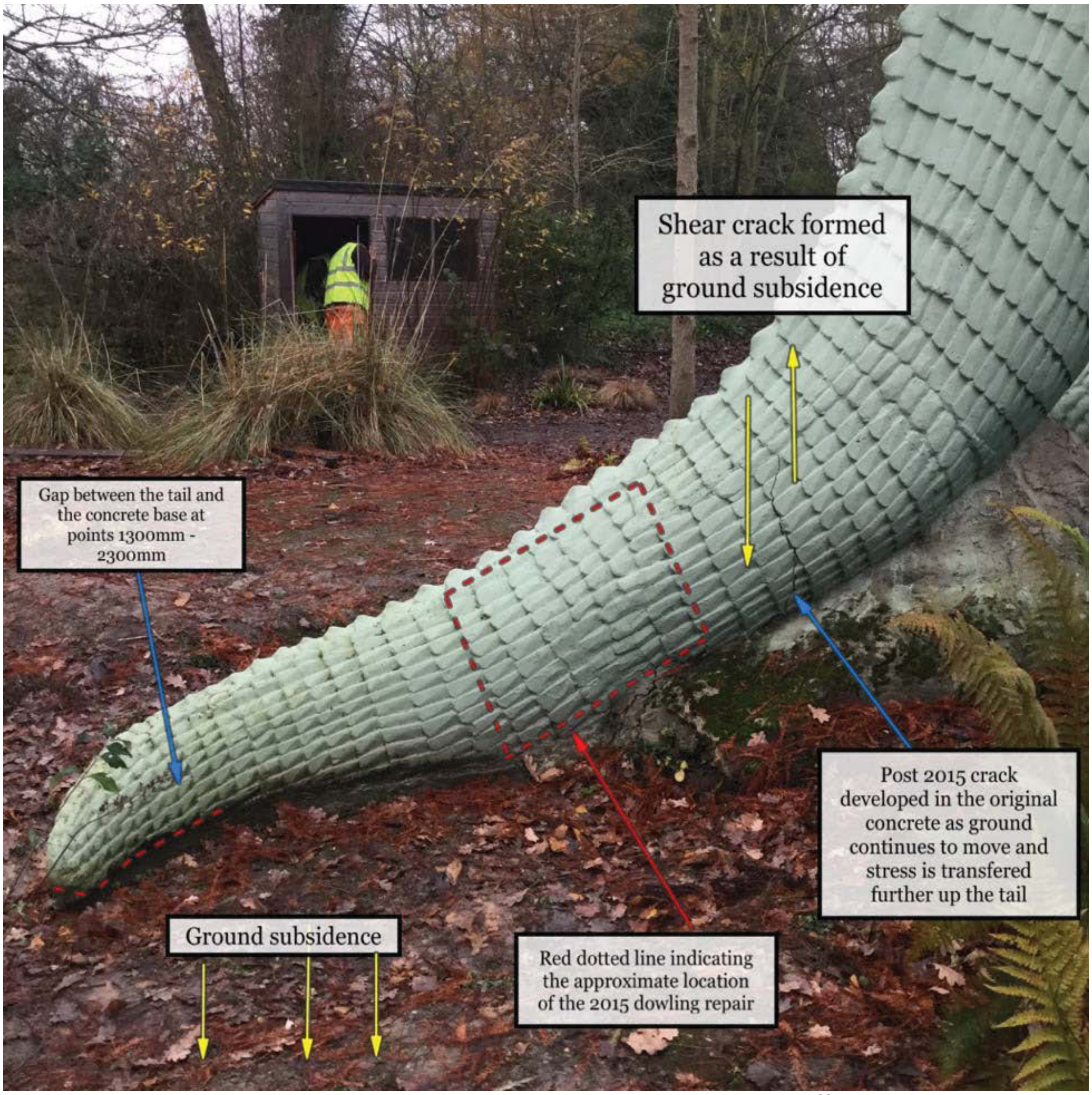


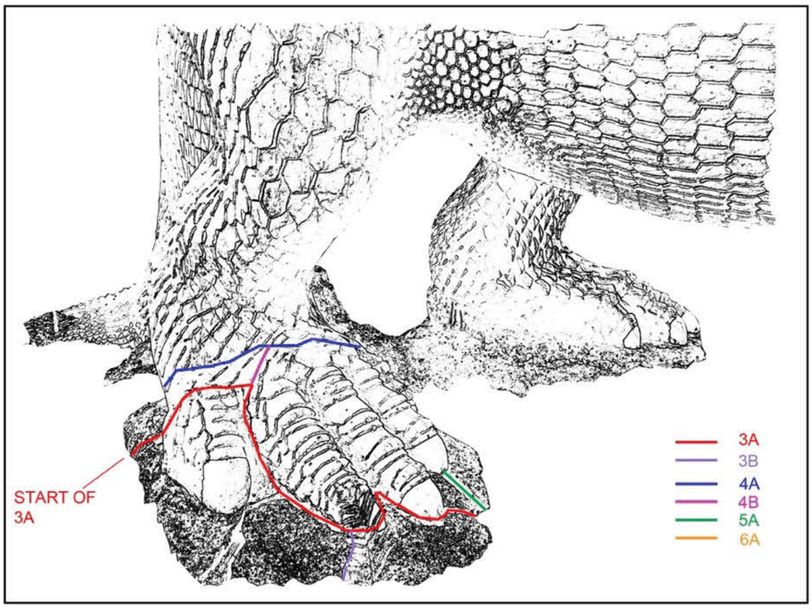
Plate 65- Analysis of structural deterioration – Tail[60]

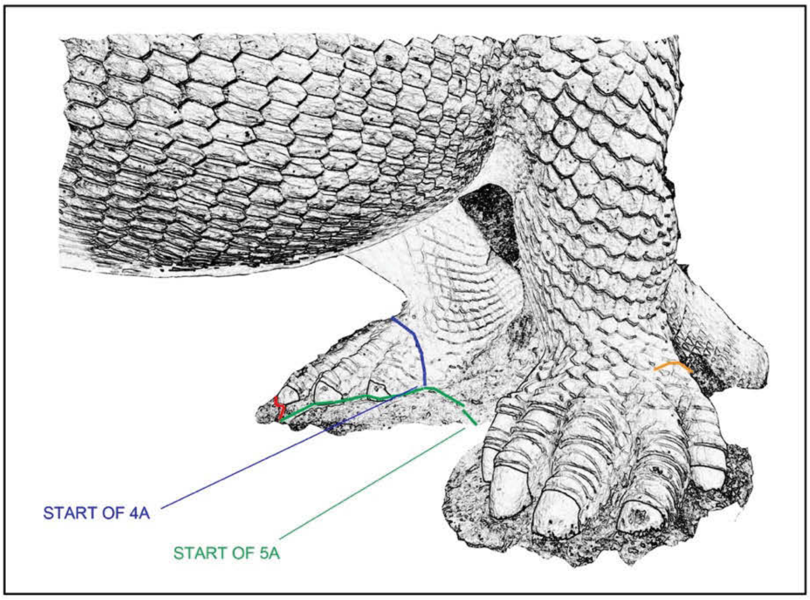
[60] Carpenter, I. (2017). Analysis of structural deterioration – Tail [Unpublished Photograph].

4.2.2

BACK FEET

The cracks were identified, measured and recorded on 15.12.2016. They were re-measured and recorded on 15.03.2017.





Plates 66 and 67- Diagrams depicting the location of the cracks.

Summary of the Back Left and Right Feet

- The back right foot has three primary cracks, identified as 3a,4a and 5a. Cracks 3a and 4a both start in the concrete base and extend over the foot, both cracks have secondary cracks, identified as 3b and 4b.
- Crack 5a does not extend into the foot and is limited to the concrete base, following the site of a repair made in 2015.
- Between 15.12.2016 and 15.03.2017, primary cracks 3a,4a,5a have increased *at points* in both width and depth – see graphs/tables 3.0, 4.0 and 5.0.
- Crack 3a, between points 590-1100mm, displays an almost continuous length of spalling concrete, with numerous losses and disassociated fragments. Losses at points 950mm and 1050mm have occurred between 15.12.16 and 15.03.17. See plates 85-88.
- Crack 4a follows the site of a 2015 repair. Point 290-510mm along the crack displays delaminating repair concrete, with total disassociation of fragments occurring between 15.12.16 and 15.03.17. See plates 90,91.
- The back left foot has one hairline crack, identified as 6a. This showed no change in dimension between the two dates.
- There was only a very slight change in the width of the secondary crack 3b and no change in 4b.

Results from the monitoring of the back left and right feet between 15.12.16 and 15.03.17 indicate a series of cracks, forming and increasing in width and depth at points, along the top of the back right foot and in the concrete base of the foot. These cracks are occurring at the sites of the previous 2015 repairs, indicating that these are progressive cracks caused by ground subsidence. The back right leg, formed around a 9ft (274cm) cast iron pipe which extends down into the ground, shows no evidence of cracking. Cracking appears at the point of stress where the apparently hollow foot meets the ridged leg. The back left leg displays only one short hairline crack, which has not increased dimensions between the two dates, suggesting that the ground is more stable on the left hand side of the dinosaur and subsiding on the right hand side. The numerous losses along crack 4a are the result of delaminating concrete applied during the 2015 restoration. The concrete has not adhered sufficiently to the concrete substrate and further delamination is developing.

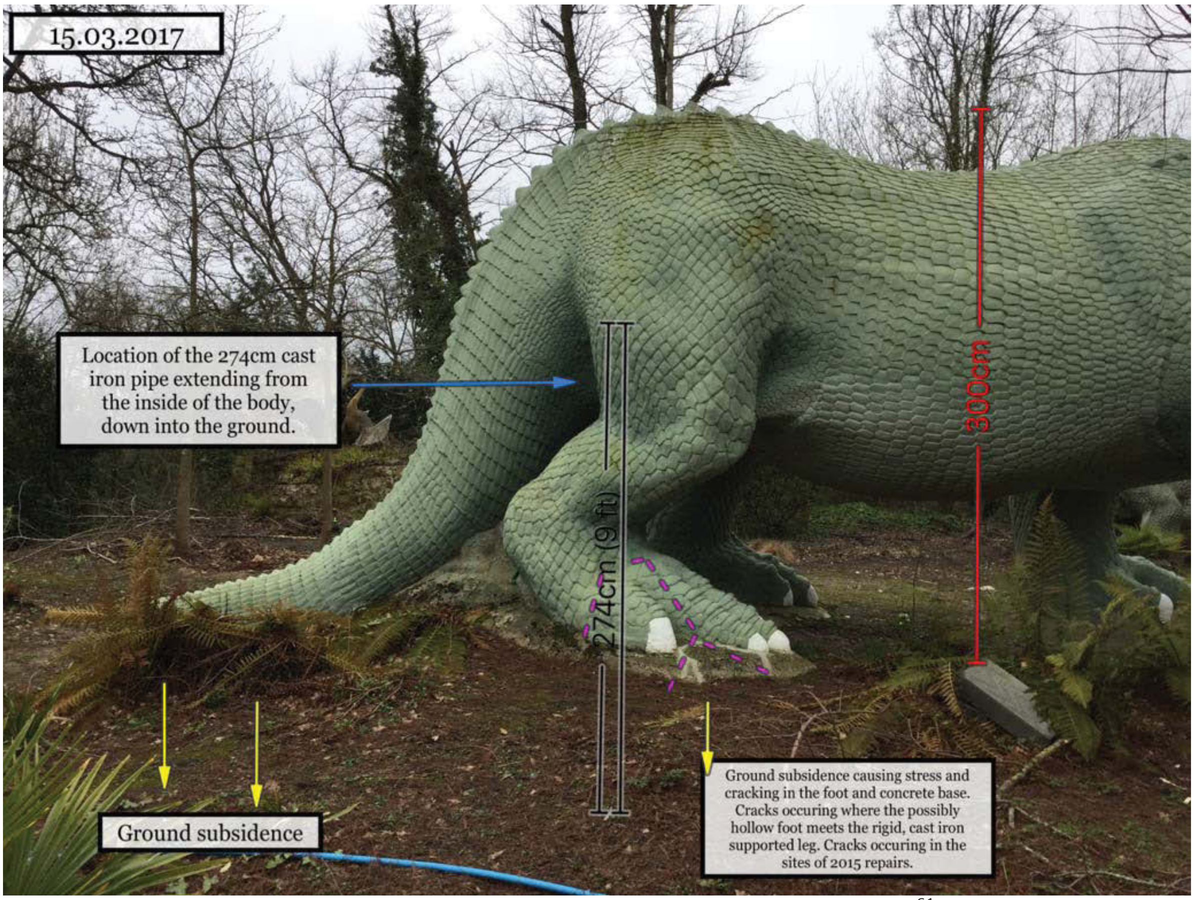


Plate 68- Analysis of structural deterioration – back legs[61]

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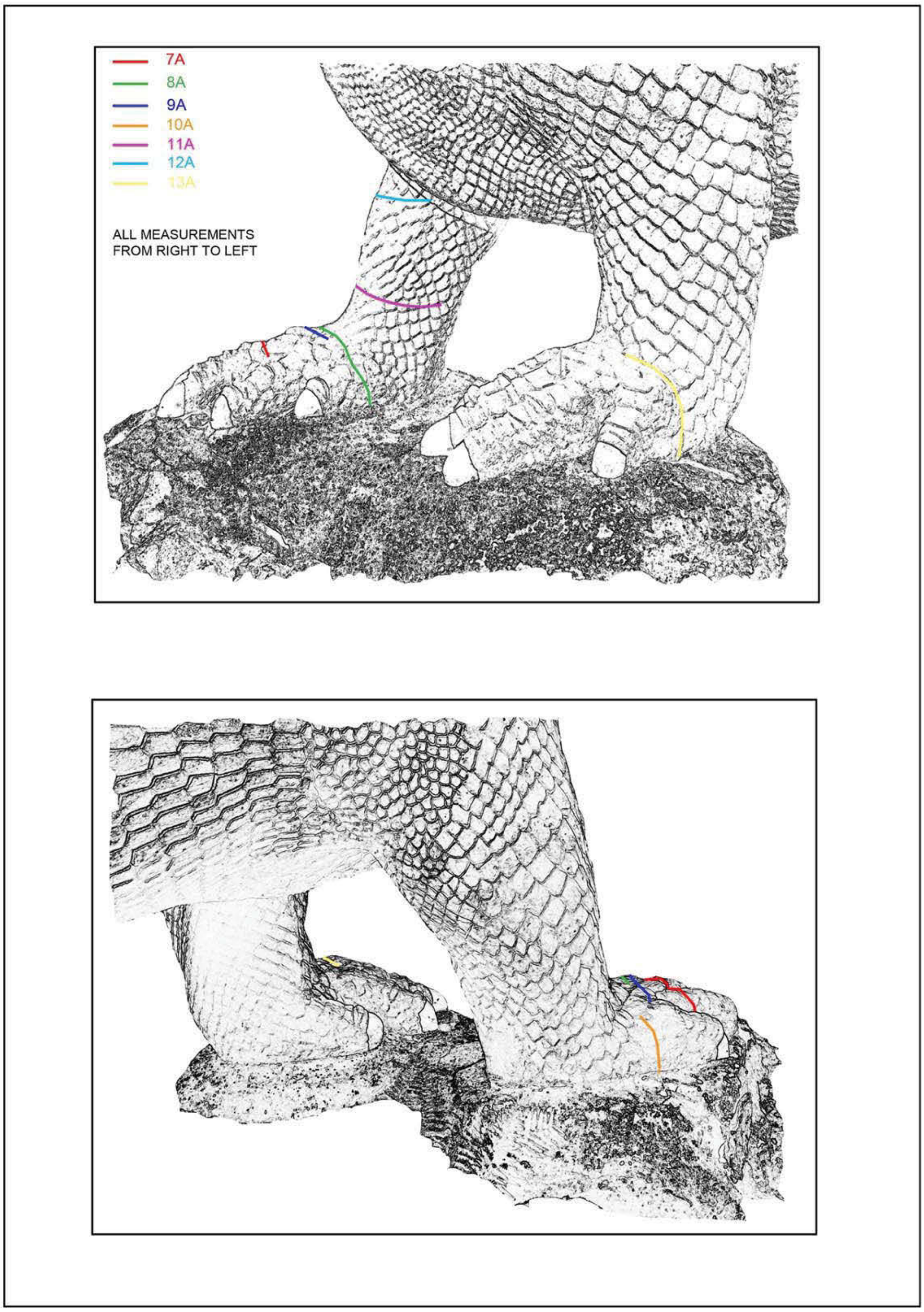
[61] Carpenter, I. (2017). Analysis of structural deterioration – Back Legs. [Unpublished Photograph].

4.2.3

FRONT FEET AND LEGS

The cracks were identified, measured and recorded on 15.12.2016. They were re-measured and recorded on 15.03.2017.



Plates 69 and 70. Diagrams depicting the location of the cracks.

Summary of the Front Right and Left Feet

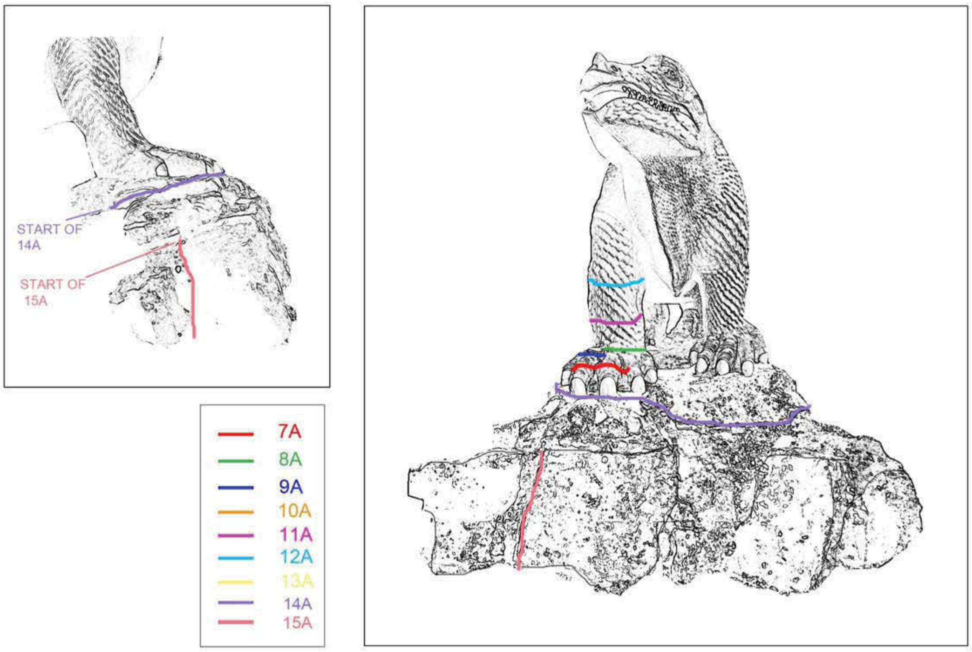
- The front right foot has six hairline cracks, identified as 7a,8a,9a,10a,11a and 12a. There are no secondary cracks.
- The front left foot has one hairline crack, identified as 13a and no secondary cracks.
- Between 15.12.2016 and 15.03.2017 crack 7a increased in width and depth between points 400mm-600mm. This increase is due to a loss in the paint layers, along the site of a 2015 crack restoration. See plate 97 and graph 7.0.
- Cracks 8a-13a have seen no increase in dimensions between 15.12.2016 and 15.03.2017.

Results from the monitoring of the front right and left feet between 15.12.16 and 15.03.17 indicate a series of hairline cracks. These cracks have formed since the 2015 restoration (Cliveden, 2015.) Crack 7a is the only crack to have increased in dimensions between 15.12.16 and 15.03.17. This increase is due to a loss in the paint layer, not due to increased cracking in the concrete. The delamination of the paint is possibly due to water ingress, facilitated by the hairline crack. All the cracks appear to be on the sites of previous restorations.

4.2.4

PLINTH

The cracks were identified, measured and recorded on 15.12.2016. They were re-measured and recorded on 15.03.2017.

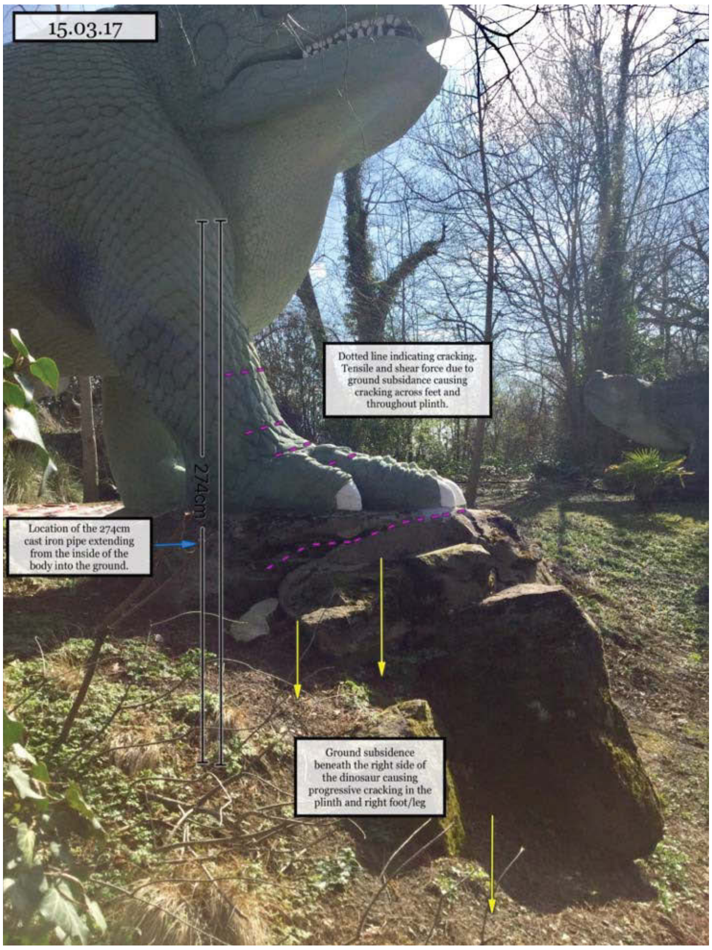


Plates 71 and 72. Diagrams depicting the location of the cracks 14a and 15a.

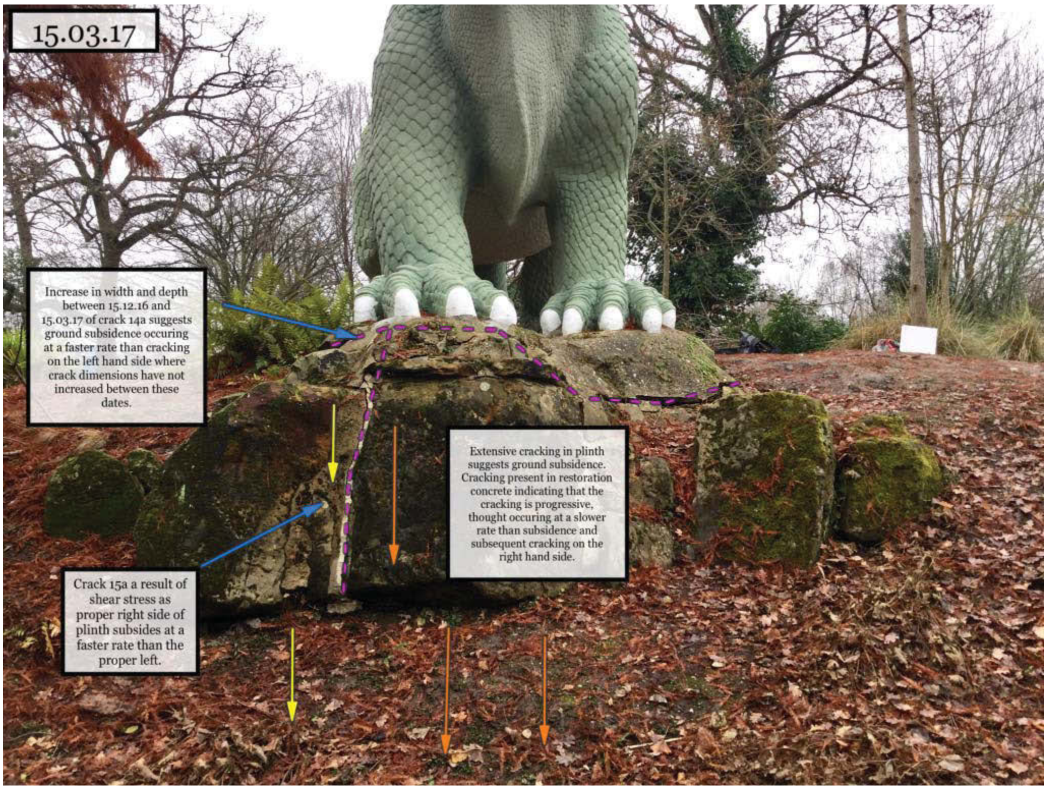
Summary of the Weald Sandstone Plinth

- The front plinth displays an extensive network of cracks. The two most prominent cracks were identified for monitoring, one horizontal 14a and one vertical 15a. See plates 71 and 72 for location.
- Crack 14a runs horizontally, through the site of previous concrete repairs, many of which are undocumented restorations.
- Points 400mm to 800mm of crack 14a run through concrete applied to fill a crack during the 2015 restoration (Cliveden 2015). This crack has increased in both width and depth between 15.12.16 and 15.03.17. See graph/table 14.0.
- Points 1400 to 3900mm is an areas comprising of numerous restorations, with many loose and disassociated fragments and large sections of concrete. See plates 102 and 103 - particularly points 1800mm and 2700mm.
- Points 1400 to 3900mm have seen no change in dimensions between 15.12.16 and 15.03.17, however the deterioration of previous historical repairs indicate progressive cracking.
- Crack 15a runs vertically through historical repair concrete between two boulders as a result of shear stress due to ground subsidence.
- Apart from an increase in depth at point 0mm, crack 15a has not increased in width or depth between 15.12.16 and 15.03.17.

The plinth beneath the front right and left feet consists of large boulders of Weald sandstone and concrete. The extensive cracking in the historical concrete repairs indicate the cracking is progressive and due to ground subsidence. The increase in the width and depth of crack 14a on its proper right hand side and the apparent stability of dimensions of the crack on the left hand side suggest that the ground is subsiding at a faster rate beneath the right side of the dinosaur. See plates 73 and 74.



Plates 73 and 74 – Analysis of structural deterioration – Front Plinth[62]

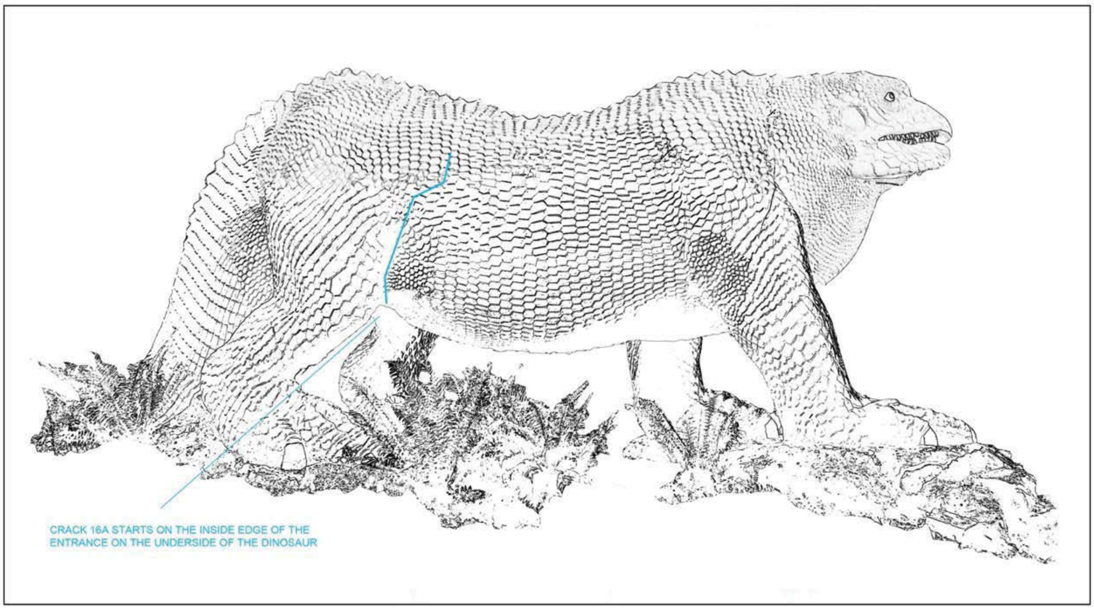


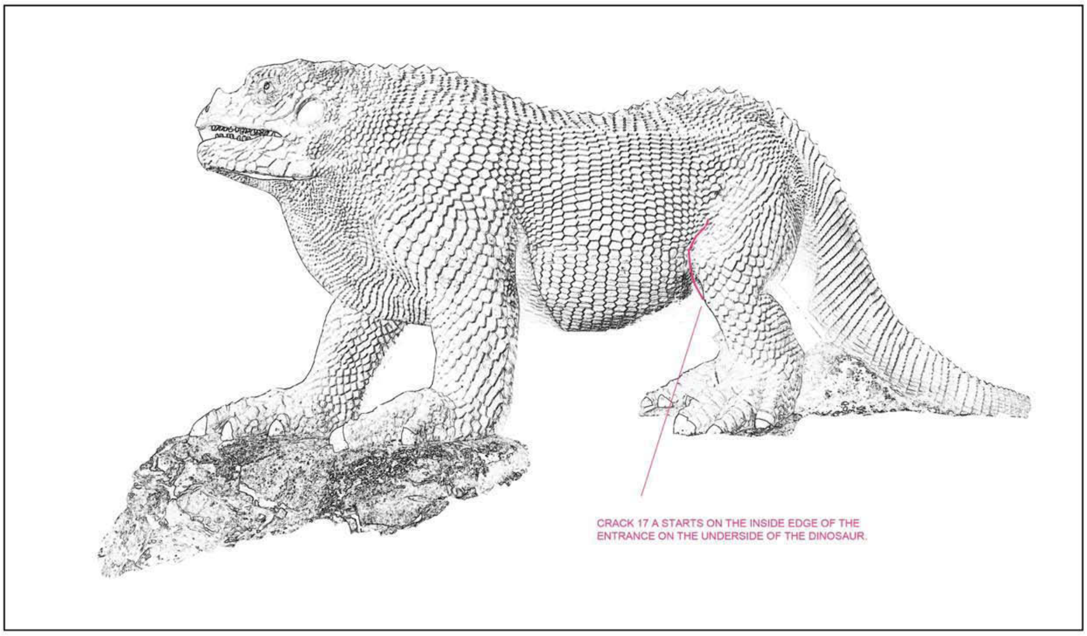
62 Carpenter, I. (2017). Analysis of structural deterioration – Front plinth. [Unpublished Photograph].

4.2.5

BODY

The cracks were identified, measured and recorded on 15.12.2016. They were re-measured and recorded on 15.03.2017.





Plates 75 and 76-. Diagrams depicting the location of the cracks 16a and 17a

Summary of the Body

- The body has two primary cracks, identified as 16a and 17a. See plates 75 and 76.
- Both cracks start on the inside edge of the entrance to the dinosaur (on its underside), 16a on the right and 17a opposite on the left. The location of the cracks is fairly symmetrical. See plates 109 and 111.
- Both crack's widest and deepest points are on the underside of the dinosaur, emanating from the entrance. Both cracks then taper to a hairline from point 500/600mm onwards.
- Crack 16a increased in both width and depth between points 200mm-600mm between the dates 15.12.16 and 15.03.17. See graph 16.0.
- Crack 17a increased in both width and depth between points 100mm-500mm between the dates 15.12.16 and 15.03.17. See graph 17.0.
- Neither crack increased in length between 15.12.16 and 15.03.17.

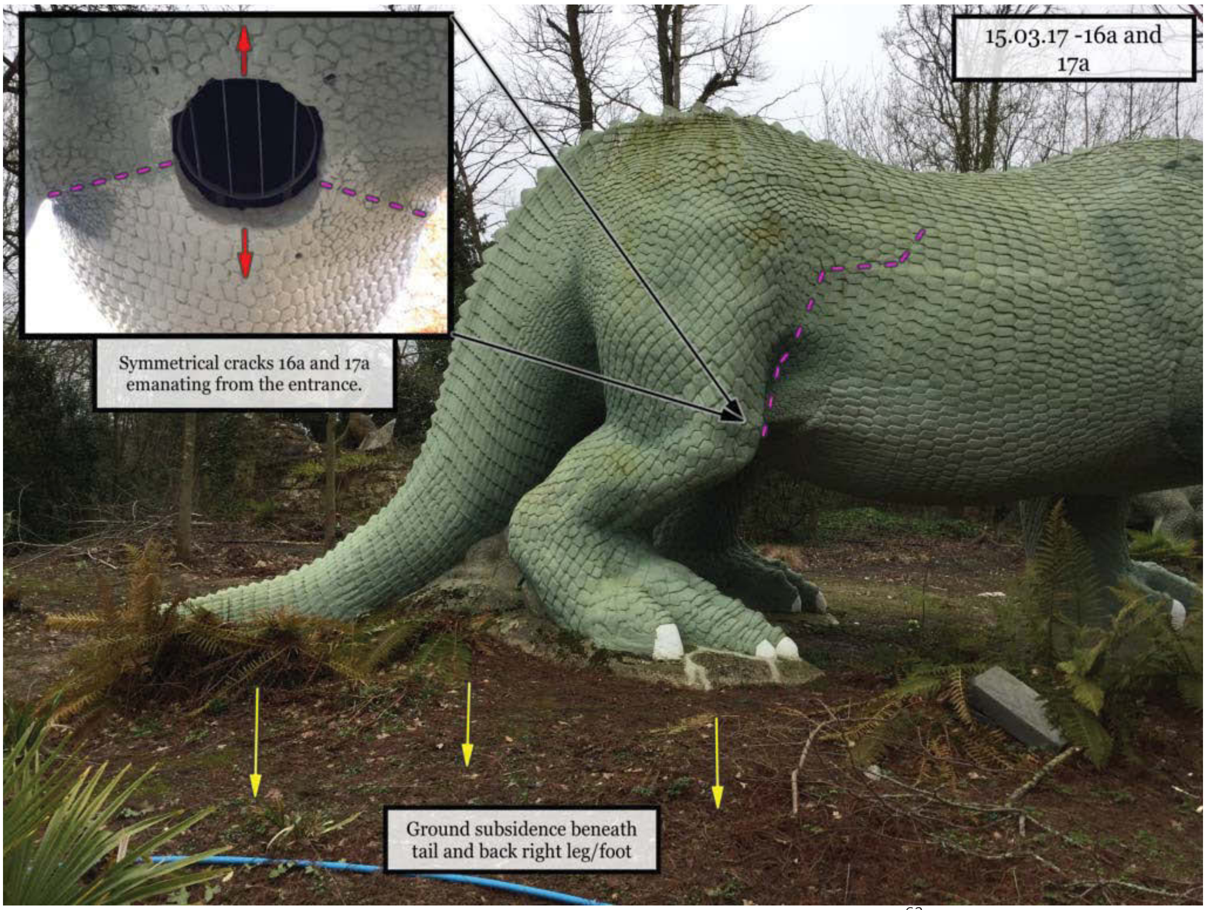


Plate 77- Analysis of structural deterioration – Body[63]

[63] Carpenter, I. (2017). Analysis of structural deterioration – Body. [Unpublished Photograph].

4.2.6 CONCLUSION

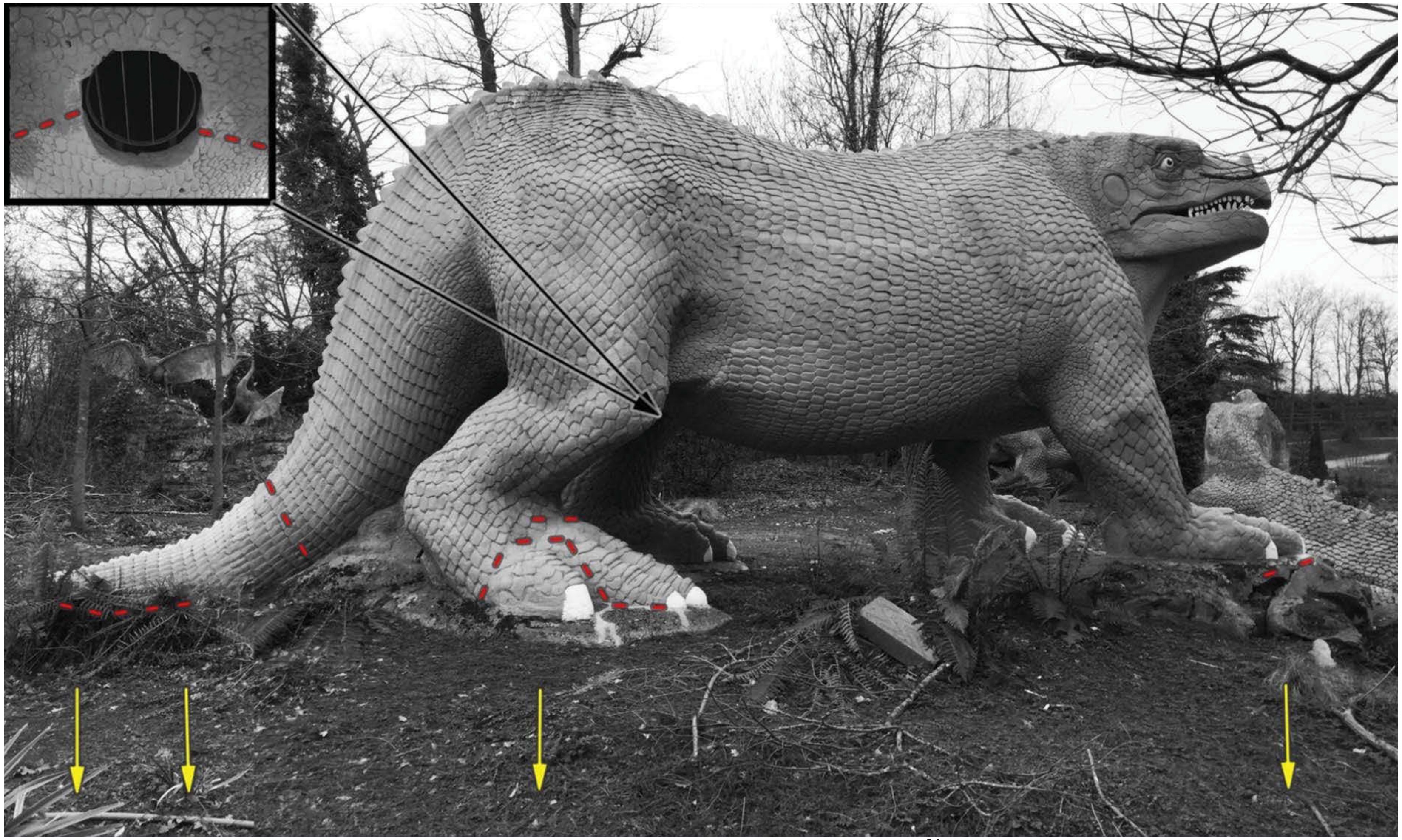


Plate 78- Conclusion of Structural Analysis[64]

Red dotted lines - Cracks that have developed since the 2015 restoration and have *further increased* in width and depth between 15.12.16 and 15.03.17

Yellow Arrows - Indicating ground subsidence beneath the proper right side of the dinosaur

[64] Carpenter, I. (2017). Conclusion of Structural Analysis – Full Iguanodon. [Unpublished Photograph].

CONCLUSION - ANALYSIS OF CRACK MONITORING

The recording and measuring of cracks in the Standing Iguanodon between the 14.12.2016 and 15.03.2017 identified four significant points -

- Of the 27 cracks identified for monitoring, 26 had formed *after* the 2015 restoration.
- 41% of the cracks have increased, at points, in both width and depth between 10.12.2016 and 15.03.2017.
- 81% of the cracks start from a point at the ground before progressing across the Iguanodon.
- 89% of the cracks formed after the 2015 restoration occur to the proper right of the Iguanodon.

The identification of cracks formed after the 2015 restoration reveals that the Iguanodon is subject to progressive cracking. Over the three-month monitoring period, many of the cracks saw an increase in dimensions and have subsequently incurred losses, both to original concrete, restoration concrete and restoration paint layers. Such deterioration *may* have been exacerbated by water ingress over the Winter period. The position and location of the cracks, the vast majority starting from a point at the ground, to the proper right and at the site of pervious restorations, clearly indicate that the cracks are a result of the ground subsiding to the right and tail end of the Iguanodon (see plate 78).

The rapidity and progression of the deterioration indicate that previous treatments have not satisfactorily addressed the structural issues effecting the deterioration of the Iguanodon. Furthermore, the 2015 restoration of the tail, particularly the inclusion of a rigid steel dowel and new restoration concrete are most certainly responsible for the transfer of stress up the tail and the development of new cracking in the original concrete.

Results show that without stabilisation of the ground to the right, tail end and front plinth, further ground subsidence and further structural deterioration of the Standing Iguanodon is most certainty inevitable.

5.0

DISCUSSION

The conservation of 3D cultural heritage requires accurate condition reporting over time in order to monitor deterioration and devise appropriate treatment proposals. This thesis presents the development a new methodology for monitoring deterioration using 3D digitisation by way of photogrammetry for precision mapping, together with computer analysis and digital data storage. The thesis demonstrates the application of this methodology taking as a case study a much-loved example of 3D cultural heritage, the Standing Iguanodon in Crystal Palace Park, London.

The results can be divided into two sections;

1. The outcome and implications of using 3D digitalisation to record and monitor condition.
2. The results and future implications concerning the physical condition of the Standing Iguanodon established as a result of the crack monitoring program.

5.1 – Photogrammetry and 3D Digitalisation

The study has demonstrated that by employing the techniques of photogrammetry, a 3D digitisation of a large and complicated 3Dimensional object can be created using no specialised equipment and employing commercially available processing software. This digitalisation can provide an accurate record of the condition of the object, to compare deterioration over time and as a site onto which information can be mapped and observations annotated.

The value of creating online, open access 3D digitalisations of cultural objects has been recognised and utilised by a number of the world's leading museums. The research in this thesis has demonstrated the relative ease of the process when applied to large and complex objects that exist *outside* cultural institutions and in the public domain. The digitalised model and associated research in this thesis are being made available via two distinct platforms: The Archaeology Data Service (ADS) and Sketchfab. The ADS, hosting the large, high resolution model and Sketchfab lower resolution, 'user friendly' models. Both are open access, available to download and licenced under Creative Commons.

The long-term preservation of the digital model and associated research has been secured by its storage with the Archaeology Data Service, an organisation whose core objective is the long-term preservation, promotion and dissemination of digital data relating to Archaeology and Cultural Heritage at York University. The promotion of the project through the ADS, combined with the broad and varied community of users of Sketchfab and the open access status of the project should encourage use of the digital files, *use* being recognised as a key factor in the long-term preservation of *any* form of archived information.

The study revealed some important lessons for future applications of the methodology. The most significant being the time needed to capture and process the data, as creating a high-resolution model is extremely time consuming. The original intention was to create an even higher resolution model, however the time limitations meant that a compromise had to be made as the project progressed. Future increases in computational power will contribute greatly to the speed and efficiency of data processing, however, in the meantime, a strategic approach is recommended for future projects. This can be achieved by establishing, at the outset, the level of resolution *necessary* for the intended project and using that as a parameter for creating a suitably low resolution model. This would certainly increase the speed and reduce the time required for the post processing of data. If in the future, more information is required from the model, the original dataset of photographs can be re-processed at a higher resolution to create a more detailed model.

A further challenge relates to necessary skills. The capturing of data needed for photogrammetry is a straight forward process requiring no specialised equipment and can be easily taught to willing volunteers. However, although the software needed is readily available, the processing of the data, particularly for a large and complex item, does require fairly advanced computing skills which are likely to fall outside the skill set of most current conservation practitioners. There are however increasing numbers of workshops available in photogrammetry and 3D modelling, many of which are free[65]. These are designed as an introduction to the subject, which can be followed up with online tutorials and supported by the abundance of information supplied by the vast online 3D imaging community.

The final challenge concerns data storage. This project has been extremely fortunate to have the support from the Archaeology Data Service, who have offered to store and maintain the data permanently, wavering their usual fee[66]. Museums and institutions are likely to have well established

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[65] An example of which being a free day-course in London organised by the Thames Discovery Program and funded by engineering project Tideway. Participants are expected to be Windows/Mac OS competent, but no previous experience of 3D modelling is necessary.

[66] Neither can this project be classified as 'Archaeology', making its acceptance into the ADS repository particularly exceptional.

and carefully managed data storage repositories, however public/local council owned works such as the Crystal Palace Dinosaurs do not and have very limited funds with which to establish suitable systems. Free data repositories are available, including Figshare (the temporary storage repository for this project), however the responsibility of quality control, maintenance and promotion/dissemination relies on the depositor, a potentially problematic solution for long term storage. An open access data repository such as the ADS established *specifically* for conservation projects, would be an enormously beneficial resource for the cultural heritage sector. Not only would this be a long-term solution for the storage of large digital files and accompanying data, but it would mean greater accessibility to previous research and reports. This would lead to increased efficiency and could encourage a diversification of knowledge through new audiences and new engagement. Furthermore, it would result in increased transparency and accountability for high profile conservation projects such as the restoration of the Standing Iguanodon.

5.2 – The Crack Monitoring Programme

The results of the crack monitoring programme undertaken indicated that the Standing Iguanodon is subject to progressive cracking which is a result of the ground subsiding beneath the proper right and tail end of the dinosaur. The rate of damage caused by this subsidence is rapid enough to have seen an increase in dimensions, at points, of 41 % of the cracks over the 3-month monitoring period. These results are consistent with the repeated speculation over the past 25 years by conservators and engineers involved in the restoration of the Standing Iguanodon. This is the first study however, to document the precise location and dimensions and to undertake a monitoring programme which confirms the progressive structural deterioration of the work. Ideally, the monitoring would have lasted a full year, rather than only 3 months, nevertheless, the rate of deterioration was rapid enough to be able to record over this limited period.

It would be hugely beneficial to undertake a monitoring programme and to digitise several of the other Crystal Palace Dinosaurs, particularly those judged to be experiencing structurally related deterioration such as the Sitting Iguanodon, the Hylaeosaurus and the Megalosaurus. This would help to end speculation concerning the cause of cracking in the concrete and could be used to create a more appropriate treatment proposal for any future conservation/restoration work. Accurate long term structural assessments could be made with precision, by repeat digitisations and comparisons in the future.

The preservation of the Crystal Palace Dinosaurs will always be a challenge. Their construction with somewhat ad hoc materials and their exposed position in a public park means they inevitably experience the agents of deterioration. However, fundamental their preservation is the need for a condition monitoring and *maintenance* program, for all the dinosaurs, to be implemented as soon as possible. This form of preventive conservation would help to create more appropriate treatment proposals, would identify issues and concerns before they escalate and could help negate the need for very expensive restoration work. Creating 3D digitisations, with the help of volunteers would be an excellent way to record their condition and encourage community participation in the project.

6.0

CONCLUSION

This study has demonstrated how to create a 3D digitalisation of a large and complex object without the need for specialised equipment. It shows how this can be used to record and monitor condition and deterioration. The methodology can be an especially useful tool for understanding large and complex objects as a whole, particularly when assessing and documenting structural changes over time. This is well-illustrated in the case study of the structural deterioration of the Standing Iguanodon in Crystal Palace Park which demonstrated significant changes in a short 3-month period. The data indicated that such deterioration will continue to occur, therefore this report strongly recommends that structural treatment is undertaken to stabilise the subsiding ground to prevent further deterioration.

This report has shown how conservation reporting of this kind can be made widely and easily accessible using digital publishing platforms with a long term digital preservation plan in place. Furthermore, by adopting an open access policy and Creative Commons licencing, the model and all associated research can be scrutinised, further developed and used in future research. An online open access data repository specifically for conservation projects will be necessary for the long- term preservation of digital research and reports and opening up such research would be enormously beneficial to the cultural heritage sector in relation to collaboration and for outreach to the wider community.

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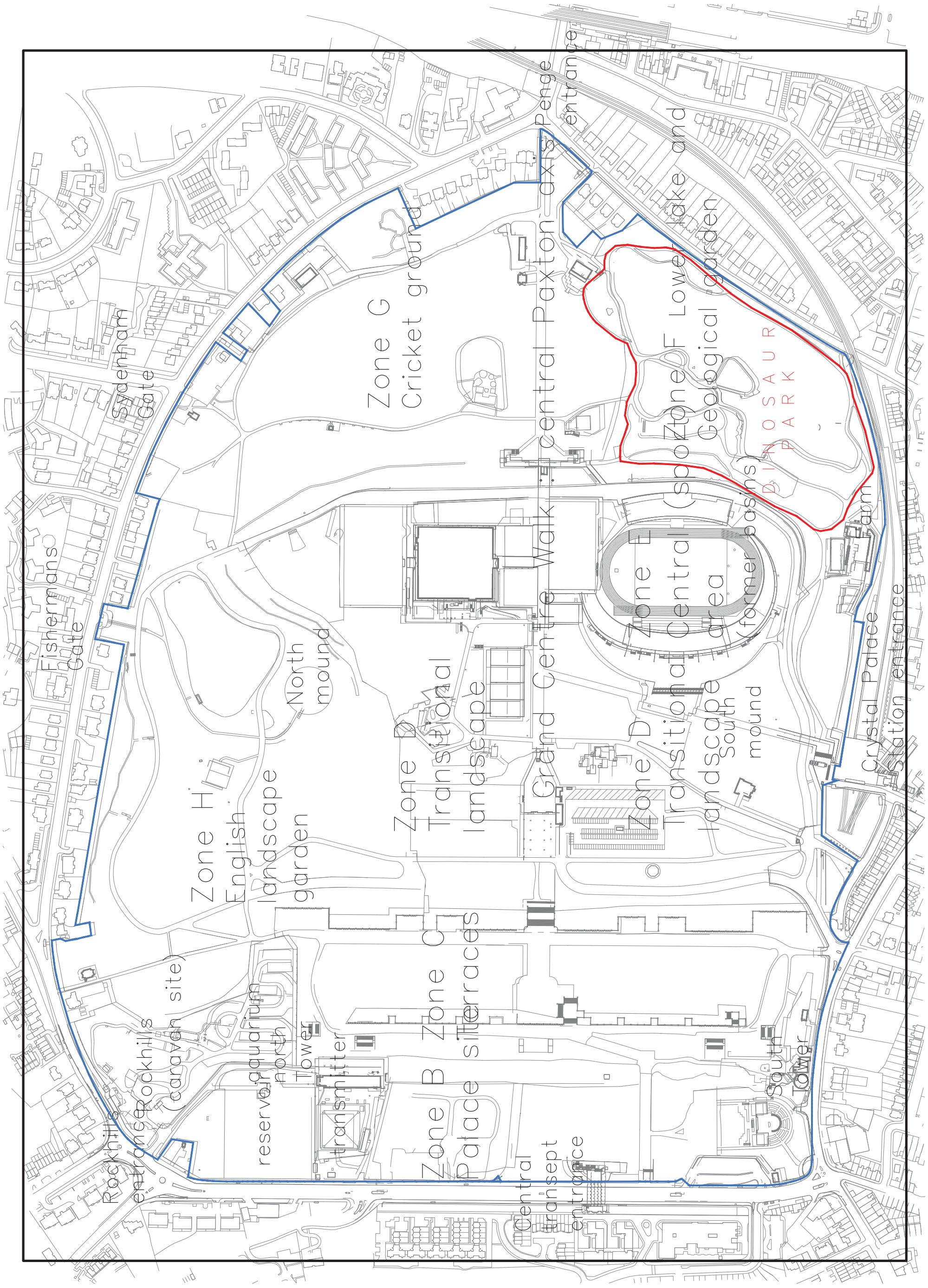
Walker, J. (2017). Bankruptcy, 1909 - The Crystal Palace Foundation. [online] Crystalpalacefoundation.org.uk. Available at: http://www.crystalpalacefoundation.org.uk/history/bankruptcy-1909-2 [Accessed 16 Feb. 2017].

Waterhouse Hawkins, Benjamin. 1854. On Visual Education as Applied to Geology, Illustrated By Wyncoll, K. (2013). Monster Builder. Crystal Palace Matters. The Journal of the Crystal Palace Foundation. No.63 p2-4

APPENDIX I

Plate - 79

Site Map of Crystal Palace Park – Area in Red Indicating the Dinosaur Park[67]



[67] The Morton Partnership (2016). *Crystal Palace Improvement Scheme Invitation to Tender for the Repair and Restoration of the Geological Illustrations and Statues of Pre-Historic Animals the Re-Building of the Weir and Other Associated Work at Crystal Palace Park, London*. London, Appendix D.

Plate 80

Map of the Dinosaur Park including Plan of Statues[68]

[68] The Morton Partnership (2016). *Crystal Palace Improvement Scheme Invitation to Tender for the Repair and Restoration of the Geological Illustrations and Statues of Pre-Historic Animals the Re-Building of the Weir and Other Associated Work at Crystal Palace Park, London*. London, Appendix D.

APPENDIX II

Risk Assessment

Reference Number	Hazard (including who is at risk)	Likelihood without control 1-4	Severity without control 1-4	Risk 1-16	Control measures	Likelihood with control 1-4	Severity with control 1-4	Risk 1-16
1	Uneven ground - trip hazards - Myself and assistants.	2	2	4	Sturdy boots with good grip and steel toe caps, knee pads.	2	1	2
2	Working inside the dinosaur - Myself - Injury incurred by working In enclosed space, damage to clothes and equipment.	4	2	8	Good lighting, knee pads, overalls. Assistant to pass and receive equipment. Step ladder to access the space easily.	1	2	2
3	Ladder - Myself - risk of falling off	2	4	8	Assistant to hold the ladder when it is being used.	1	3	3
4	Ladder - Assistant - Equipment dropped onto the head of assistant.	3	3	9	Only the minimum amount of equipment taken up ladder. Hold equipment with two hands. Place camera strap around neck.	3	1	3
5	Ladder - Equipment - damage to equipment if dropped.	3	3	9	Only the minimum amount of equipment taken up ladder. Hold equipment with two hands. Place camera strap around neck.	1	3	3
6	Ladder - damage to sculpture	3	4	12	Cover all areas of the ladder that may come into contact with the	1	4	4

					work with Plastizote.			
7	Scaffolding- Myself - risk of falling off	3	4	12	Safety rails	1	4	4
8	Scaffolding - things drop on the head of assistant	3	4	12	Take minimum numer of items onto the scaffolding. Assistant to keep aware at all times. Keep equipment in one bag when not in use and secure the bag to the scaffolding.	1	4	4
9	Scaffolding - Damage to the surrounding areas and to the work	4	4	16	Scaffolding to be erected and dismantled by qualified technitian. To be erected at a safe distance so it does not come into contact with the work.	1	4	4
10	Crossing the lake in waders - risk of slipping and falling over, getting stuck in mud - Myself and Assistant	4	3	12	Wear waders, use a long stick for balance and keep other hand free for stability. Cross one at a time.	1	2	2
11	Crossing the lake in waders - damage to equipment.	4	4	16	Carry all equipment in a waterproof back pack, so both hands are free for stabilisation	1	1	1

APPENDIX III

Software Requirements for Viewing the Full Scale Digital Model

1. Viewing the model requires a fairly up to date browser. Use the website below to check and update your browser. This is open source and free.

   https://updatemybrowser.org/

2. To view the .obj file you will need some form of 3D image editing program. There are numerous options available. Recommended is Blender as Blender is open source and free. Use the link below to download the software.

   https://www.blender.org

3. To import the file into Blender, follow the instructions below –

- Launch from the file → Import/Export menu
- Set the options in the user interface (Default options should be ok in most situations)
- Press the Import/Export button
- Select the file

If you need help navigating the model then this is a helpful video –

https://vimeo.com/9567714

Software Requirements for Viewing the Model in Sketchfab

If you encounter problems in viewing the model in Sketchfab, follow the instructions below-

1. Check the compatibility of your browser with the software with this link –

   https://help.sketchfab.com/hc/en-us/articles/203059088-Compatibility

2. If your browser needs updating then use the website below to check and update your browser. This is open source and free.

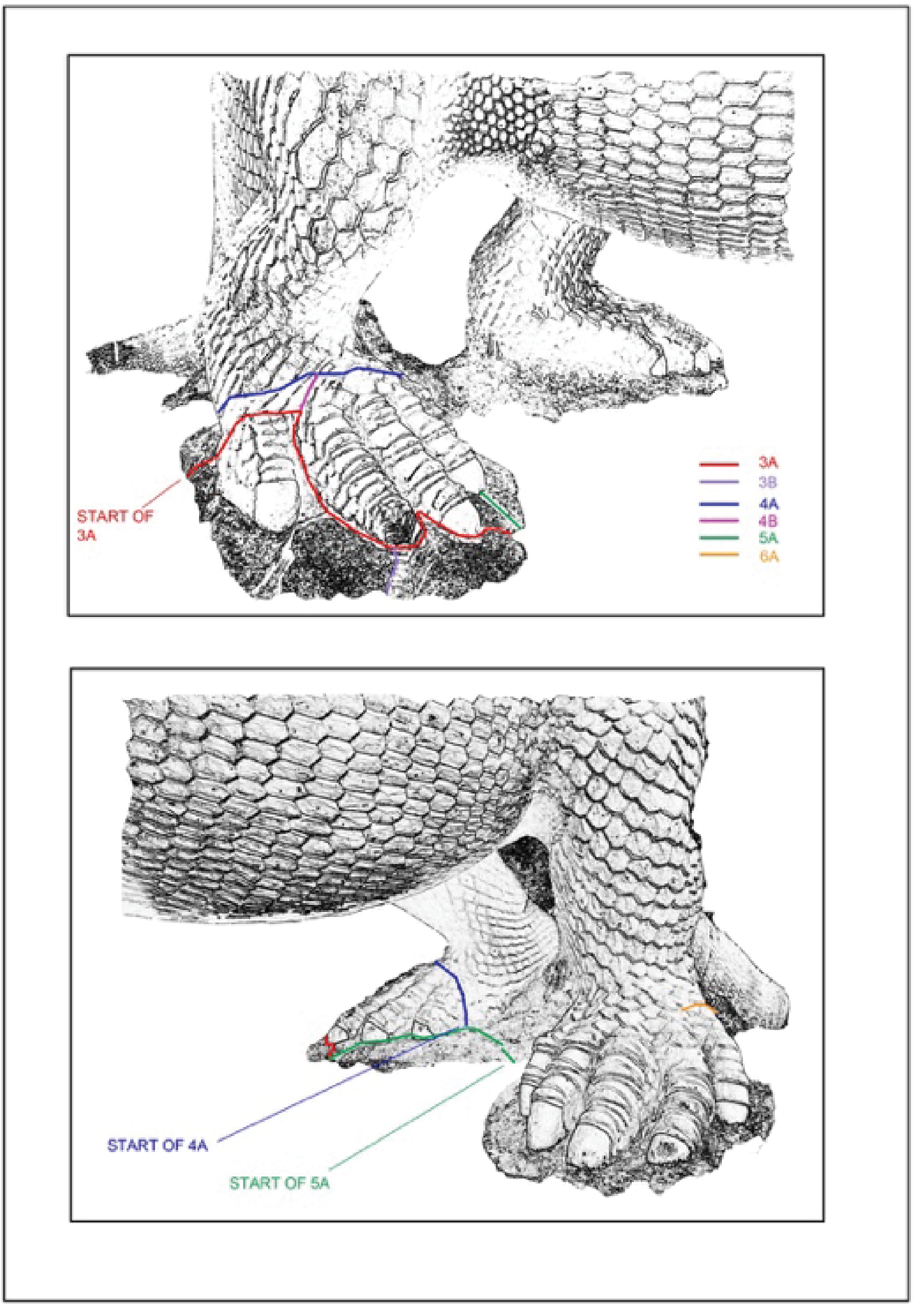
   https://updatemybrowser.org/

APPENDIX IV

Appendix IV contains the data relating to Chapter 4.2 and includes all photographs, graphs and tables relating to the crack measuring and monitoring programme not included in the main text.

BACK FEET -

The cracks were identified, measured and recorded on 15.12.2016. They were re-measured and recorded on 15.03.2017.



Plates 81 and 82 – Diagram of Back Feet.

Crack 3A – see plates 81 and 82- for location.

Below- Detail images depicting progressive deterioration related to cracking. Numbers refer to the measurement points along the length of the crack in millimetres.

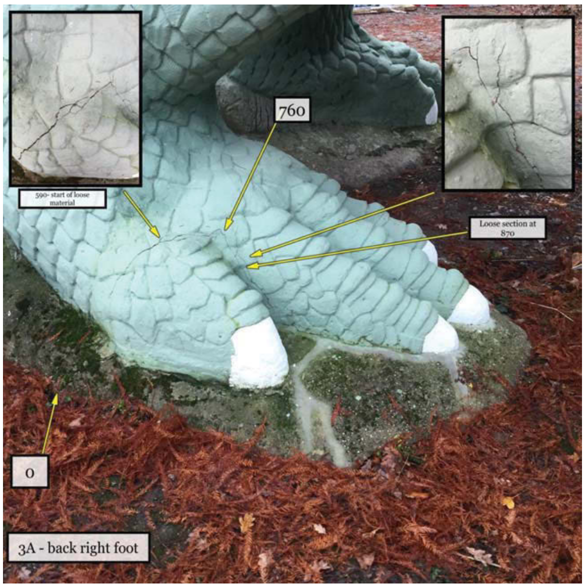


Plate 83- Crack 3A - Photographed **15.12.16**.

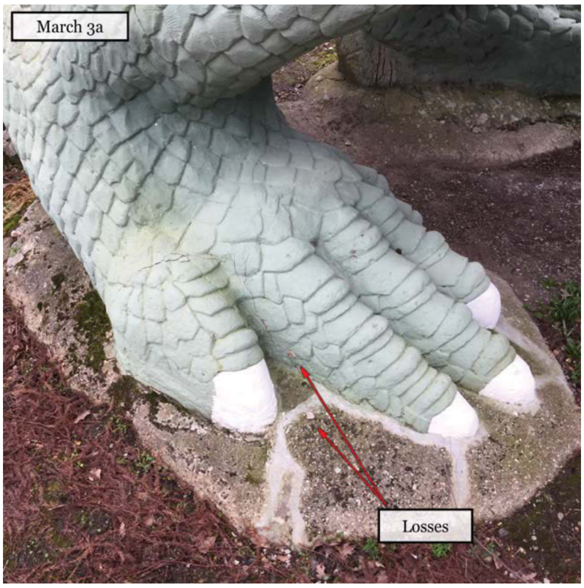


Plate 84- Photographed **15.03.17** – visible losses.

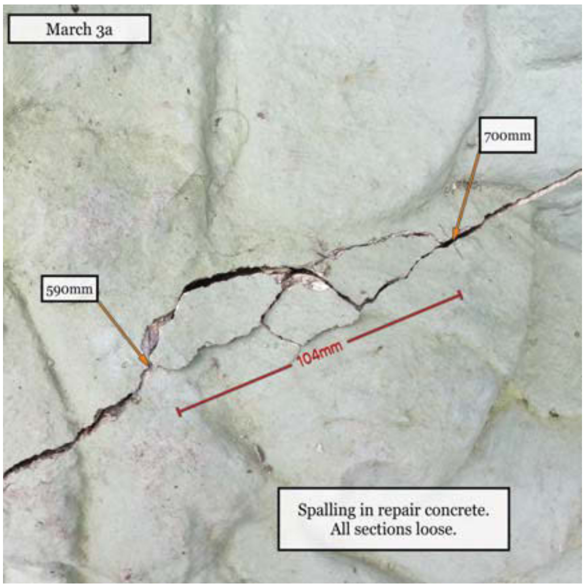


Plate 85-

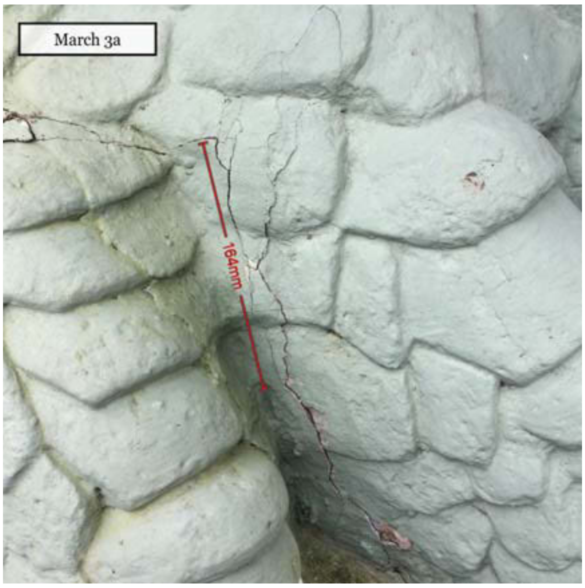


Plate 86-

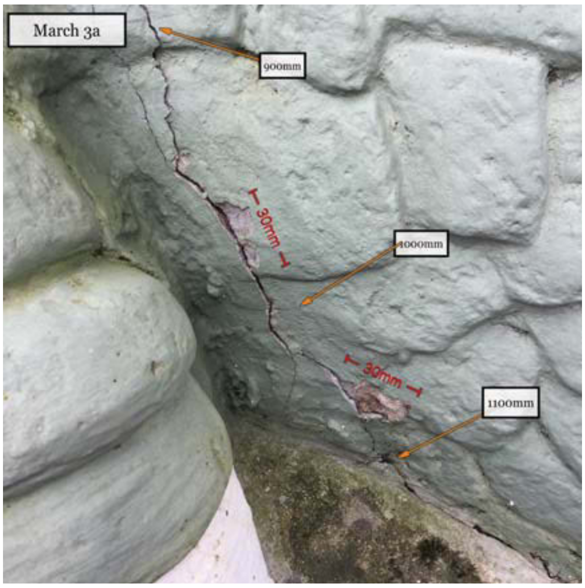


Plate 87.

Plate 88.

Plates 83-88- photographed 15.03.17. Details of cracking and spalling in the concrete, including visible losses and detached fragments since 15.12.16[69]

DATA

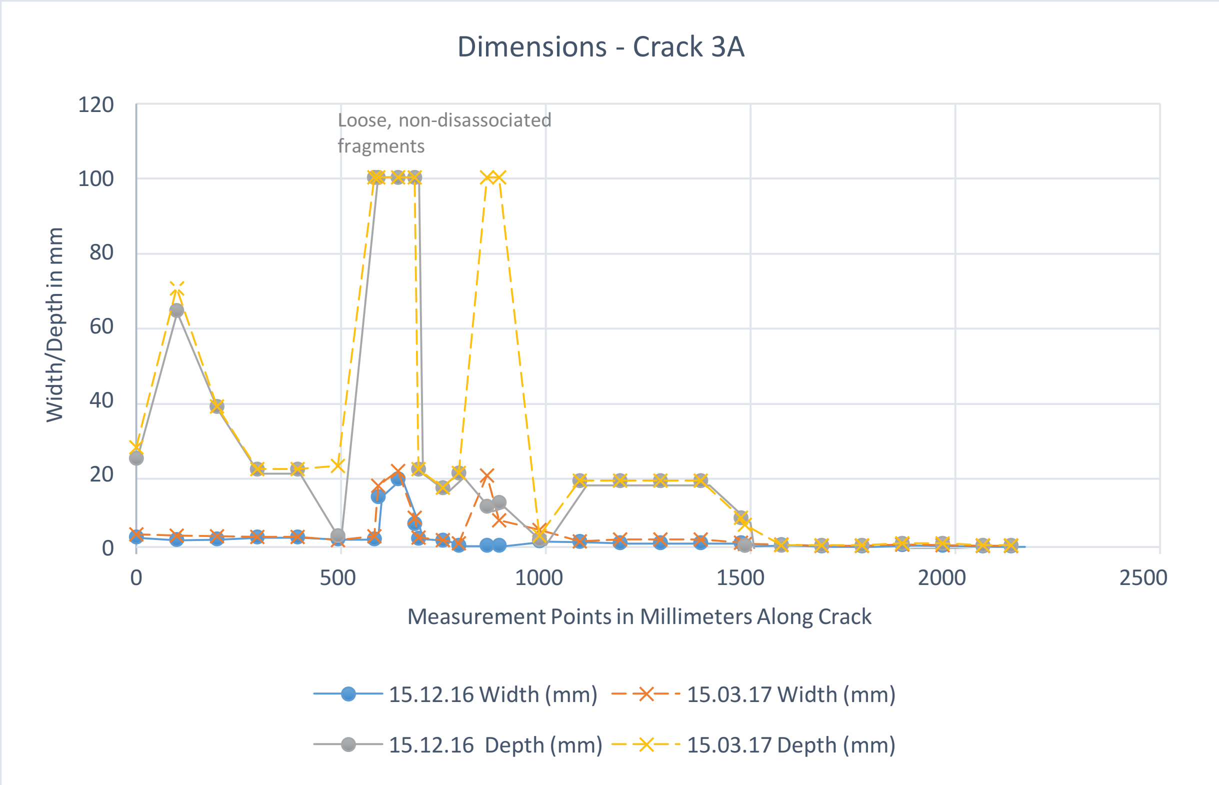
The graphs display the length, width and depth measurements for each individual crack. Starting at 0mm (the crack's origin point), the measurements were recorded every 100mm along the length of the crack and at points of noticeable deterioration.

Due to the accuracy limitations of the depth gauge, depth values of 100mm indicate values 100> and depth values of 0.5 indicate values of <0.5.

Loose, but non-disassociated fragments were recorded as having a depth of 100mm as these points were too fragile to take accurate readings.

Measurements were recorded on **15.12.2016** and again on the **15.03.2017**.

[69] Carpenter, I. (2016). Crack 3A [Unpublished Photographs].

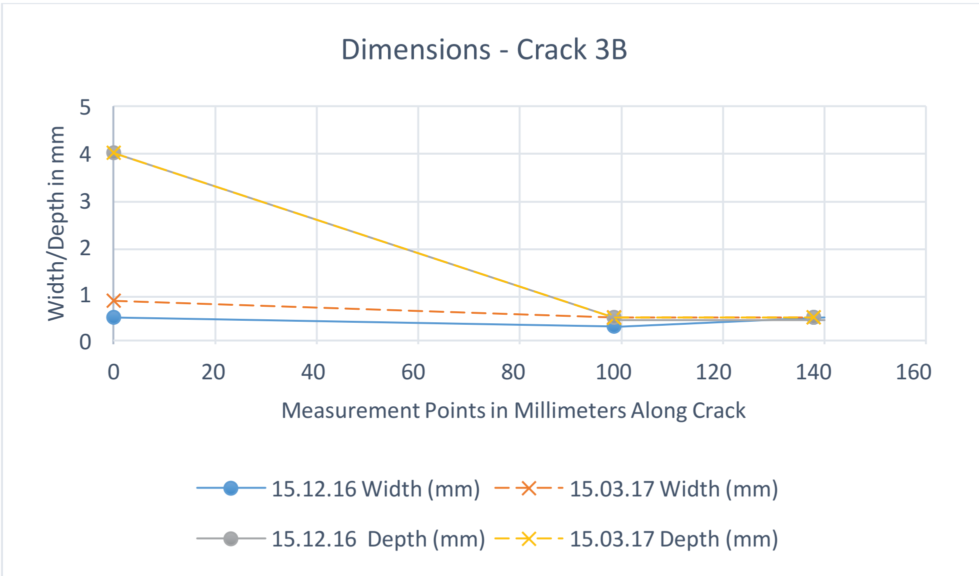


Graph 3.0

Table 3.0 – Crack 3A

Measurement Points Along Crack (mm)	15.12.16 Width (mm)	15.03.17 Width (mm)	△ Width (mm)	15.12.16 Depth (mm)	15.03.17 Depth (mm)	△ Depth (mm)
0	2.68	3.39	0.71	24	27	3
100	2	3.05	1.05	64	70	6
200	2.24	2.86	0.62	38	38	0
300	2.75	2.79	0.04	21	21	0
400	2.65	2.78	0.13	21	21	0
500	2.25	1.81	-0.44	3	22	19
590	2.25	2.83	0.58	100	100	0
600	13.7	16.5	2.8	100	100	0
650	18.4	20.57	2.17	100	100	0
690	6.35	7.85	1.5	100	100	0
700	2.4	2.47	0.07	21	21	0
760	1.81	1.81	0	16	16	0
800	0.45	0.92	0.47	20	20	0
870	0.45	19.27	18.82	11	100	89
900	0.45	7.29	6.84	12	100	88
1000	1.67	4.6	2.93	2	3	1
1100	1.5	1.5	0	18	18	0
1200	1.1	2	0.9	18	18	0
1300	1.1	2	0.9	18	18	0
1400	1.1	2	0.9	18	18	0
1500	1.1	1.1	0	8	8	0

1510	0.5	0.9	0.4	0.5	6	5.5
1600	0.65	0.65	0	0.5	0.5	0
1700	0.3	0.3	0	0.5	0.5	0
1800	0.3	0.3	0	0.5	0.5	0
1900	0.65	0.65	0	1	1	0
2000	0.45	0.45	0	1	1	0
2100	0.3	0.3	0	0.5	0.5	0
2170	0.3	0.3	0	0.5	0.5	0



Graph 3.1

Table 3.1 – Crack 3B

Measurement Points Along Crack (mm)	**15.12.16 Width (mm)**	**15.03.17 Width (mm)**	**△ Width (mm)**	**15.12.16 Depth (mm)**	**15.03.17 Depth (mm)**	**△ Depth (mm)**
0	0.5	0.85	0.35	4	4	0
100	0.3	0.5	0.2	0.5	0.5	0
140	0.5	0.5	0	0.5	0.5	0

Crack 4a and 5a – see plate 19 for location. Detail images depicting progressive deterioration related to cracking. Numbers refer to measurement points along the length of the crack in millimetres.

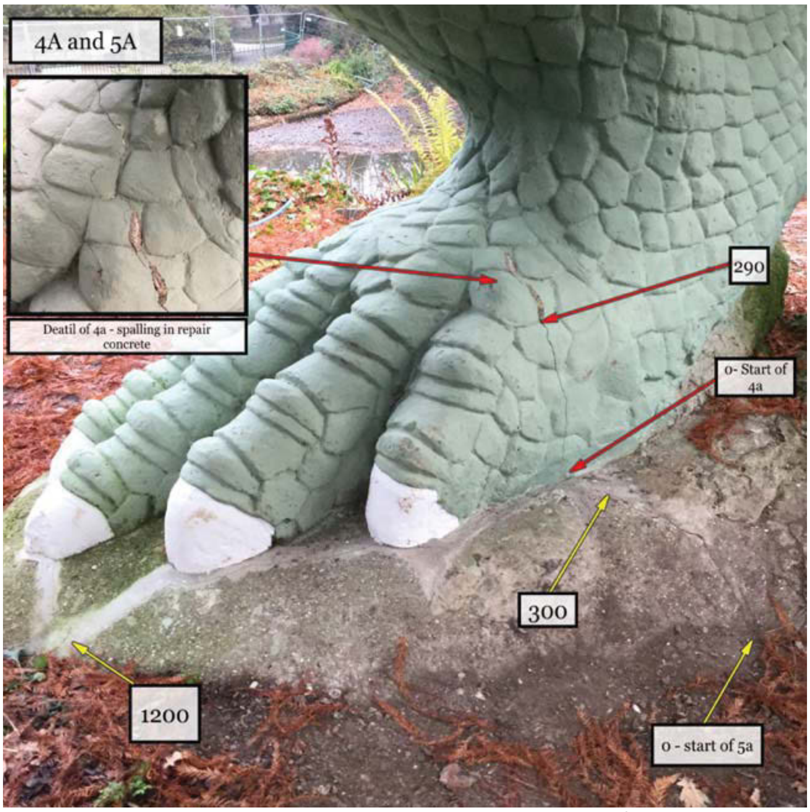
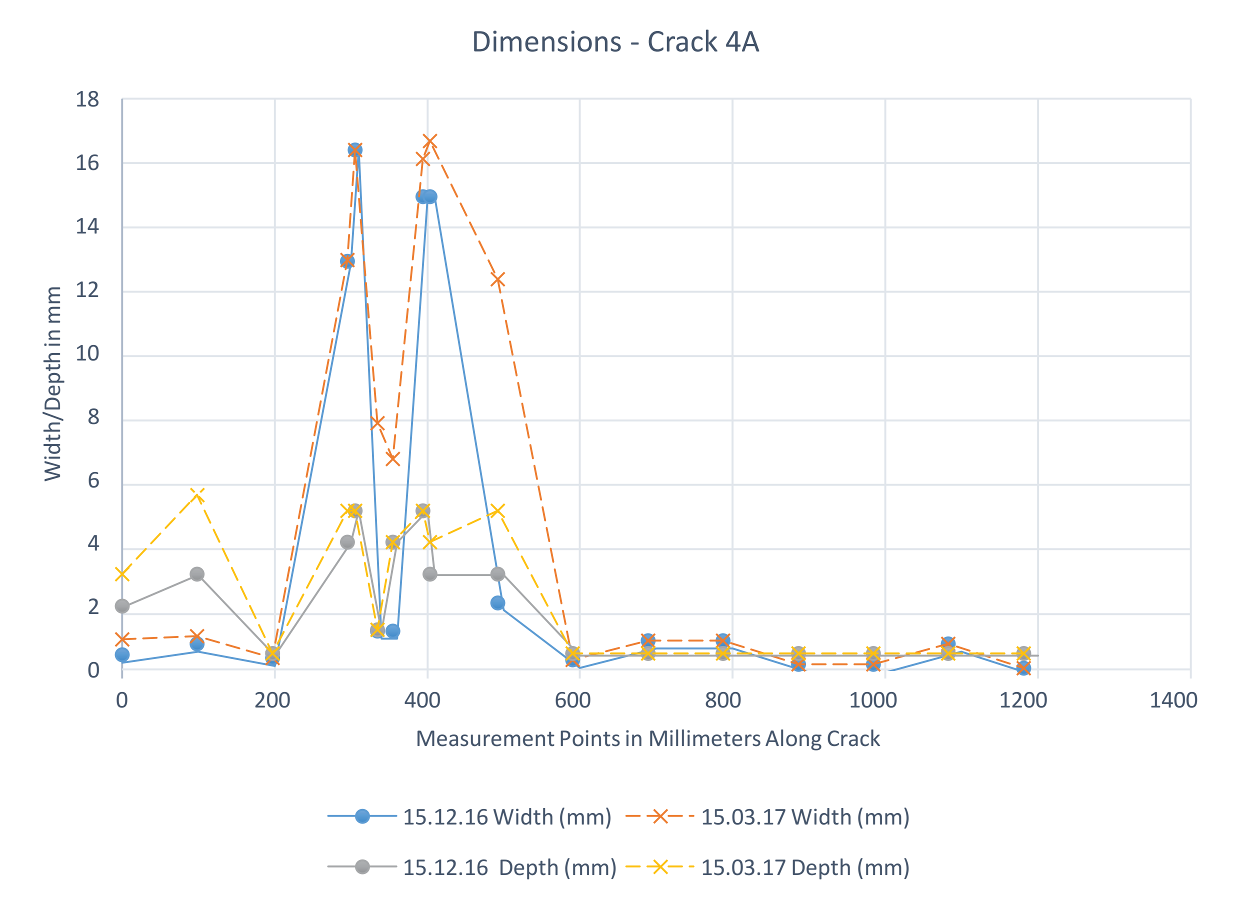


Plate 89. Crack 4A and 5A – Photographed **15.12.16**[70]

Plates 90 and 91. Crack 4A **–** Photographed **15.03.17** – disassociated losses incurred since 2016[71]

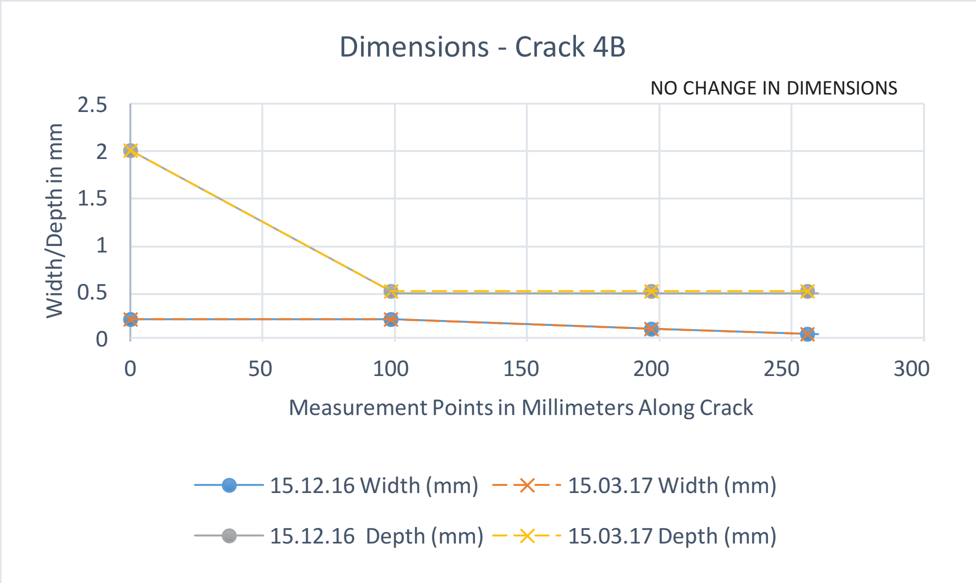
[70] Carpenter, I. (2016). Crack 4A [Unpublished Photographs].
[71] Carpenter, I. (2016). Crack 4A [Unpublished Photographs].



Graph 4.0

Table 4.0 – Crack 4A

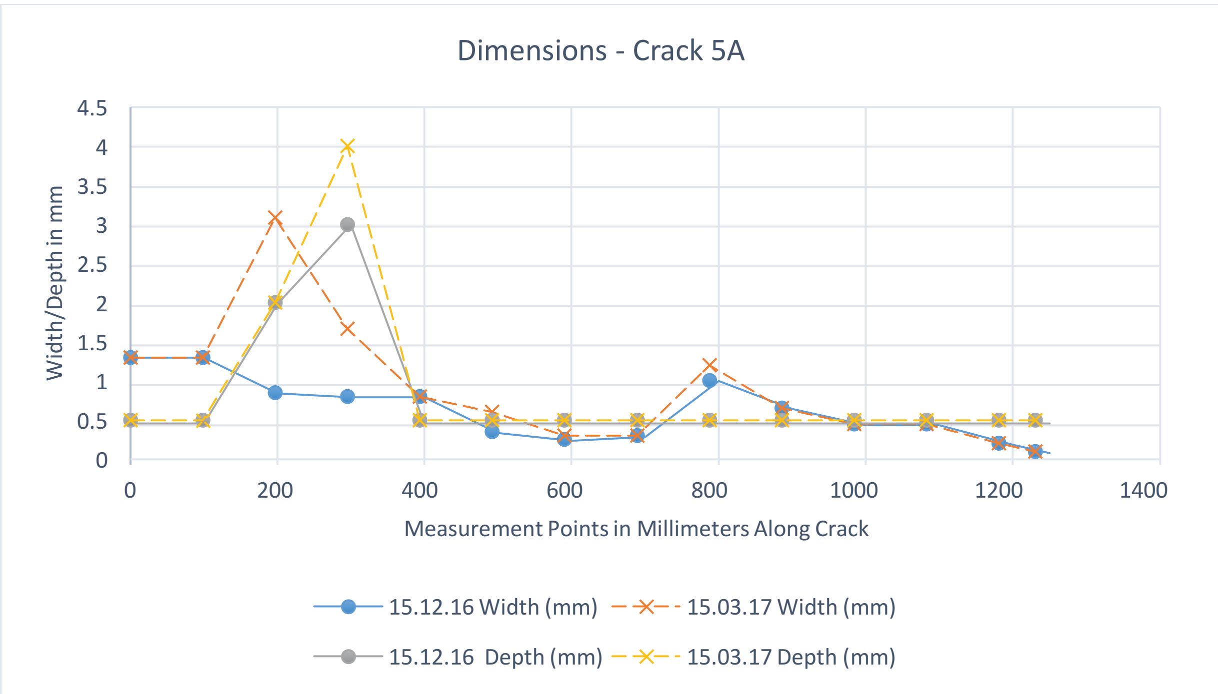
Measurement Points Along Crack (mm)	15.12.16 Width (mm)	15.03.17 Width (mm)	△ Width (mm)	15.12.16 Depth (mm)	15.03.17 Depth (mm)	△ Depth (mm)
0	0.45	0.95	0.5	2	3	1
100	0.8	1.05	0.25	3	5.5	2.5
200	0.35	0.35	0	0.5	0.5	0
300	12.87	12.9	0.03	4	5	1
310	16.37	16.37	0	5	5	0
340	1.2	7.76	6.56	1.24	1.24	0
360	1.2	6.64	5.44	4	4	0
400	14.91	16.09	1.18	5	5	0
410	14.91	16.66	1.75	3	4	1
500	2.1	12.3	10.2	3	5	2
600	0.3	0.3	0	0.5	0.5	0
700	0.9	0.9	0	0.5	0.5	0
800	0.9	0.9	0	0.5	0.5	0
900	0.15	0.15	0	0.5	0.5	0
1000	0.15	0.15	0	0.5	0.5	0
1100	0.8	0.8	0	0.5	0.5	0
1200	0.04	0.04	0	0.5	0.5	0



Graph 4.1

Table 4.1 – Crack 4B

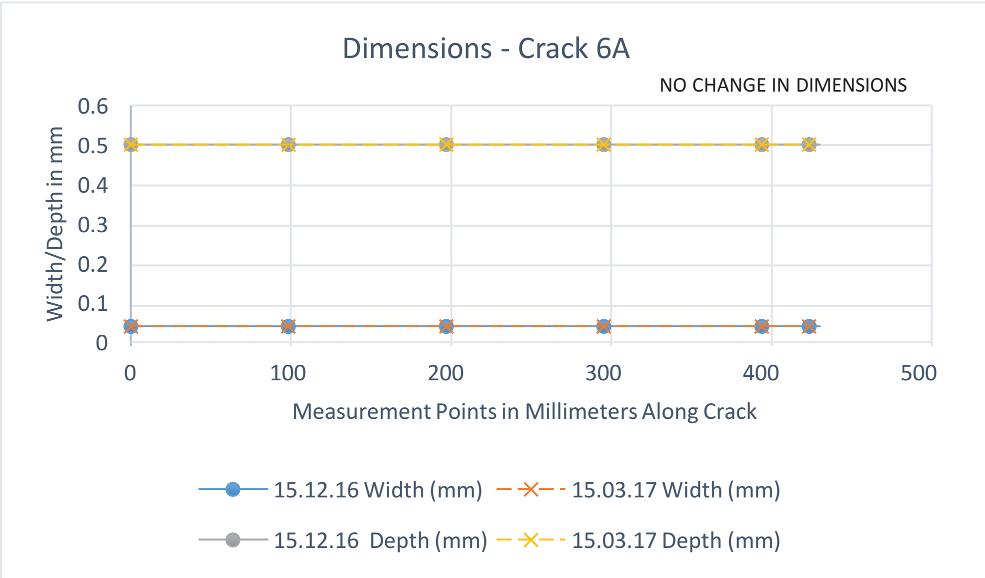
Measurement Points Along Crack (mm)	15.12.16 Width (mm)	15.03.17 Width (mm)	△ Width (mm)	15.12.16 Depth (mm)	15.03.17 Depth (mm)	△ Depth (mm)
0	0.2	0.2	0	2	2	0
100	0.2	0.2	0	0.5	0.5	0
200	0.1	0.1	0	0.5	0.5	0
260	0.04	0.04	0	0.5	0.5	0



Graph 5.0

Table 5.0 – Crack 5A

Measurement Points Along Crack (mm)	15.12.16 Width (mm)	15.03.17 Width (mm)	△ Width (mm)	15.12.16 Depth (mm)	15.03.17 Depth (mm)	△ Depth (mm)
0	1.3	1.3	0	0.5	0.5	0
100	1.3	1.3	0	0.5	0.5	0
200	0.85	3.09	2.24	2	2	0
300	0.8	1.67	0.87	3	4	1
400	0.8	0.8	0	0.5	0.5	0
500	0.35	0.6	0.25	0.5	0.5	0
600	0.25	0.3	0.05	0.5	0.5	0
700	0.3	0.3	0	0.5	0.5	0
800	1	1.2	0.2	0.5	0.5	0
900	0.65	0.65	0	0.5	0.5	0
1000	0.45	0.45	0	0.5	0.5	0
1100	0.45	0.45	0	0.5	0.5	0
1200	0.2	0.2	0	0.5	0.5	0
1250	0.1	0.1	0	0.5	0.5	0

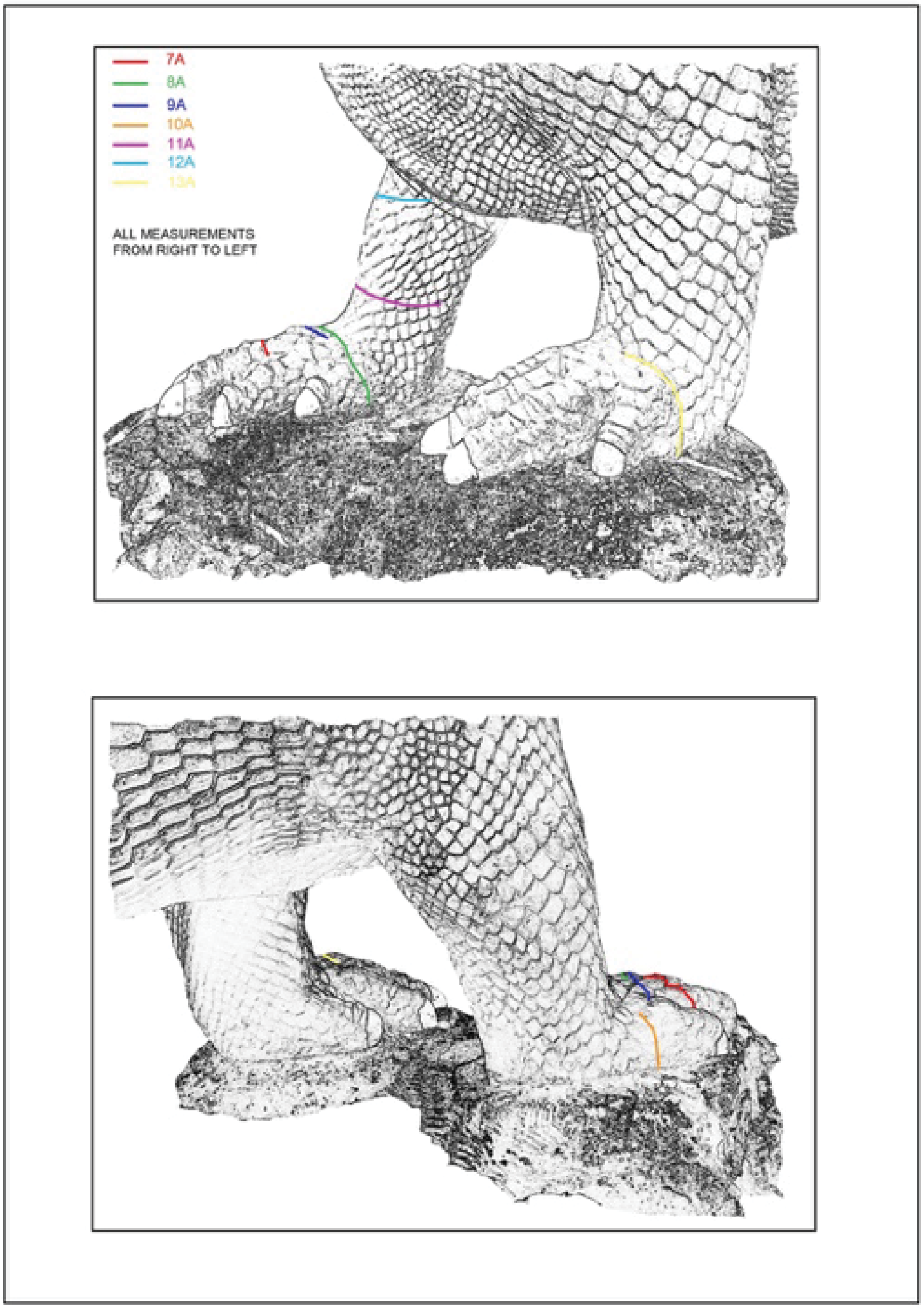


Graph 6.0

Table 6.0 – Crack 6A

Measurement Points Along Crack (mm)	15.12.16 Width (mm)	15.03.17 Width (mm)	△ Width (mm)	15.12.16 Depth (mm)	15.03.17 Depth (mm)	△ Depth (mm)
0	0.04	0.04	0	0.5	0.5	0
100	0.04	0.04	0	0.5	0.5	0
200	0.04	0.04	0	0.5	0.5	0
300	0.04	0.04	0	0.5	0.5	0
400	0.04	0.04	0	0.5	0.5	0
430	0.04	0.04	0	0.5	0.5	0

The cracks were identified, measured and recorded on 15.12.2016. They were re-measured and recorded on 15.03.2017.



Plates 92 and 93. Diagrams depicting the location of the cracks.

Cracks 7a - 13a – see plate 92 and 93 for locations. Numbers refer to measurement points along the length of the crack in millimetres.

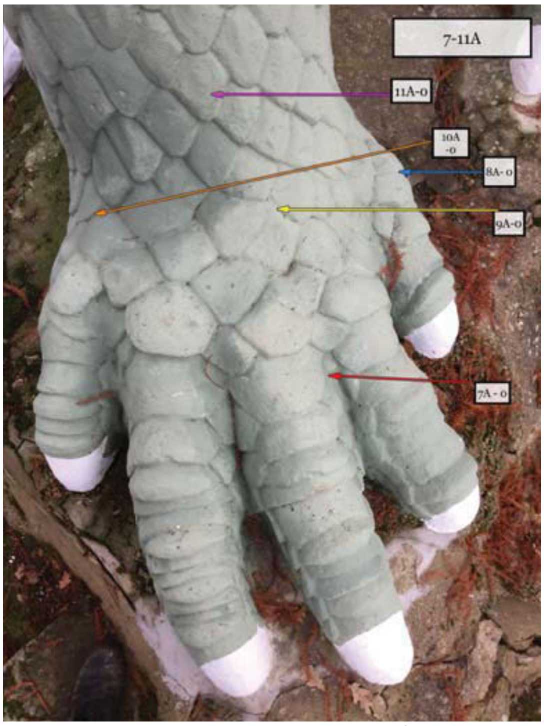


Plate 94. Photographed **15.12.16**[72]

Plate 95. Photographed **15.12.16**[73]

Plate 96. Photographed **15.12.16**[74]

[72] Carpenter, I. (2016). Front Feet Cracks [Unpublished Photographs].
[73] Carpenter, I. (2016). Front Feet Cracks [Unpublished Photographs].
[74] Carpenter, I. (2016). Front Feet Cracks [Unpublished Photographs].

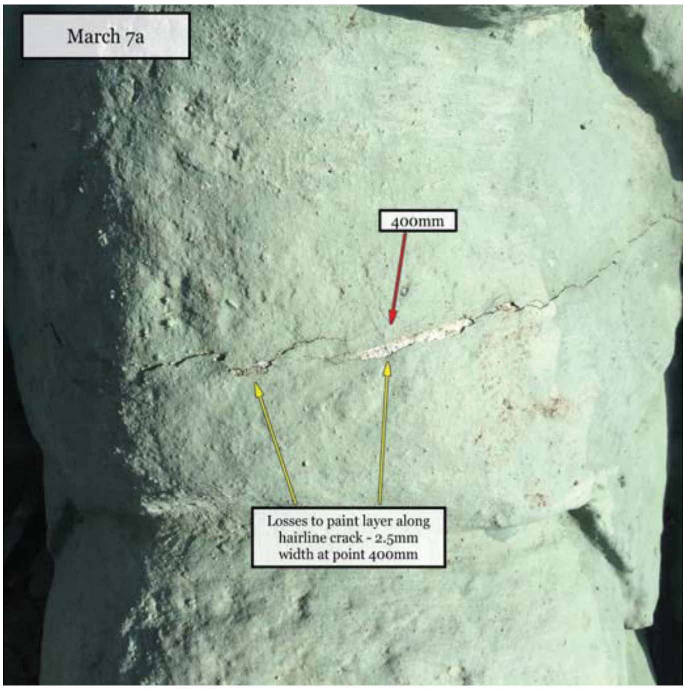


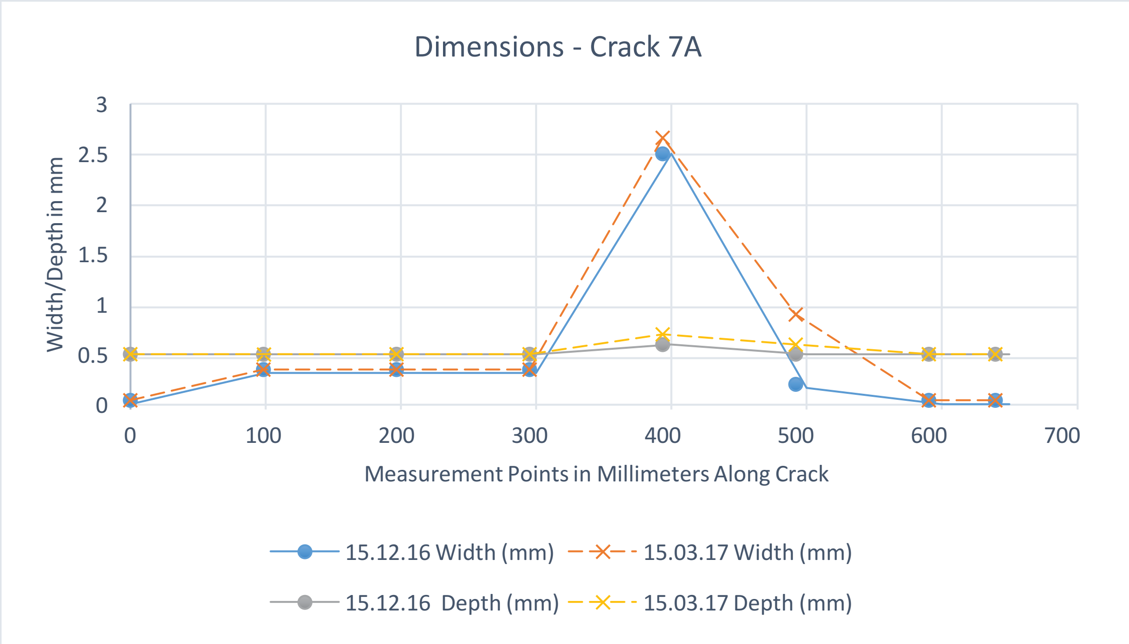
Plate 97 – Photographed **15.03.17 -** Crack 7a – delamination and loss of paint along the crack[75].

DATA

The graphs display the length, width and depth measurements for each individual crack. Starting at 0mm (the crack's origin point), the measurements were recorded every 100mm along the length of the crack and at points of noticeable deterioration.

Due to the accuracy limitations of the depth gauge, depth values of 100mm indicate values 100> and depth values of 0.5 indicate values of <0.5.
Loose, but non-disassociated fragments were recorded as having a depth of 100mm as these points were too fragile to take accurate readings.
Measurements were recorded on **15.12.2016** and again on the **15.03.2017**.

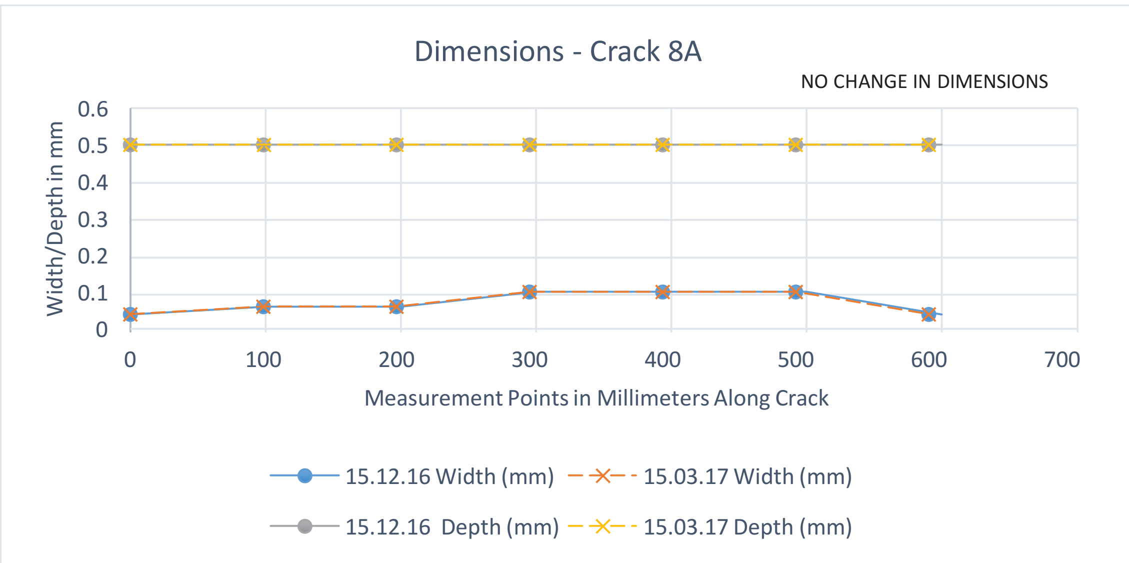
[75] Carpenter, I. (2016). Detail of Crack 7a [Unpublished Photographs].



Graph 7.0

Table 7.0 – Crack 7A

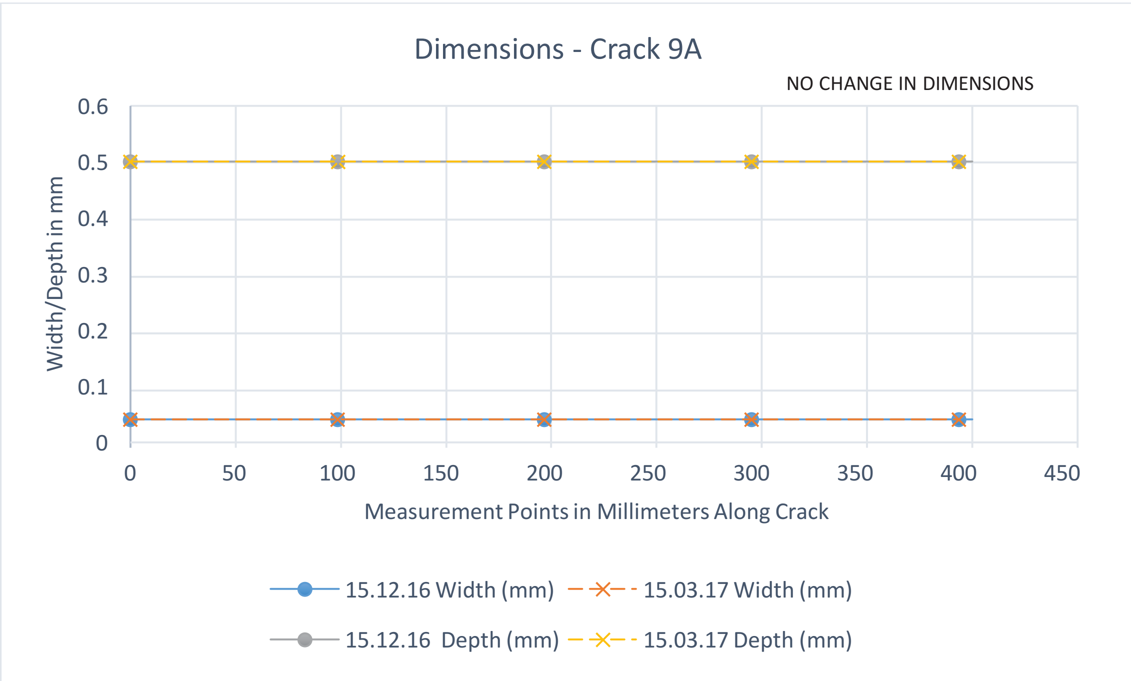
Measurement Points Along Crack (mm)	15.12.16 Width (mm)	15.03.17 Width (mm)	△ Width (mm)	15.12.16 Depth (mm)	15.03.17 Depth (mm)	△ Depth (mm)
0	0.04	0.04	0	0.5	0.5	0
100	0.35	0.35	0	0.5	0.5	0
200	0.35	0.35	0	0.5	0.5	0
300	0.35	0.35	0	0.5	0.5	0
400	2.5	2.66	0.16	0.6	0.7	0.1
500	0.2	0.9	0.7	0.5	0.6	0.1
600	0.04	0.04	0	0.5	0.5	0
650	0.04	0.04	0	0.5	0.5	0



Graph 8.0

Table 8.0 – Crack 8A

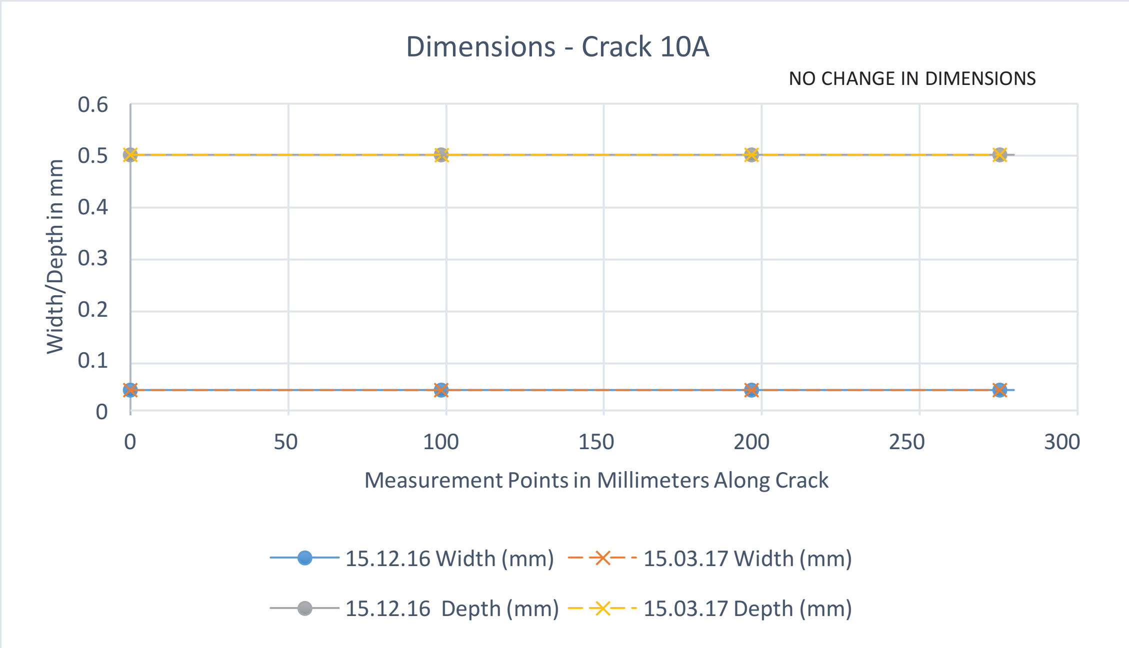
Measurement Points Along Crack (mm)	15.12.16 Width (mm)	15.03.17 Width (mm)	△ Width (mm)	15.12.16 Depth (mm)	15.03.17 Depth (mm)	△ Depth (mm)
0	0.04	0.04	0	0.5	0.5	0
100	0.06	0.06	0	0.5	0.5	0
200	0.06	0.06	0	0.5	0.5	0
300	0.1	0.1	0	0.5	0.5	0
400	0.1	0.1	0	0.5	0.5	0
500	0.1	0.1	0	0.5	0.5	0
600	0.04	0.04	0	0.5	0.5	0



Graph 9.0

Table 9.0 – Crack 9A

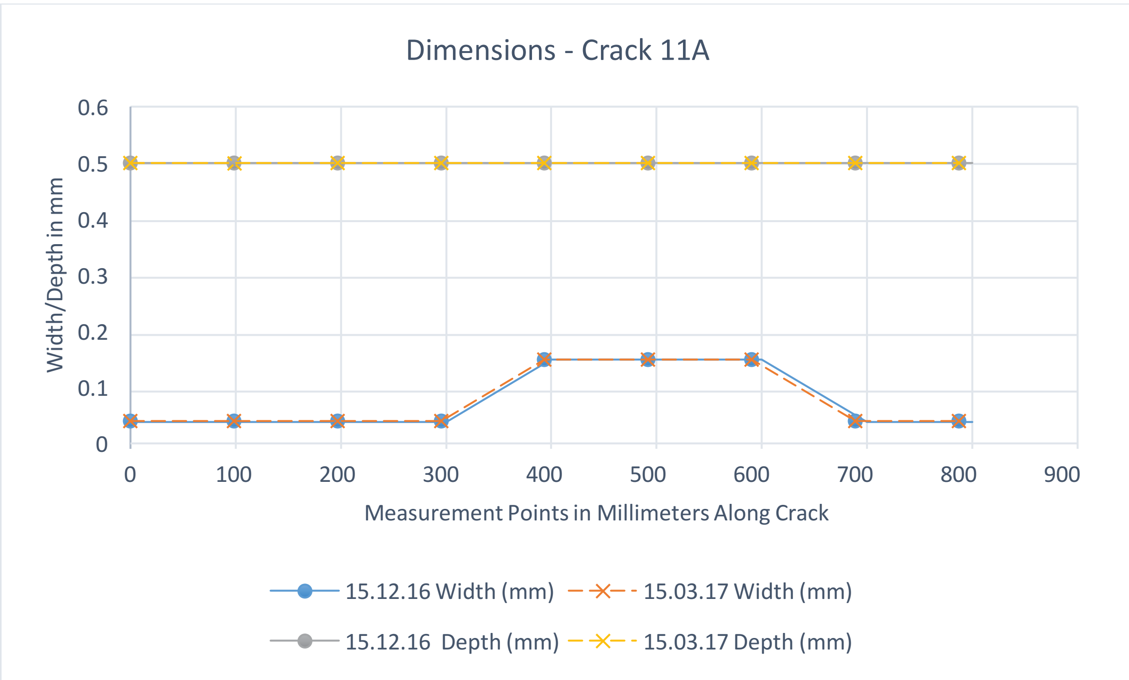
Measurement Points Along Crack (mm)	15.12.16 Width (mm)	15.03.17 Width (mm)	△ Width (mm)	15.12.16 Depth (mm)	15.03.17 Depth (mm)	△ Depth (mm)
0	0.04	0.04	0	0.5	0.5	0
100	0.04	0.04	0	0.5	0.5	0
200	0.04	0.04	0	0.5	0.5	0
300	0.04	0.04	0	0.5	0.5	0
400	0.04	0.04	0	0.5	0.5	0



Graph 10.0

Table 10.0 – Crack 10A

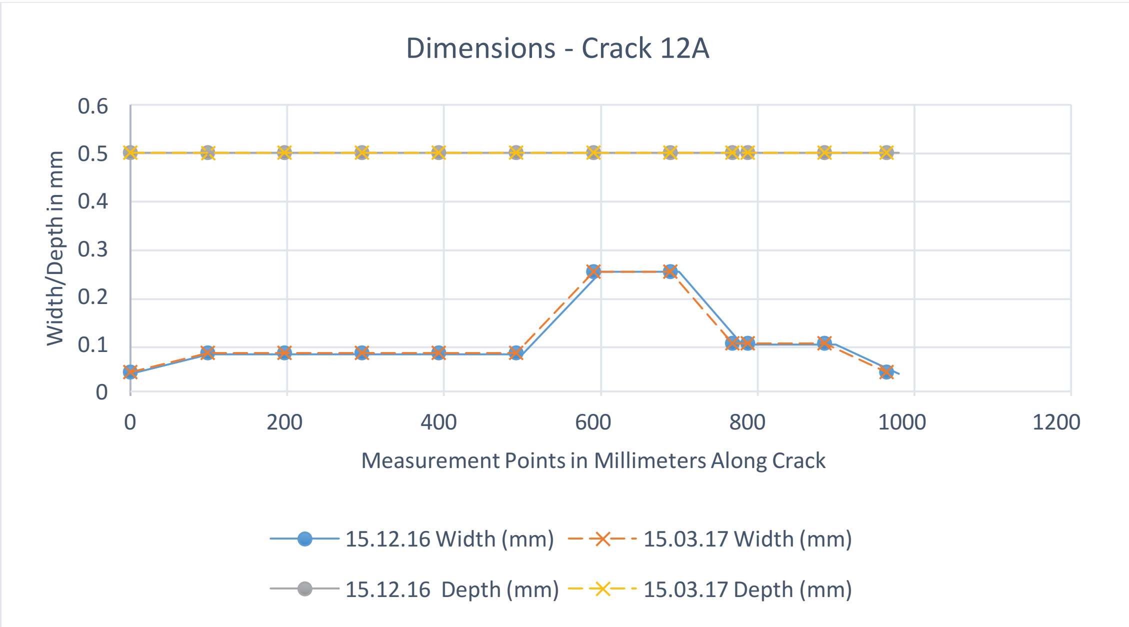
Measurement Points Along Crack (mm)	15.12.16 Width (mm)	15.03.17 Width (mm)	△ Width (mm)	15.12.16 Depth (mm)	15.03.17 Depth (mm)	△ Depth (mm)
0	0.04	0.04	0	0.5	0.5	0
100	0.04	0.04	0	0.5	0.5	0
200	0.04	0.04	0	0.5	0.5	0
280	0.04	0.04	0	0.5	0.5	0



Graph 11.0

Table 11.0 – Crack 11A

Measurement Points Along Crack (mm)	15.12.16 Width (mm)	15.03.17 Width (mm)	△ Width (mm)	15.12.16 Depth (mm)	15.03.17 Depth (mm)	△ Depth (mm)
0	0.04	0.04	0	0.5	0.5	0
100	0.04	0.04	0	0.5	0.5	0
200	0.04	0.04	0	0.5	0.5	0
300	0.04	0.04	0	0.5	0.5	0
400	0.15	0.15	0	0.5	0.5	0
500	0.15	0.15	0	0.5	0.5	0
600	0.15	0.15	0	0.5	0.5	0
700	0.04	0.04	0	0.5	0.5	0
800	0.04	0.04	0	0.5	0.5	0

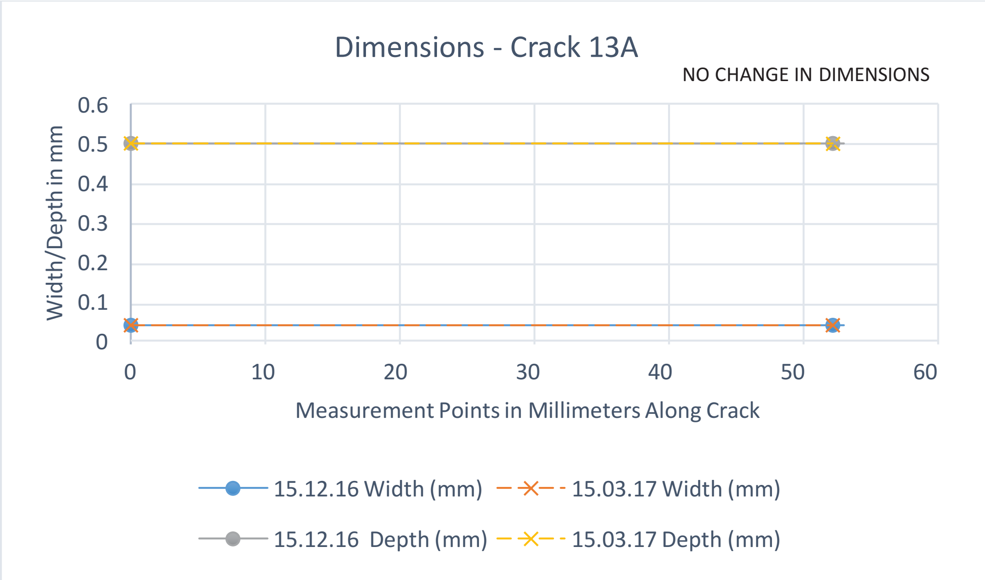


Graph 12.0

Table 12.0 – Crack 12A

Measurement Points Along Crack (mm)	15.12.16 Width (mm)	15.03.17 Width (mm)	△ Width (mm)	15.12.16 Depth (mm)	15.03.17 Depth (mm)	△ Depth (mm)
0	0.04	0.04	0	0.5	0.5	0
100	0.08	0.08	0	0.5	0.5	0
200	0.08	0.08	0	0.5	0.5	0
300	0.08	0.08	0	0.5	0.5	0
400	0.08	0.08	0	0.5	0.5	0
500	0.08	0.08	0	0.5	0.5	0
600	0.25	0.25	0	0.5	0.5	0
700	0.25	0.25	0	0.5	0.5	0
780	0.1	0.1	0	0.5	0.5	0

800	0.1	0.1	0	0.5	0.5	0
900	0.1	0.1	0	0.5	0.5	0
980	0.04	0.04	0	0.5	0.5	0



Graph 13.0

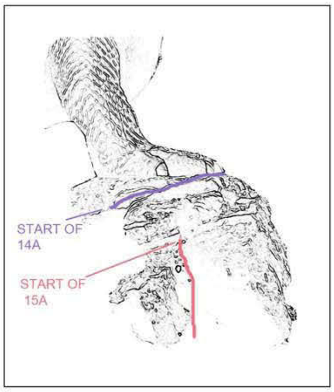
Table 13.0 – Crack 13A

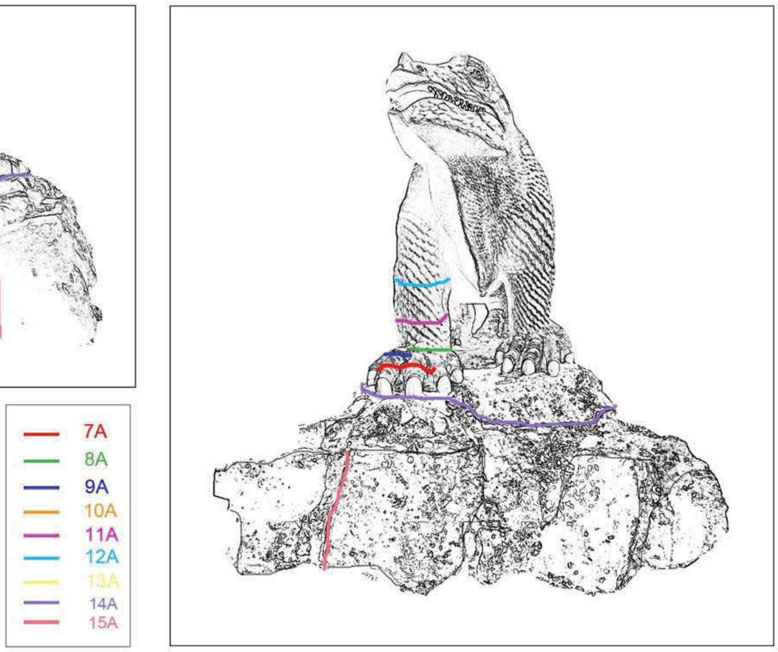
Measurement Points Along Crack (mm)	**15.12.16 Width (mm)**	**15.03.17 Width (mm)**	**△ Width (mm)**	**15.12.16 Depth (mm)**	**15.03.17 Depth (mm)**	**△ Depth (mm)**
0	0.04	0.04	0	0.5	0.5	0
53	0.04	0.04	0	0.5	0.5	0

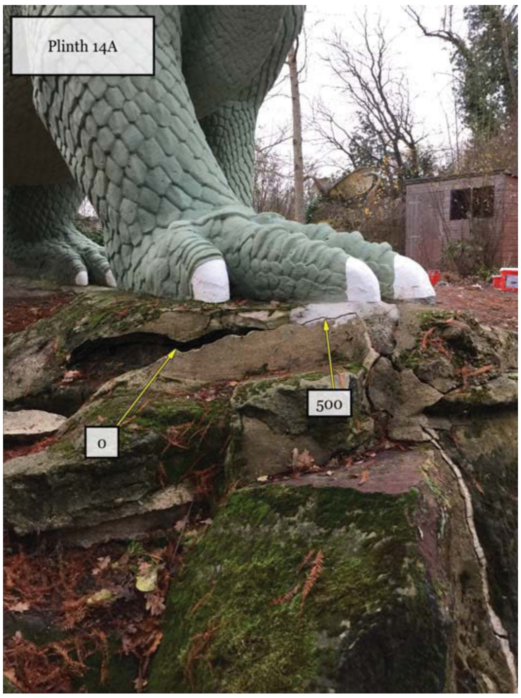
PLINTH

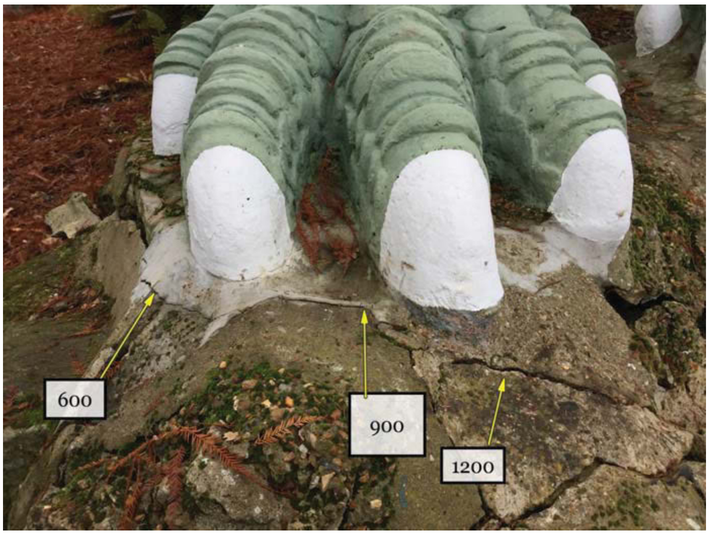
The cracks were identified, measured and recorded on 15.12.2016. They were re-measured and recorded on 15.03.2017.

Plates 98 and 99. Diagrams depicting the location of the cracks 14a and 15a.









Plates 100 and 101.

Plates 100 and 101 – Photographed 15.12.16 - Crack 14a [76]

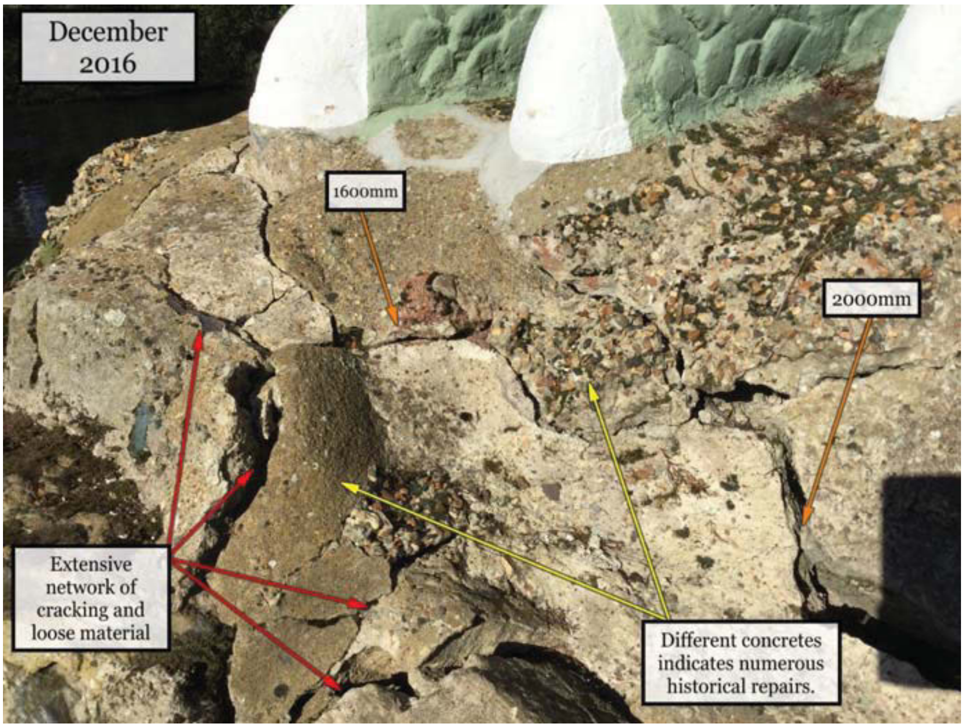


Plate 102- Photographed 15.12.16 – Complexity of crack network[77]

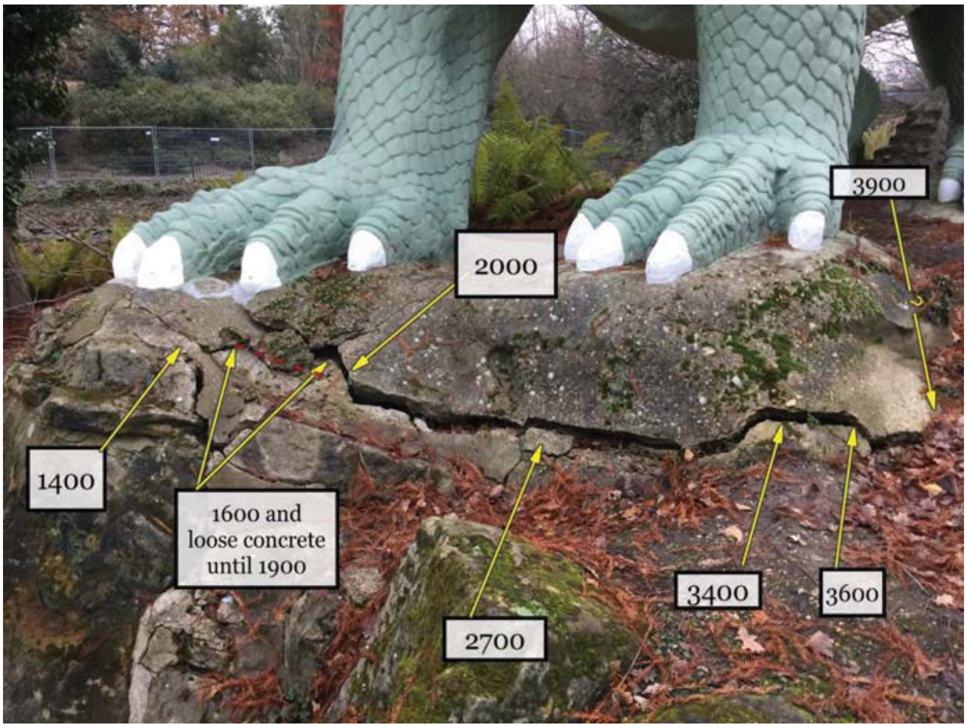


Plate 103- Photographed 15.12.16 – Crack 14A[78]

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[76] Carpenter, I. (2016). Crack 14a [Unpublished Photographs].
[77] Carpenter, I. (2016). Crack 14a [Unpublished Photographs].
[78] Carpenter, I. (2016). Crack 14a [Unpublished Photographs].

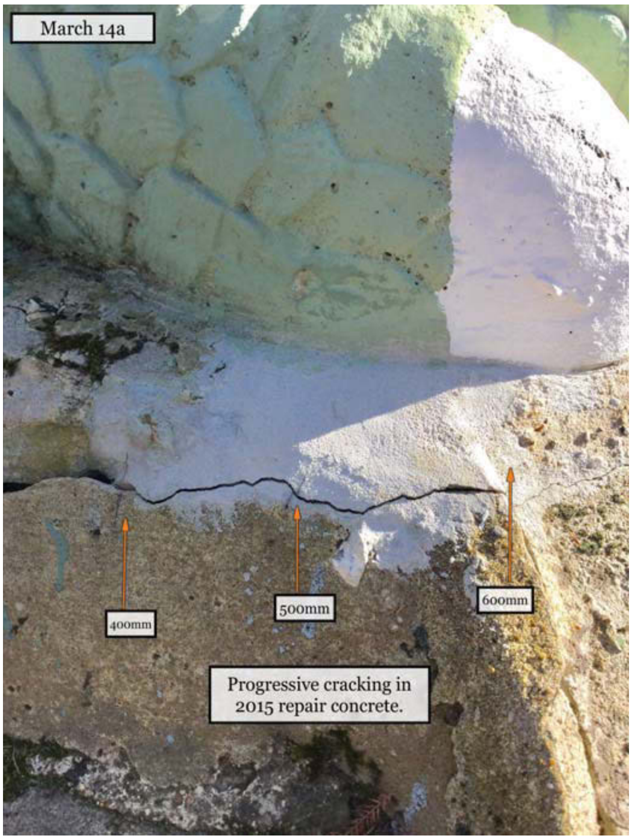


Plate 104 – Photographed **15.03.17** – Crack 14A. Increase in width and depth between points 400-600mm between 15.12.16-15.03.17. Crack occurring in 2015 restoration concrete[79]

Plate 105- Photographed **15.12.16** – Crack 15A[80]

[79] Carpenter, I. (2016). Crack 14a [Unpublished Photographs].
[80] Carpenter, I. (2016). Crack 15a [Unpublished Photographs].

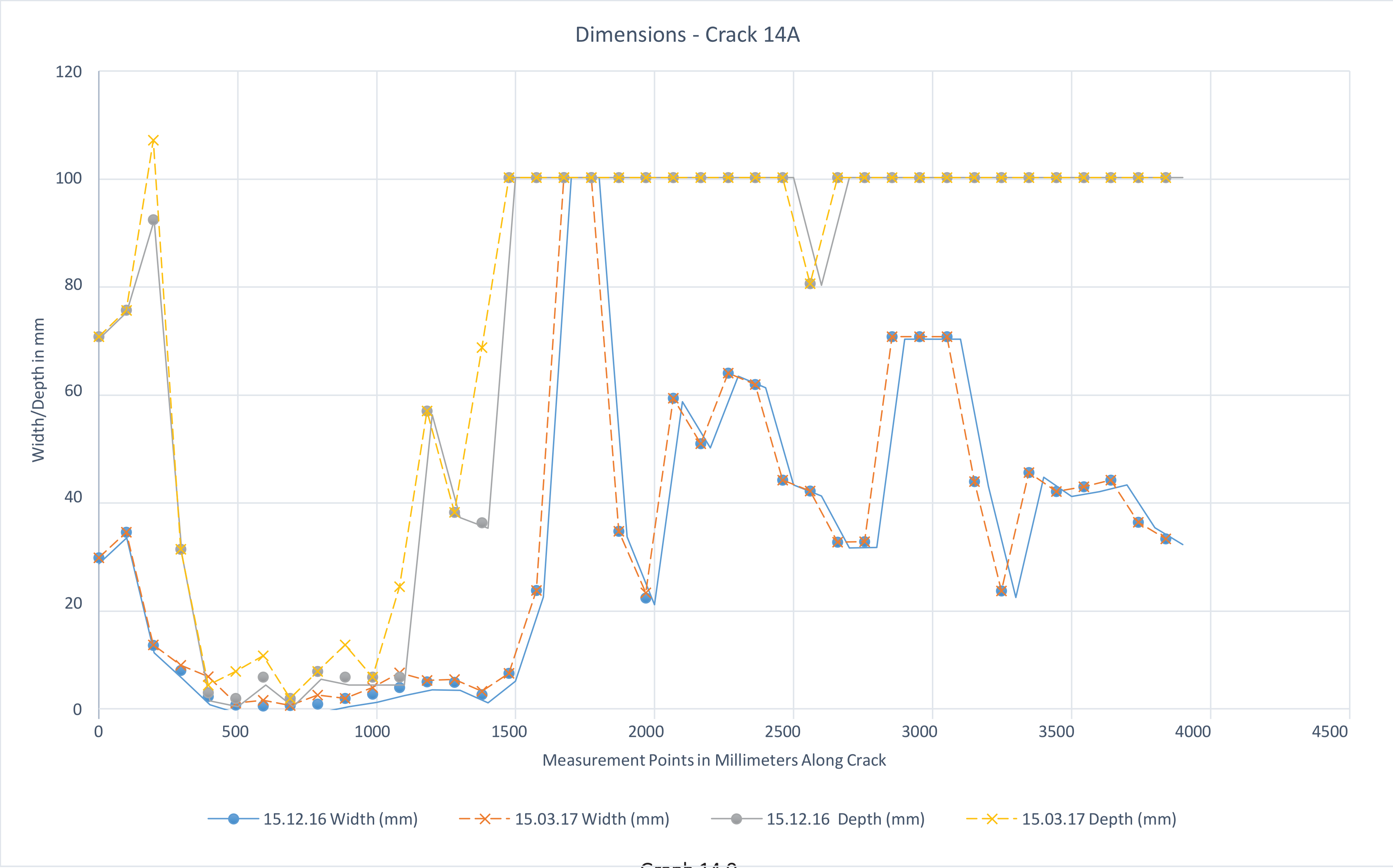
DATA

The graphs display the length, width and depth measurements for each individual crack. Starting at 0mm (the crack's origin point), the measurements were recorded every 100mm along the length of the crack and at points of noticeable deterioration.

Due to the accuracy limitations of the depth gauge, depth values of 100mm indicate values 100> and depth values of 0.5 indicate values of <0.5.

Loose, but non-disassociated fragments were recorded as having a depth of 100mm as these points were too fragile to take accurate readings.

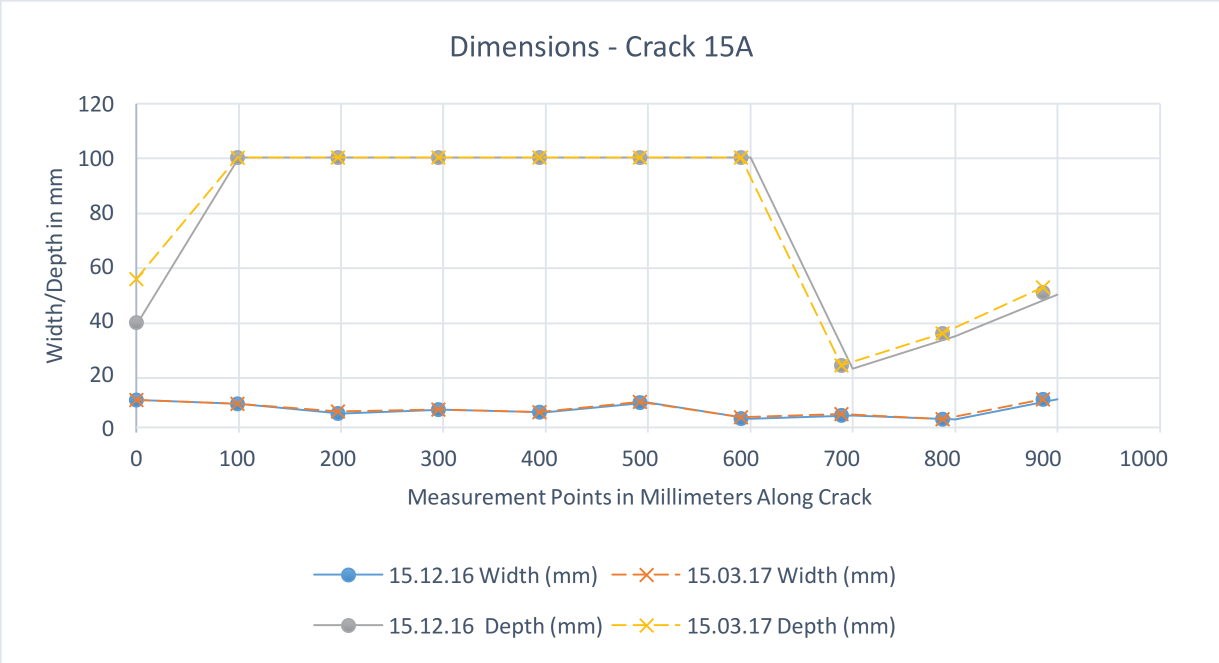
Measurements were recorded on **15.12.2016** and again on the **15.03.2017**.


Dimensions - Crack 14A
Width/Depth in mm
Measurement Points in Millimeters Along Crack
15.12.16 Width (mm)
15.03.17 Width (mm)
15.12.16 Depth (mm)
15.03.17 Depth (mm)

Graph 14.0

Table 14.0 – Crack 14A

Measurement Points Along Crack (mm)	**15.12.16 Width (mm)**	**15.03.17 Width (mm)**	**△ Width (mm)**	**15.12.16 Depth (mm)**	**15.03.17 Depth (mm)**	**△ Depth (mm)**
0	28.38	28.38	0	70	70	0
100	33.19	33.19	0	75	75	0
200	11.93	12.05	0.12	92	107	15
300	7.23	8.18	0.95	30	30	0
400	2.3	6.02	3.72	3	4.5	1.5
500	0.7	1.1	0.4	2	7	5
600	0.5	1.6	1.1	6	10	4
700	0.65	0.65	0	2	2	0
800	0.9	2.58	1.68	7	7	0
900	1.95	1.96	0.01	6	12	6
1000	2.72	3.99	1.27	6	6	0
1100	4.04	6.8	2.76	6	23	17
1200	5.12	5.33	0.21	56	56	0
1300	5	5.52	0.52	37	37	0
1400	2.63	3.33	0.7	35	68	33
1500	6.66	6.66	0	100	100	0
1600	22.29	22.29	0	100	100	0
1700	100	100	0	100	100	0
1800	100	100	0	100	100	0
1900	33.45	33.45	0	100	100	0
2000	20.87	21.87	1	100	100	0
2100	58.49	58.49	0	100	100	0
2200	49.91	49.91	0	100	100	0
2300	63.14	63.14	0	100	100	0
2400	61.01	61.01	0	100	100	0
2500	43	43	0	100	100	0
2600	41	41	0	80	80	0
2700	31.37	31.37	0	100	100	0
2800	31.49	31.49	0	100	100	0
2900	70	70	0	100	100	0
3000	70	70	0	100	100	0
3100	70	70	0	100	100	0
3200	42.8	42.8	0	100	100	0
3300	22.16	22.16	0	100	100	0
3400	44.5	44.5	0	100	100	0
3500	40.91	40.91	0	100	100	0
3600	41.8	41.8	0	100	100	0
3700	43.01	43.01	0	100	100	0
3800	35.07	35.07	0	100	100	0
3900	32	32	0	100	100	0



Graph 15.0.

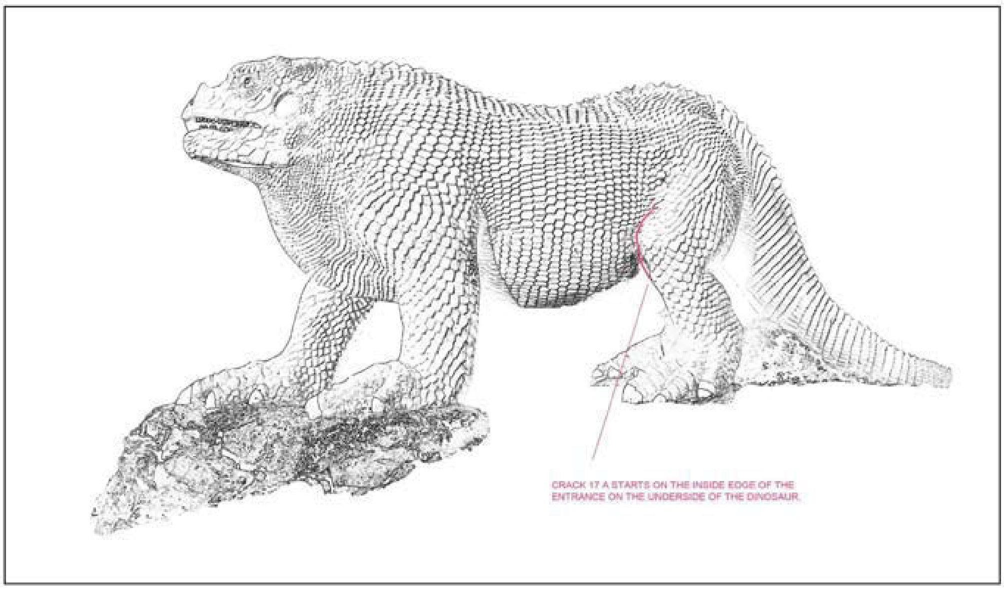
Table 15.0 – Crack 15A

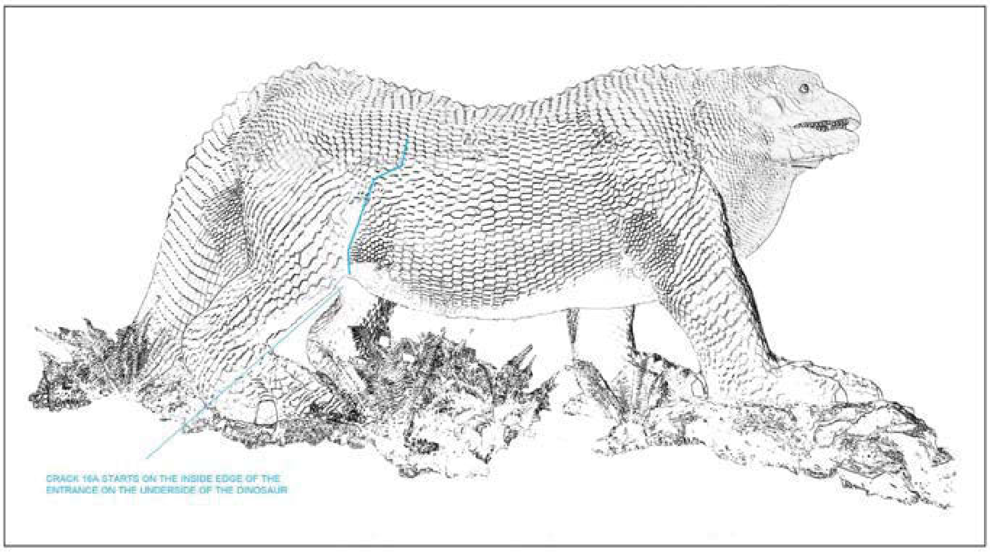
Measurement Points Along Crack (mm)	15.12.16 Width (mm)	15.03.17 Width (mm)	△ Width (mm)	15.12.16 Depth (mm)	15.03.17 Depth (mm)	△ Depth (mm)
0	10.23	10.23	0	39	55	16
100	8.9	8.9	0	100	100	0
200	5.4	6.07	0.67	100	100	0
300	6.65	6.65	0	100	100	0
400	5.9	5.9	0	100	100	0
500	9.4	9.66	0.26	100	100	0
600	3.5	3.99	0.49	100	100	0
700	4.5	5.07	0.57	23	23	0
800	3.19	3.19	0	35	35	0
900	10.6	10.6	0	50	52	2

BODY

The cracks were identified, measured and recorded on 15.12.2016. They were re-measured and recorded on 15.03.2017.

Plates 107 and 108. Diagrams depicting the location of the cracks 16a and 17a





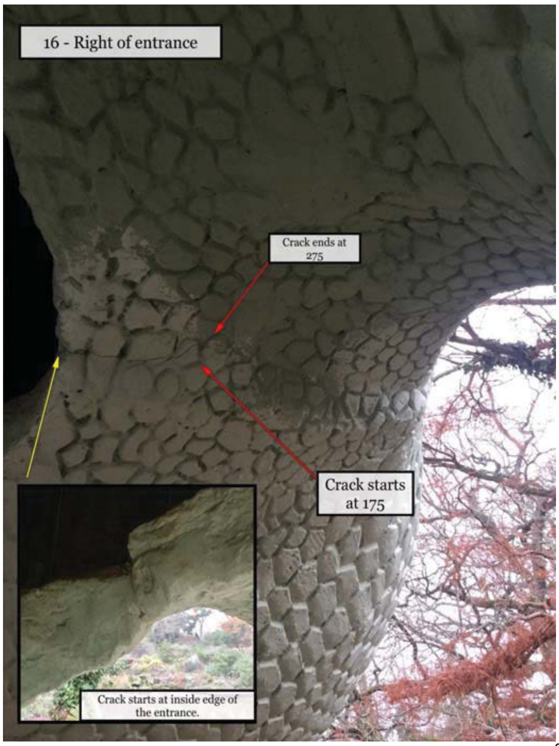


Plate 109- Crack 16a – Photographed **15.12.16**[81]

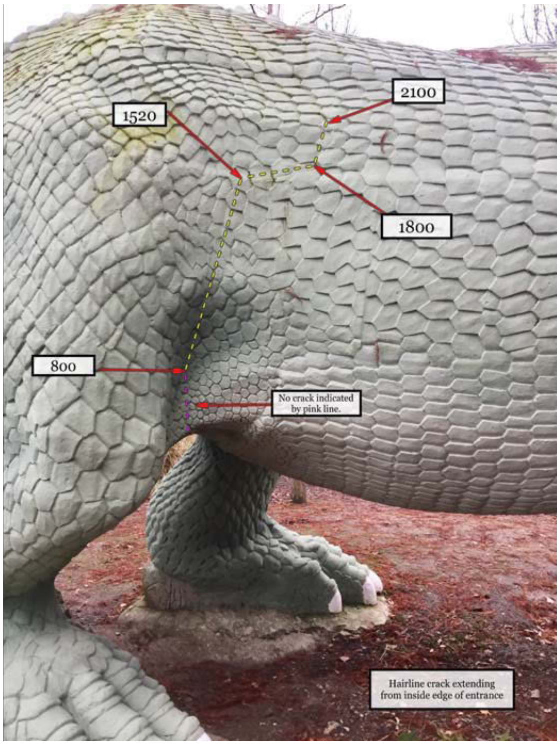


Plate 110- Crack 16a – Photographed **15.12.16**[82]

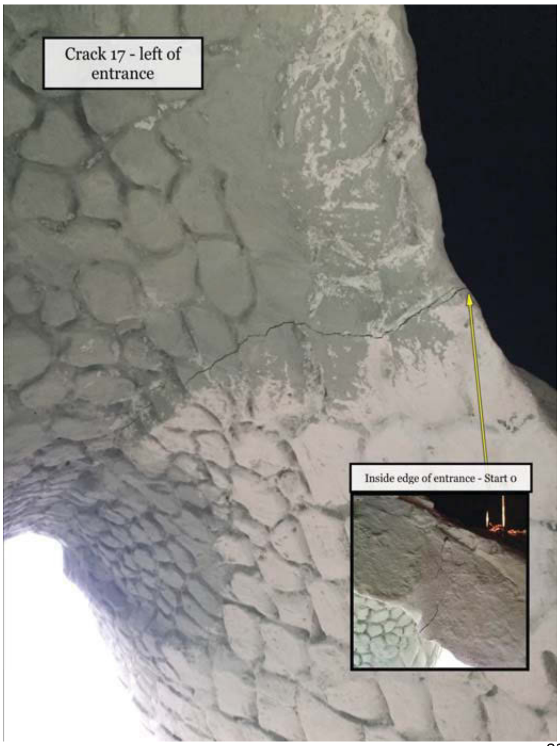


Plate 111– Crack 17a – Photographed **15.12.16**[83]

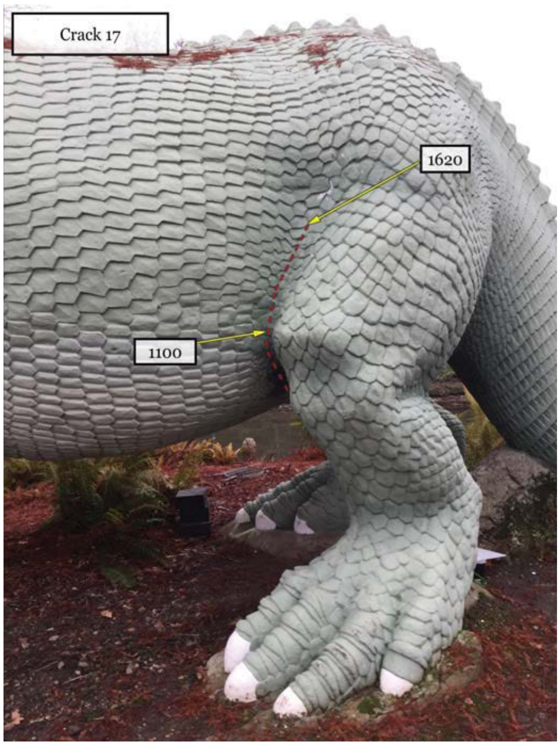


Plate 112– Crack 17a – Photographed **15.12.16**[84]

[81] Carpenter, I. (2016). Crack 16a [Unpublished Photographs].
[82] Carpenter, I. (2016). Crack 16a [Unpublished Photographs].
[83] Carpenter, I. (2016). Crack 17a [Unpublished Photographs].
[84] Carpenter, I. (2016). Crack 17a [Unpublished Photographs].

DATA

The graphs display the length, width and depth measurements for each individual crack. Starting at 0mm (the crack's origin point), the measurements were recorded every 100mm along the length of the crack and at points of noticeable deterioration.

Due to the accuracy limitations of the depth gauge, depth values of 100mm indicate values 100> and depth values of 0.5 indicate values of <0.5.

Loose, but non-disassociated fragments were recorded as having a depth of 100mm as these points were too fragile to take accurate readings.

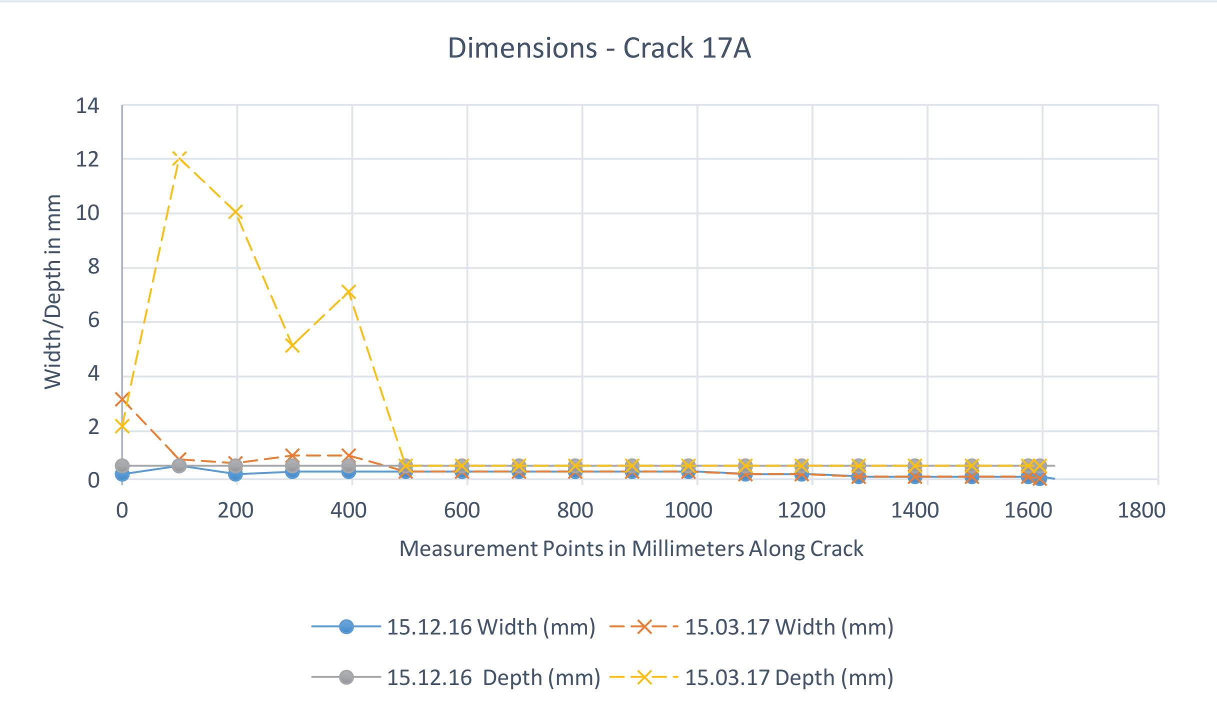
Measurements were recorded on **15.12.2016** and again on the **15.03.2017**.

Graph 16.0

Table 16.0 – Crack 16A

Measurement Points Along Crack (mm)	**15.12.16 Width (mm)**	**15.03.17 Width (mm)**	**△ Width (mm)**	**15.12.16 Depth (mm)**	**15.03.17 Depth (mm)**	**△ Depth (mm)**
0	0.5	0.5	0	0.5	0.5	0
100	0.2	0.2	0	0.5	0.5	0
175	0.04	0.04	0	0.5	0.5	0
200	0.5	0.5	0	0.5	0.5	0
300	0.5	1	0.5	0.5	0.5	0
400	0.5	1	0.5	0.5	0.5	0
500	0.2	0.8	0.6	0.5	0.5	0
600	0	0	0	0.5	0.5	0
700	0	0	0	0.5	0.5	0

800	0.2	0.2	0	0.5	0.5	0
900	0.2	0.2	0	0.5	0.5	0
1000	0.2	0.2	0	0.5	0.5	0
1100	0.2	0.2	0	0.5	0.5	0
1200	0.2	0.2	0	0.5	0.5	0
1300	0.2	0.2	0	0.5	0.5	0
1400	0.2	0.2	0	0.5	0.5	0
1500	0.2	0.2	0	0.5	0.5	0
1520	0.2	0.2	0	0.5	0.5	0
1600	0.2	0.2	0	0.5	0.5	0
1700	0.2	0.2	0	0.5	0.5	0
1800	0.2	0.2	0	0.5	0.5	0
1900	0.2	0.2	0	0.5	0.5	0
2000	0.2	0.2	0	0.5	0.5	0
2100	0.2	0.2	0	0.5	0.5	0



Graph 17.0

Table 17.0 – Crack 17A

Measurement Points Along Crack (mm)	**15.12.16 Width (mm)**	**15.03.17 Width (mm)**	**△ Width (mm)**	**15.12.16 Depth (mm)**	**15.03.17 Depth (mm)**	**△ Depth (mm)**
0	0.2	3	2.8	0.5	2	1.5
100	0.5	0.75	0.25	0.5	12	11.5
200	0.2	0.6	0.4	0.5	10	9.5
300	0.3	0.9	0.6	0.5	5	4.5
400	0.3	0.9	0.6	0.5	7	6.5
500	0.3	0.3	0	0.5	0.5	0

600	0.3	0.3	0	0.5	0.5	0
700	0.3	0.3	0	0.5	0.5	0
800	0.3	0.3	0	0.5	0.5	0
900	0.3	0.3	0	0.5	0.5	0
1000	0.3	0.3	0	0.5	0.5	0
1100	0.2	0.2	0	0.5	0.5	0
1200	0.2	0.2	0	0.5	0.5	0
1300	0.1	0.1	0	0.5	0.5	0
1400	0.1	0.1	0	0.5	0.5	0
1500	0.1	0.1	0	0.5	0.5	0
1600	0.1	0.1	0	0.5	0.5	0
1620	0.04	0.04	0	0.5	0.5	0