NONCONTACT ASSESSMENT OF HIGHWAY SURFACE VULNERABILITY TO WATER INDUCED DAMAGE

Phillip Millar *
Lecturer in Civil Engineering: Land Surveying and GIS, University of Ulster, Northern Ireland, UK
* University of Ulster, Jordanstown Campus, Shore Road, Newtownabbey, Co. Antrim, BT37 0QB, United Kingdom   p.millar@ulster.ac.uk

David Woodward
Reader in Infrastructure Engineering, University of Ulster, Northern Ireland UK

ABSTRACT: The contribution of surface macro-texture to effective and efficient drainage is well established. Failure of a pavement to discharge surface water will impact wet skid resistance and road safety. In addition there may be also significant potential for physical damage to the surface due to freeze/thaw and/or hydraulic forces applied to pockets of trapped water. This paper reports the findings of a study which demonstrates the potential of models of surface micro-topography to highlight and delineate areas of water containment. In this study, triangular irregular networks (TIN) were constructed for a range of remotely captured surface textures. They were combined with raster overlays and depth classified in a proprietary spatial information system to highlight potential areas of water lock-in. Critical entrapment depths are specified for the full range and diversity of textures. The TIN data may be used to gauge the potential susceptibility of a pavement to surface breakdown and trigger appropriate remedial measures.

KEY WORDS: Networks, macro-texture, entrapment, spatial, classification, micro-topography

1. INTRODUCTION

Highway surfaces are vulnerable to the potentially damaging effects of protracted exposure to cold and wet weather including rain or melting snow and ice containing de-icing salts. Cyclic freeze/thaw mechanisms and hydraulic pressures can subject a pavement surface to significant stresses exacerbated by pockets of entrapped standing water. Identification and characterization of vulnerable surfaces forms the basis of the research presented in this paper and extends the work summarized in Millar and Woodward [1]. The ability to identify and rank the vulnerability of surfaces is significant in allowing finite resources to be to be concentrated where they are most needed thus contributing to a culture of sustainability. Millar and Woodward [1] noted that the extent to which water can accumulate on highway surfaces leads inevitably to a consideration of surface textures. Flinstch et al. [2] described this as the feature of the road surface that ultimately determines most tire-road interactions such as wet friction, noise, splash and spray, rolling resistance and tire wear. The complex nature of surfacing materials, the many variables and their interactions have led to development of numerous methodologies and technologies for characterizing surface texture.

These range from the simple sand patch method for static spot testing to high speed laser based dynamic systems each of which inputs to the prediction of risk and performance. Bushan [3] observed that modelling of rough surfaces is difficult because they have a random structure. Erdogan et al. [4] described a study of aggregate shape based on a combination of X-ray computed tomography, two and three dimensional image analysis and three dimensional particle reconstructions. Erdogan et al. [4] stated that acquiring true full three dimensional images using this system is challenging as the scanning process could take hours. The research presented in this paper is based on an approach which goes beyond methods based on estimation of a single geometry such as the sand patch test. Such tests offer little direct insight to processes occurring at the tyre surface interface. In this study TIN datasets are generated within a spatial information system from digital images of discrete areas of highway surface texture. Millar et al. [5] have shown that manipulation of TIN data can contribute to the assessment of performance of asphalt samples In this study the TIN meshes are classified to highlight areas of texture potentially at risk due to protracted water entrapment. The vulnerability of a

surface is expressed in the form of a simple risk index comprising the ratio of the plan area of entrapped water to the overall plan area of the surface model.

2. AIM AND OBJECTIVES

The aim of this study was to establish classified surfaces as a viable method of assessing the risk of highway surfaces to the detrimental effects of freestanding entrapped water. This is defined in Millar and Woodward [1] as water entrapped in small pockets having a definable perimeter within the area of a tread-block. Alternatively it may also be classified as an area of surface water with no clear drainage path. Whilst both affect asphalt surface phenomena, each has its own implications in respect of risk to the pavement. The paper has a number of objectives. First is to show that the surface micro-topography of a discrete area of highway surface can be reasonably derived from digital images. In this study micro-topography is surface relief modeled at sub-millimeter mesh intervals. This is demonstrated by superimposing original raster images of shallow road markings over contoured models to confirm their correspondence. Second is to confirm the appropriateness of the sample area and its geometric integrity. This is confirmed by comparison of data derived from sand patch tests and TINs. Finally the correlation of TIN properties and areas of water entrapment with statistical measures is investigated. Vulnerability of a surface to the effects of entrapped water is presented as a simple risk index expressed as the estimated plan area of a sample at risk over the total sample area. The area at risk is estimated from the classified models generated by the spatial information system.

3. METHODOLOGY

Slimane et al. [6] noted that road surfaces can be considered as 3D textured images in which micro-asperities existing on aggregate surfaces are the micro-texture and aggregate contours are the macro-texture. Their study noted the difficulties associated with extracting surface relief information from images. This study adopts a similar approach presented by Millar and Woodward [5] i.e. stereo photo image pairs captured of real surfaces under non controlled ambient lighting conditions at 23 locations in Italy, France and the United Kingdom. The surfaces varied significantly in material type, age and wear. Following image capture the mean texture depth was estimated using the sand patch method in accordance with BS 598-105 [7]. A typical test setup for one location is shown in Figure 1.

Figure 1: Typical image capture configuration

The simple arrangement of stainless steel rules was used to provide scale for subsequent processing of the stereo images. The orientation of the images is arbitrary as a result but the models can be transformed to simulate camber or crossfall and can be used to generate a theoretically unlimited number of profiles in any direction and orientation. In order to characterize the surfaces, the transformed images were meshed at a 0.2mm interval. A typical surface model is shown in Figure 2.
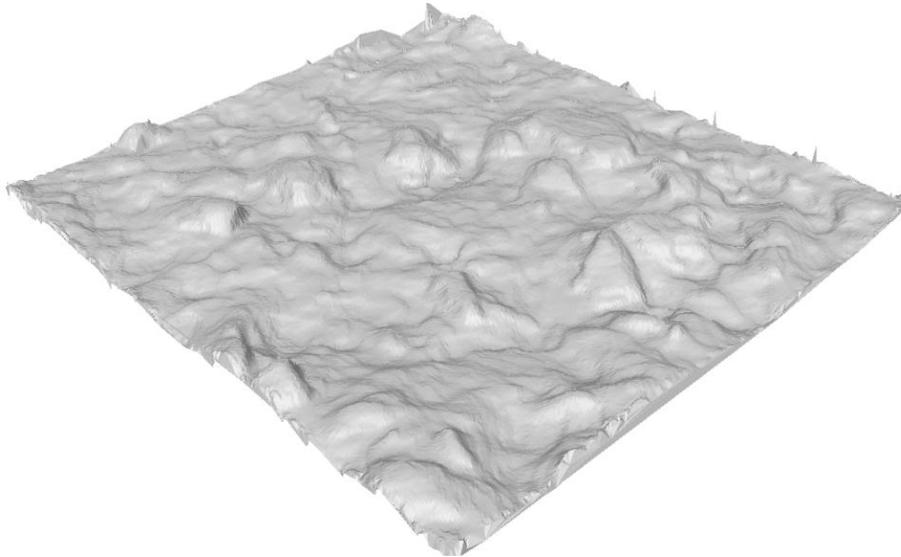

Figure 2: Three dimensional ArcGIS TIN mesh for a polished asphalt concrete
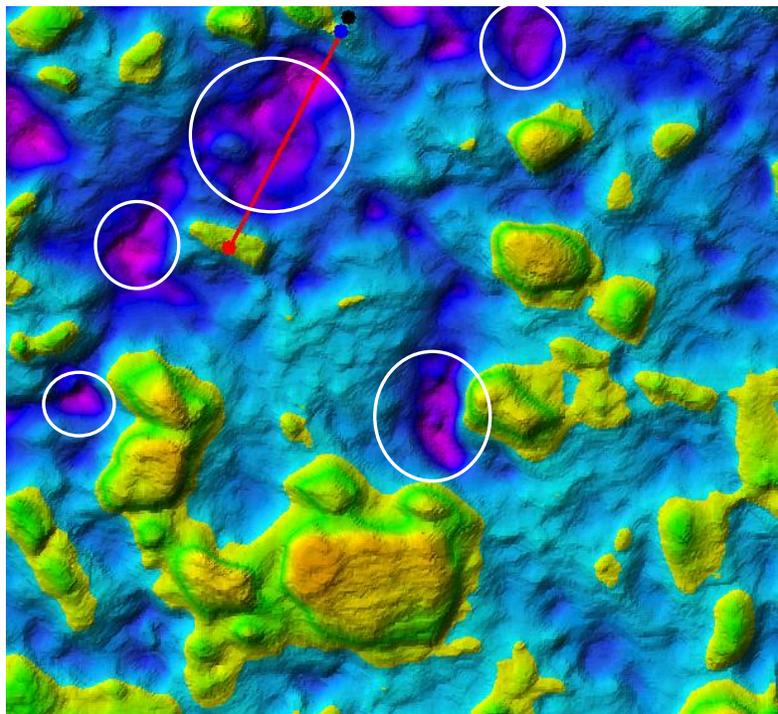
Figure 3: ArcGIS depth classified surface showing potential areas of water entrapment

The density of the mesh gives the model the appearance of a solid. The Cartesian coordinates of the triangle vertices was exported as a simple text file of comma separated values and imported to a proprietary GIS. It was then converted to a points feature class shape file and then added to a TIN surface. Having reformed the

surfaces they were depth banded at 0.1mm intervals commencing at the lowest elevation for each model. The asphalt concrete surface shown in Figure 2 is shown on plan in Figure 3 classified at a 0.1mm vertical interval in order to enhance the surface relief. To avoid unnecessary occlusion the contours are not displayed. A number of potential areas of water entrapment are circled. The profile of an area though the section line in the upper left quadrant is shown in Figure 4. The potential for water and ice to accumulate and become entrapped is clearly shown in the profile.
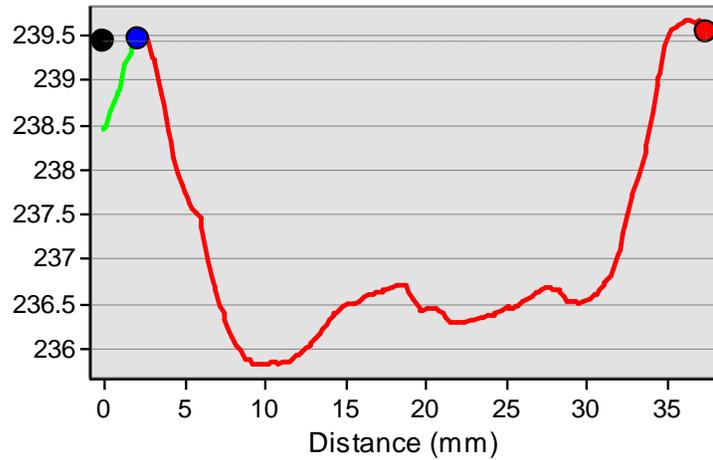
Figure 4: ArcGIS profile through potential area of entrapped water

A raster overlay of each of the original images was superimposed over or, where necessary transformed to the surface of each model as shown in Figure 5. This was in order to associate the enclosed areas with the configuration of the surface.
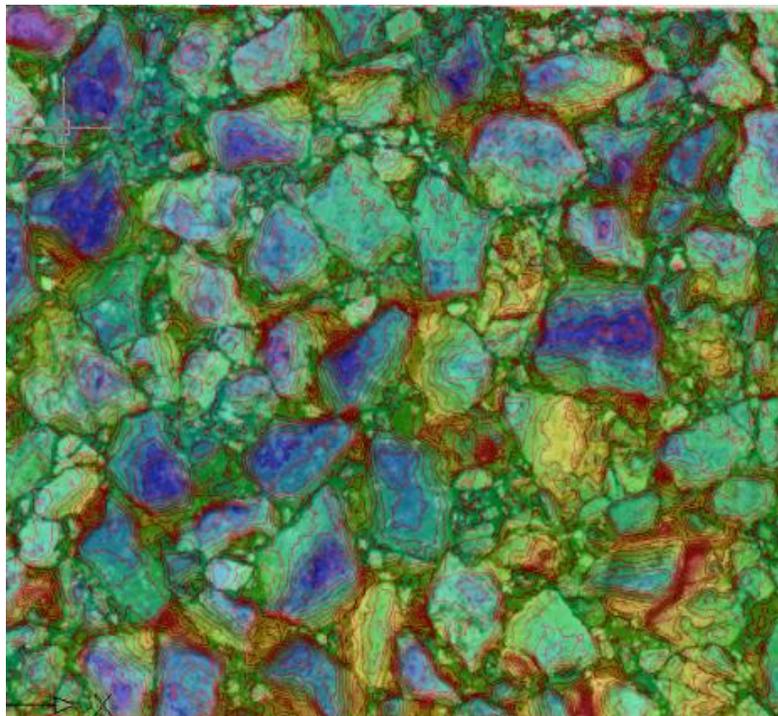

Figure 5: Civil3D mesh with raster overlay of 6mm/14mm chip seal and 0.5mm contours

Descriptive statistics and frequencies were generated for each of the coordinate datasets. The objective of this was to determine whether the highway surface textures assessed were randomly rough. This was investigated by testing the conformity of the elevation frequency distribution to a normal distribution. Zhu and Zhu [8] noted that the tendency is typically to characterize a surface by a one figure statistic of pavement profile data whilst discarding a rich body of useful pavement information. This type of analysis allows additional information to be obtained from the models that is not available from older types of surface profiling method.

4 RESULTS

Each of the 23 image pairs was processed and areas of potential water entrapment delineated across the full range of textures. It was found that all surfaces showed some capacity for water entrapment. For example Figure 6 shows a model of a 14mm crushed gravel asphalt concrete classified at 0.1mm vertical interval and its corresponding raster overlay. Potential pockets of water are clearly delineated in the left image at 1mm above the lowest elevation as white areas. No potential areas of entrapped water were found at a level higher than 3.5mm above the lowest elevation across the full range of surfaces modelled.
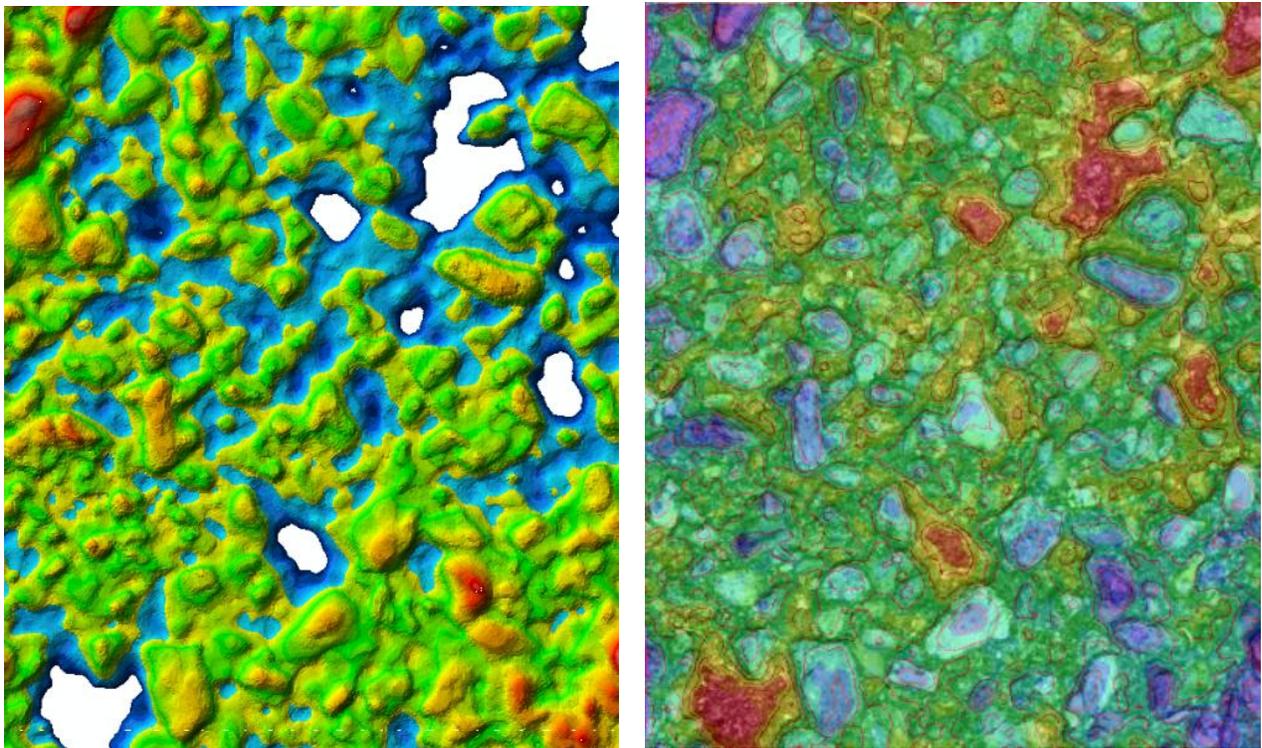

Figure 6: ArcGIS model of a 14mm asphalt concrete classified at 0.1mm vertical interval compared with a Civil3D model with raster overlay
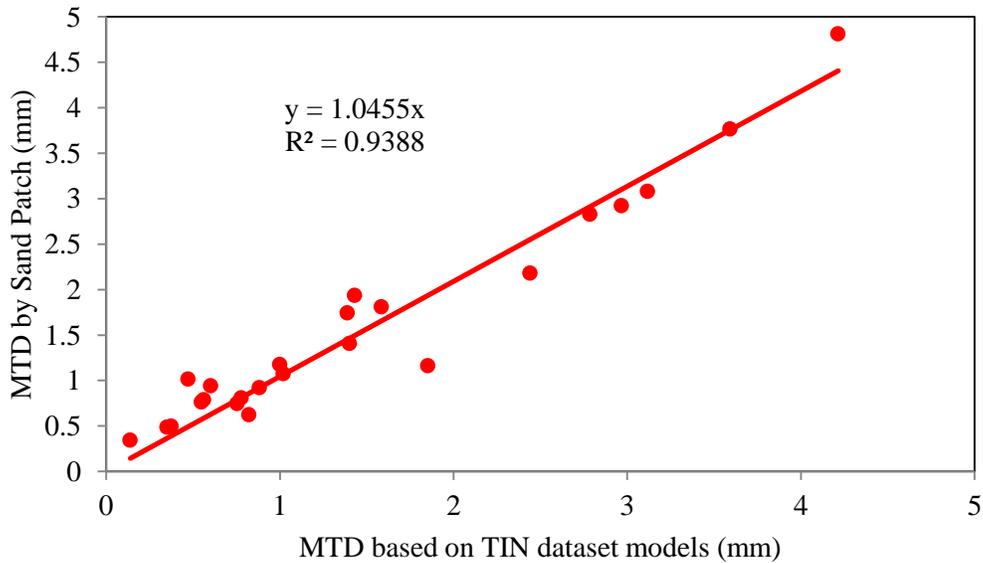
$$y = 1.0455x$$
$$R^2 = 0.9388$$

Figure 7: Correlation of MTD estimated by sand patch and DEM from the TIN dataset models

Correlation of mean texture depths (MTD) based on sand patch and volumetric estimation from the TIN dataset models found a linear relationship with a R^2 value of 0.939 as shown in Figure 7. Elevation frequency analysis of the data sets indicated that the majority of surface elevations are normally distributed. Figure 8 and 9 compare the distributions for a 14mm/6mm chip seal and 14mm size chip seal. Figure 8 shows a normal distribution whilst Figure 9 shows the heavily trafficked 14mm single size chip seal characterised by pronounced areas of discrete surface relief. Surface elevations are expressed in millimetres above the lowest elevation value for each model. Figure 10, 11 and 12 show the original image, raster and 3D model for the 14mm chip seal. The 3D model clearly shows the variation of the surface texture.
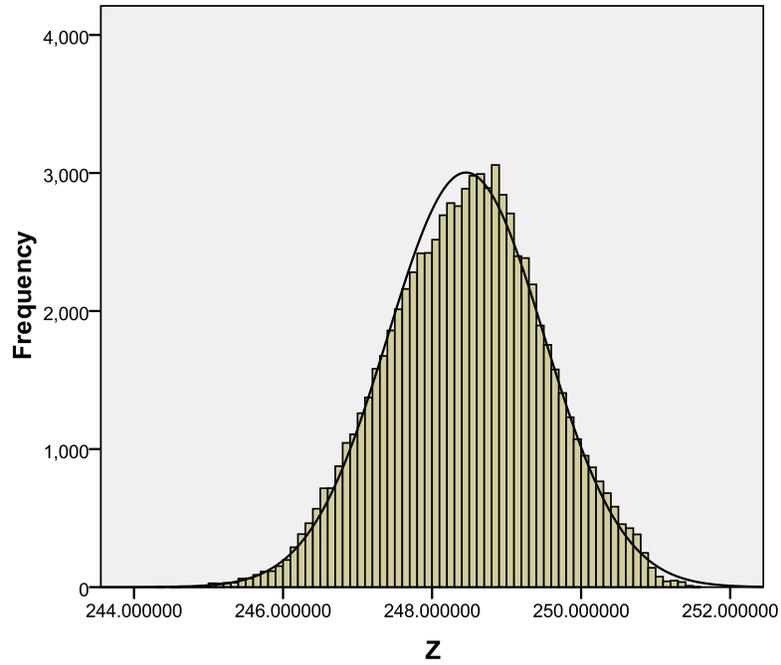
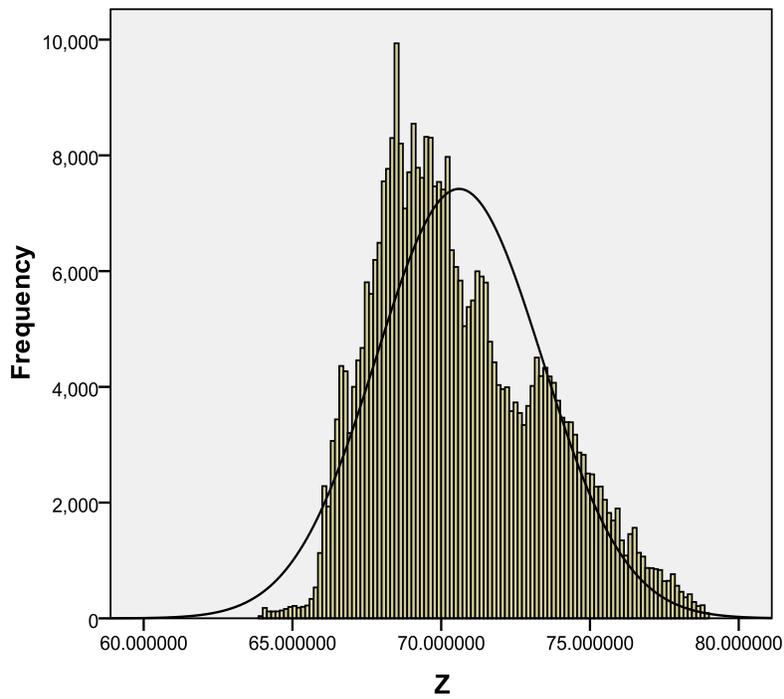Figure 8: Elevation (z mm) frequency distribution for a 14mm/6mm chip seal

Figure 9: Elevation (z mm) frequency distribution for a heavily trafficked 14mm single size chip seal

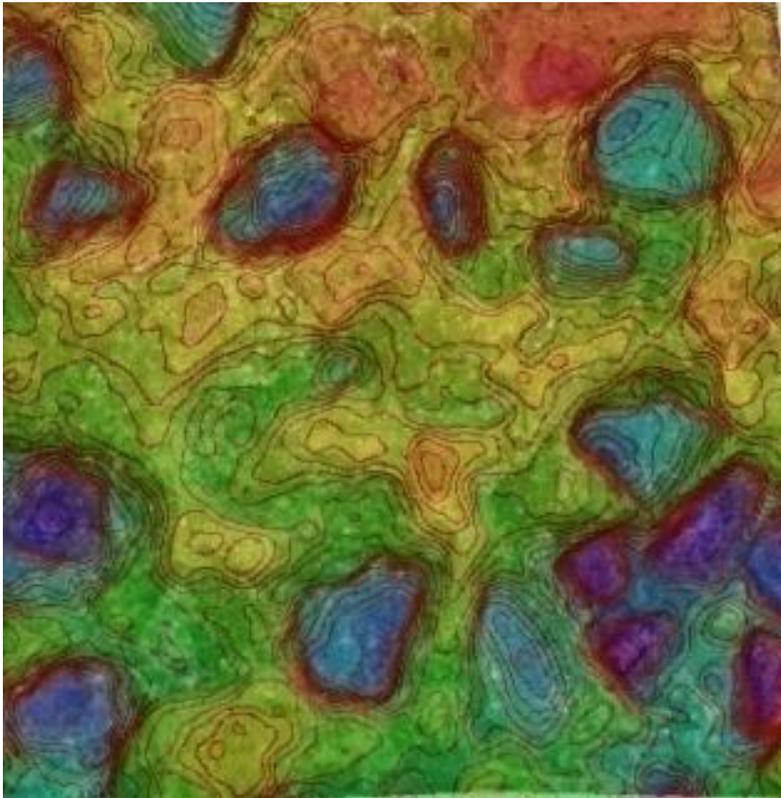Figure 10. Original digital image of the 14mm chip seal

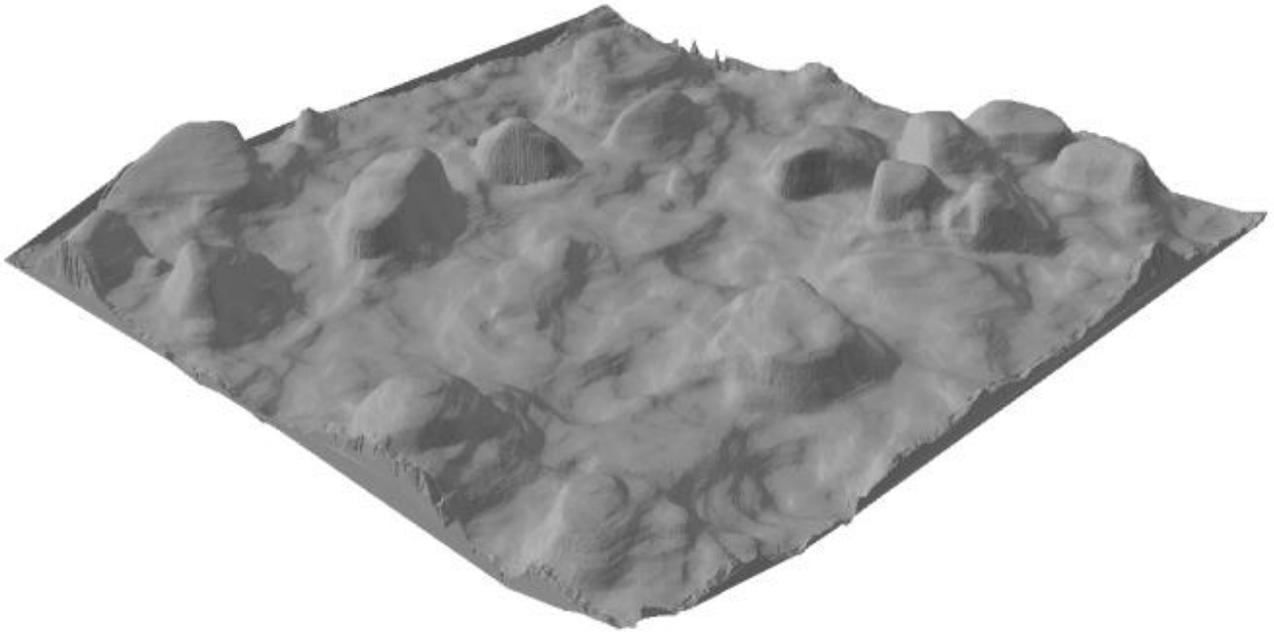Figure 11. Civil3D model of the 14mm chip seal with raster overlay

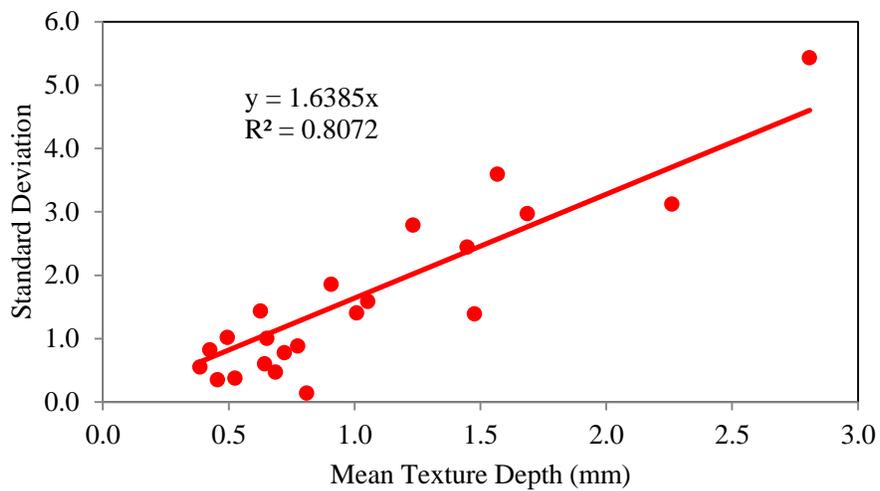Figure 12. ArcGIS 3D model of the 14mm single chip seal

Figure 13. Correlation of mean texture depth and standard deviation

Correlation of mean texture depth and standard deviation of the elevation frequencies found a R^2 value of 0.807 as shown in Figure 13. However, when the area of potential water entrapment was correlated with mean texture depth poor correlation was found as shown in Figure 14.
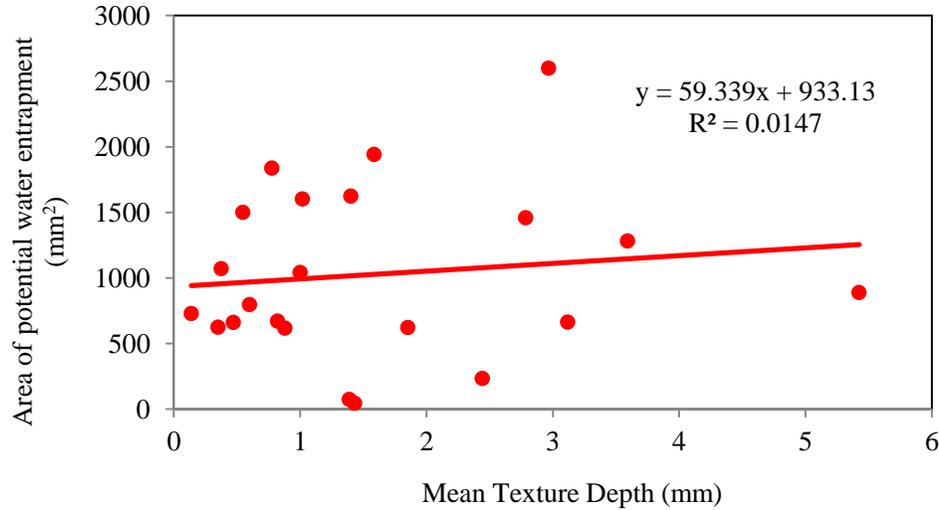
Figure 14. Plot of mean texture depth against area of water entrapment

A simple Risk Index was determined for each surface based on the ratio of the plan area of potential water entrapment to the total plan area of the sample. The Risk Index values ranged from 0.007 to 0.165 with a median value of 0.087. Figure 15 shows the resulting plot and poor correlation between these two values. The data in Figure 15 has been subdivided into the different types of surfacing to see if this apparent lack of correlation could be improved. The plot shows that such sub-division does not improve the correlation.
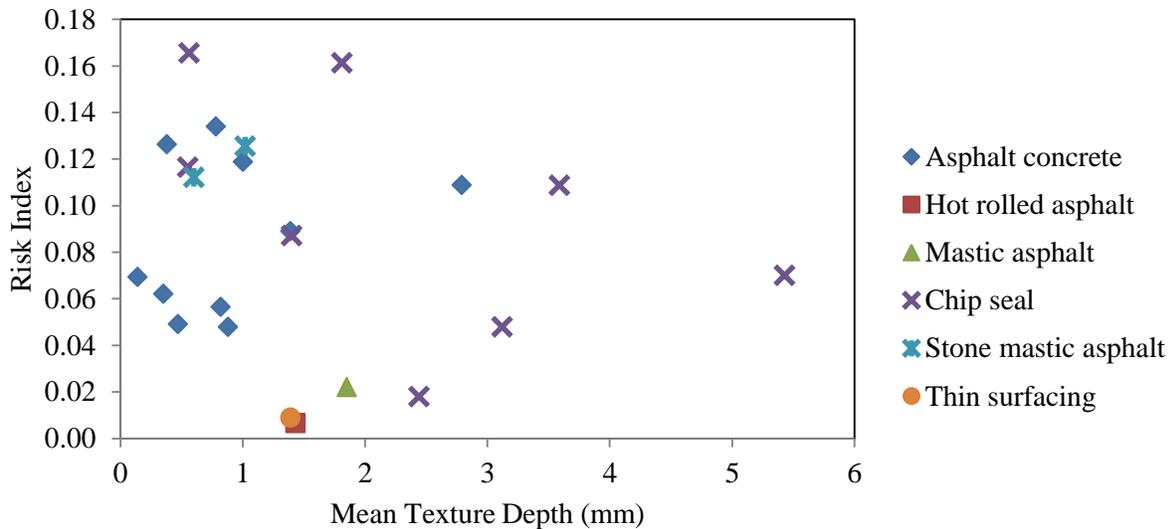

Figure 15: Plot of Risk Index against mean texture depth for all samples

5. DISCUSSION

The ability of depth classified models to indicate risk of water entrapment has been shown. Figures 2 and 12 show that surface relief can be visually well represented. The surface micro-topography and raster overlays show good correlation as shown in Figures 5, 6 and 11. The mean texture depth estimated from the 3D models correlate strongly with that determined using the sand patch method as shown in Figure 7 i.e. 3D methodology is robust and establishes a level of confidence.

All surfaces assessed were shown to entrap water. However, the method is not deemed suitable for porous asphalt materials because it not possible to model their interconnected void structure. For the range assessed, no surface showed a tendency to entrap water at levels higher than 3.5mm above the lowest elevation, although this was applicable to one surface only. For the majority of surfaces investigated the cut off levels fall within 1.5mm to 2.5mm above the lowest elevation. The use of a closer vertical classification interval will improve resolution and more accurate estimates of the areas of surface at risk.

Elevation frequency distributions such as that shown in Figure 9 are heavily skewed and show distinct peaks. Figure 10 shows the model corresponding to Figure 9 which displays pronounced protrusion of aggregate particles on a heavily trafficked surface. According to Kerr et al. [9] a dataset containing a few extreme values can skew frequency distributions significantly. This can indicate a level of error or bias in some types of research study due to subjectivity introduced by the researcher. As the authors of this study had no influence on the surface relief from which the models were constructed it seems reasonable to conclude that the skew is indicative of some aspect of the surface properties.

Figures 14 and 15 show poor correlation between area of water confinement and Risk Index with mean texture depth measured using sand patch. Figure 14 and 15 indicate that a low textured surface may show high risk whilst a highly textured surface may have a relatively low risk of water entrapment. The plot of Risk Index against mean texture depth shows no obvious correlation with surface type. This suggests that simple estimation of texture depth gives limited indication of a surface's capacity for surface water retention. It also reinforces the suggestion by Millar and Woodward [1] that the concept of assessing the performance of a surface from a single geometry is fundamentally flawed and offers little insight into the interactions at the tire-surface interface. As yet, the authors are not aware of a relationship between Risk Index and traffic safety.

6. CONCLUSION

The research summarized relates to new information about an asphalt surfacing. Whilst sand patch and laser techniques of texture depth measurement have been used for many years, they do not indicate whether water can become entrapped on the surface and so lead eventually to durability issues. Using the techniques outlined in this paper it is possible to delimit areas at potential risk. The lack of an obvious correlation with mean texture depth further strengthens the authors view that this an area that offers considerable scope especially with predicting the durability of asphalt surfacing materials.

REFERENCES:

[1]   Millar, P., and D. Woodward. Application of Digital Elevation Models to Delineate Areas of Residual Water in Highway Surfaces, *Proceedings of ITRN 2010, 31st August to 1st September 2010*, University College Dublin, Ireland.
[2]   Flintsch, G.W., E. de Leon, K. McGhee and I.L Al-Quadi, I. L., Pavement Surface Macrotexture Measurement and Application. *Journal of the Transportation Research Board*, Vol 1860, pp. 201-209, 2003.
[3]   Bushan, B., Contact mechanics of rough surfaces in tribology: multiple asperity contact, *Tribology Letters,* Vol. 4, pp. 1-35, 1997.
[4]   Erdogan, S., P. Quiroga, D. Fowler, H. Saleh, R. Livingstone, E. Garboczi, P. Ketcham, T. Hagedorn and S. Satterfield. Three Dimensional shape analyses of coarse aggregates: new techniques for and preliminary results on several different coarse aggregates and reference rocks. *Cement and Concrete Research*, Vol 36 (2006), pp. 1619 – 1627, 2006.
[5]   Millar P., D. Woodward and A Woodside. Use of Close Range Terrestrial Photogrammetry to assess Accelerated Wear of asphalt concrete surfacings. *The Sixth International Conference on Maintenance*

and Rehabilitation of Pavements and Technological Control, July 8-10, 2009, POLITECHNICO DI TORINO, Italy. Torino, pp. 734-740.

[6]   Slimane A., M. Khoudeir, J. Brochard and M. Do. Characterization of road micro-texture by means of Image Analysis. *Wear (2008),* Vol. 264, pp. 464-468, 2007.

[7]   BS 598-105. Sampling and examination of bituminous mixtures for roads and other paved areas. Part 105: Methods of test for the determination of texture depth, 2000.

[8]   J. Jim Zhu, Wenli Zhu, Stochastic Modeling of Pavement Roughness, 28th Southeastern Symposium on System Theory, pp. 28 – 33, 1996.

[9]   Kerr A. W., H. K. Hall and S. A. Kozub S.A. *Doing Statistics with SPSS.* London, Sage Publications Ltd, 2003.