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CORRELATION OF PUNDIT ULTRASONIC PULSE VELOCITY WITH STRENGTH OF PALM KERNEL SHELL CONCRETE

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Abstract: Ultrasonic Pulse Velocity (UPV) measurement is one of the most popular non–destructive techniques used in the indirect assessment of mechanical properties of concrete and other materials. This paper investigates the relationship between UPV and the compressive strength of palm kernel shell (PKS) concrete to develop strength based quality assurance model for construction of PKS concrete pavement. A total number of 420 cubes (150mm x 150mm x 150mm) and 28 PKS concrete slabs were casted for the PKS concrete nominal mix proportions of 1:1:1, 1:1:2, 1:1½:3 and 1:2:4 and at varying water/cement ratios of 0.3, 0.4, 0.5, 0.6 and 0.7. The PKS concrete elements of cubes and slabs were cured in water at laboratory temperature and cured for 3, 7, 14, 21, 28, 56 and 91 days. They were then subjected to nondestructive tests using the Pundit apparatus (Model PC 1006) to determine the ultrasonic wave transit time, path length, velocity and elastic modulus at the various ages. The unconfined compressive strengths of the PKS concrete were determined after each of the pulse velocity determination to establish a velocity–compressive strength data set. Results show that the UPV and the compressive strength of concrete increased with age but decreased with increase in w/c ratio, while the unit change in properties varies with mix proportions. The PKS concrete produced for the four nominal mixes and w/c ratios of 0.5 and below are good while the ones for w/c ratio of more than 0.5 are fairly good according to IS 1881 (1983). The compressive strength–UPV models developed for all mixes were in the form of logarithm equation, $\alpha_1 \ln(x) + c$ at R^2 value of 94.9 – 99.3 %, with the respective range of values of the characteristic parameters α_1 = 1.836 – 10.740 and c = 0.273 – 3.112 with the lower values representing weaker concrete.
Keywords: Palm kernel shell concrete, Ultrasonic pulse velocity, Nondestructive technique, Compressive strength

1. INTRODUCTION

Nondestructive test (NDT) methods are used to determine hardened concrete properties and to evaluate the condition of concrete in deep foundations, bridges, buildings, pavements, dams and other concrete construction. For this paper, nondestructive testing is defined as testing that causes no structurally significant damage to concrete. Nondestructive test methods are applied to concrete construction for four primary reasons: (i) quality control of new construction; (ii) troubleshooting of problems with new construction; (iii) condition evaluation of older concrete for rehabilitation purposes; and (iv) quality assurance of concrete repairs. It emphasizes on methods that have been applied to measure physical properties other than the strength of concrete in structures, to detect flaws or discontinuities, and to provide data for condition evaluation (Tomsett, 1980). The various NDT methods can be divided into two groups: (1) those whose main purpose is to estimate strength; and (2) those whose main purpose is to evaluate conditions other than strength, that is, to evaluate integrity. It is clear that the most reliable tests for strength are those that result in superficial local damage, and the term in–place tests are preferred for this group. The integrity tests, on the other hand, are nondestructive, and mostly based on visual inspections.

Ultrasonic Pulse Velocity (UPV) is a non destructive technique that involves measuring the speed of sound through materials in order to predict material strength, calculate low–strain elastic modulus and/or to detect the presence of internal flaws such as cracking, voids, honeycomb, decay and other damage. The technique is applicable where intrusive (destructive) testing is not desirable and can be applied to concrete, ceramics, stone and timber. The main strength of the method is in finding general changes in condition such as areas of weak concrete in a generally sound structure. Absolute measurements should be treated with caution. At the same time, the UPV technique is not always practicable in testing sound concrete. Especially, in investigation of crack depth, it is ineffective if the crack is water filled. The performance is also often poor in very rough surfaces. Sometimes good contact requires the use of a coupling gel between the transducers and the structure. This may be aesthetically unacceptable on some structures. The leading portable UPV test instrument is the Pundit Ultrasonic Testing Machine.

The ultrasonic pulse velocity technique is used for evaluating the non destructive method of testing for quality of concrete by transmitting an irrational pulse to travel a known distance through a concrete. Some researchers, previously, made use of the ultrasonic pulse velocity (UPV) of concrete to predict compressive strength and it is fundamental in such research work to study the relationship between UPV and compressive strength (Lin et al., 2003). Pulse velocity is influenced by many variables such as mix proportions, aggregate type, age of concrete, moisture content, and other factors (Lin et al., 2003). The factors significantly affecting the concrete strength might have little influence on UPV. As a result, a strength estimate made with the pulse velocity method is not a broad spectrum technique. Therefore, the relations derived can be used for structures made with same materials at any time during its service period.

Previous studies concluded that, for concrete with a particular mix proportion, there is a good correlation between UPV and the compressive strength. No clear rules have been presented to describe how the relationship between UPV and the compressive strength of concrete changes with its mix proportion. Therefore, there exists a high uncertainty when one tries to make use of UPV to predict the strength of concrete in different mix proportions. It has also been established that UPV of hardened concrete is predictable based on its mix proportion. In addition, it has been known that the compressive strength of concrete corresponds with the mix proportion (Mahure et al., 2011). Lawson et al (2011) and Mahure et al (2011) developed theoretical UPV–strength models for normal concrete with high correlation at different times.

Palm kernel shell (PKS) concrete, a new/emerging waste material, when used as substitutes for some of the natural materials used in rigid pavement construction provides protection for the environment by conserving natural resources, including the lands for mining and for landfills. Benefits also include economic development opportunities and reduced pollution hazards, thus protecting human health. In addition, with a greater use of recyclable materials from landfills for road construction, governments that operate waste management facilities could find a market for the materials, and divert a greater amount of material from their landfills. The introduction of recycled waste materials in construction works will provide a new source of aggregate, thus extending the life of sand and gravel mines, extending the life of the regional landfill, and eliminating costs for processing the road waste materials at the landfill.

Thus, this paper tries to adopt different mix proportions and water/cement ratios of PKS concrete as a medium to investigate the relationship between UPV and the compressive strength of hardened PKS concrete.

2. JUSTIFICATION OF STUDY

Traditionally, quality assurance of concrete construction and condition assessment for structural adequacy have been performed largely by visual inspection of the construction process and sampling by coring the concrete for performing standard tests on fresh and hardened specimens. This approach does not provide data on the in–place properties of concrete. NDT methods offer the advantage of providing information on the in–place properties of hardened concrete, such as the elastic constants, density, resistivity, moisture content, and hardness characteristics. Coring to examine internal concrete conditions and obtain specimens for testing is a sort of introduction of weak spots to the whole structure. This approach limits what can be detected, while the cores only provide information at the core location and coreholes needed to be repaired. The assessment of in situ compression strength of a rigid pavement structure plays a key role in the evaluation of its safety, feasibility in terms of strength at the time of production and the knowledge of the main physical properties of the concrete and its state. Maintenance of rigid pavements is more effective if the deterioration rate of the strength could be monitored as the pavement is being affected by traffic and weather conditions.

3. AIM AND OBJECTIVES

This paper is aimed at indirectly determining in–situ, the mechanical properties of a PKS concrete through the direct characterization of non–strength physical properties and conditions of hardened palm kernel shell concrete elements. The specific objectives, therefore, are to:

(a) determine the Ultrasonic Pulse Velocity (UPV) of hardened PKS concrete cubes and slabs at varying nominal mixes and curing ages using the Pundit Apparatus,
(b) determine the compressive strengths of the same PKS concrete specimens as used in (a),
(c) determine the trend of the characteristic compressive strength and other properties of the PKS concrete at various ages and mixes,
(d) develop the statistical relationship between the Ultrasonic Pulse Velocity (UPV) and compressive strength of PKS concrete,

4. MATERIALS AND METHODS

Palm kernel shells, acquired from wastes of small scale palm oil milling centre's were washed, dried and evaluated for suitability for production of nominal mixes of 1:1:1, 1: 1: 2, 1:1½:3 and 1: 2: 4 for water/cement ratios of 0.3, 0.4, 0.5, 0.6 and 0.7. They were batched, cured and tested for compressive strength at 3, 7, 14, 21, 28, 56 and 91 days. A total number of 420 cubes were produced. Prior to crushing, the PKS concrete cubes were subjected to NDT with the Pundit Apparatus (Model PC 1006) to determine respective transit time, velocity of the pulse and elastic modulus in accordance with the specification of the British standard (BS EN 12504–4, 2004)..

UPV–compressive strength relationship of hardened PKS concrete was proposed for the concrete cubes. The quality of PKS concrete in terms of uniformity, incidence etc. was also assessed using the IS Code, BS, 1881, 1983.

Table 1: Suggested Quality Criteria for Concrete. Source: IS Code, BS, 1881, 1983

Pulse Velocity (km/sec)	Concrete Quality (Grading)
Above 4.0	Very Good
3.5 to 4.0	Good
3.0 to 3.5	Medium
Below 3.0	Poor

5. RESULTS AND ANALYSIS

The statistical analysis results of the UPV and compressive strength tests are presented in Tables 2 – 9. The corresponding graphical presentations are shown in Figures 1 – 4.

Table 2: Compressive Strength (N/mm²) versus Ultrasonic Pulse Velocity (m/s) of PKS Concrete (1:2:4 Mix Ratio)

Age (Days)	w/c = 0.3		w/c = 0.4		w/c = 0.5		w/c = 0.6		w/c = 0.7	
	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)
3	1.32	4.211	1.12	3.723	0.72	3.214	0.58	2.986	0.42	2.157
7	2.76	4.630	2.45	4.386	2.06	3.760	1.75	3.233	1.38	2.464
14	4.23	5.036	3.84	4.700	2.93	4.278	2.56	3.852	2.12	3.085
21	5.52	5.542	4.61	5.286	3.78	4.874	3.32	4.292	2.85	3.612
28	6.50	5.731	5.53	5.498	4.75	5.142	3.95	4.639	3.31	3.936
56	7.18	6.268	6.27	5.889	5.76	5.551	4.93	4.962	3.72	4.395
91	7.20	6.324	6.29	6.008	5.80	5.701	4.95	5.089	3.77	4.412

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Table 3: Compressive Strength (N/mm²) versus Ultrasonic Pulse Velocity (m/s) of PKS Concrete (1:1½:3 Mix Ratio)

Age (Days)	w/c = 0.3		w/c = 0.4		w/c = 0.5		w/c = 0.6		w/c = 0.7	
	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)
3	1.80	4.407	1.52	4.054	1.08	3.785	0.89	3.314	0.71	2.657
7	5.20	4.761	4.61	4.451	4.12	4.075	2.75	3.890	2.07	3.270
14	9.21	4.978	8.04	4.777	6.21	4.369	4.81	4.139	3.96	3.642
21	11.91	5.638	9.33	5.392	7.23	4.922	5.72	4.411	4.66	4.147
28	13.12	5.828	10.12	5.686	8.52	5.321	6.37	5.046	5.06	4.302
56	15.80	6.560	13.18	6.163	10.29	5.649	8.63	5.383	7.15	4.838
91	15.81	6.465	13.20	6.275	10.33	5.787	8.65	5.492	7.18	5.056

Table 4: Compressive Strength (N/mm²) versus Ultrasonic Pulse Velocity (m/s) of PKS Concrete (1:1:2 Mix Ratio)

Age (Days)	w/c = 0.3		w/c = 0.4		w/c = 0.5		w/c = 0.6		w/c = 0.7	
	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)
3	2.13	4.516	1.82	4.328	1.41	4.159	1.06	3.675	0.93	3.247
7	8.12	5.059	7.63	4.658	5.18	4.466	4.53	4.042	3.89	3.551
14	13.13	5.333	11.98	4.986	9.58	4.662	7.64	4.322	5.75	3.974
21	17.21	5.744	15.05	5.502	13.10	5.230	9.15	4.722	6.83	4.347
28	19.52	6.045	18.16	5.886	14.80	5.732	11.02	5.441	8.32	4.902
56	21.49	6.685	19.25	6.450	16.47	5.975	12.22	5.699	9.13	5.288
91	21.50	6.793	19.27	6.584	16.51	6.254	12.25	5.806	9.16	5.435

Table 5: Compressive Strength (N/mm²) versus Ultrasonic Pulse Velocity (m/s) of PKS Concrete (1:1:1 Mix Ratio)

Age (Days)	w/c = 0.3		w/c = 0.4		w/c = 0.5		w/c = 0.6		w/c = 0.7	
	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)	Compressive Strength	UPV ($x10^3$)
3	2.83	4.787	2.07	4.615	1.79	4.378	1.42	4.162	1.08	3.513
7	10.20	5.157	8.67	4.891	6.64	4.520	5.84	4.220	4.26	3.830
14	15.22	5.498	13.43	5.117	11.27	4.870	9.74	4.560	7.55	4.109
21	18.85	5.884	16.86	5.658	15.54	5.450	13.21	5.148	11.46	4.676
28	21.12	6.216	19.64	6.017	17.92	5.823	15.66	5.672	13.88	5.278
56	22.56	6.813	20.72	6.662	19.61	6.273	17.53	5.950	15.12	5.587
91	22.60	6.925	20.78	6.747	19.64	6.445	17.57	6.175	15.18	5.626

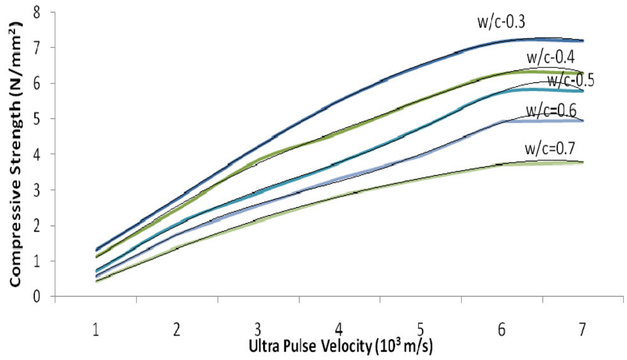

Figure 1. Graph of compressive Strenght against UPV [1:2:4 mix]

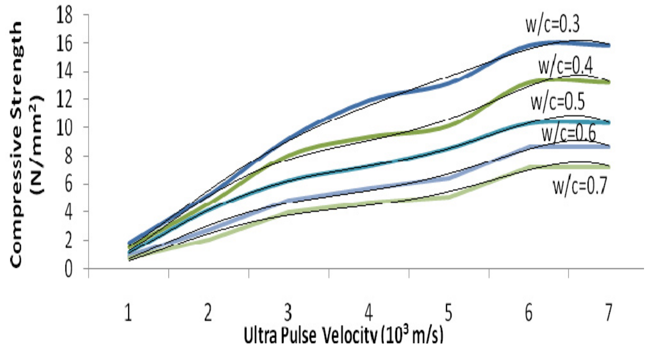

Figure 2. Graph of compressive Strenght against UPV [1:1½:3 mix]

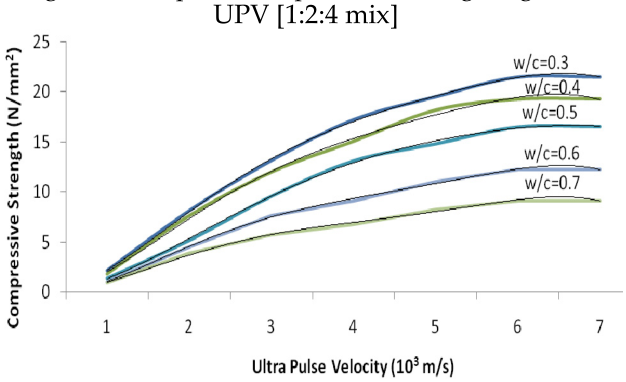

Figure 3. Graph of compressive strenght against UPV [1:1:2 mix]

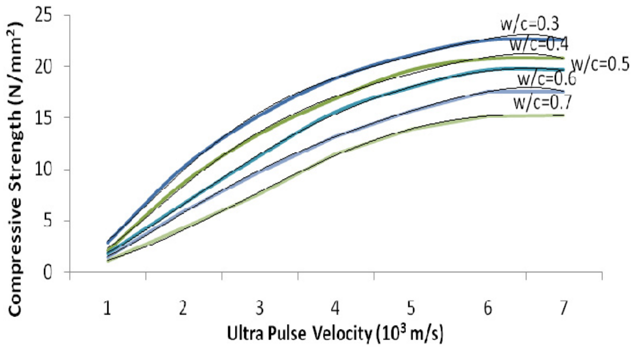

Figure 4. Graph of compressive strenght against UPV [1:1:1 mix]

The resulting equations relating compressive strength to ultrasonic pulse velocity of PKS concrete is shown in Table 6.

Table 6: Equations Relating Compressive Strength, y (N/mm^2) and UPV, x (km/s) of PKSC

1:2:4 Mix	
y = 3.296ln(x) + 0.943;	R^2 = 0.978……..(1) for w/c = 0.3
y = 2.847ln(x) + 0.833;	R^2 = 0.983..……(2) for w/c = 0.4
y = 2.742ln(x) + 0.345;	R^2 = 0.965……...(3) for w/c = 0.5
y = 2.348ln(x) + 0.288;	R^2 = 0.970..……..(4) for w/c = 0.6
y = 1.836ln(x) + 0.273;	R^2 = 0.987 ……..(5) for w/c = 0.7
1:1$^1/_2$:3 Mix	
y = 7.712ln(x) + 1.014;	R^2 = 0.981…….(6) for w/c = 0.3
y = 6.211ln(x) + 1.006;	R^2 = 0.975..…...(7) for w/c = 0.4
y = 4.890ln(x) + 0.869;	R^2 = 0.989…….(8) for w/c = 0.5
y = 4.125ln(x) + 0.379;	R^2 = 0.962…….(9) for w/c = 0.6
y = 3.437ln(x) + 0.211;	R^2 = 0.949…….(10) for w/c = 0.7
1:1:2 Mix	
y = 10.691ln(x) + 1.698;	R^2 = 0.989…..…(11) for w/c = 0.3
y = 9.621ln(x) + 1.591;	R^2 = 0.988……..(12) for w/c = 0.4
y = 8.491ln(x) + 0.665;	R^2 = 0.980..…....(13) for w/c = 0.5
y = 6.115ln(x) + 0.819;	R^2 = 0.991..…….(14) for w/c = 0.6
y = 4.426ln(x) + 0.895;	R^2 = 0.993..…….(15) for w/c = 0.7
1:1:1 Mix	
y = 10.740ln(x) + 3.112;	R^2 = 0.989 …….(16) for w/c = 0.3
y = 10.260ln(x) + 2.097;	R^2 = 0.988……..(17) for w/c = 0.4
y = 10.010ln(x) + 1.005;	R^2 = 0.982……..(18) for w/c = 0.5
y = 8.974ln(x) + 0.637;	R^2 = 0.984..……(19) for w/c = 0.6
y = 8.046ln(x) + 0.009;	R^2 = 0.966……..(20) for w/c = 0.7

6. DISCUSSION OF RESULTS

The Ultrasonic Pulse Velocity (UPV) is the measure of the quality of concrete. The UPV values of the PKS concrete for all w/c ratios, ages and mix proportions fall within 2.0 and 7.0 km/sec. Compared with UPV values in Table 1, PKS concrete produced for all the mix proportions and w/c ratios of 0.3, 0.4 and 0.5 are either good while the ones for w/c ratio of 0.6 and 0.7 are fairly good only.

Tables 2 – 5 show the compressive strength versus ultrasonic pulse velocity of PKS concrete for the nominal mixes and water/cement ratios. These are presented graphically, respectively in Figures 1 – 4. Results show that compressive strength and UPV increase with advancement of age but decrease with increase in water/cement ratio. At the same age, both UPV and compressive strength of PKS concrete with low w/c ratio are higher than those with high w/c ratio mainly because of the denser structure of concrete with lower w/c ratio. Also, for all the nominal mixes, the PKS concrete with high w/c ratio (w/c = 0.7) at the age of 7 days have UPV values of between 70 and 75% of that of 28 days, but the corresponding compressive strengths are between 50 and 55%. Similarly, at the age of 7 days, PKS concrete with low w/c ratios (w/c = 0.3) have UPV values that fall in the range 80–85% of that at 28 days while the corresponding compressive strengths are in the range 55–60%. These imply that, the UPV and compressive strength growth rates of high and low w/c ratio concrete are significantly different at an early age. As a result, the relationship between UPV and compressive strength of PKS concrete becomes unclear when age and mix proportion are taken into consideration simultaneously. This observation suggests that it is be better to separately consider the effect of age and mix proportion on UPV and compressive strength relationship. For the mix proportions under consideration, Figures 1 – 4 were meant to determine the UPV and compressive strength values of hardened PKS concrete having w/c ratio values of 0.30, 0.40, 0.50, 0.60 and 0.70.

The curves of the relationship between ultrasonic pulse velocity and compressive strength drawn for PKS concrete with the corresponding w/c ratios yielded the equations 1 – 20 presented in Table 6. For the five w/c ratios, the relationship between UPV and compressive strength of PKS concrete is good for the mix proportions with a very high coefficient of correlation, R^2 in the range 0.949 – 0.993. This indicates relevance between data points and the regression curves.

7. CONCLUSIONS

Several attempts have been made towards either developing new procedures of estimating the compressive strength and other properties of concrete or towards using the existing methods for getting more reliable and dependable information of the quality of concrete in the years to come without disturbing the structure. This paper investigated the relationship between the Ultrasonic Pulse Velocity (UPV) and compressive strength of PKS concrete and also shown the influence of the mix proportions, water/cement ratios and the age of concrete on the relationship between UPV and compressive strength. Based on the studies, the following conclusions are drawn:

(a) The PKS concrete produced are either good of fairly good.
(b) The compressive strength and UPV increase with advancement of age but decrease with increase in water/cement ratio.
(c) Both UPV and compressive strength of PKS concrete with low w/c ratio are higher than those with high w/c ratio at the same age mainly because of the denser structure of concrete with lower w/c ratio.
(d) The UPV and compressive strength growth rates of high and low w/c ratio PKS concrete have a significant difference at an early age. As a result, to clearly define the relationship between UPV and the compressive strength of PKS concrete with different mix proportions, it is necessary to eliminate the interference caused by the different UPV and compressive strength growth rates of concrete at early ages.
(e) The equations obtained from the simulation curves can be used to determine the compressive strengths of the concrete mix proportions.
(f) There is a unique relationship between compressive strength and UPV logarithm model of the form $\alpha_1 \ln(x) + c$, that can be used to describe the strength of PKSC at R^2 values of 94.9 – 99.3 %, indicating relevance between data points and the regression curves.
(g) When the developed equations are used for concrete mixes with same concrete grades and w/c ratios but different materials from different projects, the predicted compressive strength of concrete will show more variation from the actual strength of the specimens.

RECOMMENDATIONS

i. In order to fulfill the quest by governments in developing countries, especially Nigeria to satisfy the initiative of global best practice for recycling wastes in road pavement, the use of locally available materials, such as the PKS is recommended in infrastructural development for the construction of road structures of foot bridges, road medians and pavement for pedestrian walk in the urban multilane highways.
ii. The recycle of PKS biomass waste material from palm oil farming helps preserve natural resources as a sustainable material and maintains ecological balances, must be encouraged in order to effectively address the environmental pollution caused by indiscriminate dumping of PKS.
iii. The UPV results should be used to (a) check the uniformity of concrete, (b) detect cracking and voids in concrete, (c) control the quality of concrete and concrete products by comparing results to a similar made concrete, (d) detect the condition and deterioration of concrete, (e) detect the depth of a surface crack, and (f) determine the strength, and indeed the development of time–elastic deterioration trend for a PKSC pavement.
iv. For further studies, the effect of changes in the volume fraction of cement paste, the source of PKS coarse aggregate (hinterland and coastal), the weather combined with traffic, the UPV–strength relationship should be examined for development of fatigue and other performance–based characteristics of PKS concrete pavement.

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