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Utilization of Reclaimed Asphalt As An Effective Unbound Aggregate Base Course (Wet Mix Macadam) Material, A Case In India

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ABSTRACT

The study was focused on determining the materials property of recycled granular materials containing different percentages of recycled asphalt pavement (RAP) to use as an unbound aggregate base course (WMM) material. Laboratory tests and field implementation were carried out to determine the physical and mechanical properties of virgin aggregates and various aggregate-RAP blends at different percentages. The results were used to evaluate the strength of granular layer for pavement construction through proper compaction and control of RAP usage. The tests were also conducted to check the standards and requirements specified by the Ministry of Road Transport and Highways (MORT&H) using the procedures of the Indian Standard (IS).The sieve analysis test results showed that gradation of material RAP 1 and RAP 2 are better than the virgin aggregate gradation currently used. The sieve analysis of RAP 1 and RAP 2 are more similar, so the average of both taken as RAP. The Proctor tests have been conducted with RAP and VA with individually and different percentage. The laboratory MDD is being decreased as the RAP percentage increases. The laboratory CBR results showed that the blends with high content of virgin aggregate achieved high bearing capacities. The Low CBR values were achieved by neat RAP materials of 100% RAP and it's more than 100%. The blends containing 100% VA resulted in higher CBR values. RAP materials implemented in field as an unbound aggregate base course material (WMM) for trial found satisfied and achieved the field compaction criteria. Beyond determining materials property, the study review and asses current material production and road maintenance activity to consider major economic and environmental benefits emanated from using the recycled materials instead of virgin aggregate productions. In this regard, the economic benefits by using RAPs resulted in 50% saving of virgin aggregate production costs annually. In addition to economic benefits, re-use of RAPs may reduce road construction wastes generated from road maintenance.

1. Introduction

In the transportation industry, the reutilization of asphalt pavement has become very common. The term Recycled Asphalt Pavement or RAP, may be defined as removed and/or reprocessed pavement materials containing asphalt and aggregates. During the repair and rehabilitation of existing asphalt pavements, RAP is generated. RAP consists of good quality, well-gradedasphalt cementcoated aggregates. Utilization of RAP in new roadway construction not only prudent use of natural resources but also resolve the dumping of C & D waste. Further, energy consumption also reduced through the use of RAP in roadway construction by reducing the processing and haulage of virgin aggregate materials.

In most engineering applications, RAP has performed satisfactorily when it is blended with conventional aggregates as granular base/sub base. Some of the benefits of RAP aggregates that have been properly incorporated into granular base applications include: adequate bearing capacity, acceptable resilient modulus, good drainage and durability (Cong Luo, 2014). Environmental and economic efficiency use of RAP as aggregate base course (WMM) material by blending with virgin aggregates will result in a material with high bearing capacity and strength. This study was designed for experimental investigation of utilizing RAP as an unbound aggregate base (WMM) course material by blending with a virgin aggregate material to evaluate environmental, economic, social and engineering benefits in road constructions. The experimental approaches for engineering aspect determinations such as: Gradation analysis, Proctor compaction tests, California Bearing Ratio (CBR) test and field implementations were conducted in laboratory and fields, yet they were not quite enough for detail investigations.

2. Literature Review

Thecost of spiraling of asphalt pavement manufacturing, have increased demand for recycling. Use of RAP, which is generated during rehabilitation or reconstruction of the existing asphalt concrete layers, is a sustainable approach for waste utilization. The reason behind recycling and reusingthe construction waste is, preservation of non-renewable natural resources.As per the Wisconsin Department of Transportation (WSDOT), up to 20 percent RAP can be blended with conventional crushed aggregates as base course materials.Collins (1994) noted that applications for RAP,can be done in unbound base and sub base. Mokwa and Peebles (2005), proved that the blending of RAP with conventional aggregate, causes little changes in the properties of the base course material.Cong Luo, (2014) discussed that maximum 60 percentage of RAP can be used as base course material. Thogersen et al, 2013 described about the use of RAP in the European practice. Saeed, (2007) and Edward et al, (2015), described that, in USA, many state DOTs actively promote the use of recycled materials.The use of RAP in unbound base layers or HMA layerscan be used up to 30% by weight (Road and Transportation ResearchAssociation, 2012). According to the Idaho Transportation Department (2012), RAP can be mixed up to 50% for sub base applications. According to Iowa DOT (2014), Up to 50% RAP is allowed in the granular sub base. New York State DOT (2008) Standard Specifications allows “Alternate C” sub base construction using at least 95% reclaimed bituminous material with a maximum top size of 2 in. In the Netherlands, where landfill is banned for construction and demolition waste, approximately 100% of RAP is used road construction. In United Kingdom, Series 800 of Specification for Highway Works (Department for Transport, 2014), 50% RAP by weight is permitted in unbound sub base mixtures where as 100% RAP is permitted in unbound aggregate mixture. According to the Florida DOT (FDOT) specifications,use of 100% RAP is allowed only for non-traffic base applications, like at bike paths and paved shoulders.But not allowed for road way due to its lower bearing capacity as well as higher long term deformations in creep.

3. Need Of Study

The general objective of this research is to evaluate the effectiveness of utilizing RAP as an unbound aggregate base course (WMM) material to ensure better performance in strength resulting in economic environmental benefits. A specific objective of this study is to:

- Carry out laboratory tests on selected RAP and virgin aggregates, VA to explore the way of producing better aggregate base course (WMM) material;
- Determine the cost-effectiveness of utilizing RAP than producing and using virgin aggregate;

- Recommend viable suggestions on RAP usage as aggregate base course (WMM) material to benefit the Country in general.

4. Methodology And Experimental Studies

For the purpose of this case study we have considered a various factorial survey. They are:

4.1. Materials and Sampling:

Having survey on the above junctions it was found that in most of the cases the Zebra crossing were not adequately visible. Many vehicles approached mid-block crossing at high speeds. Access to Zebra crossing from footpath was blocked by parked vehicles. In most of the cases, signal systems are not spontaneous and active, so pedestrians get confused. Pedestrians are found of not using the Zebra crossing even if they are available at various junctions. The images given below define the existing scenario more clearly.

4.1.1. Sampling of Materials:

RAP 1: This sample was particularly taken from milling point at Km. 119+000, (Nalanga Bhadrak, RHS), NH 200 (New NH-53), Odisha and being executed by Dilip Buildcon Limited (DBL). Figure 4.1 down shows the milling of Asphalt surfaces. The test materials assigned as the RAP 1 at Km. 410+100, RHS (Duburi - Chandikhole, NH 200 (New NH 53), based on rehabilitation and up-gradation, km. 388.376 to Km.488+074 in the state of Odisha under NHDP-III, on EPC mode, Package-III).

Figure 4.1: *@ km. 119+000, Milling Area*

RAP 2: This was taken from the Stockpile of RAP material processed by milling operation (seeFigure 4.2 below). The sample represents various gradations and physical conditions since it was taken during dumping of trucks in stockpile area. The milled materials were produced in the Km. 117+480 to 117+830 (RHS) (Nalanga-Bhadrak, RHS), NH 200 (New NH-53), Odisha and being executed by Dilip Buildcon Limited (DBL).

Figure 4.2: *Stock Pile @ 62+000, LHS (Dankari Quarry)*

Virgin/Pure Aggregate: Crushed basaltic aggregate for unbound base course layer is being used for the running project from owned DBL crusher plant. It is currently faced with a quality quarry raw materials of basaltic rocks. The virgin aggregate sample for this test was taken from this plant stocks because of the above reasons. Figure 4.3 below shows a sample taken that represents virgin aggregate material for aggregate base course (WMM).

Figure 4.3: *Samples representing virgin aggregates, VA*

4.2. Experimental Program:

'If it can be shown that an unbound material containing RAP meets the specifications for grading, density and CBR which are normally applied to fresh materials, then it should be acceptable to use the RAP as aggregate road base (WMM). In this study to investigate the behavior of granular materials containing RAP, the tests were divided into two categories: physical property tests and mechanical behavior tests. The physical property tests were performed to determine the basic material properties (including

gradation, optimum water content and maximum dry density) through sieve analysis and Proctor compaction tests. The CBR test was carried out to evaluate the strength/stiffness characteristics of the materials.To obtain an improved understanding for proper use of RAP in granular base/subbase layer and the behavior of aggregate-RAP blends under various conditions, the following tasks were performed and the test matrix and the corresponding testing designations are summarized and shown in Table 4.1 and Table 4.2 below respectively. Fresh aggregate could, if necessary, be blended with the RAP to modify the particle size distribution.
Preparation of aggregate-RAP blends with 0%, 25%, 50%, 75% and 100% RAP content are stated below:

1) 0% RAP with 100% virgin aggregate (used as a control mix);
2) 25% RAP blended with 75% virgin aggregate;
3) 50% RAP blended with 50% virgin aggregate;
4) 75% RAP blended with 25% VA; and
5) 100% RAP material.

For the study, the strength related tests like gradation test by sieve analysis, density, optimum moisture content, proctor compactionand CBR test were conducted. Field implementation/construction of aggregate-RAP blend was also done as an aggregate base course (WMM) layer for early analysis of rutting, bleeding and compaction characteristics.

Material / Test	Physical Property Test		Mechanical Behavior	
	Sieve Analysis	Proctor Test	CBR	Field Implementation
VA (100%)	Yes	Yes	Yes	Yes
RAP (100%)	Yes	Yes	Yes	Yes
VA (75%) + RAP (25%)	Yes	Yes	Yes	No
VA (50%) + RAP (50%)	Yes	Yes	Yes	Yes
VA (25%) + RAP (75%)	Yes	Yes	Yes	No

Table 4.1: *Summary of test matrix carried out in this stud*

Laboratory test	Test method
Sieve analysis of fine and coarse aggregates	IS 2386:P-1
Moisture-density relations of soils using Heavy Compaction proctor having 4.9 kg Rammer and a 450-mm height	IS 2720:P-8
Standard method of test for the California Bearing Ratio (CBR)	IS 2720:P-16 / AASHTO T193
Determination of Dry Density of Soils by Sand Replacement Method	IS 2720:P-28

Table 4.2: *Summary of test matrix carried out in this study*

Figure 4.4: *Sample procedures and tools in CBR test of this study*

4.3. Field Implementation And Construction:

To compare the field density test (FDT) of the base course material and laboratory compaction results and to examine some unexpected behavior of RAP materials used as granular base course during and after construction, field implementation was done. This implementation was proposed to reduce limitations in necessary laboratory tests like modulus of resilient and other deformation tests besides common tests of aggregate granular (WMM) materials. Even though no scientific measures and standards were used finally, because of factors explained under the Scope and Limitation part of Chapter One, this study was conducted to show the performance of aggregate base course (WMM) layer constructed for trial using RAP and blends on a trail patch, connective approach to base camp laboratory of the running project, Duburi - Chandikhole, NH 200 (New NH 53) at Km. 410+100, LHS. In these implementation activity materials of 100% RAP, 100% VA, 50% RAP + 50% of VAblends were used.

Figure 4.5: *Distress Road section location before laying.*

5. Results And Disscussions

5.1. Gradation Test Results:

Strength is highly dependable on gradation of materials that needs compaction to fill out voids. So,the strength increases with the use of well-graded coarse-grained aggregates. In some cases, as the increase in strength is very crucial and materials with highest values of technical specifications must be used. The study conducted the test based on the standards and specifications described under methodology and experiments. The samples were taken from three different locations. The samples were separated in the laboratory using mechanical sample splitter and the sieves were arranged according to MORT&H Standard (IS) from the lowest pan and increased to the highest as follows: 0.075mm, 0.600mm, 2.36mm, 4.75mm, 11.20mm, 22.40mm, 45.00mm and 53.00mm.

Sieve (mm)	RAP 1	RAP 2	RAP (Average)	VA	RAP (25%) + VA (75%)	RAP (50%) + VA (50%)	RAP (75%) + VA (25%)	**Limit Table 400-10, (MORT&H)**
53.0	100	100	100	100	100	100	100	**100**
45.0	99.8	99.1	99.45	98.3	98.68	99.05	99.43	**95-100**

22.4	73.6	70.2	71.9	69.7	70.68	71.65	72.63	**60-80**
11.2	49.1	47.7	48.4	48.9	48.95	49.00	49.05	**40-60**
4.75	32.5	30.3	31.4	36.6	35.58	34.55	33.53	**25-40**
2.36	17.6	19.2	18.4	25.5	23.03	20.55	18.08	**15-30**
0.600	10.8	10.6	10.7	13.6	12.15	10.7	9.25	**8-22**
0.075	2.9	2.1	2.5	5.9	5.15	4.4	3.65	**0-5**

Table 5.1: *Gradation Summery of Materials RAP 1, RAP 2, RAP (avg), VA and blends.*

As we see from Table 4-1, the materials gradation looks well graded with similar distribution with each other. But, after 0.600mm sieve, the amount of materials got lower but within the specification requirement. Though the sieve analysis of RAP 1and RAP 2, have not more difference, the average of the material has been taken as RAP for the study. The gradation of each blends in different percentage were show no significant change on particles distribution. This is because of the similarity in particles size distribution of the materials RAP and VA. The results are illustrated in Figures 5.1 below in logarithmic gradation curves. Figure 5.1 shows gradation of RAP, VA materials and blends in different percentage used as a control test on logarithmic curves.

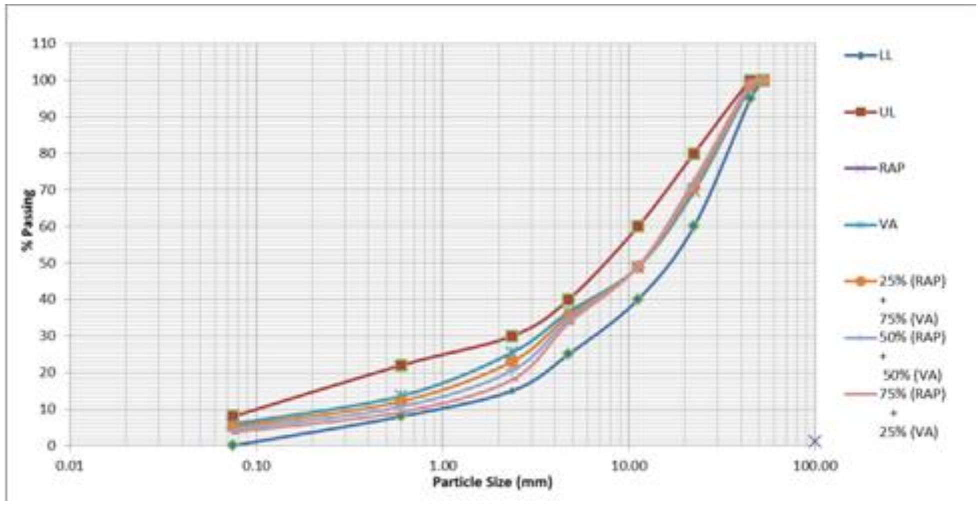

Figure. 5.1: *(Particle Size Gradation, RAP, VA and their blends)*

To clearly layout and compare the particle size distribution of those materials, their results were plotted on a common logarithmic chart as shown in Figure 4-2 below. However, except the increments in fine particles of RAP after sieve size of 2.36mm, the particle gradation of all the three materials of RAP and VA were almost similar and well graded.

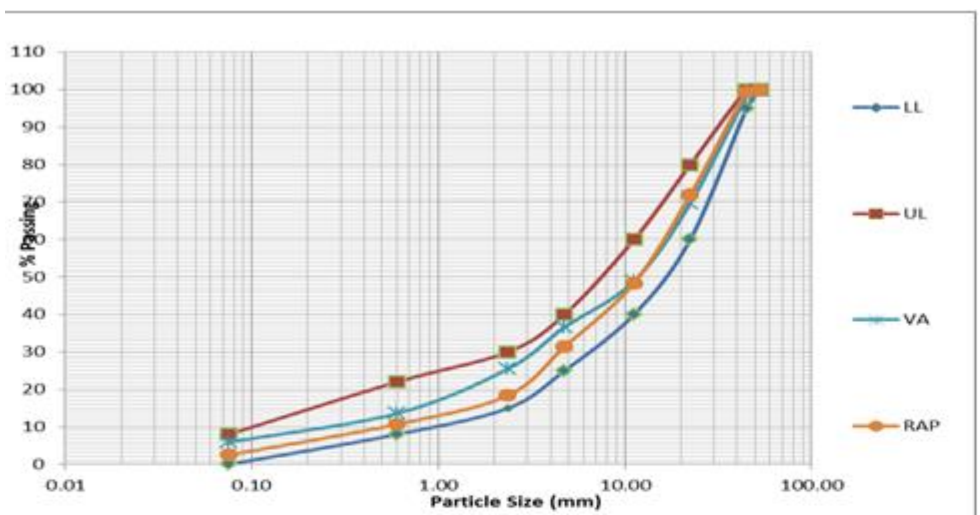

Figure. 5.2: *(Particle Size Gradation, RAP and VA)*

IS Sieve Designation (mm)	Percent by weight passing the IS Sieve
53.00	100
45.00	95—100
26.50	
22.40	60—80
11.20	40—60
4.75	25—40
2.36	15—30
0.600	8—22
0.075	0-5

Tables 5.2: *Gradation Requirements for Aggregate Base Course (WMM) material*

Table 5.2, above shows the MORT&H specification of aggregate base course (WMM) having maximum size 53.0mm and nominal size 45.0mm. Figure 5.2 above shows that the logarithmic gradation curve of tested materials and MORT&H requirement ranges, that the materials percentage passing should be placed between the upper and lower limit. The chart shows that, after sieve size of 2.36 mm the materials percentage passing is reduced with the RAP and blending in comparison to VA. This shows that there is a particle size distribution gap of finegrained materials, this have an effect on compaction and expected laboratory and field density of the materials.From those results, we can say that gradation of material RAP is better or same as to the virgin aggregate gradation. Likewise, the presence of those RAP materials in road construction as an aggregate base course (WMM) layer will be important in improving materials performance with respect to gradation and compaction by blending with virgin materials in addition to getting an alternative material.

5.2. Proctor Test Results:

The Proctor tests for maximum dry density are used to determine the optimum moisture content and maximum compacted dry density for each material. The heavy compaction Proctor test was included in this test in order to further characterize the test mixes and their responses to greater compacted effort using 4.9 kg rammer and 450mm drop height. Tests and samples from RAP material was mixed with virgin aggregate in different percentages as shown in Table 5.3 below in respect of 100%, 75% 50%, 25% used to determine the optimum water contents and maximum dry densities. Since the gradation of RAP is the same the study considered their densities mainly affected and varied by compaction. The Proctor test results for each test mix are summarized in Table 5.3 below.The laboratory test results reflect the general expectation that greater compaction efforts seen in the modified Proctor test yield lower optimum moisture contents. It can also be noted from Table 4-3 that laboratory optimum moisture content and dry density results vary significantly between RAP and VA, this is to be anticipated as the physical characteristics of the materials, the individual test blend gradations, the RAP processing mechanism and existed/recycled asphalt layer condition.

Test	VA (100%)	VA (75%) + RAP (25%)	VA (50%) + RAP (50%)	VA (25%) + RAP (75%)	RAP (100%)
MDD	2.243	2.210	2.186	2.150	2.10
OMC	6.95	6.8	6.7	6.5	6.16

Table 5.3: *Moisture-Density Relationship*

The Proctor compaction result showed that the dry density of VA material is greater than RAP and RAP blend materials. However, the optimum moisture content at which all materials achieve the dry density is nearly the same. This shows that moisture requirement of RAP material to use as a base course would be similar with little variable effect. Figure 5.3 shows that Dry density of materials increased with slight decrement in optimum moisture content. A material of RAP mixes with high content of virgin aggregates, VA such as blend of 75% VA and 50% VA developed high densities relative to other mixes. Figures 5.3 illustrate the moisture-density relationships developed using heavy compaction proctor test.

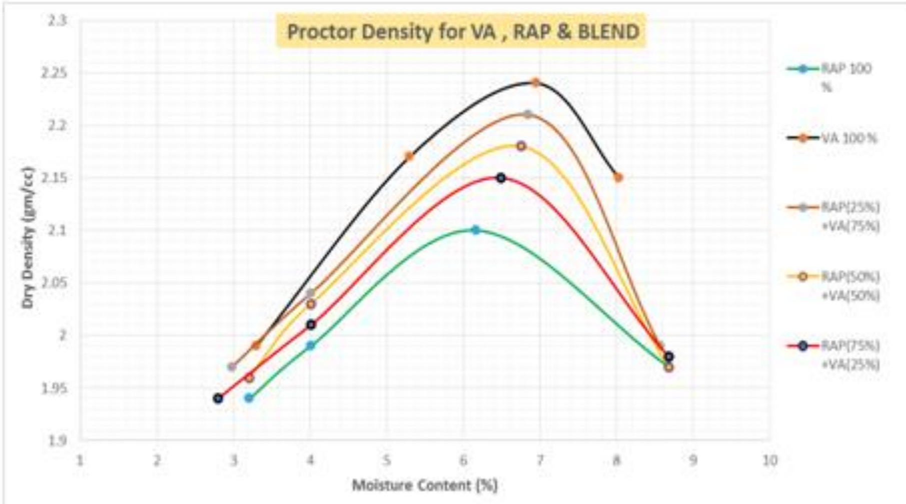

Figure 5.3: *Moisture-Density Relationship*

5.3. California Bearing Ratio Test Results:

Three different specimens were prepared for each material blends and compacted in five layers with 10, 30 and 65 blows to each layer. The test machine used the load with penetration rate of 1.25 mm/min. The load readings at penetrations of 0.50, 1.00, 1.50, 2.00, 2.5, 4.00, 5.00, 7.5, 10.0 and 12.5 mm were recorded and the results of stress versus penetration depth were plotted to determine the CBR for each materials blend on variable dry density and compaction conditions. Table 5.4 below shows the results of experiments conducted to determine the CBR of each materials blend.

Sample Designation	Compaction Test		MDD @ 98%	CBR Test			CBR @ 98% MDD
	MDD	OMC		Blows	DD (gm/cc)	CBR (%)	
VA (100%)	2.243	6.95	2.198	10	1.909	102.2	123
				30	2.267	126.5	
				65	2.501	146.0	
VA (25%) + RAP (75%)	2.150	6.50	2.107	10	1.662	68.1	108
				30	2.007	102.2	
				65	2.216	111.9	

VA (50%) + RAP (50%)	2.180	6.75	2.136	10	1.75	77.9	112
				30	2.08	107.1	
				65	2.228	121.7	
VA (75%) + RAP (25%)	2.210	6.8	2.166	10	1.890	82.7	116
				30	2.170	116.8	
				65	2.320	131.4	
RAP (100%)	2.100	6.16	2.058	10	1.60	63.3	105
				30	1.94	97.3	
				65	2.18	111.9	

Table 5.4 *Results of CBR test for VA and RAP blends*

The data summarized in Table 5.4 shows Dry density results of materials of each blend increasing as compaction application increases. The result show that CBR values of RAP were ranging from 105% to about 118%. From compaction laboratory test result, it can be observed that there is a big difference between 100% RAP material and more specifically, the maximum dry-densities of compacted RAP was observed at 2.100 g/cm3 with that of VA at 2.243 g/cm3. Depending on the dry densities and CBR values, the DD-CBR relation graph was plotted and the governing CBR value was determined at 98% of MDD curve.

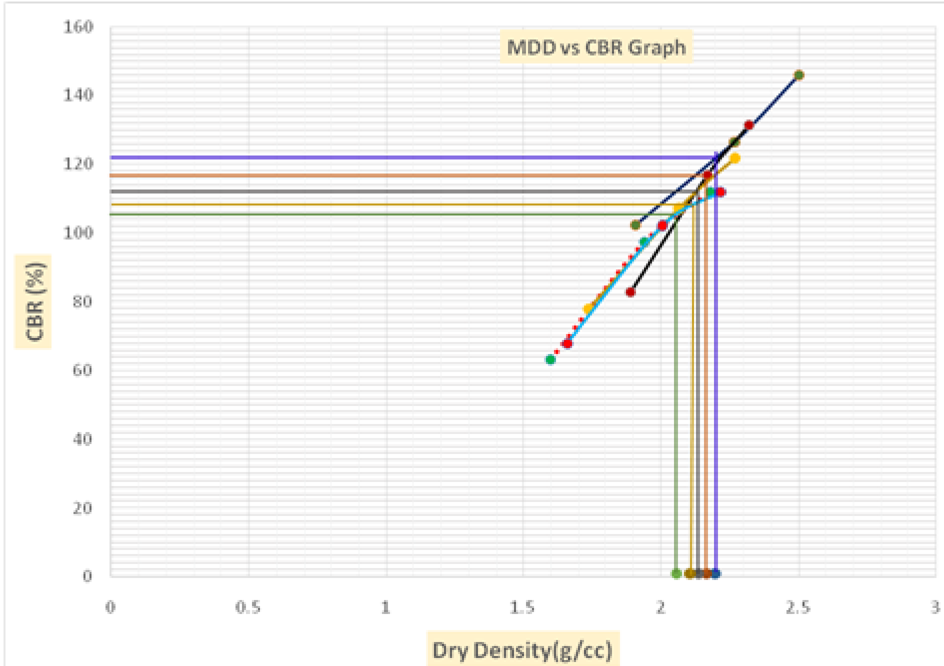

Figure 5.4: *CBR at 98% MDD from CBR-Dry density graph*

A sample density-CBR relation graph of three materials is shown in Figure 5.4 above. This relation was derived from the results of densities determined at 10, 30 and 65 blow compactions CBR values. For each compacted specimen, CBR values at load penetration of 2.50 and 5.00 were determined. And the dry densities were estimated at each specimen before soaking. Those results were used to construct a relationship graph CBR versus dry densities. As shown above from three materials, the curve for 100% RAP shows a lower value of CBR density relation. Unlikely, the materials with the higher contents of VA exhibited great CBR values relatively. Even though, the dry densities in each compaction samples are important in estimation of CBR value, 98% of maximum dry density which was taken from proctor test results is major determinants of CBR value of each material from the CBR versus density graph. The CBR values were taken from the chart Recorded data and analysis results of CBR for all material blends are provided Appendix C. As summary of CBR tests in this study, it is known that higher RAP contents show lower CBR value; this is because of RAP particles characteristically tend to attract and hold moisture, which in turn causes RAP particles and fragments to come together to form larger conglomerates. At high RAP concentrations, this can result in segregation and heterogeneity in the mix, leading to problems with constructability and the consequent development of inconsistent strength properties in the compacted granular material.

5.4. Field implementation observation and results:

The trial implementation was done using the materials named as 'RAP' base camp laboratory of the running project, Duburi - Chandikhole, NH 200 (New NH 53) at Km. 410+100, LHS being executed by M/s Gammon India Limited. The milling activity is conducted around Km. 119+000, (Nalanga Bhadrak, RHS), NH 200 (New NH-53), Odisha and being executed by M/s Dilip Buildcon Limited (DBL). The asphalt layer which was milled had combination of binder and wearing courses. The defect or distresses seen on the pavement layer were alligator crack and layers fragmentation. Materials designations in this field implementation of constructing an aggregate base (WMM) course using RAP materials are shown below in Table 5.5 with the area covered; thicknesses used and achieved field compaction percentage with respect to the laboratory density.

Materials	Area covered (m^2)	Thickness used (m)	Compaction (%)	
			Achieved	Requirement
100% RAP	90	0.2	98.7	98
100% VA	163	0.2	99.2	
50% VA+50% RAP	117	0.2	99.0	

Table 5.5: *Material designations for field implementations*

All the materials in the above designations were placed, mixed and distributed using an equipment, Grader [Figure 4-5] and compacted having 80-100 KN by applying variable vibratory effects and repeated passes

Figure 5.5: *RAP Aggregate Base course / WMM Placement*

6. Conclusions And Recommendations

The result from sieve analysis shows that there is a particle size distribution gap of fine grained materials; this has an effect on compaction and expected laboratory and field density of the materials. The presence of RAP materials in road construction as an aggregate base course layer will be important in improving materials performance with respect to gradation and compaction by blending with virgin materials, in addition to getting an alternative base course material. Dry density of materials was increased with slight decrement in optimum moisture content. Materials of RAP mixed with high content of virgin aggregates, VA such as blend of 75% VA and 50% VA developed a high density relatively with other mixes. The change in laboratory proctor density compaction results indicate that the number of compaction drops and the number of compacted layers have an effect in achieving the expected dry density. For all materials, the maximum dry density increased and optimum water content decreased as the compaction effort increased. Thus, it is clear that the change of compaction method can make significant difference in density, and consequently result in different material especially on materials of higher RAP content. The CBR value results were relatively good, achieving above 100% for all of the tests. Furthermore, the blends with high content of virgin aggregate, VA achieved high bearing capacities which were similar and above the control mix. The key observation was that the neat RAP materials are being achieved more than 100%.The trial implementation done by using the materials 100% VA shows some segregations and disturbance in compacted layers. The same thing happens at 50% RAP and 50% VA mix layers in a little extent. But, the base course layer constructed by 100% RAP develops a strong bond between aggregate particles. Based on the results from a complete CBR results the bearing resistance of materials which have a blend equal and lower than 50% of RAP content are sufficient enough to use as an aggregate base course (WMM) material.

hen the asphalt pavements are badly deteriorated, overlay may not be economical and reconstruction can be a feasible solution by removing these pavement surfaces. By processing, these removed surfaces into recycled asphalt pavement material, the amount of using freshly crushed aggregate will have reduced, which implies that the additional cost expended on virgin aggregate are reduced when the optimum amount of RAP is mixed with virgin aggregates. The use of RAP in road base layer is technically viable, save costs and protection of the environment.

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