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Use of 3D modeling to assess pothole growth

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ABSTRACT: This paper considers the use of 3D modeling to quantify the growth of pot holes. These are a common problem around the world and cause problems with the road user and those involved with its maintenance. Assessing the size of a pothole, or being able to understand their growth has not really been considered in the literature. 3D modeling techniques based on stereo photogrammetry were used to quantify 2d and 3d parameters of potholes. The experiment was carried out the laboratory. Roller compacted slabs were prepared and an artificial pothole created on its surface. This was photographed and a 3D model created. The artificial pothole was enlarged and the process repeated. At each stage the actual diameter, circumference and volume of the hole was determined. The 3D models were analyzed using DigitalSurf MountainsMap software. Good correlation was found between parameters from the 3d model and those measured. It is proposed that this method gives a simple and robust method to better understand potholes.

1 INTRODUCTION

A pothole is a localized road surface breakdown caused by factors including winter freeze-thaw weather conditions, moisture presence and inappropriate pavement construction. Last year over 1.7 million potholes were repaired in England at a cost of £90.9 million (ALARM, 2014). The carriageway maintenance backlog was approximately 12 years. The ALARM report concluded that research is required to make better use of funding. Although there has been work carried out into why they form and how they may be repaired relatively little research has considered how their physical parameters may be quantified and so better understood.

A pothole is a type of road surface texture. There are different scales of texture classified on wavelength i.e. microtexture, macrotexture, megatexture and surface roughness. These texture scales influence tyre-pavement interaction including skid resistance, surface drainage, surface noise and rolling resistance. Microtexture relates to the roughness of aggregate particles and contributes to skid resistance. Macrotexture relates to bulk removal of surface water, noise generation and rolling resistance. Pothole defects are referred to as examples of megatexture with wavelengths in the range of 50 mm to 500 mm.

Methods of texture measurement have been available for many years. For example, the PSV test for aggregate microtexture and the use of the volumetric patch technique for macrotexture. 2D laser technologies have been developed and used on devices such as TRACS for traffic-speed condition surveying. Research is now evaluating the use of 3D modeling and areal texture parameters to better understand road surface texture at its different wavelengths.

There are different techniques to create the 3D model e.g. using laser devices or stereo photogrammetry. Researchers such as Dondi et al (2010) and Sagiorgi (2012) have used laser devices to investigate change in surface texture roughness and potential collection of surface water. Although laser devices can produce good 3D models they tend to be quite slow and require expensive equipment. In contrast, stereo photogrammetry can use an ordinary SLR camera and the models are quite quick to produce.

A version of stereo photogrammetry, called close range photogrammetry (CRP) is used in this paper to produce 3D models of potholes for analysis. CRP has many potential applications in highway engineering for pavement surface texture investigation, monitoring and maintenance. Some of these applications have been developed by Millar (2012) and McQuaid (2015). For example, Millar and Woodward (2012) found good correlation with the volumetric patch technique derived Mean Texture Depth (MTD).

This paper summarizes an application of CPR which compared pothole data such as diameter, circumference, depth and volume determined from manual measurement of the actual pothole and from analysis of the pothole 3D model.

2 METHODOLOGY

The research methodology involved a number of stages. This included the application of the CRP method to make 3D models, the manufacture of potholes in the laboratory, manual measurement of pothole parameters and determining pothole parameters from the 3D models.



Figure 1. Calibrated steel framework of control points.

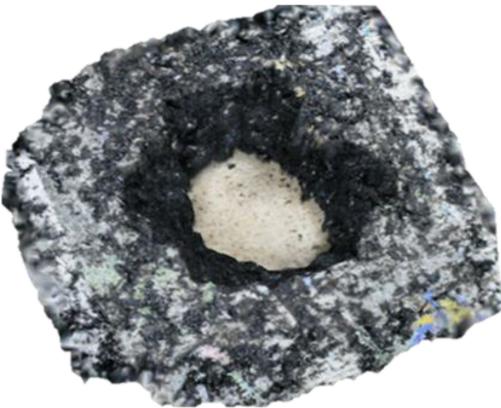


Figure 2. Example pothole TIN created and displayed in Zephyr.

2.1 Application of the CRP method

Triangular Irregular Network (TIN) 3D pothole models were made using 3DF Zephyr photogrammetric software. Zephyr requires multiple images to be captured of the pothole with at least 60% forward and 30% side overlap across the images. A Canon 6D EOS SLR camera with a 100 mm macro lens was used. The camera was handheld and used natural lighting conditions during image capture.

A steel framework of control reference points was used for scale. This is shown in Figure 1. The distances between individual control points were calibrated to two decimal places using a digital micrometer gauge. The use of this control framework allowed recovery of surface elevation and orientation for the created TIN. For the 3D capture of potholes in-situ, the use of a steel rule is sufficient. Following capture the images were imported into 3DFLOW 3DF Zephyr Pro photogrammetric software with relevant calibration documents. The use of filtering was minimized.

An example TIN of a pothole is shown in Figure 2, as displayed in Zephyr. The TIN file was then converted to a XYZ file format using MeshLab and exported to Digital Surf MountainsMap 7 spatial information

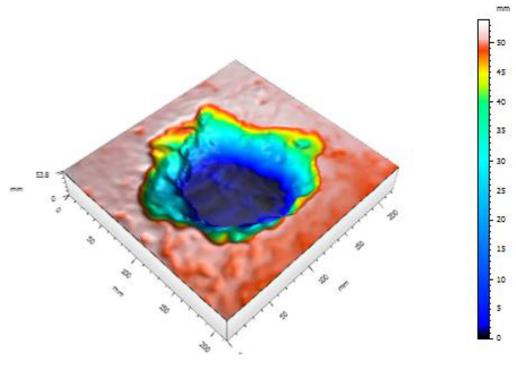


Figure 3. Color depth classified TIN of example pothole TIN displayed in MountainsMap.

software for analysis. The TIN mesh underwent initial operators to prepare the surface for analysis. This included leveling of the surface with respect to a least squared plane. An Area of Interest (AOI) was selected to remove redundant data from the TIN. Figure 3 shows a TIN that has been color depth classified in MountainsMap. The color depth classification is used to emphasize change in the z-axis elevation.

2.2 Assessment of a manufactured pothole

The laboratory 3D modeling experiments used potholes that were made in the laboratory. This used poorly compacted slabs of asphalt concrete made with 160/220 pen grade bitumen that were $275 \times 275 \times 40$ mm in size. They were poorly compacted using a hand roller in the steel control framework as shown in Figure 1.

A 3D model of the AC specimen was made. A number of coarse aggregate particles were removed from the center of the specimen using a screwdriver to represent an embryonic pothole. A second 3D model was created of the specimen. The embryonic pothole was enlarged using a hammer and chisel and 3D models made at each stage of enlargement.

The secure positioning of the specimen in the control framework ensured consistent orientation of the captured TINs with time as the pothole got larger. Stage 0 refers to the original specimen surface. Stage 4 refers to the pothole at its maximum size. Figure 4 shows the TIN for the pothole at Stage 4.

Figure 5 presents a composite of pseudo color images for the manufactured potholes for Stages 0, 1, 2, 3 and 4 displayed in MountainsMap. Manual measurements were taken at each stage. Its diameter was recorded at three locations and an average calculated. A digital micrometer gauge was used to measure maximum depth.

A modified sand replacement method (BS 1377) was used to determine the volume of the pothole. A container of sand with a known weight was used to infill the pothole. The weight of sand not required was used to calculate the weight of the sand used. This



Figure 4. Laboratory manufactured pothole TIN at Stage 4, created and displayed in Zephyr.



Figure 6. Real in-situ pothole with steel rules for control purposes.

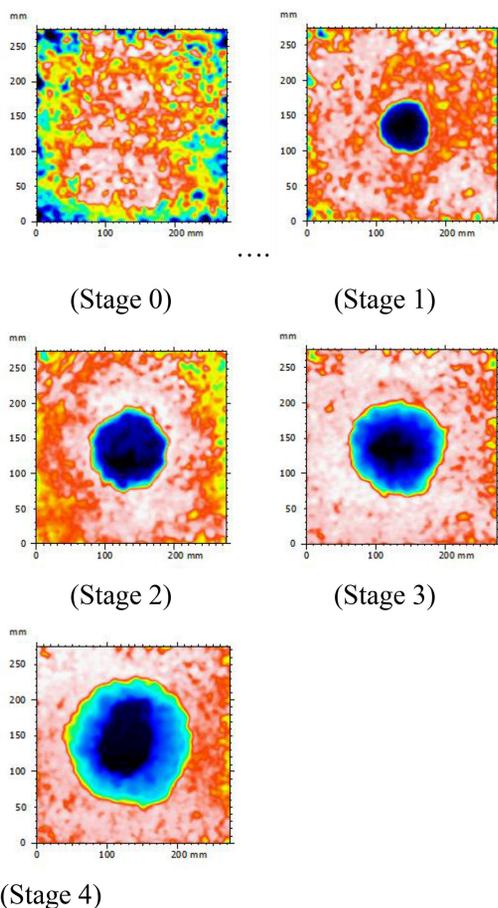


Figure 5. Comparison of 2D MountainsMap images for laboratory manufactured pothole at Stages 0, 1, 2, 3 and 4.

weight along with its corresponding density gave an approximate volume for the pothole. These manually recorded dimensions enabled comparisons to validate the dimensions obtained from MountainsMap analysis of the 3D model.

2.3 CRP assessment of a real pothole

The practicality of the CRP method was validated using real potholes. Figure 6 shows an example pothole. The two steel scale rules are used for control purposes. Images were taken using two devices i.e. the 20 mega-pixel Canon 6D SLR EOS camera used in the laboratory investigation and an Apple iPhone with 5 megapixel camera. Although the iPhone camera takes an image with less resolution these types of device are readily available and may offer better practicality for the user.

3 RESULTS

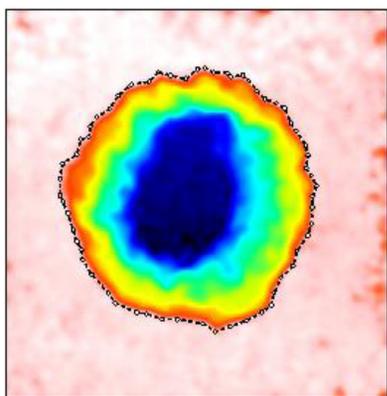
Many types of 2D and 3D surface texture parameter measurement, in accordance with BS EN ISO 25178-2 (2012), are possible using the MountainsMap software. For the purposes of this paper only a few of the possible methods were used. This included a volume of a hole or a peak study. This study allows the volume and maximum depth of a determined hole/peak to be calculated along with the surrounding redundant material. Figure 7 shows an example output of this study procedure. In this method, the user must select the edge of the pothole.

The distance measurement study was used to determine the diameter of the pothole for each TIN. Similar to the manual measurement, the diameter was recorded at three locations along the pothole TIN circumference and an average determined. Similar to the previous study this can also be subjective.

Table 1 presents the manually measured average diameter, maximum depth and volume data for Stages 1 to 4. Table 2 presents the same parameters measured from the corresponding TINs using MountainsMap. No measurements were recorded for the Stage 0 TIN as the pothole had not been formed.

The Abbott-Firestone curve (AFC) study was used to determine the volume of the void in the formed pothole. The AFC is a volume ratio based curve. An example AFC curve is shown in Figure 8.

The curve is divided into four volume parameters; volume of peak material (Vmp), volume of core



| Parameters | Unit | Hole | Peak |
|-------------------|-----------------|--------|-------|
| Surface | mm ² | 25265 | 0.00 |
| Volume | mm ³ | 561068 | 0.00 |
| Max. depth/height | mm | 39.6 | 0.331 |
| Mean depth/height | mm | 22.2 | 0.00 |

Figure 7. Volume of a hole or a peak study for Stage 4 pothole TIN.

Table 1. Manual measurements for the laboratory manufactured pothole.

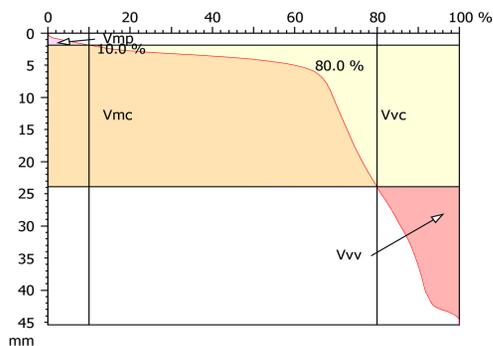
| Stage | Average Diameter (mm) | Maximum depth (mm) | Volume (mm ³) |
|-------|-----------------------|--------------------|---------------------------|
| 0 | — | — | — |
| 1 | 35.67 | 10.00 | 5178 |
| 2 | 111.33 | 23.25 | 159142 |
| 3 | 130.00 | 31.00 | 234547 |
| 4 | 174.00 | 40.00 | 589482 |

Table 2. MountainsMap measurements for the laboratory manufactured pothole.

| Stage | Average Diameter (mm) | Maximum depth (mm) | Volume (mm ³) |
|-------|-----------------------|--------------------|---------------------------|
| 0 | — | — | — |
| 1 | 34.47 | 7.04 | 3373 |
| 2 | 111.33 | 23.20 | 129163 |
| 3 | 129.00 | 32.90 | 220071 |
| 4 | 173.00 | 39.60 | 561068 |

material (Vmc), volume of core voids (Vvc) and volume of valley voids (Vvv). The software adopts upper p (10%) and lower q (80%) default Areal Material Bearing Ratio (AMBR) limits. These are adjustable and allow investigation into how the surface texture of the pothole changes with depth.

The AFC Vvc value approximates the volume of the pothole. By adjusting the lower p and upper q AMBR limits, the void volume/loss of material can be determined. Figure 9 presents the change in Vvc with depth into the surface texture for all five stages



| Parameters | Value | Unit |
|------------|-------|-------------------|
| Vmp | 61.8 | ml/m ² |
| Vmc | 14763 | ml/m ² |
| Vvc | 7294 | ml/m ² |
| Vvv | 2363 | ml/m ² |

Figure 8. AFC for stage 4 pothole defect TIN displayed in MountainsMap.

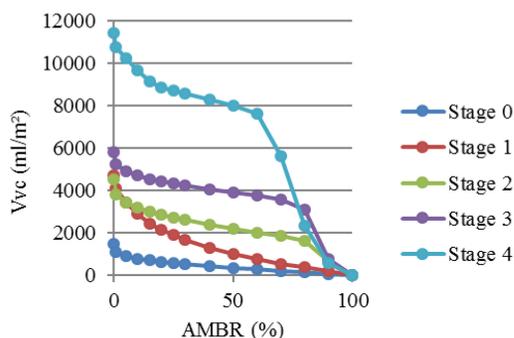


Figure 9. Vvc against AMBR for all five stages, derived from the AFC.

of the laboratory manufactured pothole. The prominent kink in the AFC plots shown in Figure 9 illustrate development of the pothole as it gets larger.

Single or multiple profiles can be extracted from the pothole TIN in MountainsMap. A step height calculation study can be carried out on the profile. An example is displayed in Figure 10. This study determines multiple steps across a profile and calculates parameters correspondingly. The step height calculation in Figure 10 reports a maximum depth of 38.9 mm for the pothole model. This compares with the compacted depth of 40 mm for the test specimen.

Figure 11 shows the real pothole example modeled in Zephyr using the images taken using the SLR camera. Table 3 compares the average diameter, maximum depth and volume for this pothole based on images for the SLR camera and the iPhone camera.

4 DISCUSSION

The data recorded manually was compared with that from the 3D models. Figure 12 plots the pothole

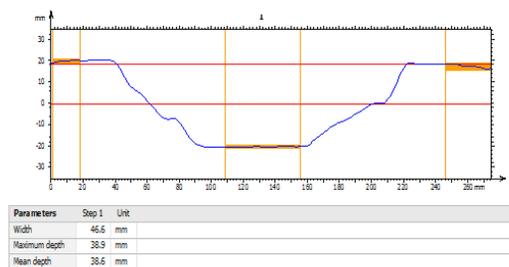


Figure 10. Step height calculation study for Stage 4 pothole TIN, in MountainsMap.



Figure 11. Real pothole TIN captured using Canon 6D camera device created and displayed in Zephyr.

Table 3. Real pothole measurements recorded using MountainsMap for both camera devices.

| Camera | Average Diameter (mm) | Maximum depth (mm) | Volume (mm ³) |
|----------|-----------------------|--------------------|---------------------------|
| Canon 6D | 217.00 | 63.00 | 1105122 |
| iPhone | 215.67 | 61.50 | 10919014 |

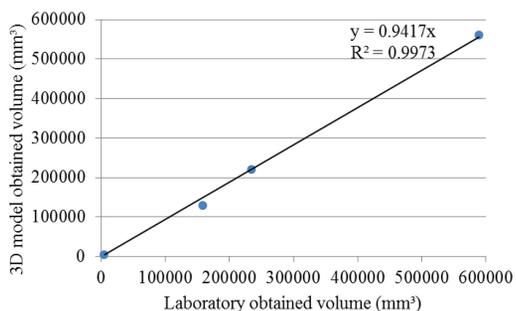


Figure 12. Comparison of pothole volume data for Stages 1, 2, 3 and 4.

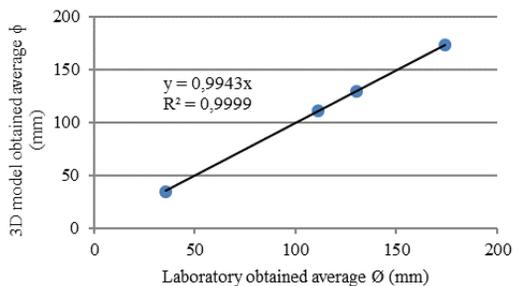


Figure 13. Comparison of pothole diameter data for Stages, 1, 2, 3 and 4.

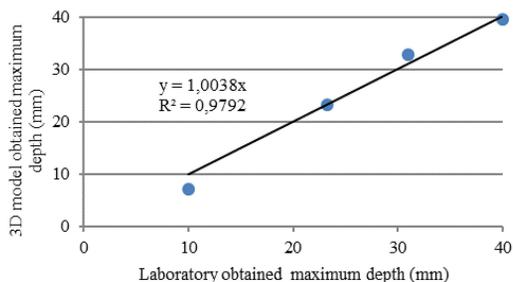


Figure 14. Comparison of pothole maximum depth data for Stages 1, 2, 3 and 4.

volume data from the volume of a hole or a peak study and the modified sand replacement test. This shows a linear relationship with a R^2 of 0.9973.

The plot shows a slight under-recovery for the 3D model data compared to the modified sand replacement method. This may be due to the difficulty of capturing texture at increasing depths into the surface. However, it is considered that this under-recovery is insignificant in relation to the scale of the texture being investigated. Figures 13 and 14 compare the MountainsMap TIN and manually measured average diameter and maximum depth data respectively.

Good correlations were found for both sets of data. For example, the slab thickness was 40 mm, the 3D model data in Table 2 showed the maximum depth of the pothole to 39.6 mm. The example step height calculation study presented in Figure 10 recorded a maximum depth of 38.8 mm. The variation in these recorded depths is insignificant in terms of the scale of the surface texture being investigated.

This agreement of different methods of measurement and analysis gives confidence in the use of 3D modeling. The good correlations between pothole volume, average diameter and maximum depth confirm the accurate recovery of surface texture with the use of the CRP method.

Figure 9 shows the AFC derived parameter V_{vc} plotted against the corresponding AMBR for each pothole stage. With the upper limit q maintained at 100%, the lower limit p was altered. When p is equal to 0% AMBR, maximum V_{vc} is found. At this point the limit

p is set at the top of the surface texture; therefore the full pothole falls within the core zone of the AFC profile.

Stage 4 recorded the highest V_{vc} , with Stage 0 demonstrating the smallest. The remainder of Figure 9 demonstrates how the volume of voids i.e. loss of material decreases with depth into the surface. Despite the expected relationship shown in Figure 9, Stage 1 and 2 do not fully agree with the trend at low AMBRs. At 0 to 10% AMBR, Stage 2 is expected to have a higher V_{vc} parameter, as its TIN represents an increased volume of a pothole. It was suspected that this initial variation at 0 to 10% AMBR is due to the presence of surface noise in the Stage 1 TIN.

With further consideration of the AFC, this did not appear to be the case. Therefore it was concluded that it was due to the way in which the pothole was made larger using the hammer and chisel. Between Stages 1 and 2 the pothole defect was increased horizontally and vertically. Between Stages 2 and 3 the pothole defect was predominantly increased vertically.

The real pothole had a more irregular shape compared to the one formed in the laboratory. Table 3 shows good comparison between the captured TINs for the SLR and iPhone devices. The lower resolution images of the iPhone had a minimum effect at the scale of texture being investigated.

5 CONCLUSION

The non-contact use of 3D modeling using Close Range Photogrammetry has been shown as an accurate method of analyzing manufactured potholes in a controlled laboratory environment. Strong linear relationships were found between diameter, circumference, depth and volume datasets. The AFC analysis demonstrated how volume changes with depth and with time.

The findings of the investigation show that 3D modelling using CRP offers a method to better understand real pothole. This new type of data can have a wide range of application from quantify pothole growth to optimising the maintenance of pothole defects of our road network within reduced budgets.

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