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Investigating the Mechanical Behavior of Reclaimed Asphalt Pavement (RAP) Bases in Large Scale Test Box

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ABSTRACT

The objective of this research was to assess the elastic deformations and permanent strains of reclaimed asphalt pavement (RAP) material as a base layer when it is treated or untreated with pozzolanic cement under cyclic loads. A large-scale cyclic plate loading testing (CPLT) device was developed for studying the mechanical characteristics of pavement base layer. The laboratory test results indicated that when the RAP percentage of the mixtures increased, elastic deformations and permanent strains increased, but the opposite was true when the cement percentage increased. It was concluded that 100% RAP material can be used in base layers with 3% pozzolanic cement. The obtained deformation values and strain rates can be used as reasonable default design input values by pavement designers when using RAP as a substitute for natural aggregate base layers.

Keywords: RAP, CPLT, elastic deformation, permanent strain.

1. INTRODUCTION

To reduce the costs of construction and disposal of used pavement materials, Turkey is increasingly recycling these materials when reconstructing highway pavements. Since most recycled asphalt aggregate (RAP) material is used in hot-mix asphalt pavements, there is a general lack of data pertaining to the mechanical properties for RAP material in other to guide possible future applications, notably pavement unbound base layers. Several authors performed laboratory studies of RAP material, focusing on tests of interest to base layer construction, including proctor compaction experiment, California Bearing Ratio (CBR) and resilient modulus to assess the suitability of RAP as a base layer material [1-8].

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The bearing capacity of the base layers strongly depends on the RAP content mixed with the conventional natural aggregate (NA). In general when the percentage of RAP material in mixtures exceeds 20-25%, the required CBR value for the base layer decreases as discussed by several authors [9- 11]. Some researchers reported that the RAP content of the base layer mixtures should be limited to a maximum of 50% by weight [1, 12].

In the literature, there is no study found on the performance of cyclic plate loading test of cement treated and untreated base layers with different RAP percentages. The triaxial load test was used mostly in determining the deformation characteristics. The cyclic plate loading test (CPLT) used by Thakur [13] was performed on 100% RAP pavement base layer reinforced with geocell. The CPLT provides preliminary determination of deformation in the laboratory environment to represent field traffic loads.

Highter et al. [14] reported that larger elastic deformation values would be obtained when the RAP percentage in RAP-NA mixtures is increased.

Pokharel et al. [15] conducted CPLT tests on base layers. In this study, geocell-reinforced granular bases with three types of infill materials (Kansas River (KR) sand, quarry waste (QW), and AB-3 aggregate) were tested and compared with the unreinforced bases under 150 loading cycles. The study experimentally investigated the effect of the geocell reinforcement on the permanent deformation and percentage elastic deformation of the granular bases. The test results showed that the amount of elastic deformation was slightly higher at the beginning of the load cycles but later stabilized to a constant value. Unreinforced QW showed approximately 0.5 mm elastic deformation and unreinforced AB-3 showed about 0.7 mm elastic deformation at the end of the 150th loading cycle.

The resilient response of the granular material is important for the load-carrying capacity of the pavement and the permanent strain response, which characterizes the long-term performance of the pavement [16]. Papp et al. [17] studied the permanent deformation characteristics of recycled concrete aggregate (RCA), RAP and a dense-graded aggregate in base and subbase applications by conducting cyclic triaxial tests and reported that the resilient modulus for RAP in the laboratory testing was higher than that of the conventional materials. However, RAP also had the highest permanent strain after 100,000 repetitions.

Thompson and Smith [6] stated that permanent strains are an important characteristic for determining wearing layer performance. Some researchers have observed that permanent strains increase when RAP percentage increases in RAP-NA mixtures [18-22].

Attia [18], Bennert et al. [19], Garg and Thompson [20] and Kim and Labuz [21] found that the relationship between permanent strains and the number of loading and unloading cycles of 50% RAP and 100% RAP in a linear fashion.

Bennert and Maher [1] indicated that as the RAP percentage in RAP-NA mixtures increases, the cumulative permanent strains obtained at the end of 100,000 loading-unloading cycles increase compared to the 100% NA. Furthermore, the increase in the RAP percentage in the mixture increased the permanent strain rate. The largest strains were obtained at 100% RAP material [23].

In order to allow a higher load distribution capacity in pavements, in comparison to unbound materials, the treatment of the granular materials of road bases/subbases with cement is a good option [24].

2. MATERIALS

2.1. RAP Material

The RAP material used in this study was obtained from main municipal roadway overlay in Trabzon city, Turkey. The RAP material used was not processed after milling only the material over 25 mm sieve was removed. Results of sieve analysis indicated that both the RAP and NA materials were classified as A-1-a type soils according to the AASHTO soil classification system. The filler content (<0.075 mm) of RAP was 3.3%. The plant-mix base layer (PBL) gradation did not allow for more than 10% of the material to pass the 0.075 mm sieve in AASHTO design criteria.

An extraction test following the specifications in AASHTO T-164 [25] showed the asphalt content of 100% RAP was 5.5% by weight. The ASTM D 1557 [26] Modified Proctor test was performed on the RAP material. The maximum dry density (MDD) for RAP was 1.952 t/m^3 at an optimum moisture content (OMC) of 7.2%. Specifications require that the base layer materials have a soaked CBR greater than 120. However, the result of soaked CBR test performed on RAP material according to AASHTO T-193 [27] indicated that it does not meet CBR base layer requirements of 120 alone.

2.2. Natural Aggregate (NA) and Cement

The NA was obtained from a local quarry pit in Trabzon province, Turkey. The NA with loss of weather resistance (with Mg_2SO_4) of 4.56%, abrasion (Los Angeles) of 12.0%, flatness index of 13.0% and water absorption of 1.81% was used in this study. The maximum dry density of the NA was 2.2 t/m^3 at a moisture content of 5.8%. The measured soaked CBR value was 178. 1, 2 and 3% of pozzolanic cement was added to the RAP-NA mixtures in order to increase the CBR up to 120. The pozzolanic cement type was CEM IV 32.5 R.

3. METHOD

The first step of the test program was to determine the untreated 100% RAP content mixture that meets the criteria for grading and soaked CBR for the PBL as specified by the Turkish Department of Transportation (TurkeyDOT) specification. In this specification, the minimum soaked CBR criterion to be provided for PBL is 120, while the maximum amount of mineral filler (<0.075 mm) is limited to 10% [28]. 1, 2 and 3% cement content by dry weight was added to the mixture to meet the requirements.

The second step was to compare the elastic deformations of cement treated and untreated RAP base mixtures to the 100% NA mixes as a reference under cyclic plate loadings.

3.1. Preparation of Mixtures

Sieve analysis, compaction and soaked CBR tests were performed on RAP-NA mixtures that contained 100, 60, 50, 40, 30, 20, 10 and 0% RAP. The CBR testing was performed according to AASHTO T-193 to determine the bearing capacity of NA and RAP mixtures compacted at optimum moisture. For the tests, five replicates were prepared for each mixture. As the

RAP percentage increased the dry density and optimum moisture content decreased. The lowest CBR corresponded to the mix containing 100% RAP. Similar to the behavior of dry density, the CBR values increased, as the percentage of RAP in the aggregate mixture decreased. In maximum untreated mixture with RAP which had the CBR greater than 120 was 20% RAP-80% NA mixture. Results indicated that 20% RAP-80% NA with no cement is a good option when used in the base layer.

Some RAP-NA mixes that did not meet the 120 soaked CBR criteria were tested with different percentages of cement. Three levels of cement content, 1, 2 and 3%, by dry weight were used. The maximum RAP percentages that met the 120 soaked CBR criteria and 100% NA as the control mix were selected for CPLT. Mixtures of aggregate containing 20% RAP-80% NA, 60% RAP-40% NA-3% cement, 100% RAP-3% cement and 100% NA produced CBR greater than 120. Modified Proctor and soaked CBR test results of the mixtures meeting the soaked CBR criteria are given in Table 1.

Table 1 - Modified Proctor and soaked CBR test results of the mixtures

Mixtures (%)			Modified Proctor		Soaked CBR
RAP	NA	Cement	OMC (%)	MDD (t/m^3)	
-	100	-	6.00	2.23	178
20	80	-	5.10	2.15	130
60	40	3	4.82	2.10	147
100	-	3	4.60	2.092	138

3.2. Test Setup

The base layers were prepared with four mixtures separately, with cement treated and untreated blends in maximum RAP content, which meet the min. 120 CBR criterion, and 100% NA as the control mix, then subjected to CPLT. These mixtures are composed of 20% RAP-80% NA, 60% RAP-40% NA-3% cement, 100% RAP-3% cement and 100% NA (Figure 1).

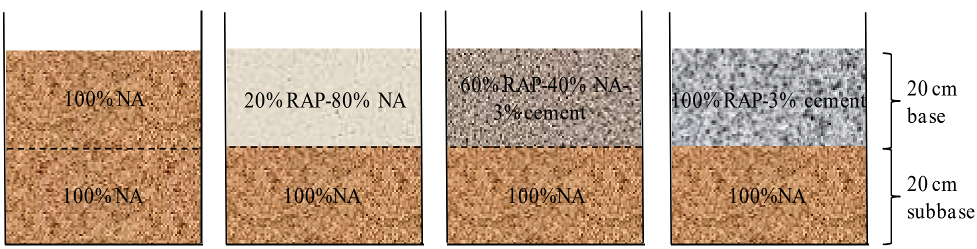

Figure 1 - Prepared base sections

The total compacted thickness of each of the base and subbase layers was 20 cm. The prepared mixtures were placed inside the test box in a lift thickness of 5 cm for four lifts to achieve 98% compaction. The quantity of RAP placed in each lift was calculated by multiplying the volume of that lift by the density of the mixtures. The prepared base layer mixtures were compacted at its optimum moisture content which corresponded to 98% of the maximum dry density. Cement-treated base sections were cured for 7 days in test tank after compaction.

Figure 2 showed the test apparatus used to compact the base and subbase layers. A large-scale (1 m×1 m×0.8 m) steel test tank was constructed for CPLT. The subbase layer of 20 cm thickness consisted of 100% NA. The subbase in the tank compacted to a dry density approximately equal to 98% of the maximum dry density. Compression of the underlying and base layers was accomplished by mounting a steel plate to the loading piston.

(a) (b)

Figure 2 - Compaction assessments (a) subbase layer (b) base layer

It was observed that the preliminary work carried out by the loading piston made 10 loading cycles and 98% or more of the compression was carried out by increasing the load to 20 tons capacity per cycle. The test setup consists of 3 different external components, mainly; 3 displacement transducers (LVDTs) placed at different intervals on the surface, 2 strain gauges placed in the base layer and 20 ton force exerting capacity load cell placed on the loading plate. A load cell was used for measuring the load applied; LVDTs and strain gauges are used to measure displacements and strains respectively. All of the cables of the displacement transducers and strain gauges were connected to a data recorder.

A 300 mm in diameter steel circular plate is used to apply cyclic loading on the test sections. The cyclic loads having a peak value of 40 kN and a trough value of 0 kN were applied on the loading plate at a loading wave frequency of 0.77 Hz. The peak value of the load was selected to simulate the single wheel load of 40 kN, which corresponds to a tire pressure of 550 kPa.

Strain gauges were used to measure the strains that developed at different locations of the base layer during cyclic loading. The strain gauges used in this study had a resistance of 120 ohms, a gauge factor at 24 °C of 1-2 and ±7500 microstrain capacity. Figure 3 showed the strain gauges at the middle of the base layer were placed horizontally 100 mm below the surface. Strain gauges were oriented in the line identical to the width of the test box at distances of 250 and 400 mm from the center (SG-1 and SG-2, respectively).

Figure 3 - Strain gauge placements in the base layer

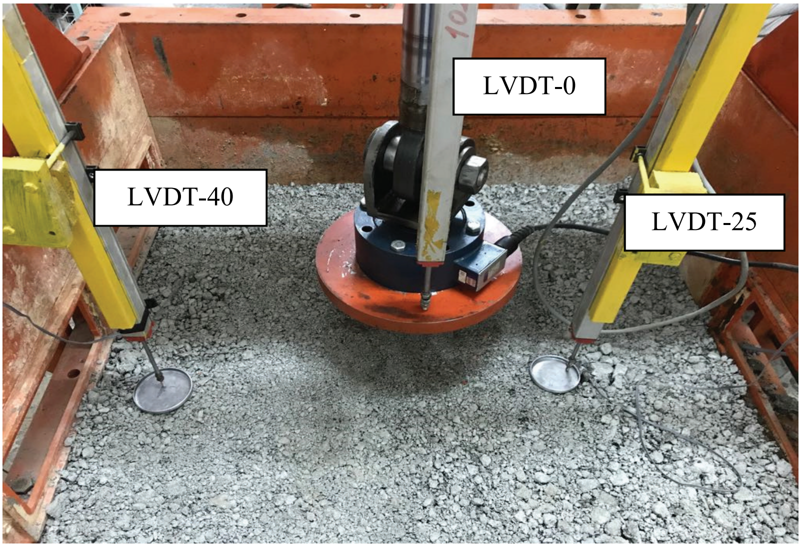

Figure 4 - The configurations of LVDTs

The vertical surface displacements at the plate center and different distances from the center were measured by the linear variable displacement transducers (LVDTs). LVDTs had two displacement ranges: 0 to 50 mm and 0 to 100 mm. One displacement transducers of 100 mm limit were affixed on the loading plate center. Two displacement transducers of 50 mm limit each were affixed at distances of 250 and 400 mm away from the center of the loading plate. The displacement transducers were positioned on the loading plate and base layer surface (Figure 4).

After all the sensors are positioned, the test was performed. Vertical displacements were obtained separately from the base layers prepared from the mixtures over 100 loading cycles. 100% NA was used as the control base material for comparison with the recycled materials at base layer test sections.

4. TEST RESULTS AND DISCUSSION

In this study, according to the data obtained from the LVDT data, sitting deformations are shown positive (+) and swelling deformations are shown negative (-) in graphs. Moreover, the strain was positive under tension and negative under compression.

4.1. Elastic Deformations

The recoverable portion of the deflection during a loading pulse was designated as the elastic deformation. Deformations were measured when the base layer was loaded with the maximum load (40 kN) and unloaded to the minimum load (0 kN). The variation of elastic deformation due to the number of loading cycles was measured by the LVDTs placed at different distances. Figure 5 showed the vertical elastic deformations of 100% NA mixture, at the center of the plate and 250 and 400 mm away from the center of the plate.

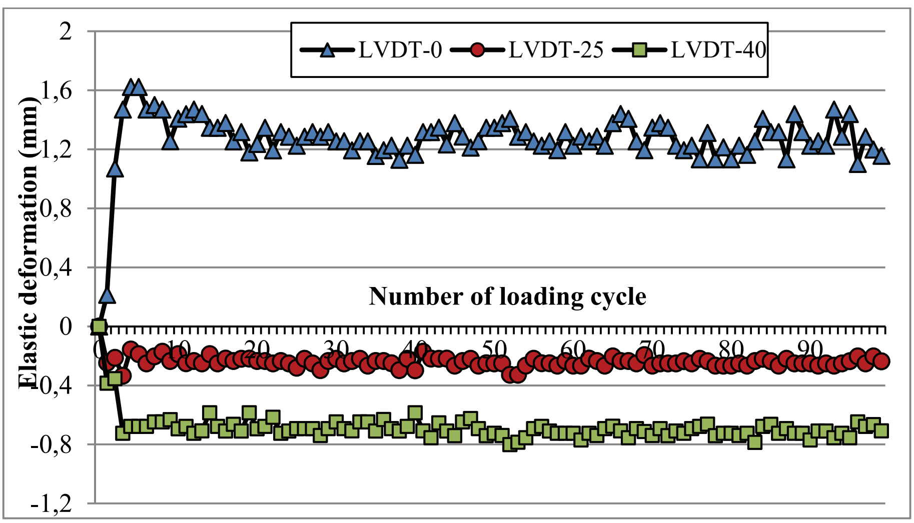

Figure 5 - The elastic deformations of 100% NA mixture versus the number of loading cycles

The surface deformations exhibited a vertical elastic deformation of about 1.4 mm at the center of the plate as a result of 100 loading cycles and the form of settlement. The amount of deformation was approximately 0.2 and 0.7 mm, respectively, compared to the data obtained from the LVDTs at 250 and 400 mm away from the plate center, and the form of swelling. It was shown that the surface elastic deformation was higher at the center and decreased with the distance from the center.

It is shown that the surface elastic deformation (i.e., the rebound during the unloading of each cycle) was higher at the center and decreased at the distances of 250, and 400 mm away from the center. The elastic deformation as shown in Figure 5 increased up to 5 cycles of loading and then decreased slightly to a small rate then stabilized until the end of the test.

The graphics of the elastic deformation of the base layer containing 20% RAP+80% NA mixture are shown in Figure 6.

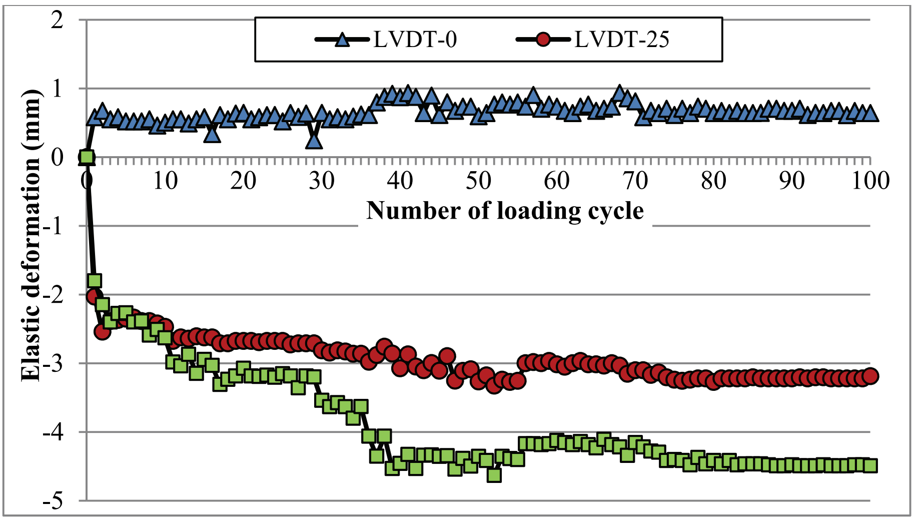

Figure 6 - The elastic deformations of 20% RAP-80% NA mixture versus the number of loading cycles

Figure 6 showed an elastic deformation of about 0.8 mm in the form of settlement under the center of the plate as a result of 100 loading cycles. The amount of elastic deformation was approximately 3.2 and 4.5 mm, respectively, obtained from the LVDTs at 250 and 400 mm away from the plate center. Elastic behavior increased as the distance from the plate increased.

The elastic deformation value obtained under the plate for 20% RAP-80% NA mixture was found to be 2 times lower than the elastic deformation value (1.4 mm) of the base layer conventionally made with 100% NA. This comparison demonstrates that the RAP bases had less elastic responses under loading plate than the NA bases due to the asphalt cement content of the RAP aggregates. However, the elastic deformation at 25 and 40 mm distance from the center of the loading plate was higher than the values obtained from the 100% NA base section (3.2 and 4.5 mm, respectively). The elastic deformation value obtained from the LVDT-25 was 16 times that of the base layer of 100% NA, while the value at the LVDT-40 was about 6.5 times that of the base of 100% NA. This indicates that the asphalt-containing RAP material trapped under the loading plate with cyclic loading adheres to each other as the number of cycles increase, but the swelling at 250 mm and 400 mm distant points, which are not cramped, are more frequent. That is, the elastic deformation resistance formed at the center of the plate of 100% NA was higher than the 20% RAP blended base section, and this resistance decreases as the distance from the plate center increases. In this context, Highter et al. [14] suggested that the assumption that larger elastic deformation values will be obtained in the case of increased RAP percentage in RAP-NA mixtures is valid for the material out of the plate.

Figure 7 showed the elastic deformations of the base layer made with 60% RAP-40% NA-3% cement mixture.

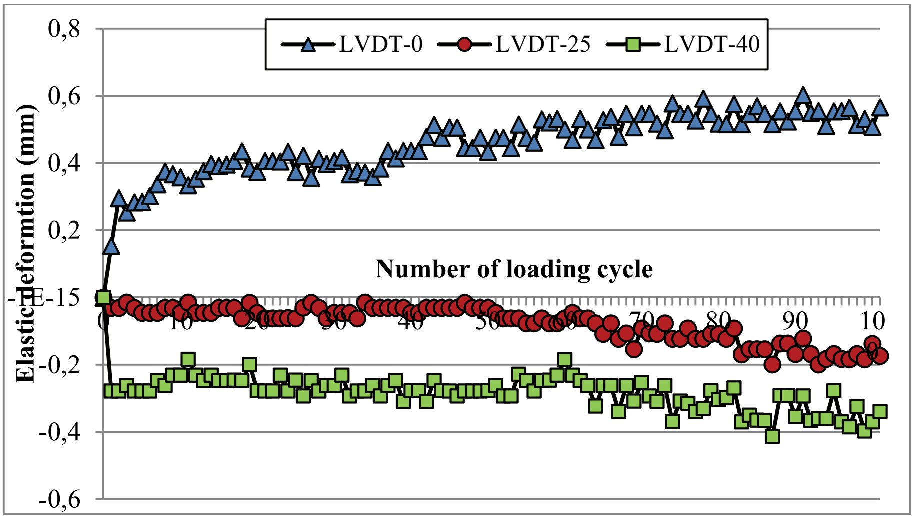

Figure 7 - The elastic deformations of 60% RAP-40% NA-3% cement mixture versus the number of loading cycles

As a result of the 100 loading cycles, an elastic deformation of approximately 0.55 mm in the form of settlement under the center of the plate is observed. According to LVDT-25 and LVDT-40, the amount of elastic deformation was approximately 0.2 mm and 0.3 mm, respectively, and deformation in the form of swelling was also observed. The elastic deformation value obtained under the plate in the 60% RAP-40% NA-3% cement mixture was observed to be 60% less than the elastic deformation value of the base layer made entirely with 100% NA (1.4 mm). The elastic deformation value taken with the LVDT-25 is the same as the value obtained from the section at 100% NA and is determined as 0.2 mm. The measurement taken with the LVDT-40 showed that the elastic deformation is about 0.3 mm, which is about half of the 0.7 mm deformation obtained from the 100% NA base section.

Despite the increased RAP percentage in the mixture, the 60% RAP-40% NA-3% cement mixed base layer showed the same elastic behavior as the 20% RAP-80% NA mixture. The reason why elastic deformation values are close to each other despite the increase of the RAP percentage used is the treatment with cement. Despite a 40% increase in RAP percentage, 3% cement treatment caused the base layer to exhibit similar elastic behavior under cyclic loading.

The graphics of the elastic deformations of the base layer at different locations, made with 100% RAP-3% cement mixture are shown in Figure 8.

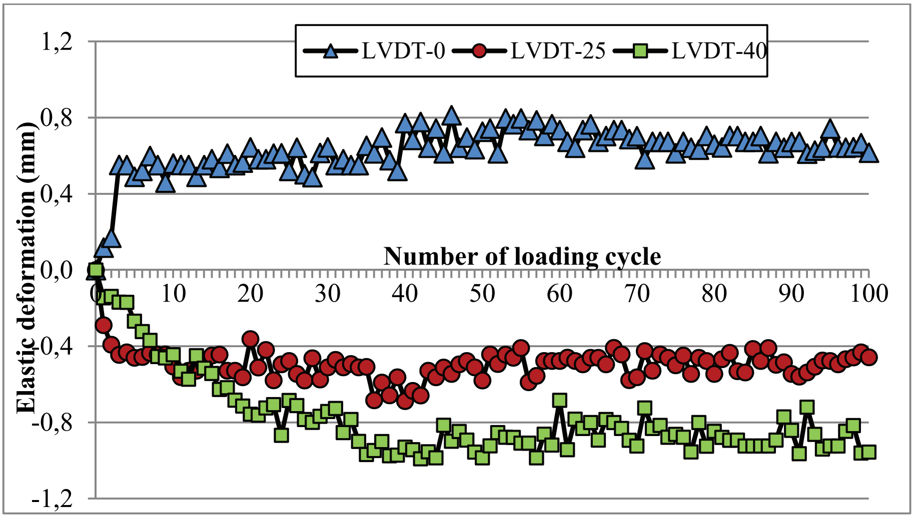

Figure 8 - The elastic deformations of 100% RAP-3% cement mixture versus the number of loading cycles

As a result of the loading cycle of 100, an elastic deformation of about 0.6 mm was observed in the form of settlement with the LVDT-0 for 100% RAP-3% cement mixture. The amount of elastic deformation was about 0.5 mm and 0.9 mm respectively according to the data obtained from LVDT-25 and LVDT-40. It was observed that the elastic deformation value obtained under the plate in the 100% RAP-3% cement mixture was 55% less than the base layer (1.4 mm) made entirely with 100% NA. The elastic deformation value obtained with the LVDT-25 was determined to be 2.5 times greater than the value obtained from the section at 100% NA. The measurement taken with the LVDT-40 showed that the elastic deformation is 0.9 mm, which is 20% greater than the 0.7 mm deformation obtained from the 100% NA base layer. At the end of the 10th cycle, the amount of elastic deformation under the plate center was about 0.6 mm. Thakur [13] obtained elastic deformation values of approximately 2.5 mm under the center of the plate at the end of the 100th cycle as a result of cyclic plate loading test in a base layer of 150 mm thickness prepared with 100% RAP material.

4.2. Permanent Strains

A possible reaction force on the wall of the tank may develop between the material and the steel frame during the loading cycles. For this reason, SG-2 was placed in a horizontal position at a point 400 mm away from the center, near the tank edge. In addition, SG-1 device was placed at a distance of 250 mm from the loading plate center to monitor the changes in distance of the strains. The changes in the loading cycle taking measurements with SG-1 and SG-2 placed 250 and 400 mm away from the center of the plate were investigated for each base layer mixtures. The permanent strains of the base layer due to distance which is prepared with 100% NA are shown in Figure 9.

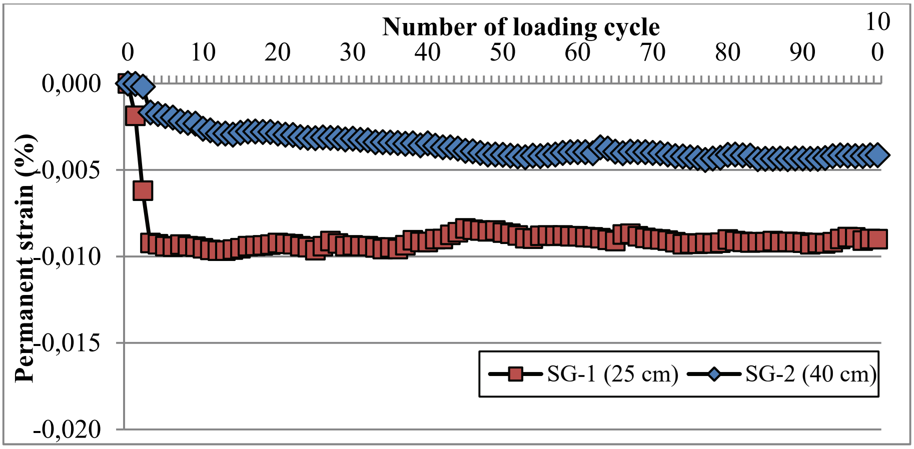

Figure 9 - The measured permanent strain rates of 100% NA mixture versus the number of loading cycles

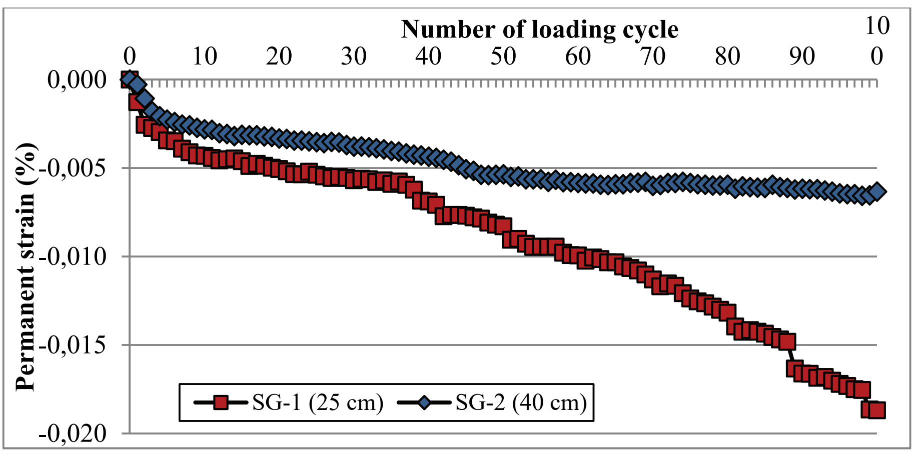

Figure 10 - The measured permanent strain rates of 20% RAP-80% NA mixture versus the number of loading cycles

At the distances of of 250 and 400 mm away from the loading plate center the strains were under tension from the beginning to the end of the test. In the initial loading cycles, a sudden increase in the strains was observed and remained almost the same after 5 loading cycles. A permanent strain rate of about 0.004% was observed in SG-2 (400 mm away from the center of the plate), while a change of about 0.009% in SG-1 (250 mm away) was observed. That is, as one moves away from the center of the plate, the strains decrease. The permanent strain changes of base layer made with 20% RAP-80% NA mixture during the loading cycles of SG-1 and SG-2 are shown in the graphic in Figure 10.

In the initial loading cycles, it is seen that a sudden increase is observed at SG-2, 400 mm away from the center of the plate, and at the SG-1, 250 mm away. At the end of the 100 loading cycles, strain rate of about 0.006% was observed at SG-2, while the strain rate of about 0.018% at SG-1 occurred. The strain changes taken from the SG-1 and SG-2 during the loading cycles of the base layer made with 60% RAP-40% NA-3% cement mixture are shown in Figure 11.

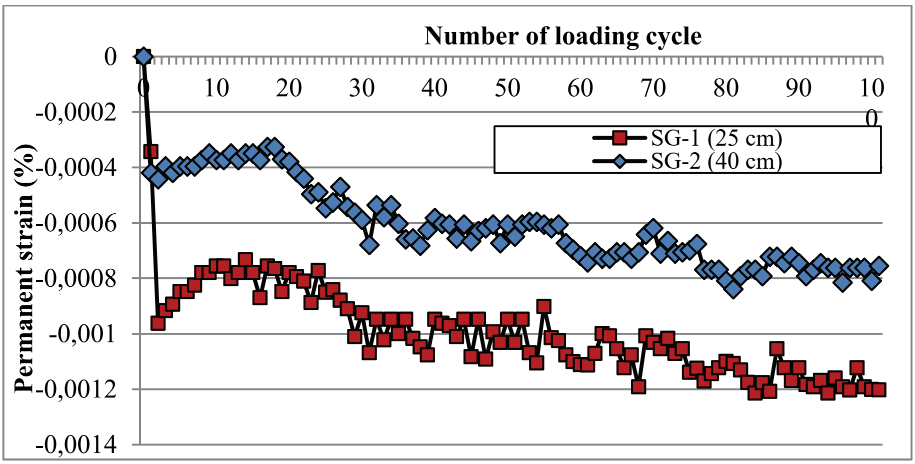

Figure 11 - The measured permanent strain rates of 60% RAP-40% NA-3% cement mixture versus the number of loading cycles

It was determined that initial strains in SG-1 and SG-2 change rapidly, decreased by about 75th cycle, and remained almost constant in the subsequent cycles. The strain rate of about 0.0012% was observed at SG-1, while a change of about 0.0008% at SG-2 occurred. Compared with the base layer made with 100% NA, the strain rates showed a decrease. At the end of the 100 loading cycles, the amount of strain in SG-1 was about 85% lower than that of 100% NA. The strain rate of 100% NA base was 0.009%, while that of 60% RAP-40% NA-3% cement base was 0.0012%. Furthermore, the strain rate obtained at SG-2 for 100% NA base was 0.004% while it decreased by 80% to 0.0008%.

The strain changes caused by the loading cycles, taken from the base layer made with 100% RAP-3% cement mixture and taken with SG-1 and SG-2 devices respectively placed 250 and 400 mm away from the center of the loading plate, are shown in the graph in Figure 12.

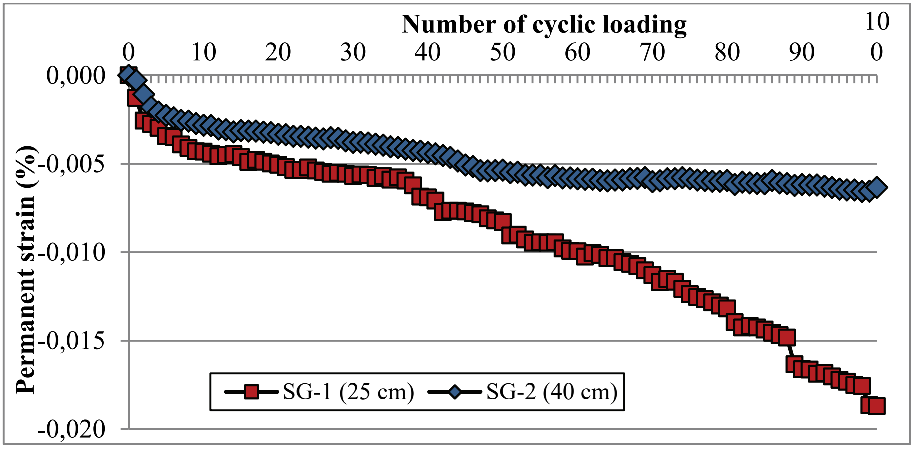

Figure 12 - The measure permanent strain rates of 100% RAP-3% cement mixture versus the number of loading cycles

The largest strains were obtained from 100% RAP-3% cement base layer. At the end of the 100 loading cycles, strains of about 0.018% at SG-1 and about 0.006% at SG-2 for 100% RAP-3% cement mixture were formed. It was observed that the strains obtained from SG-1 continued steadily after about 50 cycles, but in SG-1 increased linearly.

At the end of the 100th cycle, the strains in SG-1 were doubled to 0.018% compared to that of 100% NA mixture. In addition, the strains for 100% NA according to the measurement in SG-2 were 0.004%, it showed a nearly double increase to 0.007% for 100% RAP-3% cement mix. The strain rates obtained from SG-1 and SG-2 for 100% RAP-3% cement mixture were the same as the mixture for 20% RAP-80% NA. Although increasing the RAP percentage in the mixture increases the strains, the strains obtained in the case of increasing the RAP percentage from 20% to 100% are the same in SG-1 and SG-2. It is considered that the reason for the decrease in strain rates is that the cement contained in the 100% RAP-3% cement mixture reduces deformation.

5. CONCLUSIONS

Based on the cyclic plate loading test (CPLT) results presented for the RAP bases, the following conclusions are made:

- As the RAP percentage in the mixtures increases, elastic deformations are increased out of the loading plate but decreased under the plate. The largest elastic deformations for untreated mixtures were obtained at 100% NA mixture under the plate and at 20%RAP-80%NA mixture out of the plate. This is due to the fact that the aged bitumen surrounding the RAP aggregates which adhered the aggregates together due to the compression under the repeated loads.
- Cement treatment reduced the elastic deformations at significant rates. The smallest elastic deformation and strain changes were obtained at 60% RAP-40% NA-3% cement

mixture for all distance. This comparison demonstrates that the cement-treated bases had less elastic responses than the untreated bases due to the binding feature of the cement. The RAP materials with cement treatment can be substituted for unbound aggregate base layers on pavement projects as a reconstruction strategy.

- Unlike cement, the strain rates increased as the RAP percentage in the mixtures increased. The largest strains obtained at 20% RAP-80% NA and 100% RAP-3% cement mixtures. As you moved away from the center of the loading plate, the strains decreased.
- The two most important factors determining road performance were permanent deformation and rutting. But due to poor base, subbase or subgrade conditions, it is difficult to construct roads of good quality. Hence it is important that the design of these layers is well made. Since the deformation of the base layer under traffic loads could adversely affect the coating layer, base layer materials with the least deformations are preferred. However 100% RAP material was too weak and soft as a base layer material therefore, it was blended with natural aggregate and treated with pozzolanic cement to increase the strength and stiffness in this study. Excessive deformations caused by the use of high RAP content significantly reduced with pozzolanic cement treatment. For this reason, the recommended mixture for use in the base layer was 60% RAP-40% NA-3% cement mixture that leads to the lowest deformation and strain rate values.
- This study showed how the RAP material affected the performance of base layers and showed that it was a viable alternative to natural aggregate when treated with pozzolanic cement. The obtained elastic deformation values could be used as reasonable default design input values for pavement designers when the RAP material used as a substitute for natural aggregate base or subbase layer material.

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