

Assessing Asphalt and Concrete Pavement Surface Texture in the Field

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ABSTRACT

The incorporation of safety characteristics into the traditional pavement structural design or in the functional evaluation of pavement condition has not been established yet. The design has focused on the structural capacity of the roadway so that the pavement can withstand specific level of repetitive loading over the design life. On the other hand, the surface texture condition was neither included in the AASHTO design procedure nor in the present serviceability index measurements. The pavement surface course should provide adequate levels of friction and ride quality and maintain low levels of noise and roughness. Many transportation departments perform routine skid resistant testing, the type of equipment used for testing varies depending on the preference of each transportation department. It was felt that modeling of the surface texture condition using different methods of testing may assist in solving such problem. In this work, Macro texture and Micro texture of asphalt and cement concrete pavement surface have been investigated in the field using four different methods (The Sand Patch Method, Outflow Time Method, British Pendulum Tester and Photogrammetry Technique). Two different grain sizes of sand have been utilized in conducting the Sand Patch while the Micro texture was investigated using the British Pendulum tester method at wet pavement surface conditions. The test results of the four methods were correlated to the skid number. It was concluded that such modeling could provide instant data in the field for pavement condition which may help in pavement maintenance management.

Keywords: texture, pavement, surface condition, testing, modeling.

تقييم نسيجة السطح الاسفلتي والخرساني للرصفة موقعا

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الخلاصة

مساهمة خصائص السلامة في تصميم الرصفة التقليدي او في التقييم الوظيفي لظروف الرصفة لم تعتمد لحد الآن. التصميم ركز على القدرة الهيكلية للطريق بحيث ان الرصفة يمكن ان تسند مستوى معين من التحميل المتكرر طيلة عمر الرصفة. من ناحية اخرى ظروف نسيجة السطح لم تضمن في خطوات تصميم (AASHTO) ولا في قياسات مؤشر خدمية الطريق. ان سطح الرصفة يجب ان يوفر مستويات كافية من الاحتكاك، نوعية القيادة، والحفاظ على مستويات منخفضة من الضوضاء والخشونة. اعتمدت العديد من اقسام النقل اختبار مقاومة انزلاق روتيني، نوع المعدات المستخدمة في الاختبار يختلف اعتمادا على المفضل لدى اقسام النقل. لقد تبين بأن نمذجة ظروف نسيج السطح باستخدام طرق مختلفة للاختبار يمكن ان تساعد في حل مثل هكذا مشكلة. في هذه الدراسة، اختبرت موقعا النسيجة الماكروية، والنسيجة المايكروية للرصفة الاسفلتية والرصفة الكونكريتية باستخدام اربع طرق (طريقة رقعة الرمل، زمن جريان الماء، جهاز البندول البريطاني، وتقنية الفوتوكرامتري). نوعين مختلفين من الرمل المنخول اعتمد في طريقة رقعة الرمل بينما النسيجة المايكروية اختبرت باستخدام طريقة جهاز البندول البريطاني على سطح الرصفة الرطبة. نتائج الاختبار للاربع طرق نمذجت وربطت في رقم انزلاق. ولقد استنتج ان مثل هكذا نمذجة تستطيع ان توفر بيانات لحظية موقعا لظروف التبليط التي يمكن ان تساعد في ادارة صيانة الرصفة.

الكلمات الرئيسية : نسجة السطح، الرصفة، حالة السطح، الفحص، النمذجة.

1. INTRODUCTION

1.1 General

Deterioration of the pavement surface (smoothing or polishing of the pavement surface), along with surface water accumulation in the form of rain, snow, or ice, can result in inadequate provision of skid resistance. Inadequate skid resistance can lead to higher incidences of skid related crashes, **Sarsam, 2009-a**. There is currently no agreement on what standards to use for optimizing skid resistance, or on a standardized testing procedure to adopt despite a significant amount of research conducted. Roadway pavements surface deteriorate with time as a result of traffic passes, environmental conditions, and poor pavement maintenance management. If this deterioration is not properly addressed, the amount of surface distress that can affect skid resistance will increase and be prejudicial to traffic, **Noyce et al, 2007**. In this sense, pavement surface characteristics are a significant issue because of its influence in preserving roadway safety. Maintaining these characteristics during pavement construction or rehabilitation may mitigate or even prevent crashes and incidents related to loss of vehicle control, hydroplaning, and/or excessive skidding, **Masad et al, 2010**. The surface quality of a pavement determines to a large degree the conditions under which safety can be maintained. Driver control of vehicles is strongly dependent upon pavement surface characteristics, geometrics, driver speed, and vehicle variables such as tire pressure, type of tread, and wheel loads. Important surface characteristics include pavement micro texture, macro texture, and drainage attributes, **Sarsam, 2009-b**. Loss of adhesion between vehicle's tires and the road surface occurs in many road accidents whether or not it is the actual cause of the accident. Over the years, tire manufacturers have done a lot of research into different types of rubber and tread pattern to improve the safety of motor vehicles. The pavement- tire interaction is affected by the texture characteristics of the pavement such as the coefficient of friction, skid resistance, and hydroplaning effect on wet surface, **Noyce et al, 2005**. Until recently, the most common test methods for determining macro texture were labor intensive and time consuming. New developments in high resolution profiler have produced methods for estimating macro texture depth at different speeds, **Fuentes et al, 2010**. The fundamental questions that need to be addressed are:

- (1) How effectively and simply does such equipment characterize pavement micro and macro texture?
- (2) How this information could be used if it were available.

1.2 Research Objectives

The main objectives of this research work are:

- a.) Evaluating the cement concrete and asphalt concrete pavement surface condition from the skid resistance point of view using field tests. The micro and macro textures were evaluated using four different testing techniques.
- b.) Evaluating the significance, feasibility of using such different field tests to measure the skid resistance.

2. MATERIALS AND METHODS

This field work was conducted at University of Baghdad in Aljadriah campus roadway, and walkway network. Rigid pavement and flexible pavement were tested, 150 locations have been selected for each pavement type. The distance between one location and another was 1.2 meter minimum. Every test location was prepared for testing by thoroughly sweeping using a plastic brush. Then, the location was visually examined so that various pavement texture could be



included, and each test location does not contain any cracks or irregularities. Then, each location was subjected to the texture determination by using various testing procedures. Similar work was reported by **Sarsam, 2011**.

2.1 Sand Patch Test:

A specific volume of each type of graded sand prepared in the laboratory by sieving (passing sieve no. 25 and retained on sieve No. 52) was spread by using a specific plastic tool on the pavement surface in a circular motion. Two types of graded sand were used. **Table 1** shows the types of sand and their densities. Then, the mean texture depth (MTD) was calculated by using equation (4), **ASTM, 2009**.

2.2 Outflow Time:

The outflow time (OFT) was measured by using the outflow meter. Outflow meter was manufactured in local market by using plastic transparent jar of 1000 ml capacity rests on rubber annulus placed on the pavement. A valve at the bottom of the cylinder is closed and the cylinder is filled with water. The valve is then opened and the time required for cylinder to be empty is measured with a stopwatch and was reported as the outflow time (OFT). This test was conducted in accordance to **ASTM, 2009**, standard procedures for determining outflow time.

2.3 British Pendulum Test:

British Pendulum Tester is operated by releasing a pendulum from a height that is adjusted so that a rubber slider on the pendulum head contacts the pavement surface over a fixed length. Friction between the slider and the pavement surface reduces the kinetic energy of the head, and the reduced kinetic energy is converted to potential energy as the pendulum breaks contact with the surface and approaches its maximum recovered height. The pavement surface was wetted with 1000 ml of water to ensure that the surface voids are saturated, and the temperature was fixed at $(25\pm 3)^{\circ}\text{C}$ during the work to prevent the effect of temperature on the British Pendulum test results. The difference between the initial and recovered pendulum heights represents the loss in energy due to friction between the slider and the pavement surface. The BPT is equipped with a scale that measures the recovered height of the pendulum in terms of British Pendulum Number (BPN). The slip speed of the BPN is very slow (typically about 6 mph). This test was conducted in accordance to **ASTM, 2009**, standard procedures for determining British Pendulum Number.

2.4 Photogrammetry Technique

2.4.1 Direct Geo-referencing

Image orientation is a key element in any photogrammetric project, since the determination of three-dimensional coordinates from images require the image orientation to be known. In aerial Photogrammetry this task has been exclusively and very successfully solved by using aerial triangulation for many decades. Thus, aerial triangulation has become a key technology and an important cost factor in mapping and Geographic Information System (GIS), **Jasim, 2011**. In this work, there was two cameras their brand Panasonic fz50 orthogonally positioned on the pavement surface by using a frame designed and manufactured especially for this research work. Where Exterior Orientation Parameters (EOP) were defined such as height of flight and it was 1.2 m, and the rotation angles (ω , ϕ , κ), so there was no need to Differential Global Position System Receiver (DGPS), and Inertial Navigation System (INS) as they are used for determining EOP for direct geo-



reference. The distance between the centers of the cameras lenses was 53.4 cm. The overlap between the two shots was 45%. This technique was adopted for 15 shot locations on rigid pavement and 15 shot locations on flexible pavement. The camera properties were mentioned in **Table 2**. The stereo photo pair were fed to the ERDAS 8.4 software that has been used for image processing. This procedure was in agreement with the work reported by **Sarsam and AL Shareef, 2015**.

2.4.2 Image processing procedure adopted

Two overlap shots for each location were inserted in ERDAS 8.4 software. Pyramid layers were generated for every shot. Cameras properties, interior and exterior orientation such as height of flight and three rotation angles (ω , ϕ , κ). Such shots locations were the same for the previous testing techniques. The software convert the two overlap shots to a three dimensional photo and calculate the texture depth by selecting several tie points in every two shots, and aerial triangulation process was applied. Such procedure was in agreement with **Sarsam et al, 2015-a**.

3. MODELING OF PAVEMENT SURFACE TEXTURE

An effort has been made to find a direct relationship between micro and macro texture, using BPN, Outflow Time, Mean Texture Depth (Sand Patch Method and Photogrammetry Technique). Many statistics software have been tried including Statistica, SPSS, and ANN but the models were weak from the statistical point of view. So it was decided to examine the feasibility of using the indirect correlation using the well-known mathematical models of skid resistance and skid number (SN) as shown in equations 1, 2, and 3.

$$SN = SNo. \text{Exp}^{-(PNG / 100) V} \quad (1)$$

$$SNo = 1.32 \text{ BPN} - 34.9 \quad (2)$$

$$PNG = 0.157 (\text{MTD}) - 0.47 \quad (3)$$

Where:

SN: Skid Number.

SNo: Skid Number at Zero Speed.

PNG: Percent Normalized Gradient.

V: Vehicle Speed.

BPN: British Pendulum Number (percent).

MTD: Mean Texture Depth (cm).

MTD was calculated from sand patch method by using both river and silica sand. The mathematical equation used is illustrated below, **ASTM, 2009**:

$$\text{MTD} = \frac{4V}{\pi D^2} \quad (4)$$

Where:

V: volume of the sand (cm³).

D: diameter of the circular patch of the sand (cm).

Another mathematical expression (equation 5) was obtained from the literature, **Noyce et al., 2005**, which correlate OFT with MTD and implemented in the SN calculation. Two cases of such relation have been tried, the first one is to calculate MTD using the equation below:

$$\text{MTD} = \frac{3.114}{\text{OFT}} + 0.636 \quad (5)$$

Where:

MTD: Mean texture depth (cm).

OFT: Outflow time (seconds).

It was found that the relation could give MTD close to one cm, then the second case tried was to take MTD value equivalent to OFT. Such finding was further supported when plotting the OFT calculated using both calculation cases as demonstrated in **Fig.1** for asphalt concrete.

3.1 Asphalt Concrete Pavement

3.1.1 Effect of Sand Gradation Type on Skid Number

Fig. 2 illustrates the relationship between SN when using two different sand types in the sand patch test (fine and coarse sand). It shows that the effect of sand type on skid number was not significant for the range of sand types adopted, the coefficient of determination was 0.9997. Such results agrees well with the work of **Sarsam, 2009-a**.

3.1.2 Effect of Testing Technique on Skid Number

Fig. 3, 4, 5, and 6 show the variation of skid number when two testing techniques were implemented. The SN calculated using sand patch (natural sand) or (silica sand) was plotted on the x-axis, while the SN calculated using OFT equivalent to MTD or calculated from Equation 5 was plotted on y-axis. Both figures indicate very good statistical relationship, however, it was noticed that at high values of skid number, (above 30), the mode start to change, and the scatter of test results are away from the trend line. Such behavior correlates well with **Doty, 1974; and Sarsam, 2012** findings.

3.1.3 Effect of Photogrammetry testing technique on Skid Number

Fig. 7, 8, 9, and 10 shows the variation of skid number when three testing techniques were implemented, the SN calculated using MTD obtained from photogrammetry technique was plotted on the x-axis, while the SN calculated using sand patch (silica and natural) sand and OFT equivalent to MTD or calculated from Equation 5 were plotted on y-axis. Each figure indicates very good statistical relationship, however, it was noticed that at high values of skid number, (above 20) the mode start to change, and the scatter of test results are away from the trend line. **Table 3** shows summary of the statistical models developed for asphalt concrete pavement and **Table 4** illustrates other researchers' models and their coefficient of determination. Models are similar to those developed by **Sarsam, 2010; and Sarsam and Ali, 2015**.

3.2. Cement Concrete Pavement

3.2.1. Effect of Sand Gradation Type on Skid Number

Fig.11 exhibit OFT calculated using both calculation cases for cement concrete pavement. **Fig.12** illustrates the relationship between SN when using two different types of sand in the sand patch

test (silica and natural sand). It shows that the effect of sand types on skid number was not significant for the range of sand types adopted, the coefficient of determination was 0.9997.

3.2.2. Effect of Testing Technique on Skid Number

Fig.13, 14, 15, and 16 show the variation of skid number when two testing techniques were implemented, the SN calculated using sand patch (silica sand) or (natural sand) was plotted on the x-axis, while the SN calculated using OFT equivalent to MTD or calculated from Equation 5 was plotted on y-axis. Both figures indicate very good statistical relationship, however, it was noticed that at high values of skid number up to 40. Similar findings are reported by **Sarsam et al, 2015-b**.

3.2.3 Effect of Photogrammetry testing technique on Skid Number

Fig.17, 18, 19, and 20 show the variation of skid number when three testing techniques were implemented, the SN calculated using photogrammetry technique was plotted on the x-axis, while the SN was calculated using sand patch (silica and natural sand) and OFT equivalent to MTD or calculated from Equation 5 were plotted on y-axis. Each figure indicate very good statistical relationship, however, it was noticed that at high values of skid number,(above 25) the mode start to change , and the scatter of test results are away from the trend line. Such findings are in agreement with the work reported by **Table 5** shows summary of the statistical models developed for cement concrete pavement.

4. CONCLUSIONS

Based on the field work and the testing adopted, the following conclusions can be drawn:

1. The OFT (sec) and the sand patch (MTD-cm) correlates well with each other and can be substituted with each other when skid number is determined.
2. Both of silica and natural sand with types limits of (passing sieve No. 25 and retained on sieve No. 52) show equivalent MTD values when implemented in sand patch method.
3. MTD obtained from photogrammetry technique correlates well with MTD obtained from sand patch or OFT.
4. OFT as tested using outflow meter correlates well with MTD calculated from statistical model (Equation 5) when substitute OFT when SN is adopted.
5. The statistical models obtained for SN calculation for cement concrete pavement adopted for all the tested values of SN up to 40 while for asphalt concrete the model represents SN values up to an average SN values of 25 only.
6. Each of the testing techniques adopted (sand patch, outflow time, photogrammetry technique) for macro texture determination and British Pendulum Test for micro texture determination are considered good enough for evaluation of pavement surface texture for the limited site condition tested.



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LIST OF Symbols

AASHTO: American Association of State Highway and Transportation Officials.
 ASTM: American Society for Testing and Materials.
 BPN: British Pendulum Number.
 DGPS: Differential Global Position System Receiver.
 EOP: Exterior Orientation Parameters.
 GIS: Geographic Information System.
 INS: Inertial Navigation System.
 MTD: Mean Texture Depth.
 OFT: Outflow Time.
 SN: Skid Number.

Table 1. Properties of Sand

Types of Sand	Density
Silica Sand (yellow)	1.44 gm./ cm ³
River Sand (gray)	1.31 gm./ cm ³

Table 2. Properties of the Digital Camera

Property	Specifications
Brand	Panasonic fz50
Focal Length	35 mm
Pixel Size	1.9 micron



Table 3. Summary of the Statistical Models Developed for asphalt concrete pavement

Mathematical Model	R ²	Y- axis SN	X-axis SN
$y = 0.9864x - 0.0153$	0.9997	MTD (cm),sand patch, silica sand	MTD (cm), sand patch, natural sand
$y = 1.1949x + 0.2705$	0.9977	OFT (sec)	MTD (cm), sand patch, natural sand.
$y = 1.2111x + 0.2923$	0.9976	OFT (sec)	MTD (cm),sand patch, silica sand
$y = 0.9373x + 0.2182$	0.9976	MTD (cm),OFT,eq.5	MTD (cm), sand patch, natural sand
$y = 0.95x + 0.2353$	0.9975	MTD (cm),OFT,eq.5	MTD (cm),sand patch, silica sand
$y = 0.7844x + 0.0054$	1	MTD (cm),OFT,eq.5	OFT (sec)
$y = 0.9952x - 0.1848$	0.9955	MTD (cm), sand patch, natural sand	MTD, photo. technique
$y = 0.9787x - 0.1745$	0.9942	MTD(cm),sand patch, silica sand	MTD, photo. technique
$y = 1.1918x - 0.1063$	0.9963	OFT (sec)	MTD, photo. technique
$y = 0.9366x - 0.0881$	0.9961	MTD (cm),OFT,eq.5	MTD, photo. technique

Table 4. Other Researchers Models

Tests	The thesis Models		Sarsam, 2009-a	
	Eq.	R ²	Eq.	R ²
SN sand patch (silica & natural)	$y = 0.9864x - 0.0153$	0.9997	$y = 1.002 x - 0.0123$	0.993
SN sand patch (silica sand) & OFT (tested)	$y = 1.2111x + 0.2923$	0.9976	$y = 1.279 x + 0.4541$	0.993
SN sand patch (natural sand) & OFT (tested)	$y = 1.1949x + 0.2705$	0.9977	$y = 1.277 x + 0.3195$	0.993

Table 5. Summary of the Statistical Models Developed for cement concrete pavement

Mathematical Model	R ²	Y- axis (SN)	X-axis (SN)
$y = 0.9946x - 0.0011$	0.9997	MTD(cm),sand patch, silica sand	MTD (cm), sand patch, natural sand
$y = 1.2134x - 0.0567$	0.9984	OFT tested (sec)	MTD (cm), sand patch, natural sand
$y = 1.2201x - 0.057$	0.9989	OFT tested (sec)	MTD(cm),sand patch, silica sand
$y = 0.9531x - 0.0486$	0.9984	MTD (cm),OFT,equation-5	MTD (cm), sand patch, natural sand
$y = 0.9583x - 0.0488$	0.9989	MTD (cm),OFT, equation-5	MTD(cm),sand patch, silica sand

$y = 0.7854x - 0.0038$	1	MTD (cm),OFT, equation-5	OFT tested (sec)
$y = 0.9977x - 0.1354$	0.9931	MTD (cm), sand patch, natural sand	MTD, photo. technique
$y = 0.9841x - 0.0881$	0.9908	MTD(cm),sand patch, silica sand	MTD, photo. technique
$y = 1.1802x - 0.1975$	0.9878	OFT tested (sec)	MTD, photo. technique
$y = 0.9274x - 0.1515$	0.9882	MTD (cm),OFT, equation-5	MTD, photo. technique

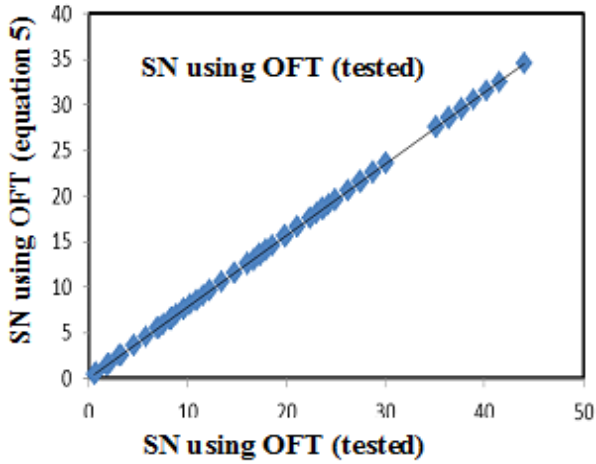


Figure. 1. OFT Calculated Using Two Cases Sand type

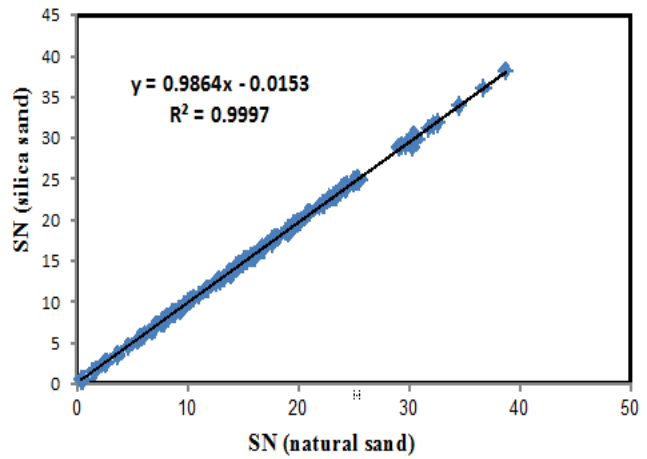


Figure. 2. Variation of Skid Number with

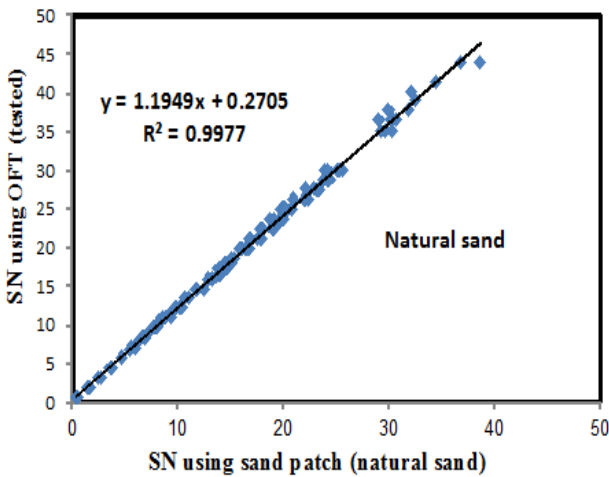


Figure. 3: Effect of Testing Technique on SN

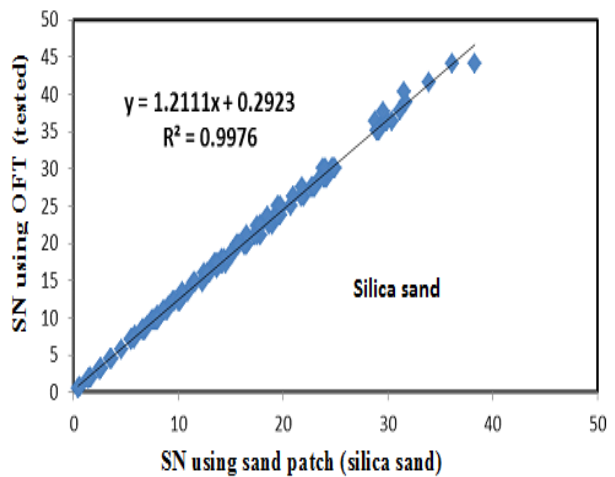


Figure. 4: Effect of Testing Technique on SN

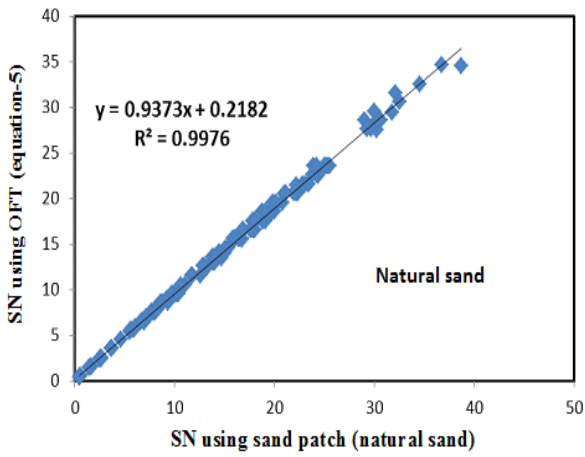


Figure 5. Effect of Testing Technique on SN

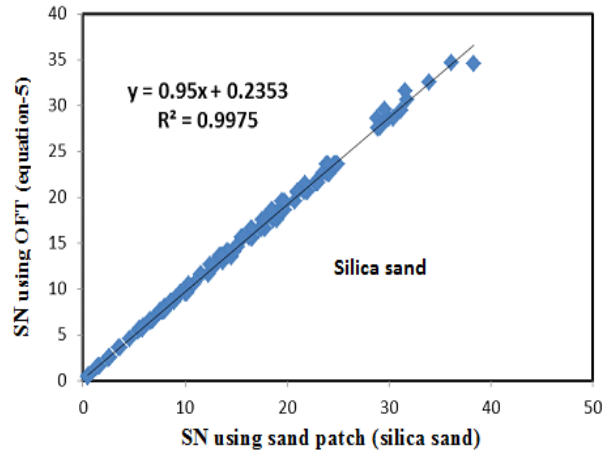


Figure 6: Effect of Testing Technique on SN

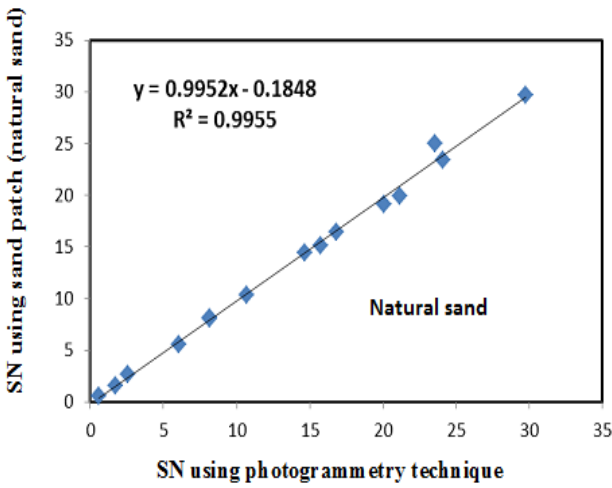


Figure 7. Variation of SN Using Photo technic

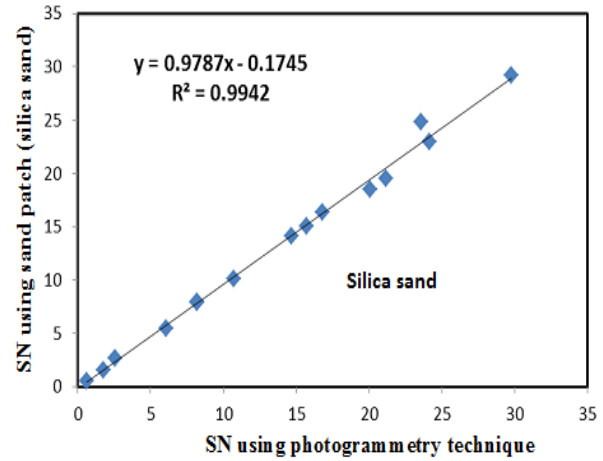


Figure 8. Variation of SN Using Photo technic

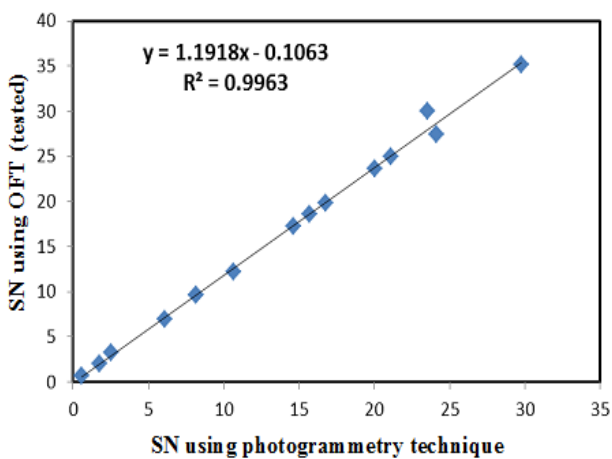


Figure 9. Variation of SN Using Photo and OFT

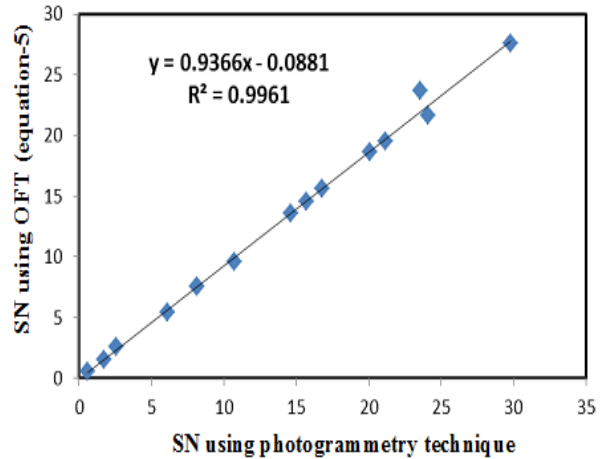


Figure 10. Variation of SN Using Photo and OFT

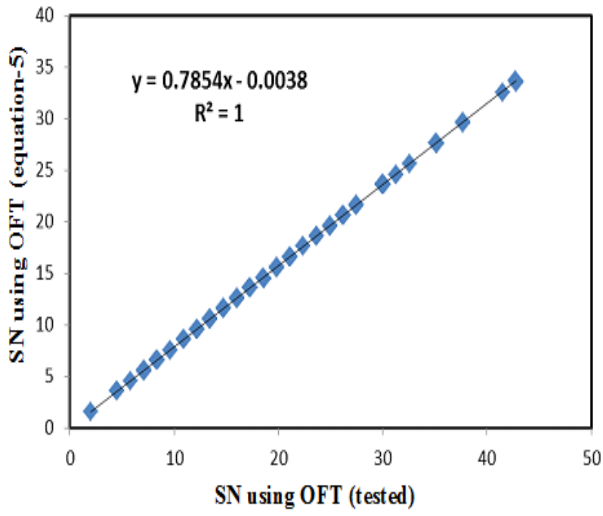


Figure11. OFT Calculated Using Two Cases

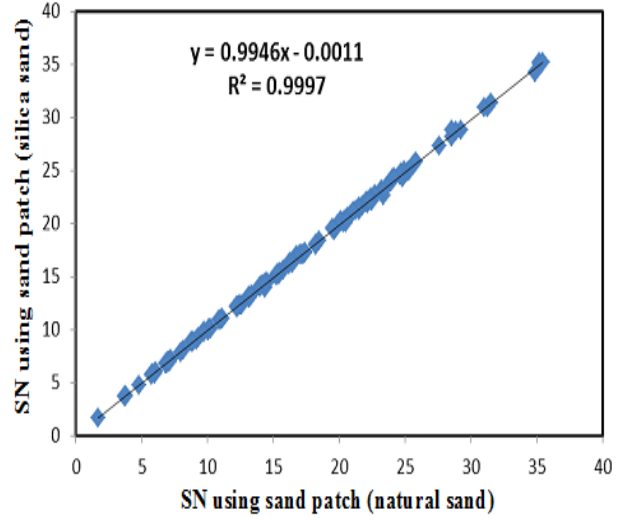


Figure12. Variation of Skid Number with Sand type

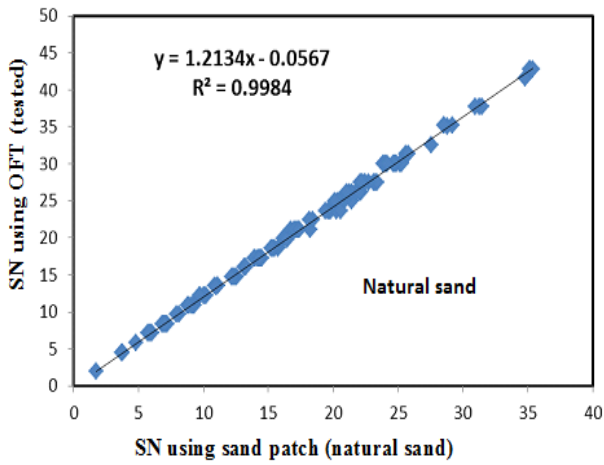


Figure 13. Effect of Testing Technique on SN

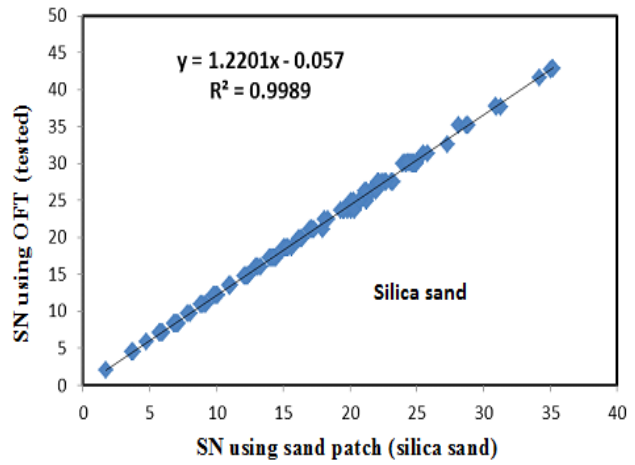


Figure14. Effect of Testing Technique on SN

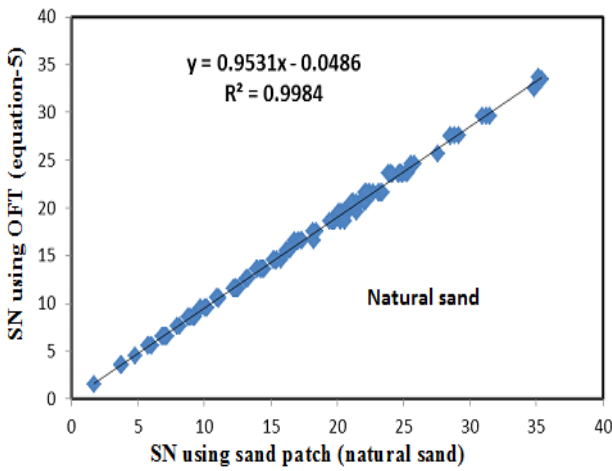


Figure 15. Effect of Testing Technique on SN

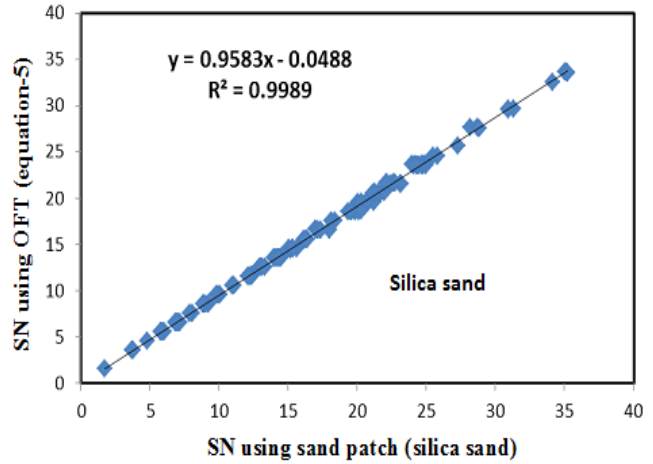


Figure 16. Effect of Testing Technique on SN

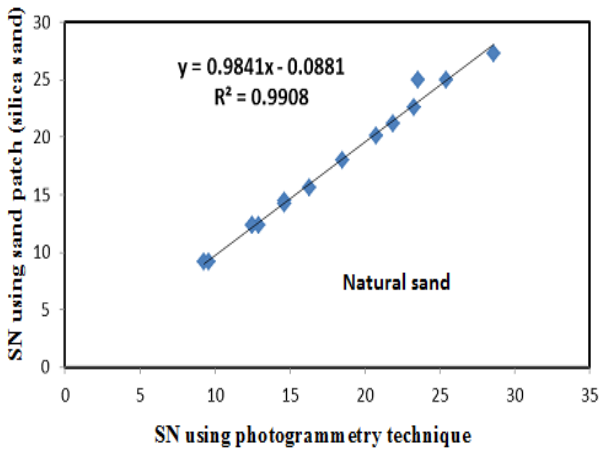


Figure 17. Variation of SN Using Photo

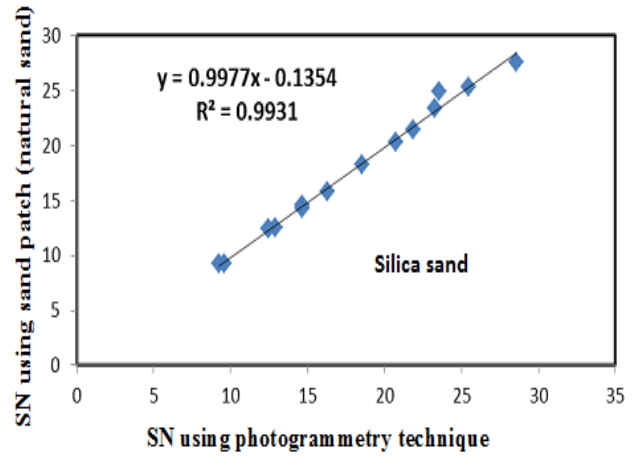


Figure 18. Variation of SN Using Photo .

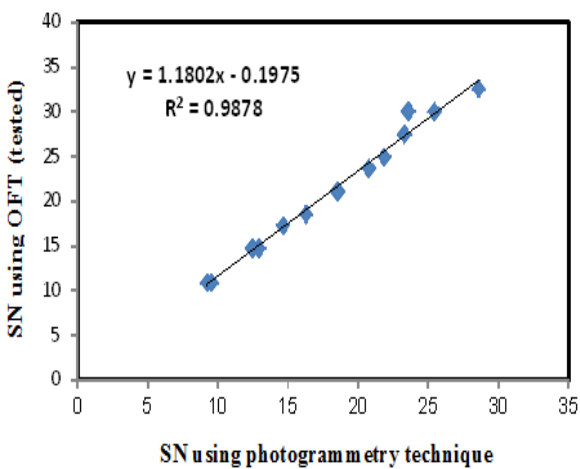


Figure 19. Variation of SN Using Photo and OFT

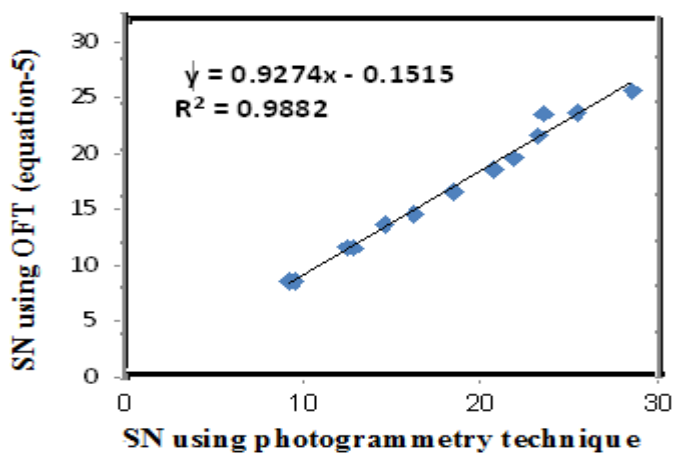


Figure 20. Variation of SN Using Photo and OFT.