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# Fractal Assessment of the Surface Texture of Pavements

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Fractal analysis was employed to evaluate the texture of profile tracers obtained from three different pavement surfaces. Fractal analysis uses the concept of the fractal dimension, D, as a way to evaluate the texture of simple and complex profiles. In this study it was determined that the fractal dimension, D, of the profiles of the pavement surfaces increased as the roughness of the texture profiles increased. For example, the smoothest of the three profiles had a fractal dimension, D, equal to 1.047; the roughest of the surface profiles had a fractal dimension, D, equal to 1.578. In addition, a good correlation was found to exist between the skid resistance of the pavement surfaces analyzed and their respective fractal dimension values. Thus, it is suggested that the fractal dimension can be used as a measure not only of the degree of roughness of the texture of the pavement surfaces but to relate surface texture to skid resistance (friction) on pavements as well.

*Keywords:* Pavements, Surface Profiles, Fractals, Fractal Dimension, Skid Resistance

## INTRODUCTION

Vehicle control is highly dependent on highway pavement surface characteristics. When pavements are dry, the friction generated between vehicle tires and the pavement is normally high. During rainy weather, water can create a critical situation by increasing the potential for hydroplaning or skidding, particularly when the skid resistance of a pavement is low. Skid resistance is defined as the frictional force that resists the sliding of tires on a pavement when the tires are prevented from rotating (Yoder and Witczak, 1975). Skid resistance is dependent upon many factors including texture of the pavement surface, tire pressure, tire tread, the presence of water, temperature, load, and vehicle speed (Road Transport Research, 1984; Shahin, 1994).

It has long been recognized that texture characteristics of a pavement surface directly influence the friction forces which pneumatic tires can develop for accelerating, steering, and breaking performance of vehicles. Many different techniques have been developed to provide a quantitative measurement of the surface texture of pavements. These techniques make use of: (a) profile tracers of pavement surfaces, (b) volumetric and drainage methods, (c) devices such as the British pendulum skid resistance tester, and (c) computer analysis of texture data obtained using depolarization detection and stereophotographic methods (Henry and Hegmon, 1975; Moore,

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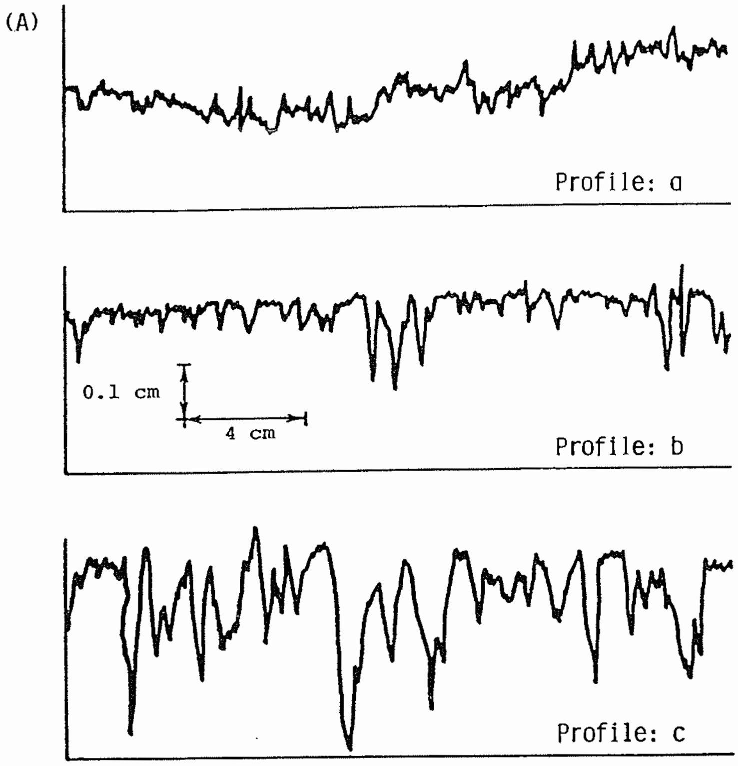

(B) Scale Segment Lengths:

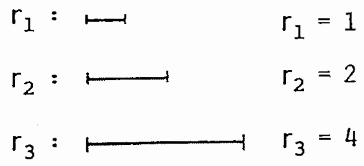

FIGURE 1 (A) Profiles of three pavement surfaces (Henry and Hegmon, 1975) (B) Segment lengths to obtain fractal dimension of profiles

1975; Howerter and Rudd, 1978; Chamberlin and Amsler, 1982; Yager and Buhlmann, 1982; Henry et al., 1984; Road Transport Research, 1984; Lees and Maynard, 1988).

TABLE I Skid resistance and texture data for pavement surfaces in Fig. 1(A) (Henry and Hegmon, 1975)

| *Profile* | *Type of Pavement* | *Skid Resistance Number, SN* | *Root Mean Square, rms (mm)* |
|---|---|---|---|
| a | Cement Concrete | 32.3 | 0.172 |
| b | Bituminous Concrete | 37.8 | 0.836 |
| c | Gravel in a Bituminous Asphalt Binder | 45.0 | 1.181 |

In the present study, a new and simple approach for evaluating the texture of pavement surfaces is presented. The new approach uses the fractal dimension concept from fractal theory (Mandelbrot, 1967, 1977). The fractal analysis will make use of profile tracers from three different pavement surfaces obtained by Henry and Hegmon (1975). The profile tracers and a description of the pavement surfaces are shown in Fig. 1(A) and Table I.

## ASSESSMENT OF THE SURFACE TEXTURE OF PAVEMENTS USING FRACTAL THEORY

The concepts associated with fractal theory were introduced by Mandelbrot in 1967. According to Mandelbrot (1967), the shape of forms in nature is usually analyzed using Euclidean geometry. According to this kind of geometry, straight lines are perfectly straight lines and curves are arcs of perfect circles. However, such perfection is seldom found in natural forms. Most of the time, the shapes of natural forms are irregular. Fractals are a relatively new mathematical concept used to describe the geometry of irregularly shaped objects in terms of fractional numbers rather than integers.

The importance of using fractals as a way to describe irregular or rough objects has been explored in recent years in articles by researchers working on the evaluation of the roughness of the profiles of aggregate and soil particles (Carr et al., 1990; Li et al., 1993; Vallejo, 1995, 1997; Yeggoni et al., 1996), and the development of cracks in pavements (Leblanc et al., 1991). This study introduces the concepts of fractal theory as a way of measuring the degree of roughness of the texture of pavement surfaces.

### The Concept of Fractal Dimension

The key parameter for fractal analysis is the fractal dimension. This value is a real number, which differs from the more familiar Euclidean or topological dimension. The latter is an integer, with a value of one for a line of any shape and two for a surface. The fractal dimension for a line of any shape varies between one and two, and for a surface between two and three. The difference between the fractal dimension and the Euclidean dimension can be explained by what happens when a thin ink line of any shape is drawn on a sheet of paper. This line has an Euclidean or topological dimension equal to one. However, if the line is drawn in such a way as to increase its wiggliness, the paper will appear to be almost covered with ink, giving the line a dimension better represented by that of the area of the sheet of paper. The area of the sheet of paper has an Euclidean dimension equal to two. Thus, the real dimension of irregular complex lines lies somewhere between that for the Euclidean line with a fine width, and the extreme of the case of complete surface cover (Turcotte, 1992). The fractal dimension measures the surface filling properties of wiggling lines and its value approaches that of the Euclidean dimension of the surface that encloses them. The fractal dimension for lines or profiles of any shape is a real number that varies between one and two. The rougher or more irregular the line, the larger is its fractal dimension.

### Methods to Measure the Fractal Dimension

Many methods have been developed to measure the fractal dimension of profiles such as those shown in Fig. 1(A). The most commonly used methods are: (a) the divider method, (b) the box method, and (c) the spectral method (Klinkerberg, 1994). In the present study, the divider method will be used to measure the fractal dimension of profiles such as those shown in Fig. 1(A). This method was chosen because it is easy to implement, and has been reported to give accurate measurements of the fractal dimension (Klinkerberg, 1994).

To explain the way the divider method works to obtain the fractal dimension of profiles, Figs. 2 and 3 are used. Fig. 2 shows two profiles, one very complex (profile ab), and the other very simple (profile a'b'). Suppose we want to measure the length of profile ab. To measure this length, we begin by setting two arms of a compass to a known distance (segment length, r) and step off the outline of the profile (Fig. 3). The

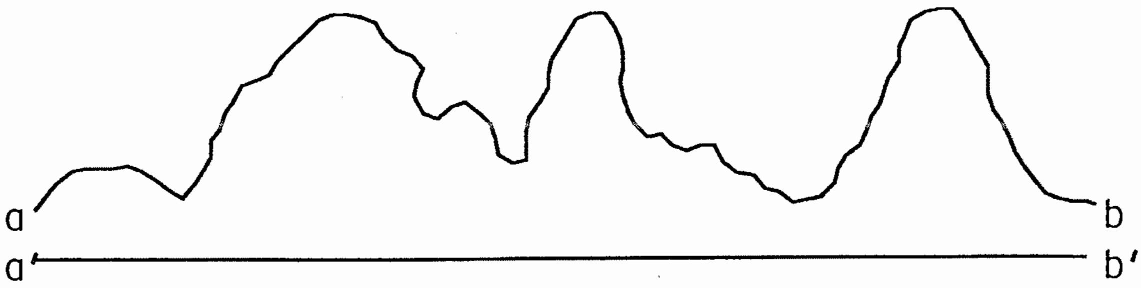

FIGURE 2 Outlines of complex profile (ab) and simple profile (a'b')

length of the profile ab is obtained by the product of the number of segments, N, and the chosen segment length, r. Using three different segment lengths, r, (the units of length being arbitrary) the length of the complex profile ab was determined (Table II). Fig. 3 shows the segment lengths used as well as the number of segments, N, needed to cover the complex profile ab. The length of profile ab obtained using three different segment lengths, r, is described in Table II. Table II also describes the results of the same procedure when it is applied to the simple profile a'b' (Fig. 2).

According to Mandelbort (1967, 1977) and Turcotte (1992), if a linear relationship develops between the number of segments, N, and the corresponding values of the segments, r, when plotted on log-log paper, the profiles represent fractal profiles. The absolute value of the slope of the linear relationship between the N and r values represents the fractal dimension, D, of the profiles.

The values of N and r for the profiles ab and a'b' (Figs. 2 and 3 and Table II) were plotted on log-log paper and the results are shown in Fig. 4. An analysis of Fig. 4 indicates that the N and r values for both profiles plotted on straight lines. The fractal dimension, D, for the smooth, simple profile a'b' (Fig. 2) is equal to one. The fractal dimension, D, for the rough, complex profile ab (Fig. 2) is equal to 1.0739.

## Significance of the Fractal Dimension D

According to Mandelbrot (1977), and Turcotte (1992), the fractal dimension, D, of the complex profile ab (Fig. 2), represents a measure of its degree of roughness. As Fig. 4 clearly indicates, the more complex the profile, the larger is the fractal dimension (D = 1 for the simple, smooth profile a'b'; D = 1.0739 for the rough, complex profile ab). Thus, the fractal dimension, D, can be used as a measure of the degree of roughness of profiles such as those depicted in Fig. 1(A).

TABLE II Data for fractal dimension calculation for profiles ab and a'b' (Figs. 2 and 3)

| *Profile* | *Segment Length (r)* | *Number of Segments (N)* | *Length of Profile (N)(r)* |
|---|---|---|---|
| ab | 1 | 79.3 | 79.3 |
| | 4 | 17.8 | 71.2 |
| | 8 | 8.5 | 68.0 |
| a'b' | 1 | 52.8 | 52.8 |
| | 4 | 13.2 | 52.8 |
| | 8 | 6.6 | 52.8 |

## THE FRACTAL DIMENSION OF PAVEMENT SURFACE PROFILES

The concept of fractal dimension was used to measure the degree of roughness of three profiles representing the surface texture of three different pavements [Fig. 1(A) and Table I]. The fractal dimension for the three profiles was obtained using the divider method. Three different segment lengths, r, (the units of length are arbitrary) were used to obtain the fractal dimension. The scales for the segment lengths used are shown in Fig. 1(B). The values of number of segments, N, and their corresponding segment lengths, r, needed to cover each of the profiles of Fig. 1(A) were plotted on log-log paper. The values of N and r for each of the three profiles plotted on straight lines (Fig. 5). The absolute value of the slope of the lines represents the fractal dimension, D, for the profiles. The values of the fractal dimension are given on the lower section of Fig. 5. An analysis of Figs 1(A) and 5 indicates that the fractal dimension, D, of the profiles increased as the roughness of the profiles increased. The smoothest of the profiles (profile a) had a fractal dimension, D, equal to 1.047. The roughest of the profiles (profile c) had a fractal dimension D equal to 1.578.

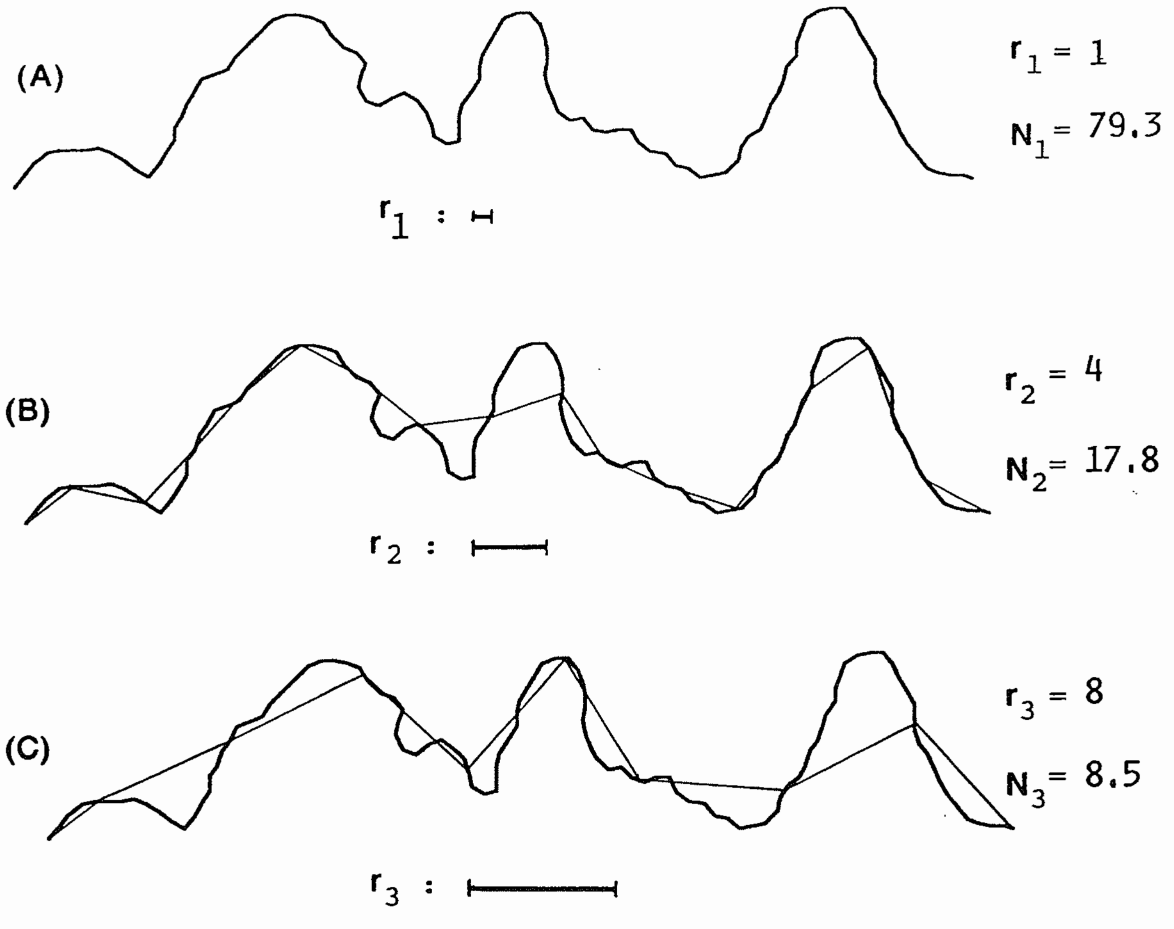

FIGURE 3 Segment lengths, r, and number of segments, N, used by the divider method to obtain the length of profile ab and its fractal dimension, D

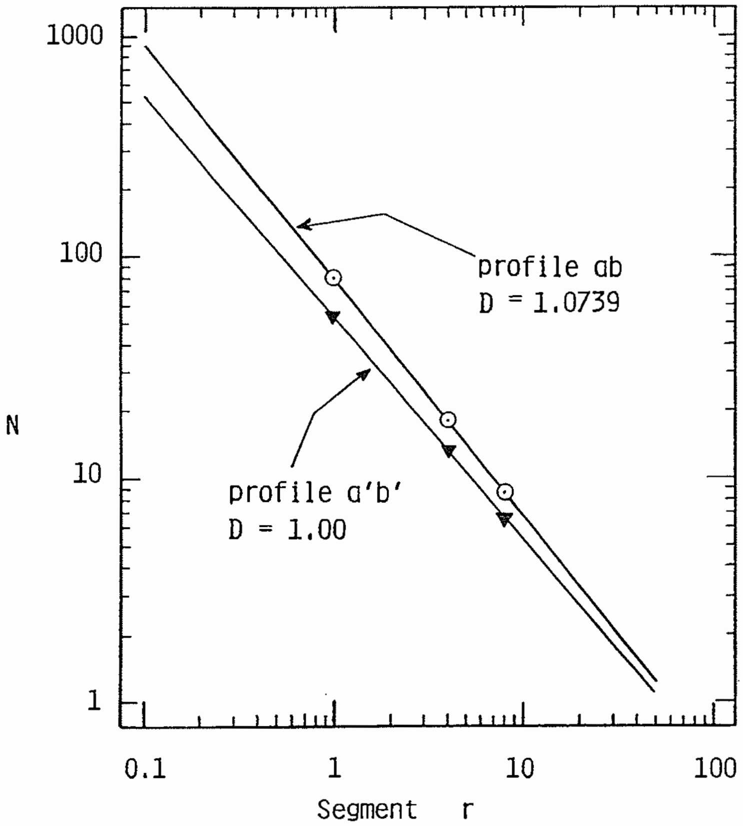

FIGURE 4 Plot of number of segments, N, versus the segment lengths, r, to obtain the fractal dimension, D, of profiles in Fig. 2

In the present study, the values of the fractal dimension, D, for the profiles of Figs. 1(A) and 5 were plotted against their Skid Resistance Numbers (SN) (Table I) in order to evaluate the level of correlation between these two parameters. The Skid Resistance Numbers reported in Table I were obtained by Henry and Hegmon (1975) following the ASTM Specification for Standard Tire for Pavement Skid Resistance Tests (E 501–73). The Skid Resistance Number (SN) represents the ratio in percentage between the tractive force applied to a standard test tire at the tire-pavement contact and the vertical load on the test wheel. The velocity used by Henry and Hegmon (1975) during their skid resistance tests was equal to 65 km/h.

Fig. 6 shows the plot of SN versus D. The values of SN and D plotted on a straight line. Using a regression analysis, a correlation coefficient equal to 0.99 was found between the SN and D values. This high level of correlation indicates that the fractal dimension could be used as a measure not only of the degree of roughness of the texture of pavement surfaces but to relate surface texture to skid resistance (friction) on pavements as well.

## CONCLUSIONS

The concept of fractals and fractal dimension as a measure of the degree of roughness of the texture of pavement surfaces has been presented. The application of fractal theory was carried out using three profile tracers representing the texture of three different

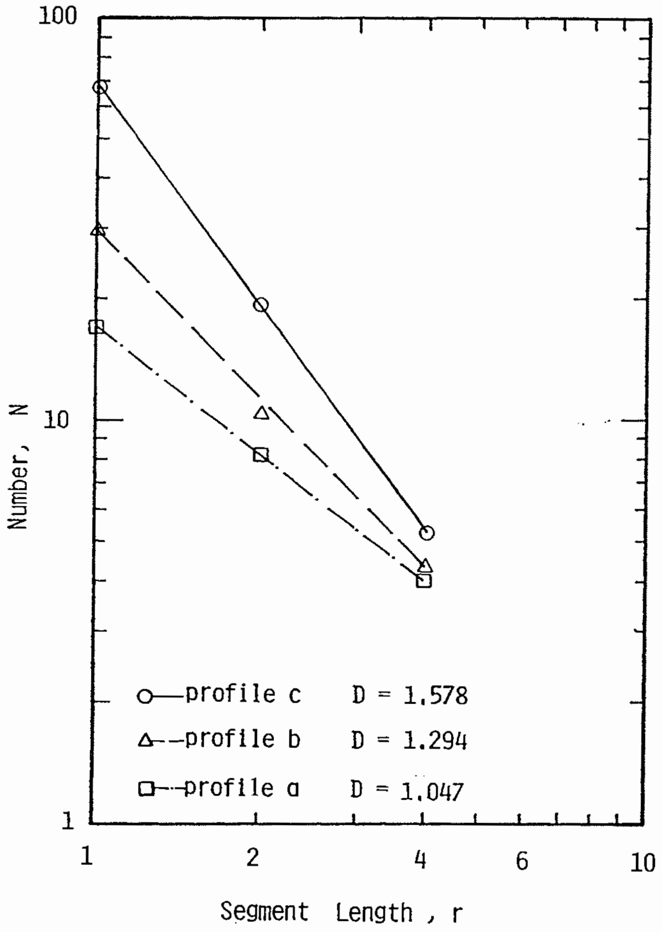

FIGURE 5 Plot of number of segments, N, versus the segment lengths, r, to obtain the fractal dimension, D, of profiles in Fig. 1(A).

pavement surfaces. The roughness of these profiles was evaluated by calculating their fractal dimension. It was determined that the fractal dimension, D, of the profiles increased as the roughness of the profiles increased. For example, the smoothest of the profiles had a fractal dimension, D, equal to 1.047; the roughest profile had a fractal dimension, D, equal to 1.578. In addition, a good correlation was found to exist between the skid resistance of the pavement surfaces analyzed and their respective fractal dimension values. Thus, the fractal dimension concept proved to be a simple mathematical tool that could be used as a measure not only of the degree of roughness of the texture of pavement surfaces but to relate surface texture to skid resistance (friction) on pavements as well.

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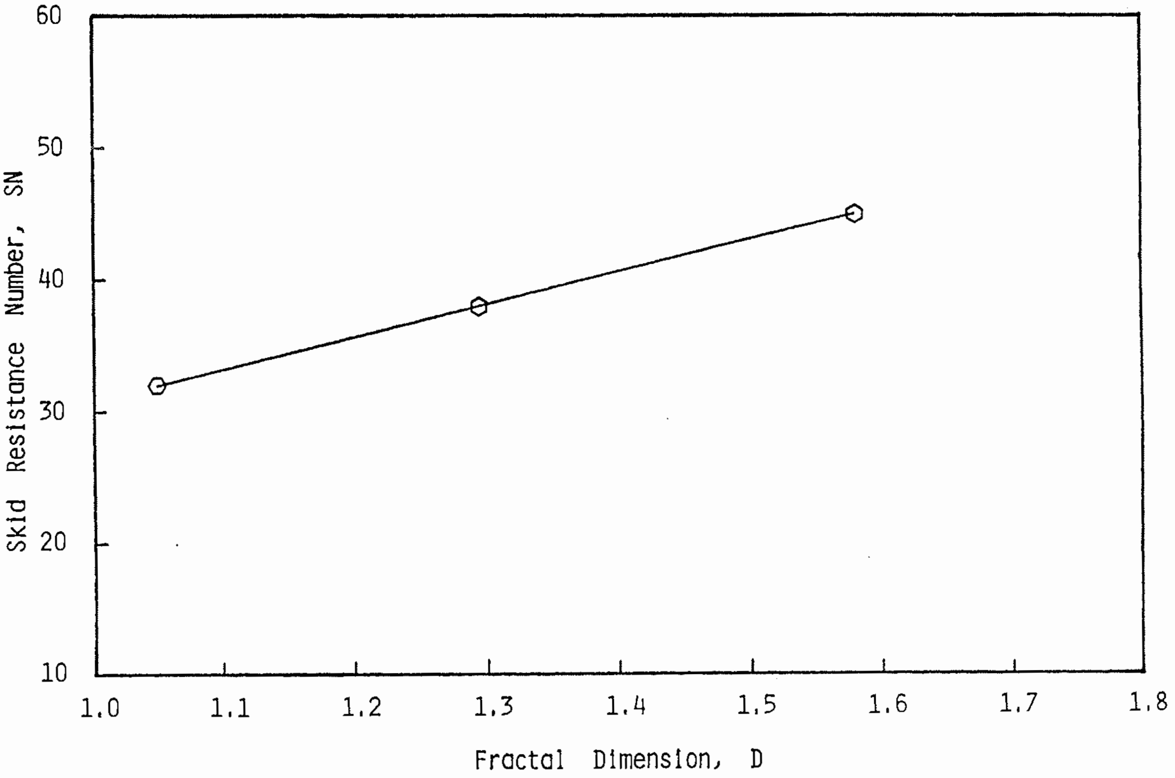

FIGURE 6 Plot of the Skid Resistance Number, SN, versus the fractal dimension, D, for the pavement texture profiles shown in Fig. 1(A)

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