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Modification of Acceptance Criteria of Sample Testing in Flexible Pavements

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Abstract--- In the present electronic age, the development of the country is going at a very fast speed. The highways play a major role in the economic development of a country which also improves the living standard of the people. With the availability of sophisticated plants and equipment, the pace of construction of highways has increased manifolds. The present system of quality control testing is time consuming and has become a major hurdle in high speed of construction. So to keep the quality control tests & quality assurance with the pace of construction, the age-old procedures of quality control will have to be re-looked. This paper involves a case study which has been carried out to find out the solution of a real life problem faced by an engineer during the construction of a highway. In this paper, we present a methodology using e-quality control system to modify the acceptance criteria of sample testing in flexible pavements. To understand the methodology a field case study is presented here.

Index Terms— Quality, e-control, BC, Density, GPS, Acceptance.

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1 INTRODUCTION

ROAD transport is the most widely prevalent and used system of transportation. The National Highways which are only 1.75% of total length of roads carries 40% of the traffic on the Indian roads. The Total Transportation Cost (TTC) on road constitutes 80% of Vehicle Operation Component (VOC) and remaining 20% of road related costs (construction, maintenance & traffic management). About 55% of oil consumption in transport sector goes to roads with the remaining 39% for railways, 6% for shipping and 0.2% for aviation [1]. The fuel conservation shall also save a huge drain of foreign exchange. There is always a demand for the better condition of roads, sufficiently wide ensuring safe & speedy movements. In this electronic age, with the use of new technologies the quality of roads is improving day by day. With the fast development of the country, the pace of construction of Highways has increased. In the present system the quality control tests are physically conducted at site and are time consuming. The numbers of tests prescribed in the codes are more which are difficult to achieve with the high speed of construction. The road construction industry is in a transition phase where more and more contracting agencies are realizing the cost benefit of sophisticated equipment oriented construction in which timely completion of project and reduction in overheads can be assured. Consequently, the Nation is benefited a lot with the achievement of high quality roads with proper workmanship in a time bound manner and without any cost over-run. With the availability of sophisticated plants and equipment and adoption of equipment intensive technology, the quality and speed of construction has enhanced considerably. Sophisticated plants which are electronically controlled are now available for every stage of construction of a highway. These plants & equipment are very costly and their cost effectiveness depends on its high volume utilization which can be achieved only with high speed of construction. With the high speed of construction, the age-old procedures of Quality Control have become a major bottleneck in time bound completion of a project. The present system of quality control is neither perfect nor matching with the speed of construction of work. With the sophistication in the processing/production of the material as well as superior workmanship in the laying, it is desirable to have a quality control system which is more “Procedure specific” so that the quality of product could be ensured without any hindrance in the progress of the work. . In keeping pace with the high speed of construction, the age old quality control methods needs to be reviewed and substituted with modern methods of quality control and quality assurance [2]. In this electronic age, e-quality control system which can automatically control the quality and quantity of the product at all stages of construction can give the confidence of quality of product.

2. EXISTING QUALITY CONTROL SYSTEM

In this section, we are discussing the existing quality control system which is useful to our main work in next session.

2.1 QUALITY ASSURANCE

Quality assurance is the planned and systematic actions necessary to provide adequate confidence that the work is satisfying all the quality requirements. Thus, the quality control system includes all those planned actions that are necessary to provide adequate confidence that the products or service will meet the requirements and is essentially a system of planning, organizing

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and controlling human skills to assure quality. The quality control involves the acceptance criteria which includes the tests, frequency of testing and tolerance limits, inspections for critical examination of the work by selected tests to determine its conformity to specifications and action taken to ensure quality.

In the existing system, the quality control tests are carried out at the three different levels; Firstly the contractor sets up a field laboratory and is supposed to carry out all the quality control tests to the stipulated frequency as per standards, at the second stage the quality control tests are being conducted by the Independent Engineer or field staff deployed for the execution of the work and at the third stage, the quality control tests are being conducted by the special quality control wing/third party.

2.2 Drawbacks of Existing Quality Control System

The following are the drawbacks of the existing quality control system:

- i) In the existing system the quality control tests are physically conducted in the field to check the quality of the work and are time consuming
- ii) The numbers of tests prescribed in the codes are more which are difficult to achieve.
- iii) The contractor does not engage requisite staff for the quality control tests.
- iv) Due to construction at large scale, quantum of testing required is very large which is difficult to achieve.
- v) The staff engaged on contract does not take interest in the quality control tests.
- vi) Sometimes the tests are not conducted at site & only bogus entries are made in the prescribed registers.
- vii) Many times the contractor simultaneously starts works on different roads relating to different departments such as Public Works Department (Building & Roads), Urban Development Authority & Marketing Board etc. and counts the same tipper load on both/all the sites.
- viii) The staff deployed for the work mixes up with the contractual agency and accepts the sub-standard work.
- ix) There is no fool proof method to check that full quantity of the material has been used at site as per desired standards.
- x) The present system of quality control is neither perfect nor matching with the high speed of construction of work.

2.3 Modern Equipment, High Volume of Production & Laying of material

With the adoption of technology and availability of sophisticated plants and equipment [3], the speed of construction has largely increased and a large volume of material/product is produced in a single day. The capacity of some of the equipment is as given below in Table No.1:

TABLE NO.1

Sr. No.	Type of equipment	Capacity of equipment	Output per day	
			Maximum	Average
1	Cone Crusher	200TPH	1500T	1200T
2	WMM plant	200MT/hr	1500Mt	1200Mt
3	Batch Mix Type Hot mix Plant	160TPH	1200Mt	1000Mt
4	Vibratory Road Roller 8-10T capacity	100cum/Hr	1000Cum	800Cum
5	Grader	100cum/Hr	1000Cum	800Cum
6	Excavator	100cum/Hr	1000Cum	800Cum

This material is laid at site layer by layer in specified thicknesses as per specifications. The average quantity of material produced & laid on the site in a single day is given below in Table No. 2:

TABLE NO.2

Sr. No.	Description	Average quantity of material laid in a day
1.	Earthwork	1000 Cum
2.	Granular Sub-base	600-800 Cum
3.	Wet Mix Macadam	1200 - 1500 MT

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4.	Dense Bituminous Macadam	1000-1200 MT
5.	Bituminous Concrete	1000-1200 MT

Each plant has large capacity of production in a day. Any delay in accepting and clearing the layer holds up the further production. So the system of checking & accepting should run commensurate with the high speed of production whereas the present system of quality control is time consuming and not matching with this speed of construction.

2.4 Requirement of Tests as per Specifications

The requirement of some of the tests as per Ministry of Road Transport & Highways (MoRTH) specifications [4] for the acceptance of material in flexible pavements is as given below in Table No.3:

TABLE NO.3

Sr. No	Type of Construction	Test	Frequency (minimum)
1	WMM	i) Aggregate Impact Value (AIV)	i) One test per 200 m3 of aggregates
		ii) Grading	ii) One test per 100 m3 of aggregates
		iii) Flakiness & Elongation Index (FI & EI)	iii) One test per 200 m3 of aggregates
		iv) Atterberg limits of portion of aggregate passing 425 micron sieve	iv) One test per 100 m3 of aggregates
		v) Density of compacted layer	v) One test per 500 m2 area
		vi) Water Absorption	vi) One test per 200 m3 of aggregates
2	DBM/BC	i) Aggregate Impact Value (AIV)	i) One test per 50 m3 of aggregates
		ii) Mix Grading	ii) One test for each 400tonnes subject to minimum 2 tests per plant per day
		iii) Flakiness & Elongation Index (FI & EI)	i) One test per 200 m3 of aggregates
		iv) Control on temperature of binder, aggregates & mixed material at the time of laying & rolling	i) At regular close intervals
		v) Density of compacted layer	i) One test per 250 m2 area
		vi) Binder control	ii) One test for each 400tonnes subject to minimum 2 tests per plant per day

2.5 Present Day Requirements

With the use of normal machinery for the construction of a highway, one cannot have any control on the various ingredients of material used. This non-control on the preparation of mix on material used in the construction of a highway gives a poor quality of road which further results into more expenditure on maintenance. This also leads to mal-practices of use of less quantities of material especially bitumen being costly one. Until and unless, the various ingredients which are required as per job mix formula or specifications are not well controlled at the initial stage of preparation of mix, the quality of the product cannot be assured. The present system of quality control testing needs to be replaced with e-quality control system which can automatically control the quality & quantity of the work at all the stages of construction & give a level of confidence for assured quality control. So, to keep pace with the high speed of construction, the age old quality control methods needs to be reviewed and substituted with modern methods of quality control and quality assurance.

3. METHODOLOGY

Firstly, we selected a project to carry out the work in field which is being carried out by National Highways Authority of India according to technical specifications laid down in IRC Manual of Specifications & Standards for 4-laning of Highways through Public Private Partnership (IRC:SP:84-2009) [5]. The e-quality control system is used with modern equipment such as batch mix type hot mix plant with electronic sensor which automatically controls proportion of different fractions and bitumen, cone crusher (integrated stone crushing & screening plant), automatic wet mix plant with moisture content controller, paver finisher with electronic sensor, vibratory road roller, nuclear density meter, total station & GPS etc [6]. The machinery used is updated as per requirements of e-quality control system for generation of data required for our study [7]. All the relevant data collected at site at various stages is placed on web site. The required tests have been performed on the materials so as to assess its

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confirmation to specifications. For better understanding of our methodology and to develop a model for acceptance criteria of sample testing in flexible pavements some preliminaries of e-quality control system are presented.

The modern equipment is updated as per requirements of e-quality control system and the live data along with live photographs in real time are placed on the website in respect of the followings:

e-control on receipt of bitumen
Generally the bitumen is received from the oil refineries. To control the pilferage of bitumen, the live photographs of the bitumen tankers taken during its weighing on automatic computerized weighing machine are placed in live time on the website with project ID indicating tanker & indent number, weight of loaded & empty tanker etc.

e-control on mixing of material at plant site
The batch mix type hot mix plant with electronic sensor (which automatically controls the proportion of different fractions of aggregates and bitumen) is used. The proportions of various ingredients required for BC are set upon the computer of batch type hot mix plant. The live data with project ID indicating tipper no., type of material, %age of each size of aggregates, temperature (of aggregates, bitumen & mixed material) and percentage of bitumen etc. is placed on the website.

e-control on weighing machine site
As soon as the tipper is filled with the mixed bituminous material, it is brought to the automatic weighing machine to carry out the weight. A camera & GPS instrument are also installed at the weighting machine site and the live data along with photograph is placed on the website indicating tipper number, type of material, weight of loaded & empty tipper location etc.

e-Control on Vehicles
A Vehicle Tracking System along with various devices such as vehicle diagnostic sensors, fuel sensor & Global Positional System (GPS) etc. is attached with each tipper carrying out the material to check the route of the vehicle at all times, fuel consumption per km., kms traveled by the vehicle in a day, working hours of vehicles/day, halt hours of vehicles/day, idle hours of vehicles/day & speed of vehicles etc. [8]. With this, the monitoring and utilization of vehicles is very effective and efficient.

e-Control on Work Site
On the start of the work with a particular tipper on the site, its photograph during unloading in the hopper of the paver is taken and the live data along with location/Reduced Distance (RD) is placed on website indicating tipper number, weight of material, temperature of material, etc. The same exercise is repeated at the end point where material of this particular tipper finishes. Thus it controls the material used in a particular reach. It also helps in reconciliation of quantity required and actual consumed.

e-control on testing of samples
Every Engineer is given a laptop enabled with GPS and Camera. While conducting the test, the live data is placed on website which includes the GPS location where test is being conducted along with the photograph of the person conducting the test. Thus, the system checks bogus entries of tests.

To understand the above methodology, let us make a valid case study on a highway construction project in India.

4. Experimental Study

To develop and validate our model, we select a live project of "Construction of NH-4 (Belgaum-Dharwad section from km 433 to km 515) being executed in the State of Karnataka, India" at an estimated cost of Rs. 480.00 crores on DBFO (Design, Built, Finance & Operation) pattern. To carry out the study we use all the tools of e-quality control system. To model the acceptance criteria of sample testing, all the required data is collected and analyzed as per the flow chart given below:

Trail length
↓
Data collection of first layer (Wet Mix Macadam)
↓

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Data collection of second layer (Dense Bituminous Macadam)
↓
Data collection of third layer (Bituminous Concrete)
↓
Results and discussions
↓
Stop

4.1 Trail Length

Thickness of layers is controlled through electronic sensor paver and the number of passes of a particular compacting roller required for a specified density of a material. Accordingly, the trail lengths of 100m length and 3.50m wide for each layer of material i.e. WMM, DBM & BC are constructed to arrive at a result for number of passes required to achieve a specified density on a particular layer. The physical tests are also conducted to check the density with different number of passes. The required density is achieved with number of passes of roller as given below in Table No.4:

TABLE NO.4
(NUMBER OF PASSES OF ROLLER TO ACHIEVE DENSITY)

Sr. No.	Type of material	Number of passes	Thickness		Density	
			Required	Actual	Required	Actual
1	WMM	5-6	125 mm	126 mm	2.37	2.38
2	DBM	4-5	85 mm	86.5 mm	2.50	2.48
3	BC	4-5	40 mm	41.3 mm	2.55	2.52

The details of further tests conducted with the above mentioned passes are given in subsequent paragraphs.

4.2 Data Collection of First Layer (WMM)

Automatic wet mix plant with moisture content controller is used. Physical tests are conducted to check the various characteristics of material. The results of 10 such sample testing of different categories of tests are tabulated below in Table No.5:

TABLE NO.5
(RESULTS OF TESTS IN WMM)

Sr. No.	Compaction Characteristics			Water Absorption	AIV	Thickness of layer (mm)		Total FI&EI	%age passing IS sieve							
	MDD	OMC	Actual FDD	(%)	(%)	Reqd.	Actual	(%)	53	45	22.40	11.20	4.75	2.36	0.60	0.075
1.	2.370	5.50	2.375	1.35	14.32	125	124	18.39	100	100	74.63	54.14	31.98	24.81	12.66	4.33
2.	2.370	5.50	2.370	1.22	14.10	125	126	18.92	100	100	71.84	54.13	33.77	24.10	14.19	3.81
3.	2.370	5.50	2.380	0.90	14.75	125	123	19.11	100	100	73.45	54.18	33.10	24.24	14.13	3.97
4	2.370	5.50	2.375	1.11	14.44	125	125	17.39	100	100	72.44	55.13	32.63	20.98	13.83	5.10
5	2.370	5.50	2.390	1.25	14.43	125	126	19.47	100	100	72.81	53.13	32.05	23.07	12.81	4.30
6	2.370	5.50	2.370	0.85	15.48	125	127	20.02	100	100	74.36	55.14	31.78	24.16	13.77	3.76
7	2.370	5.50	2.380	1.10	15.01	125	124	18.21	100	100	74.18	54.13	33.12	23.29	13.60	4.34
8	2.370	5.50	2.380	1.15	15.34	125	125	18.26	100	100	68.23	52.36	31.23	22.23	16.36	4.26
9	2.370	5.50	2.390	0.98	13.99	125	123	18.19	100	100	74.19	54.13	31.99	23.69	14.10	4.76
10	2.370	5.50	2.370	1.20	14.87	125	126	18.36	100	100	71.65	53.73	34.74	25.73	12.88	4.74

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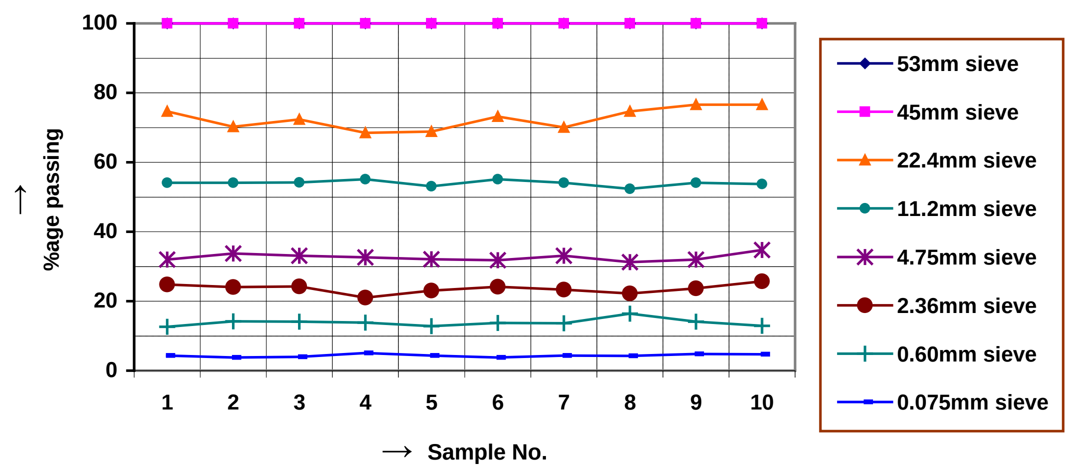
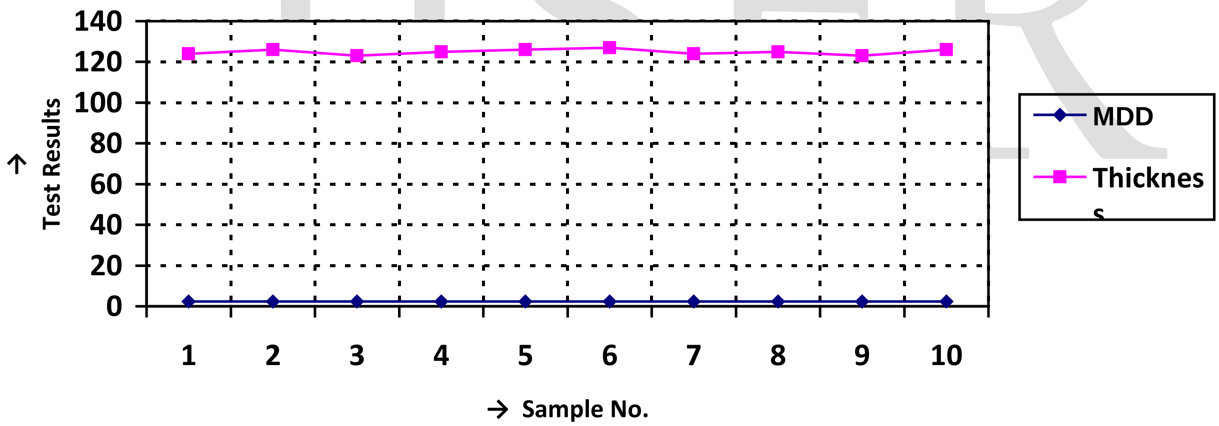
The variation in the test results is further presented in Graph No. 1 for gradation and Graph No. 2 for MDD with corresponding thickness of layer.

Graph No.1 : Gradation of aggregates in WMM



Graph No.2: for MDD with corresponding Thickness of Layer



The requirement of tests as per MORTH specifications for the acceptance of materials and the tests actually conducted are tabulated below Table No.6:

TABLE NO.6
(TESTS IN WMM IN 1 KM 4-LANE HIGHWAY)

Sr. No.	Type of Test	No. of Tests		Value of Test Results		No. of tests	
		Required	Conducted	Required	Actual	Pass	Fail

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WMM							
1.	Gradation	22	22	%age passing through sieves	%age passing through sieves	22	0
				53mm - 100% 45mm – 95-100% 22.4mm – 60-80% 11.20mm –40-60% 4.75mm – 25-40% 2.36mm – 15-30% 0.60mm – 8-22% 0.075mm – 0-8%	53mm – 100% 45mm – 100% 22.4mm – 68-75% 11.20mm – 52-56% 4.75mm – 31-35% 2.36mm – 20-25% 0.60mm – 12-17% 0.075mm – 3-6%		
2.	AIV	11	11	< 30%	14.49%	11	0
3.	FI & EI	11	11	< 30%	18.54%	11	0
4.	Atterberg limit	22	22	LL < 25% PI < 6%	22.08% 0.02%	22 22	0 0
5.	FDD	34	34	98%	98.51%	34	0

4.3 Data Collection of Second Layer (DBM)

Batch mix type hot mix plant with electronic sensor which automatically controls the proportions of different fractions and bitumen, cone crusher (integrated stone crushing and screening plant), vibratory roller, nuclear density meter, total station and GPS etc. is used. Physical tests are conducted to check the various characteristics. The data of 10 such samples is presented below in Table No.7:

TABLE NO.7
(RESULTS OF TEST IN DBM)

Sr. No.	Density		Bitumen Content		Thickness(mm)		%age passing IS sieve							
	Reqd.	Actual	Reqd.	Actual	Reqd.	Actual	45	37.5	26.5	13.2	4.75	2.36	0.3	0.075
1	2.500	2.481	4.36	4.37	85	85.00	100	100	84.35	65.24	48.34	39.02	12.43	5.22
2	2.500	2.478	4.36	4.39	85	86.5	100	100	88.74	60.32	45.12	39.12	10.88	3.00
3	2.500	2.473	4.36	4.38	85	85.33	100	100	84.38	59.74	41.89	36.79	12.46	5.02
4	2.500	2.477	4.36	4.37	85	86.33	100	100	85.57	61.76	42.49	38.64	13.63	4.35
5	2.500	2.470	4.36	4.34	85	86.50	100	97.19	82.64	61.87	46.53	36.45	13.48	3.75
6	2.500	2.482	4.36	4.38	85	86.75	100	100	81.52	58.92	49.01	36.10	12.67	5.03
7	2.500	2.474	4.36	4.35	85	87.00	100	100	75.63	65.36	51.66	35.65	10.17	4.88
8	2.500	2.483	4.36	4.35	85	88.33	100	100	91.62	65.99	40.20	39.04	15.64	2.83
9	2.500	2.486	4.36	4.38	85	86.00	100	100	79.66	68.63	45.17	36.33	12.55	4.30
10	2.500	2.472	4.36	4.36	85	86.50	100	100	83.07	59.44	48.97	33.13	15.28	4.22

The variation in the test results is further presented in Graph No. 3 & 4 for gradation of aggregates and thickness of layer/density in DBM.

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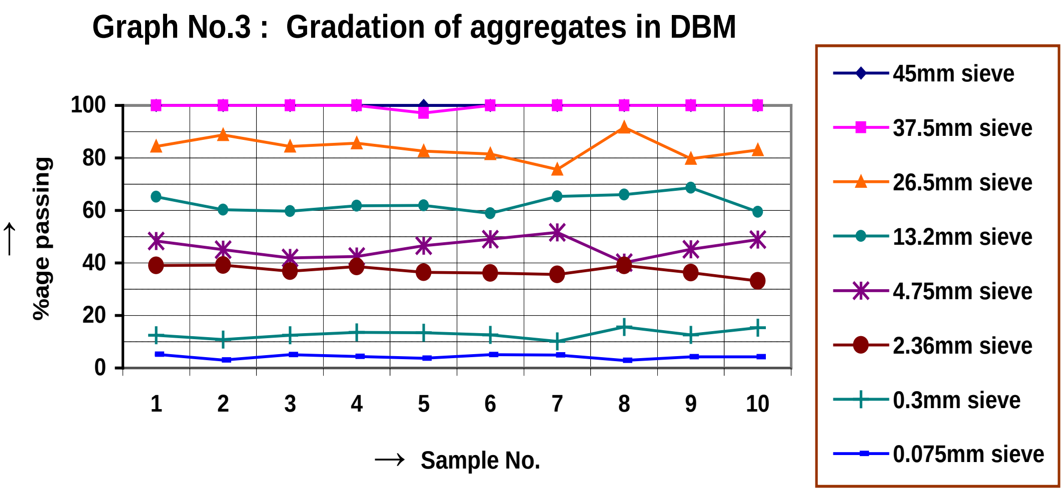

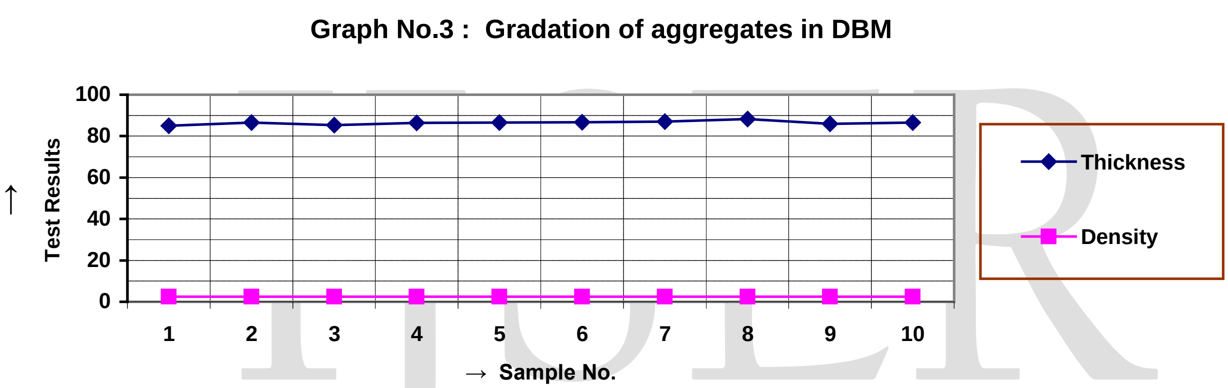

The requirement of tests for the acceptance of material as per MoRTH specifications and the tests actually performed are tabulated below in Table No.8 below:

TABLE NO.8
(TEST RESULTS IN DBM IN 1 KM 4-LANE HIGHWAY)

Sr. No.	Type of Test	No. of Tests		Value of Test Results		No. of tests	
		Required	Conducted	Required	Actual	Pass	Fail
DBM							
1.	Gradation	8	8	%age passing through sieve	%age passing through sieve	8	0
				45mm - 100% 37.5mm – 95-100% 26.5mm – 63-93% 13.2mm –55-75% 4.75mm – 38-54% 2.36mm – 28-42% 0.3mm – 7-21%	45mm – 100% 37.5mm – 97-100% 26.5mm – 75-89% 13.2mm – 58-69% 4.75mm – 40-52% 2.36mm – 33-40% 0.3mm – 10-16%		

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				0.075mm – 2-8%	0.075mm – 2-6%		
2.	Bitumen Extraction	10	10	4.36%	4.34 to 4.39%	10	0
3.	AIV	30	30	< 27%	15.25%	30	0
4	FI & EI	30	30	< 30%	22.45%	30	0
5	Marshal test	60	60	Stability - 900 KN Flow – Min. 2MM Max.4MM	Stability – 970 KN Flow – 2.3 MM	60	0
6	Field Core Density	66	66	98%	98.62%	66	0

4.4 Data Collection of Third Layer (BC)

Again Batch mix type hot mix plant with electronic sensor which automatically controls the proportions of different fractions and bitumen, cone crusher (integrated stone crushing and screening plant), vibratory roller, nuclear density meter, total station and GPS etc. is used. Physical tests are conducted to check the various characteristics. The detail of 10 such samples is tabulated below in Table No.9:

TABLE NO.9
(RESULTS OF TESTS IN BC)

Sr. No.	Density		Bitumen Content		Thick ness (mm)		%age passing IS sieve									
	Reqd.	Actual	Reqd.	Actual	Reqd.	Actual	19	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.150	0.075
1	2.550	2.515	5.40	5.38	40	40.4	100	90.22	77.35	57.07	47.07	36.10	29.99	20.55	14.64	7.06
2	2.550	2.526	5.40	5.41	40	42.00	100	92.33	75.07	55.28	47.29	38.09	28.50	21.33	15.94	6.88
3	2.550	2.524	5.40	5.41	40	42.23	100	88.45	79.35	58.10	45.28	36.28	30.56	20.24	14.34	6.11
4	2.550	2.536	5.40	5.43	40	42.64	100	87.85	80.02	55.50	43.10	35.32	29.21	21.35	15.24	5.84
5	2.550	2.520	5.40	5.39	40	41.32	100	91.34	79.22	56.28	46.84	36.24	27.84	21.84	13.94	7.00
6	2.550	2.518	5.40	5.40	40	40.55	100	90.13	78.92	55.84	44.50	35.84	30.81	20.24	14.89	7.12
7	2.550	2.524	5.40	5.40	40	41.32	100	89.22	80.14	58.15	46.35	36.33	28.48	21.35	15.00	6.44
8	2.550	2.530	5.40	5.42	40	42.15	100	88.87	81.66	55.32	46.18	35.22	30.10	21.84	13.24	6.00
9	2.550	2.516	5.40	5.39	40	42.25	100	90.55	80.24	57.18	45.38	36.32	28.32	21.33	15.98	6.88
10	2.550	2.520	5.40	5.43	40	41.35	100	88.94	77.15	54.84	46.14	36.00	29.92	20.00	14.21	6.22

The variation in the test results is further presented in Graph No. 5 & 6 for gradation and thickness of layer/density in BC.

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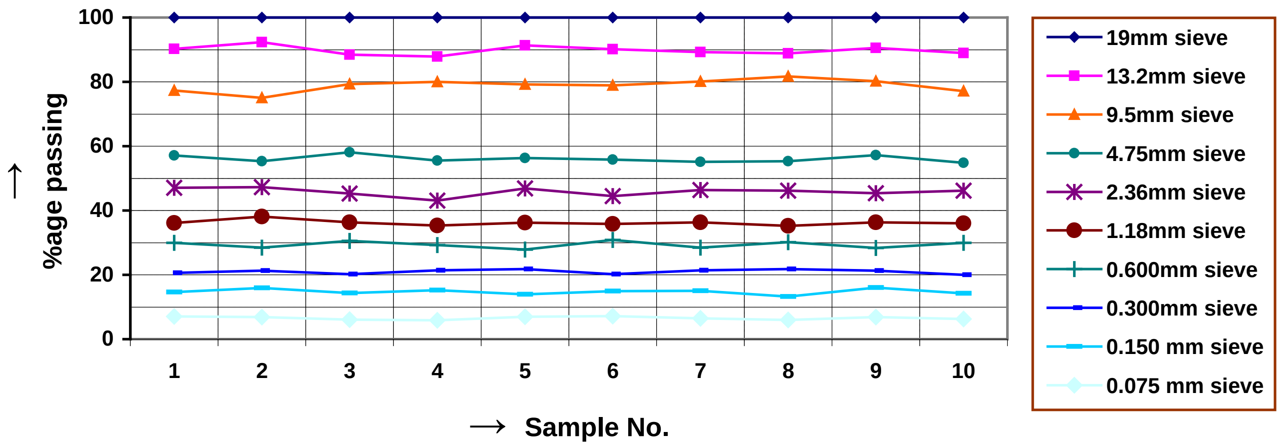
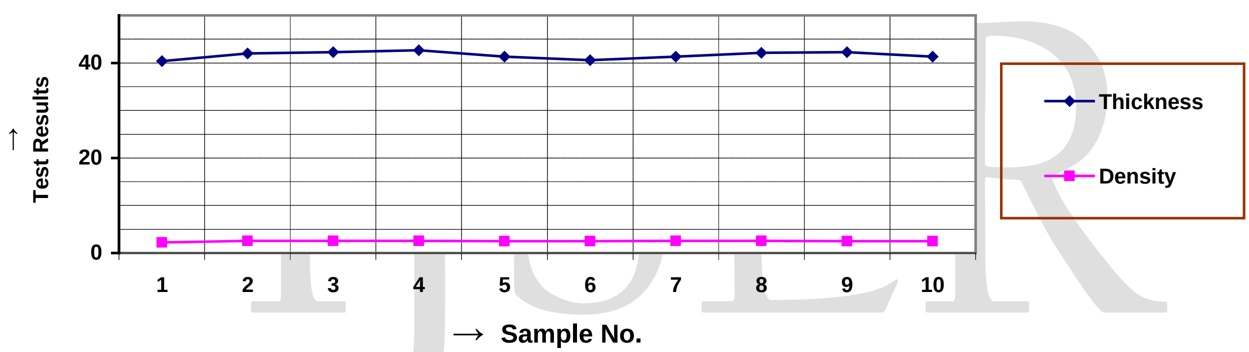
Graph No.5 : Gradation of aggregates in BC



Graph No.6: Thickness of Layer & Density in BC



The requirement of tests as per MORTH specifications for the acceptance of materials and the tests actually performed are tabulated below in Table No.10:

TABLE NO.10
(TEST RESULTS IN BC IN 1 KM 4-LANE HIGHWAY)

Sr. No.	Type of Test	No. of Tests		Value of Test Results		No. of tests	
		Required	Conducted	Required	Actual	Pass	Fail
BC							
1.	Gradation	5	5	%age passing through sieve	%age passing through sieve	5	0
				19mm –100% 13.2mm –79-100% 9.5mm –70-88% 4.75mm – 53-71% 2.36mm – 42-58% 1.18mm – 34-48%	19mm –100% 13.2mm – 87-93% 9.5mm –75-81% 4.75mm – 54-59% 2.36mm – 43-48% 1.18mm – 35-39%		

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				0.6mm – 26-38% 0.3mm – 18-28% 0.15mm – 12-20% 0.075mm – 4-10%	0.6mm – 27-31% 0.3mm – 20-22% 0.15mm – 13-16% 0.075mm – 5-8%		
2.	Bitumen Extraction	5	5	5.40%	5.38 to 5.43%	5	0
3.	AIV	14	14	< 24%	14.22%	14	0
4.	FI & EI	14	14	< 30%	21.84%	14	0
5.	Marshal test	28	28	Stability - 900 KN Flow – Min. 2MM Max. 4MM	Stability – 935KN Flow – 2.45 MM	28	0
6.	Field core density	66	66	98%	98.81%	66	0

5. Results & Discussions

The results of the case study shows that with the use of modern machinery & e-quality control system, the result of tests carried out physically is 'Pass' in all the cases. In case of WMM, the gradation of all the tests performed as shown in table no. 5 & 6 is with in the tolerance limits prescribed in the codes. The average Field Dry Density (FDD) achieved is 98.51% against requirement of 98% with the number of passes as mentioned in para 4.1. Similarly, in case of DBM & BC, the result of all the tests performed as given in table no. 7 to 10 is within permissible limits prescribed in codes. The variation in density in DBM & BC as shown in graph nos. 3 to 8 clearly shows that with the number of passes as mentioned in para 4.1, the required density achieved is 98.62% and 98.81% in case of DBM & BC respectively against the requirement of 98%. The bitumen contents in DBM vary from 4.34% to 4.39% against requirement of 4.36 % and from 5.38% to 5.43% against 5.40% in case of BC. Thus the variation in test results is very minor which is with in the permissible limits. These variation limits are also within the modified tolerance limits [9].

Thickness of various layers, as controlled by electronic paver sensor and the number of passes of a roller required for a specified density of any material after constructing trial length as given in clause 4.1, also gives the required results as shown in table no. 5, 7 & 9 leading to the economization of rolling. Thus the system is highly reliable. British Standards or Asphalt Institute guidelines do not specify the frequency of the test to be conducted on the compacted layers. It has specified the number of passes for different types of rollers, for different materials and layer thicknesses. Once the mode of compaction have been experimented on test track and accepted, a large number of acceptance tests are not pressed for.

Further, MORTH Specifications specify the same number of tests to be conducted before accepting a layer irrespective of the type of roads, machinery and equipment used for the production, laying and compaction of different layers. Thus there is a big gap for prescribed tests in the specifications. The prescribed mandatory test requirement in MORTH specifications is time consuming and is very difficult to actually perform at site with the high speed of construction. Further, when we conduct the density tests, the number of tests required as per specifications is 68 in one Km in case of DBM & 82 in case of BC as given in table No. 8 & 10. These tests are either conducted by Core Cutter Method or by Sand Replacement method. Sand replacement method is not favoured by the Engineers as it is much more time consuming and needs to be carried out in duplicate to avoid errors which further increases the workload. In both the cases, the weak spots are created at 68 & 82 sample locations which are not appreciable. The large number of tests prescribed in the codes are not only time consuming while performing with the pace of construction but also creates weak spots in the surface of the road at the sample locations. These weak spots, which are generally filled manually, can not be filled properly at a later stage. The Nuclear Density Gauge can be used provided the results obtained with it are identical to that of the conventional methods.

Thus, in the above case study the passing of all the test results in all the samples proves that there is meticulous quality control with the use of modern machinery with e-quality control system. Due to automatic in-built control in the machinery, the various ingredients are controlled & results are produced accordingly. Thus the control is at the time of use of machinery and any further test conducted produces the same results as controlled at plant site. This system where there is automatic control at the machinery runs at the same speed as that of production/construction. The quality and quantity are also ensured in this system. We can also conclude that when there is use of sophisticated and updated machinery and equipment e-quality control system is

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used, frequent testing is not recommended. Theoretically, we can say that no testing is required as quality & quantity are automatically controlled.

6. Conclusion

From the case study it reveals that with the use of modern sophisticated machinery/equipment & e-quality control system, the quality & quantity of the product is assured more precisely. The cone crusher used in this study produces the aggregates strictly to the required grading and the batch mix type hot mix plant with electronic sensor has the vital role to control the ingredients of various materials. The censured paver & vibratory rollers used for the laying of mixed material control the thickness of layers and density to the desired perfection. Thus the quality and uniformity of the finished product is as per required standards. The Vehicle Tracking System tracks all the vehicles used in the construction and controls the route of the vehicle at all times, fuel consumption per km., kms traveled by the vehicle in a day, working hours of vehicles/day, halt hours of vehicles/day, idle hours of vehicles/day & speed of vehicles etc. Thus, the system controls the malpractices and manipulation of data at different stages of construction due to availability of live data on web site. In this model, the testing system runs automatically parallel in every stage of construction and controls its quality & quantity. So, we can conclude that in the construction of a flexible pavement where e-quality control system has been used, no further testing is required at site for the acceptance of the work. The tool also controls the hidden influence like political, local etc. that a field engineer is facing in his day to day work during the construction of a work which affects its quality also. The use of this model also reduces the manpower, time and saves money. However, to check the proper functioning/working of machinery & e-quality control system, 2-3 tests of each category are recommended to be conducted physically on each day of work.

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