A DISSERTATION

ON

USE OF BITUMEN EMULSION IN WMM LAYER OF FLEXIBLE PAVEMENT

submitted in the partial fulfillment of the

requirements for the award of degree

of

MASTER OF TECHNOLOGY

in

CIVIL ENGINEERING

(With specialization in Transportation Engineering)

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this dissertation report entitled, "**USE OF BITUMEN EMULSION IN WMM LAYER OF FLEXIBLE PAVEMENT",** is being submitted in partial fulfillment of the requirements for the award of the degree of "**Master of Technology**" in Civil Engineering with specialization in Transportation Engineering submitted to the Department of Civil Engineering, Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out for a period of one year from June 2018 to June 2019 under the supervision of **Dr. G.D. Ransinchung R.N.,** AssociateProfessor, and **Dr. Praveen Kumar,** ProfessorDepartment of Civil Engineering, IIT Roorkee.

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

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ABSTRACT

In developing countries such as India , there are many limitations that do not satisfy the high volume of loads anymore (e.g., limited time schedule , lack of quantity of good quality material, budget and over loading passing trucks), the conventional methods are costly and time taking.Thus, new methods must be adopted for new roads to increase the bearing capacity of the pavements. Bitumen in its emulsified form has got wide range of applications.The concept of basestabilization with emulsion and cement can be one answer to this problem.

The prime objective of this research is to assess the suitability of bitumen emulsions in the WMM layer of the pavement. For attaining the desired objectives, cement and emulsion were used in different proportions i.e. cement(1-3%) and bitumen emulsion(2-4%). Various tests such as Modified Proctor Density test, CBR test(soaked) , UCS test(soaked) and Constant Head Permeability test were carried out on the WMM mixes. The tests were carried out on two different aggregates type that are the virgin aggregates and rap aggregates(with 60% repalcement). Wherein Proctor Density tests tell about the properties of the WMM mix, the CBR test and UCS test determine its strength. The Permeability test displays the drainage characteristics of the mix

It was inferred from the results that the WMM mix with emulsion showed a decrease in its MDD both with rap and virgin aggregates. The CBR and UCS values increased both with rap and virgin aggregates as compared to the non cement emulsion mix but still were less than the mix with only cement as modifier. The Permeability values for the mix increased with the incorporation of emulsion in the WMM mix. So,it is clear from the results that although the stiffness and cohesion increases by incorporation of emulsion, yet it is less than only cement values. On the other hand, emulsion seems to improve the drainage properties. This result justifies the use usage of emulsion modified bases in high rainfall areas. Emulsion can also be used for WMM layer in heavy traffic areas and rural areas along with incorporation of rap to cut down the cost to a significant extent.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1. GENERAL

The dispersion of fine drops of one liquid in another liquid is called an emulsion. Instead of being mixed mutually, these both liquids are coexistent. This property of emulsion is in contrast to the solutions. In bitumen emulsion the two liquids in suspension are bitumen and water. Both these are quite different in characteristics as bitumen has very high viscosity as compared to water. The size of droplets in emulsions vary from 1 to 30 μm in diameter. In this, the majority of droplets are of size <1 μm. The proportion of bitumen in emulsions can be as low as 40 % or as high as 80 %. Normally it is in the region of 60 to 70 %. The bitumen drops constitute the dispersed phase, as they are very fine, and the water forms the continuous phase.

1.2. BITUMEN AND WATER

Bitumen is an oily fluid so in reality it is immiscible with water. The chemistry of the two materials is real the cause of it. Bitumen does contain some polar components but actually it is a non-polar liquid. The term "non-polar" means that generally, The electron distributions in bitumen are evenly spread all over . The concentration of charge does not exist, thus making it non-polar. On the other hand, water is a very polar medium. The ionic species, such as H_2O, OH^- and H^+ are present in it. The polarity of H_2O molecule is due to the presence of electronegative oxygen atom and electropositive hydrogen atom This leads to some neagative charge around the oxygen atom and positive charge around hydrogen.

1.3. EMULSIFIER

So as to create a stable homogeneous blend of these two immiscible materials a surface dynamic specialist or surfactant is required. These particles are supposed on the grounds that they concentrate and are dynamic at the surface between two immiscible substances in contact. Surface action emerges because of these particles comprising of two segments with various properties. One segment is made out of a hydrocarbon tail, which is hydrophobic (water dreading) or lipophilic (oil adoring), and the other either conveys a charge or is polar, making it hydrophilic (water cherishing) or oleo phobic (oil dreading). There are three classes of surfactant-anionic, cationic and non-ionic.

1.3.1. Types of Emulsifiers

Anionic bitumen emulsifiers are typically unsaturated fats or alkyl sulfates or sulphonates. These sorts of particles were first utilized as emulsifiers during the late 1920's. So as to wind up dynamic, these atoms must be deprotonated by a base, for example, sodium hydroxide, to offer ascent to a negative charge on the head gathering.

The cationic arrangement of emulsifiers includes greasy amines and their subsidiaries. After first showing up in the 1950's, cationic emulsions have turned into the favored sort in most street applications. Cationic emulsifiers go from all type of amines to quaternary amine salts, ethoxylated amines, amides and imidazolines. So as to enact these particles, the head gatherings must be protonated by a acidic compound.

Non-ionic emulsifiers are not the same as anionic and cationic in that they don't need to be deprotonated or protonated. The head bunches in these sorts of particles are ordinarily yet not only chains of ethoxylated gatherings – $C2H2O$.The circumstance here is like that in $H2O$, in that the atom is energized as the electrons again turned out to be thought around the oxygen ions in this manner making them into centres of negative charge, leaving the carbon molecules electron lacking and, hence, positive.

As per the standard code IS 8887:2004 cationic bitumen emulsions have been classified into five types based on their setting times. The recommended use of these bitumen types as suggested in the code are:

TABLE 1.1: USES OF CATIONIC EMULSION

TYPE	RECOMMENDED USES
RS-1	Specially recommended for tack coat applications.
RS-2	Specially recommended for surface dressing work.

MS	Used for plant or road mixes with coarse aggregates minimum 80 percent, all of which are retained on 2.36 mm IS sieve and practically none passes through 180 micron IS sieve and also for surface dressing and penetration macadam.
SS-1	Used for applications such as fog seal, crack sealing and prime coat.
SS-2	Used for plant or road mixes with graded or fine aggregates, a substantial quantity of which passes a 2.36mm IS sieve and a portion of which may pass a 75 micron sieve. Examples of it are cold mix MSS, SDBC and slurry seal.

1.4. EMULSIONS

The standard of emulsification is very basic yet the science itself is profoundly intricate. In fundamental terms, an emulsion comprises of globules of one fluid scattered in a sea constant fluid phase. There are two kinds of watery emulsion, to be specific oil in water (o/w), in which the oil is the scatter phase and water in the dispersed phase, and water in oil (w/o), where water is the scattered and oil is the consistent phase. A bitumen emulsion is a case of an oil in water emulsion, under typical conditions, yet it is proposed that they can alter to water in oil emulsions during the setting procedure. Setting of bitumen emulsions includes inversion from a scattering of bitumen in water to bitumen.

The plan in a bitumen emulsion, utilizing a cationic emulsifier, is as appeared in Fig1.1 however clearly the general size of the emulsifier particles has been horribly misrepresented for diagrammatic purposes (as they are in reality just a couple of angstroms in size contrasted with micron measured bitumen drops).The bitumen drops are suspended in a constant water phase with the emulsifier living at the bitumen/water interface, along these lines balancing out the framework by bestowing a charged or polar nature to the drop surfaces in this way making them water miscible. Surfactants likewise settle the framework by keeping drops separated because of charge aversion or steric impacts.

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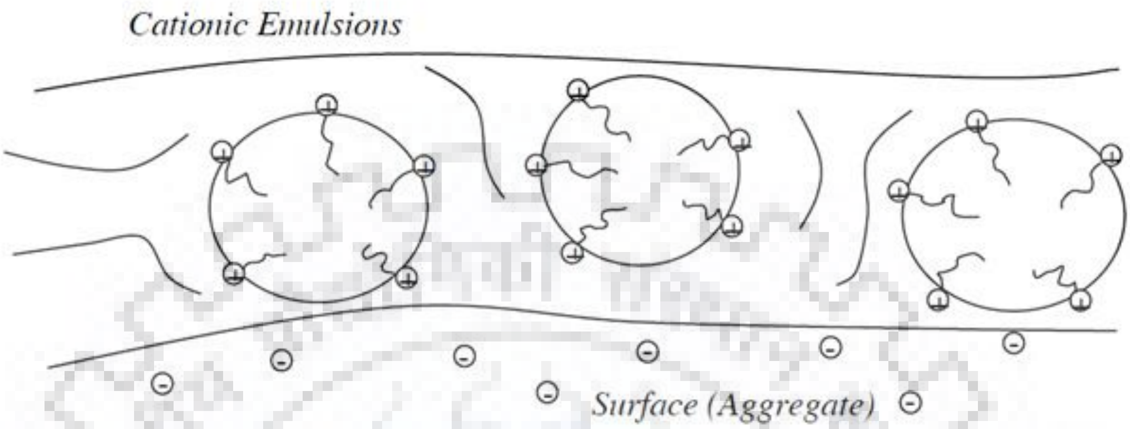

Fig. 1.1 Cationic Bitumen Emulsion

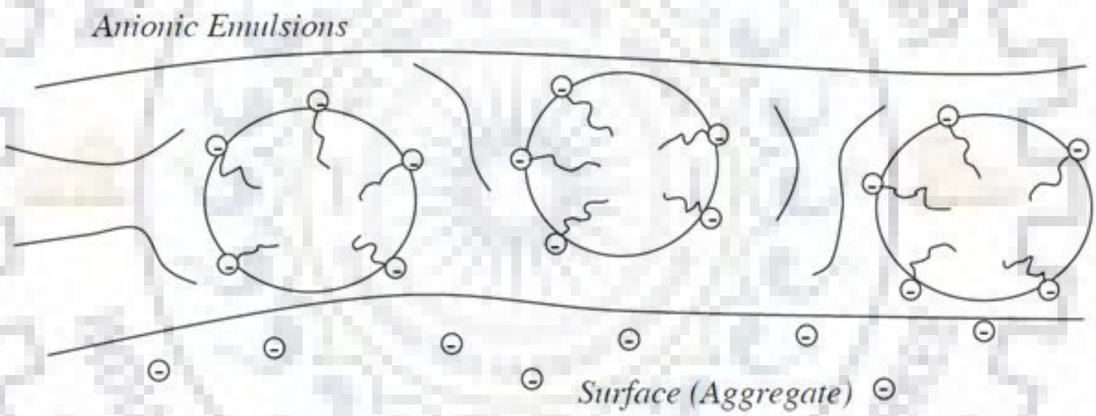

Fig. 1.2 Anionic Bitumen Emulsion

1.4.1. Breaking

In the event that the bitumen emulsion is to play out its definitive capacity as a binder, the water must separate out from the bitumen and dissipate. This division of water from bitumen is classified "breaking". A fast set emulsion will have a short breaking time (inside one to five minutes subsequent to being connected), though a medium-or moderate set emulsion may take longer time.

1.4.2. Curing

Curing includes the cohesion process. The final product is a durable film that holds the total set up with a solid adhesive bond. For this to occur, the water should totally dissipate, and the bitumen particles need to blend and attach to the total. The water is evacuated by dissipation, by weight (rolling), and by adsorption onto the total surface. The scope of surfactants accessible, confer various qualities to the emulsions they produce. Emulsions with various setting qualities are fundamental for various applications.

1.5 WET MIX MACADAM (WMM)

Wet Mix Macadam (WMM) is an improvement upon the regular WBM and is expected to be as an option and progressively durable asphalt layer. WMM is a sub-base/base course of the asphalt wherein clean, crushed graded aggregates and granular material, like, graded coarse sand are blended with water and folded into a thick mass on a prepared surface. The work might be done in layers. The thickness of an individual layer will not be under 75 mm and might be up to 250 mm.

1.5.1 Physical Requirements

Coarse aggregates shall be crushed stone/ crushed gravel/ shingle, not less than 90 percent by weight of gravel/ shingle retained on 4.75 mm sieve shall have atleast two fractured faces. According to IRC: 109-2015, the aggregates conform to the physical requirements as given in the following table:

TABLE 1.2: PHYSICAL REQUIREMENTS OF AGGREGATES

S.NO.	TEST	METHOD	REQUIREMENTS
1	LAAV TEST	IS:2386(PARTIV)	40 % (MAX.)
	AIV TEST	IS:2386(PARTIV)	30 %(MAX.)
2	FI & EI	IS:2386(PARTI)	35%(MAX.)
Either of two tests to be satisfied			

Where;

LAAV test= Los Angeles Abrasion Value test

AIV test = Aggregate Impact Value Test

FI & EI test= Combined Flakiness & Elongation Index Test

1.5.2 Grading Requirements

Materials will have particle size and shape which give high mechanical stiffness and ought to contain adequate fines to create a thick material when compacted. Non-plastic angular sand might be utilized if measure of fines total created during the crushing is deficient. The point is to accomplish most extreme impermeability perfect with great compaction and high solidness under traffic. The grading requirement according to IRC: 109-2015 is as given in the given table:

TABLE 1.3: GRADING FOR WMM

STANDARD GRADATION (AS PER IRC: 109-2015)		
Sieve size(mm)	LOWER LIMIT	UPPER LIMIT
53	100	100
45	95	100
22.4	60	80
11.2	40	60
4.75	25	40
2.36	15	30
0.6	6	18
0.075	4	8

1.6. NEED OF THE STUDY

The usage of the bitumen emulsions offer certain advantages over other construction materials in terms of environmental factors, cost savings, , energy savings and easing of logistical difficulties that is common with other bitumen types. This has been the driving force behind the use of bitumen emulsions into the road builder's palette. And if used along with cement and rap aggregates the advantages offered are just too many. The emphasis on these varies from case to case, and one such case being the incorporation of bitumen emulsion in the the WMM layer of flexible pavement. The points that underline the need of the study are:

1. The strength of the WMM layer in itself is sufficient enough to carry the loads acting on the pavement in normal load condition but in extremely high traffic

conditions the bitumen emulsion stabilisation of WMM can increase its strength by maintaining same thickness of the pavement.

2. In addition, for some projects , use of emulsion increases the construction speed and improves the structural capacity of the pavement.
3. Researches also indicate that cement–bitumen emulsion modified base can provide cost-effective solutions to many common designs and construction situations by providing additional strength and support to the pavement layers. And if used with rap aggregates the cost can come down drastically.
4. Moreover, emulsion stabilized WMM layer can distribute loads over a wider area and reducing the stresses on the subgrade.
5. It has a high load-carrying capacity, does not consolidate further under load, and reduces rutting in hot mix asphalt pavements.
6. This stabilized WMM layer will prove to be more resistant to freeze–thaw, wetting–drying deterioration as per the researches done earlier.
7. Emulsions are water based stabilizers and hence have less effect on the environment.

1.7. OBJECTIVE OF THE STUDY

The present study has been undertaken with following objectives:

1. To assess the suitability of bitumen emulsions in the WMM layer of the flexible pavement by using varying contents of emulsion(2)-4% and cement(1-3%) and obtaining an optimum percentage. This objective would help in the usage of cement–bitumen emulsion treated base in case of heavy traffic conditions.
2. To assess the suitability of bitumen emulsions in the WMM layer of the flexible pavement by using RAP aggregates and varying contents of emulsion and cement for obtaining an optimum percentage. This objective would help in construction of strong base courses by the use of emulsion and cement in areas where only locally available (low quality) aggregates are present. It would also help us make a case for the sustainable development in the construction of base courses as RAP (waste product) would be used.

The main focus of this research is to analyze the use of combined cement and bitumen emulsion in base course stabilization and examine its replacement with conventional pavement in regions with low quality material (RAP used in this case).

CHAPTER 2

LITERATURE REVIEW

2.1. LITERATURE REVIEW (INDIA)

2.1.1. Bitumen Emulsions for Warm Mix Asphalt (WMA)

Panda et al., (2017) formulated a new and greater eco-friendly option of developing warm blend Asphalt (WMA). The WMA includes a natural eco-friendly process that uses natural added substances, compound added substances and water based innovations. The natural and compound added substances are regularly all around and still include certain measure of ecological issues.

Utilizing this method, an endeavor was made to prepare warm mixes by first pre-coating the aggregates with medium setting bitumen emulsion (MS) and after that blending the semi-coated aggregates with VG 30 bitumen at a temperature lower than typically required. After various attempts, it was seen that for the most part three blending temperatures, in particular temperatures 110ºC, 120ºC and 130ºC were proper to shape the bituminous blends with homogeneity and consistency and thus were kept up all through this examination. For dense bituminous macadam, Marshall samples were prepared according to the specifications of Ministry of Road Transport and Highways (MORTH). For developing appropriate warm mix bitumen, the Marshall properties were studied. Accordingly following pints were drawn:

- The maximum indirect tensile strength value is observed for warm mixes prepared at 120 ºC with 80B:20E bitumen emulsion composition.
- As compared to other mixes prepared at 110ºC and 130ºC The tensile strength ratio and retained stability values for mix observed at 120 ºC came out to be higher.
- Out of the three temperatures attempted in this investigation, it was seen that the blend arranged at 120ºC offer maximum stability and indirect tensile strength test, fulfilling other Marshall parameters. Thus the particular blend for example blend arranged at 5.1% binder content and 80B:20E bitumen emulsion proportion was viewed as the most appropriate warm blend which is ordinarily practically identical with typical HMA.

2.1.2. Bitumen Emulsions for Different Climatic Conditions in India

Pundhir and Nanda (2006), worked on the development of bitumen emulsion based cold mix technology. They worked to cover different climatic conditions of India. For this purpose roads chosen were:

1. Jammu-Srinagar Highway NH-1A near Patnitop under snow bound area
2. Jowai-Badarpur road NH-44 near Silchar (Assam) under heavy rainfall
3. H-S road near Hanumangarh (Rajasthan) under desert climate

Field tests were done for 25mm Semi Dense Bituminous Concrete (SDBC) and 20 mm Pre Mix Carpet (PMC) for laying test areas with bituminous emulsion and control segments with bitumen of 80/100 grade. Laboratory mix designn for SDBC with bitumen emulsion was created utilizing Marshall Method. Marshall examples of blend were made, cured at 40ºC for three days and tried at 25ºC for stability and flow value. Post development construction assessments were done at a half year interim for a time of five to six years. The following conclusions were drawn as per the locations of trials:

1. Jammu-Srinagar Highway NH-1A- For both SDBC and PMC the construction of test and control section was good in the first inspection which was conducted just after the construction. After six months the deterioration in road constructed just with bitumen was more than that using emulsion. This difference in deterioration of roads increased considerably till five and a half years.
2. Jowai-Badarpur road NH-44- The results for this road were similar to that of NH-1A. Roads with emulsion performed better, showed less deterioration and pavement distress.
3. H-S road near Hanumangarh (Rajasthan)- This location showed an inconsistent result as here the performance of road with emulsion showed better results than that with bitumen , but only upto two and a half years. Same was seen for the pavement distress. But after that period, results were reversed in both.

2.1.3. Bitumen Emulsion for Rural Roads

2.1.3.1. Because of geographical requirements, rural roads projects in North Eastern States of India like Arunachal Pradesh, Assam, Manipur, Meghalaya and others take too much time. Indian government is experiencing a huge rural road improvement plan and is exceedingly worried for the rural road advancement projects in North East states. Since large numbers of the rural roads of North Eastern States are in uneven locales having substantial precipitation and numerous multiple times they need to meet exceptionally exacting ecological guidelines as good number of these ventures additionally lies in forest zone.

Considering these points N.K.S Pundhir (2006) also conducted similar studies for the rural roads of North East and came out with following results:

1. Comparative cost of bitumen surfacing with emulsion vis-a-vis hot bitumen-

TABLE 2.1: BINDER AND ITS COST

S. N.	Specification	Thickness, mm	Binder	Cost/m^2, Rs.
1	SDBC	25	Bitumen	324.08
2	SDBC	25	Emulsion	276.21
3	PMC	20	Bitumen	168.84
4	PMC	20	Emulsion	104.76

It is evident from table given above that emulsion proved to be economical than bitumen for construction of same area of the rural road.

2. Material and energy requirement for different types of renewal:

TABLE 2.2: COMPARISON BETWEEN HOT AND COLD MIXES

	Bitumen(Kg)		Energy(Kilo Cal*10^8)	
	Hot	Cold	Hot	Cold
Two Coat Surface Dressing	9800	7280	0.99	0.74
Premix Carpet + Seal Coat	9100	8645	1.02	0.91
Mix Seal Surfacing	8700	8580	1.16	0.92

Semi-Dense Bituminous Concrete	11000	11000	1.63	1.32

Based on studies it can be inferred that cold mix technology can be laid as a green paving mix on low volume roads. So it can be laid as surface course or bituminous base course for rural road construction. It is a much cheaper and energy efficient alternative to HMA.

2.1.3.2. Use of cold mixes should be evaluated for these roads. Cold mix also offers advantages like; low fuel consumption, reduction in emissions, , can be used in rainy seasons etc. Choudhary et al., (2015) through their paper presented the mix design of cold mixes.

Determination of Initial Emulsion Content -

Emulsified asphalt content designated as P can be estimated using the Asphalt Institute empirical formula given below:

$P = (0.05A + 0.1B + 0.5C) \times 0.7$

where;

P = % Initial residual bitumen content by mass of total mixture,

A = % of aggregate retained on sieve 2.36 mm,

B = % of aggregate passing sieve 2.36 mm and retained on 0.075 mm,

C = % of aggregate passing 0.075 mm.

The initial emulsion content value can be obtained by dividing P by the percentage of bitumen content in the emulsion.

Marshall Mix design criteria for Emulsified Mix-

A Marshall Mix design criterion [MORTH specification (2001)] for emulsified mixes is given below. If one or more criteria cannot be met, the mix should be considered inadequate.

TABLE 2.3: MARSHAL MIX DESIGN FOR EMULSIONS

Mix Design Criteria for Emulsified Mix Properties	Value

Marshall stability	2.2 kN
Minimum flow (in 0.25mm units)	2
Air voids (VA in %)	3-5
Percent maximum stability loss on soaking	50

TABLE 2.4: MIX COMPOSITION FOR COLD MIXES

<table>
<tr><th colspan="2">Mix composition for cold mix Mix component</th><th colspan="4">Percentage on aggregate</th></tr>
<tr><td colspan="2">Granite aggregate 20mm</td><td colspan="4">26</td></tr>
<tr><td colspan="2">14 mm</td><td colspan="4">15</td></tr>
<tr><td colspan="2">10 mm</td><td colspan="4">9</td></tr>
<tr><td colspan="2">6 mm</td><td colspan="4">15</td></tr>
<tr><td colspan="2">Dust</td><td colspan="4">35</td></tr>
<tr><td>OPC</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td>Pre-wet water</td><td>2.5</td><td>2.5</td><td>3</td><td>3.5</td><td>4</td></tr>
<tr><td colspan="2">Bitumen Emulsion</td><td colspan="4">8.06</td></tr>
</table>

This study focused on the use of cold mixes in rural road construction. The following overall conclusion can be justified.

- Cold mix can be laid on low to medium volume road. Additive can be used in cold mix to make its properties comparable to the properties of HMA.
- Cold mix can be tried for paving mix in north east region of India.
- Curing rate and mechanical properties of cold mix can be improved.

2.1.4. Effect of bitumen emulsion on setting, strength, soundness and moisture resistance of oxychloride cement

The bitumen emulsion addition improves strength and soundness of the product while decreasing the initial setting periods. Chandrawat et al., (2001) studied the effect of bitumen emulsion on oxychloride cement .The properties such as setting, strength, soundness and moisture resistance were examined. Setting time test, weathering test, Compressive strength test and Soundness test were conducted for the same. Test results showed:

- In small proportions bitumen emulsion improves strength and soundness of the products.
- However, in excess (beyond 10%)incorporation of emulsion to the mix is harmful. At the point when utilized in overabundance, slight extension in the mass volume trial is normal because of the expanding odds of staying unused magnesia in the lattice. This unused magnesia hydrates expansively and shapes magnesium hydroxide.
- On account of this, bitumen emulsion can be used as an admixture in magnesia cement is a moisture proofing and strengthening material.

2.1.5. Cold Mixed Bituminous Macadam (CMBM)

As per IRC:SP:100-2014, bituminous Macadam (BM) is an open graded bituminous mixture suitable for moderate traffic roads used for construction of bituminous base course as well as for strengthening of flexible pavements whereas, Cold Mixed Bituminous Macadam (CMBM) involve the construction of one or more courses of compacted mixture prepared with bitumen emulsion and mineral aggregate, laid immediately after mixing to required grade and camber using appropriate machinery.

According to the code for CMBM, aggregates shall consist of crushed stone, crushed slag, crushed gravel (shingle) or other suitable. The requirement of filler (material passing 75 micron sieve) in CMBM shall be met from stone dust, cement, hydrated lime or any other non-plastic mineral matter. The blended aggregates for CMBM shall satisfy the grading given in Table 3.1.

TABLE 2.5: GRADING FOR CMBM

Sieve size, mm	**Percent passing by weight**
26.5	100
19	90-100
13.2	56-88
9.5	20-55
4.75	16-36
2.36	4-19
0.3	2-10
0.075	1-4
Sand Equivalent Value (ASTM D2419)	50 Minimum
Percent Crushed Faces	75% Minimum
Bitumen Emulsion % by Weight of Mix	5% Minimum

Bitumen emulsion for preparation of CMBM shall be Medium Setting (MS), Slow Setting (SS-2) grade or a tailor made for compatibility with available mineral aggregates, conforming to IS:8887 or other international standard (ASTM or AASHTO). The actual grade of the emulsion to be used would depend on the characteristics of the aggregates. If the sand equivalent value of the aggregates is between 50 to 70, use SS-2 grade of emulsion and for sand equivalent values more than 70, use MS grade of emulsion. The

Rapid Setting (RS-1) grade of bitumen emulsion, conforming to IS:8887 shall be used in Tack Coat.

TABLE 2.6. INDICATIVE DESIGN REQUIREMENTS

i)	Number of compaction blows on each side of Marshall specimen	50
ii)	Marshall Stability at 25°C in kg (minimum), after curing the specimen in air (72 hours)	350
iii)	Marshall flow (mm) at 25°C	Max. 8
iv)	Per cent voids in mixture	10 - 14
V)	Binder content (residual bitumen) by weight of total mix (%),	min 3.5
vi)	Retained indirect tensile strength at 25°C after conditioning for 72 hours in air and 24 hours at 40°C, in water %	50

Some of the drawbacks in the code are:

1. It has not specified the role of the fillers in CMBM.
2. It does state what all modifications can be done to improve the strength of CMBM.
3. It does not give the percentage of fillers to be used so as to satisfy various in pavement construction.

2.2. LITERATURE REVIEW (ABROAD):

2.2.1. Modified Bitumen Emulsions

2.2.1.1. *Cold Bitumen Emulsion Mixes With Different Fillers*

Due to the numerous critical ecological and financial advantages that can be taken from utilizing cold asphalt mixtures(CAMs), a few research projects have been performed to think about and build up the properties of these mixes. Nassar et al., (2016) examined the upgrade of Cold Asphalt Emulsion Mixtures (CAEMs) utilizing binary and ternary mixed fillers (BBF and TBF), incorporating a top to bottom evaluation of the microstructure. Ordinary Portland bond (OPC), fly ash (FA) and ground granulated blast furnace slag (GGBS) were utilized for the BBF while silica fumes (SF) was added to the BBF to get TBF.

Indirect tensile stiffness modulus (ITSM) test, repeated load axial test (RLAT) durability tests, mineralogy and microstructure tests were led on the specimens prepared and the outcomes drawn were as per the follows:

- It was observed that when either BBF or TBF replaced the conventional filler in the mix the stiffness modulus differences were markedly increased. Stiffness modulus is generally higher than in those with BBF in CAEMs containing TBF.
- With the increase of temperature the stiffness modulus showed a decrease. This trend was very strong in both HMA. However, the type of filler determines the reduction of the stiffness modulus in treated CAEMs.
- Resistance to permanent deformation: A remarkable decrease in the permanent strains was noted by the incorporation of BBF and TBF.
- CAEMs with multi-blended fillers were less susceptible to moisture damage. Freeze-thaw tests also showed similar results.

2.2.1.2. ***Cement modified Bitumen Emulsion***

Disregarding the advantages it offers, cold mixes have not been truly assessed or used until relatively as of late. This is because of the moderate rate at which they fabricate quality or impart strength and its susceptibility to precipitation, especially during this curing period. Accordingly Needham and Brown (2000) undertook an examination, to think about the conduct of various blend as far as mechanical properties and the process associated with emulsion breaking and curing to pick up an understanding into how execution might be improved.

Various tests adhering to Dense Bitumen Macadam (DBM) criteria were conducted including stiffness modulus, resistance to permanent deformation and resistance to fatigue cracking etc. with different OPC contents on specimens. Following results were drawn from the tests:

- In contrast with the hot mix, Stiffness moduli of the emulsion mix showed an increase over several weeks. The stiffness increase rate of hot mix was almost unaffected whereas that of the emulsion mixes it increased with OPC addition level.
- Even the resistance to permanent deformation enhanced by the incorporation of the cold mix specimens with OPC. This was much better than the hot mix with or without OPC.
- The second soak test was passed only by the mixtures with OPC and hydrated lime. After the first soaking period, a higher stiffness was observed with the mixture using OPC.
- It was observed that too much use of cement led to the embrittlement of the mix. This led to the initiation of the cracks. And as soon as the cracks started, the mixes failed rapidly.

2.2.1.3. *Effects of copper slag and recycled concrete aggregate on the properties of CIR mixes with bitumen emulsion, rice husk ash, Portland cement and fly ash*

Behnood et al., (2015) examined the practicality of the utilization of copper slag and recycled concrete aggregate (RCA) as substitutes for aggregates in adjusting the gradation of cold recycled mixes made with RAP material and bitumen emulsion and the impacts of three sorts of added substances including Portland cement, fly ash, and rice husk ash were studied with detail on the properties of recycled mixes.

Tests were conducted on the mixes to study the mechanical properties. Tests included Marshall Stability and flow, indirect tensile strength (ITS), resistance to moisture damage, resilient modulus, and dynamic creep tests. Following inferences were drawn from the results obtained from the research:

- The most effective additive was found to be Portland cement. RHA was found to have very high water absorption characteristic and so must be used at low ratios and under control.
- The results of the stiffness modulus tests demonstrate that the utilization of CS with added substances in CIR (Cold In-Place Recycling) blends (that utilization bitumen emulsion) improves the resilient Modulous of the blends. The permanent

deformation of recycled mixtures gets reduced effectively by the incorporation of Portland concrete, FA and RHA.

- For reducing permanent deformation Portland cement proved to be the best additive.

2.2.1.4. *Fatigue models for recycled mixes with bitumen emulsion and cement*

The role of cement in cold recycled mixes with bitumen emulsion (CRME) has been extensively investigated. But the effect of cement on the fatigue properties of these mixes is not clearly understood. Kavussi et al.,(2010) conducted research in order to develop fatigue models for these mixes, extensive indirect tensile fatigue and resilient modulus tests were performed at different temperatures (varying from -10, 5 and 25°C) and curing times (varying from 7 to 120 days).

The general relationship between initial strain and fatigue life and resilient modulus-fatigue life relationship were developed. Two different relationships were determined for strain level below and above 300 μm/mm. Results observed were:

- Fatigue lines slopes were reduced by the addition of cement. At -10°C, the least slopes were obtained.
- The cement addition led to the reduction in fatigue life approximately at above 250 microstrain, , whereas at below 250 microstrain, the results were reversed. The stiffness and brittleness of the CRMEC showed an increase. The fracture strains were increased drastically and this led to a considerable reduction in fracture life.
- The shrinkage for mix having more than 1.5% of cement was considerable while that of below it was under control.

2.2.1.5. *A comparative study for improving the mechanical properties of cold bituminous emulsion mixtures with cement and waste materials*

Nageim et al., (2012) conducted experimental test results of a research project aimed at developing a new cold bituminous emulsion mixtures (CBEM's) containing fly ash from incinerated domestic and industrial by-products compared with those results of traditional control cold containing OPC and hot mix asphalt.

The developed CBEM's in this study incorporate percentage FA as a filler replacement in the mix with varying from 0% to 5.5% of the aggregate weight. The improvement in mechanical properties determined using the indirect tensile stiffness modulus and uniaxial compressive cyclic test, as a respected indicators of the mechanical properties. At the same time, water sensitivity test was used to investigate the durability of the new mixes. Results drawn were:

- The CBEM's containing OPC cementitious filler offered stiffness properties higher than the soft and hard traditional HMA at curing time of 14 and 125 days respectively.
- The FA filler which is a waste material prove its significant enhancing stiffness properties to CBEM's compared with OPC, plus the other characteristic such as cost and environment impacts.
- CBEM's comprised FA offered better positive effect under water sensitivity tests than the CBEM's comprised OPC.

2.2.1.6. ***Lab study on bitumen and bitumen emulsions***

Beng et al., (2009) also tried to evaluate and improve the properties of the cold mixtures. The mixture properties evaluated were: volumetric properties, indirect tensile stiffness modulus (ITSM), repeated load axial creep and fatigue. These properties were compared with conventional hot asphalt mixtures not containing any waste/recycled materials. At full curing conditions, the stiffness of the cold mixes was found to be very similar to that of hot mixtures of the same penetration grade base bitumen. Test results also show that the addition of 1–2% cement significantly improved the mechanical performance of the mixes and significantly accelerated their strength gain. The fatigue behaviour of the cold mixes that incorporated cement was comparable with that of the hot mixtures.

2.2.1.7. Impact of rapid-hardening cements on mechanical properties of cement bitumen emulsion asphalt

Cement bitumen emulsion asphalt (CBEA) is obtained by mixing bitumen emulsion, cement, aggregates and filler at ambient temperature. CBEA is thought to be a promising substitute for hot mix asphalt because of its low environmental impact and cost-effectiveness. Disadvantages of this material are the long time required to reach its full strength and the inadequate understanding of the hardening mechanisms. "With this purpose, cold mix asphalt mixtures with cationic and anionic emulsions and different types of cement (ordinary Portland, calcium sulfoaluminate and calcium aluminate cement) were studied by means of isothermal calorimetry, measurements of water evaporation and Marshall tests by Fang et al., (2016)”. Results drawn were:

- Isothermal calorimetry applied to CBEA mixtures showed that bitumen emulsion may slightly retard or accelerate cement hydration, but has no significant effect on the degree of cement hydration after a couple of days.
- The early strength of CBEA can be improved by adding small amounts of rapid-hardening cements (CSA and CAC).
- The addition of calcium sulfoaluminate and calcium aluminate cement to CBEA leads to mechanical properties after 1-day curing similar to those obtained with Portland cement after 1-week curing.

2.2.1.8. *Properties of GGBS-Bitumen Emulsion Systems with Recycled Aggregates*

A range of storage grade macadams composed of recycled aggregates from various sources and bound by bitumen emulsion and Ground Granulated Blast furnace Slag (GGBS) was investigated by Ellis et al., (2004)”. Focus was on the contribution of the bituminous and GGBS components to the mechanical properties of cold mixtures in different environments. The results show that the inclusion of GGBS may enhance stiffness and strength development in high humidity conditions whilst the bitumen emulsion renders the mixtures more ductile and maintains shelf life. Tests carried were ITSM, Fatigue, brittleness, ductility and an enhanced ITS test.

The principal effects of the GGBS upon the cold mixtures were to:

- improve the strength and stiffness modulus;
- promote progressive increase in long term stiffness;
- render mixtures more tolerant of prolonged high humidity conditions;
- have no noticeable effect upon shelf life.

2.2.1.9. Early age evolution of rheological properties of over-stabilized bitumen emulsion-cement pastes

Garilli et al., (2016) focused on the early age evolution of consistency and rheological properties of fresh bitumen emulsion-cement (BEC) pastes and the BEC paste were fabricated using a Portland limestone cement and an over-stabilized bitumen emulsion and were characterized by water to cement ratio ranging between 0.33 and 1 and by bitumen to cement ratio ranging between 0 and 1. The testing included the measurement of sedimentation tendency, setting time and evolution of viscosity with increasing storage time. Rheological measurements were also carried out on bitumen emulsion-filler mastics prepared with reference filler.

Results showed that regardless of water content, the initial and final setting time of BEC pastes increased when the proportion of bitumen with respect to cement was increased. For all tested compositions, the BEC pastes and BEF mastics are characterized by a shear thinning behaviour, i.e. viscosity decreased with increasing shear rate due to progressive breaking of their flocculated structure. When the total concentration of the dispersed phases was low, the increase in bitumen concentration with respect to cement led to a reduction in the rate of viscosity increase with storage time.

2.2.2. Properties and Behaviour of Bitumen Emulsions

2.2.2.1. *Effect of Bitumen Emulsion on Bitumen Mixes*

Miljkovic et al., (2015) conducted a research to propose a comprehensive method for evaluating the contribution of the bitumen emulsion to the bitumen mixture properties and eliminated the variable influence of the aggregate by standardising the aggregate composition of bitumen emulsion mortar (BEM). The BEM mixtures were tested with various emulsion-related parameters.

BEM mixture concept

To eliminate a variable influence of geometrical, chemical, and mechanical properties of the aggregate, the entire evaluation was decided to be conducted on the BEM mixtures of a standardised composition. BEM includes the mixture of bitumen, filler, and fine aggregate, mostly up to 2 or 2.36 mm.

To evaluate the influence of the bitumen emulsion properties and the content, and to define the reference bitumen emulsion content for the standard BEM mixture composition, specimens with the three bitumen emulsions and three different emulsion contents were tested. Specimens were initially compacted. The first three days after compaction, the specimens were cured at (20 ± 2) ºC and the relative air humidity of 95 %. Three days after the compaction, begins, so called, dry curing at the same temperature and the relative air humidity of (65 ± 5) %. To prepare the specimens, immediately before the testing, they were conditioned at ±5ºC for 8h in an environmental chamber. Thereafter, they were weighted and the dimensions were measured, which was necessary to calculate the bulk densities.

Although the mechanical properties could be determined by a wide range of test methods, the indirect tensile testing, 7, 28, and 84 days after the compaction at the test temperature of ±5ºC was selected as the most suitable. The mixtures with 11 and 12 % of emulsion had significantly higher indirect tensile strengths than the mixture with 10 % of the same emulsion. Moreover, it can be observed that as higher the increase of the indirect tensile strength between 7 and 28 days is, the lower it is between 28 and 84 days of curing. This rule is also present for the failure strain and the stiffness modulus. Based on the results of the calculated mechanical properties after 7, 28, and 84 days, it could be observed that the bitumen emulsion content of 11 % appears to be optimum.

2.2.2.2. *Fracture behaviour of bitumen emulsion mortar mixtures*

Miljkovic et al., (2014) evaluated the fracture behaviour of the bitumen emulsion mortar (BEM) mixtures, in terms of their ductility/brittleness, by considering the fracture work and the deformation energy parameters. The indirect tensile tests were conducted on mixes with different proportion of bitumen emulsion after after 7, 28, and 84 days of curing. Test results showed that:

- Ductile failure was shown by the softest bitumen type. These showed a fast loss 0f mass by evaporation and had lowest strengths.
- On the other side, the highest fracture work ratio was shown by the hardest bitumen. It showed the most brittle behaviour as it reached fracture point after 84 days of curing.
- It was observed that the specimens become more ductile from 7 to 28 days of curing. It can be inferred from the change in the deformation energy. It was also noted that specimens became brittle upto 84 days of curing.

2.2.2.3. *Mechanical properties and behaviour of in situ materials which are stabilised with bitumen emulsion*

In recent years, research on materials which are stabilised with bitumen emulsion (BSM) has been mainly aimed at characterisation, formulation and implementation. Pérez et al., (2013) reviewed the mechanical properties and parameters used in the structural design of BSM. Two main BSM techniques can be Cold in-place recycling (CIR) and Full depth reclamation (FDR).

Two categories were used to group the mechanical properties of :

1. According to their stress dependent behaviour - properties of the unbound granular materials , and
2. According to their viscoelastic behaviours - properties of HMA. Properties studied were permanent deformation, resilient modulus, dynamic modulus, creep and fatigue resistance. The critical review of the behaviour of BSM led to the following conclusions:

- There are two phases in the service life of BSM: Increase in the initial stiffness determines the first phase. This is owed to the curing and densification of the material. Stiffness is reduced in the second phase.
- Another important parameter is the RM (M_r). It is taken from dynamic triaxial tests. The addition of cement and an increment in curing time increases its value
- HMA exhibit a higher flexural stiffness than BSM. As the percentage of RAP reduces, the dynamic muodulous increases. This increase can also be observed with the increase in curing time and cement.

2.2.3. Concrete Pavements and Bitumen Emulsion

Bołtryk et al., (2017), have worked in modifying the properties of concrete with an anionic bitumen emulsion to reduce its water absorption and improve resistance to environmental aggression and to achieve the required consistency of the concrete mix superplasticizers were used. The frost resistance was observed to increase and the water absorption was noted to decrease by the usage of anionic bitumen emulsion in the concrete mixes.

The loss in the properties of concrete mixes helped to calculate the frost resistance of the mix. The properties that helped in achieving this were loss of its durability and weight, as well as its water absorption, compressive strength, density and porosity.

It was found that:

- compression strength for the concrete increased by 10% ,
- bending strength for the concrete increased by 25%,
- water penetration for the concrete decreased by at least 80% ,
- water absorption for the concrete decreased by 30–50% ,
- loss of strength reduced after 200 cycles by 0–50%.

2.2.4. Emulsion Mixes in Road Base Construction

Baghini et al., (2013) analysed in details the soil stabilization method for road bases which utilizes Portland cement and bitumen emulsion in improving soil properties and found that it increases the pavement bearing capacity (conducted via laboratory research)". The combination of Portland cement and bitumen emulsion are beneficial for the purpose of increasing the stiffness and also the elasticity of soil stabilized layer. In order to examine this, two steps were undertaken, first, by examining the Unconfined Compressive Strength (UCS) and Modulus of Elasticity (ME) on samples mixed with soil aggregates comprising Portland cement and bitumen emulsion. The data collected was analysed to show the optimum value of Portland cement and bitumen emulsion used in soil stabilization. The major findings of this research showed the importance of soil stabilization using Portland cement and bitumen in improving pavement's performances by increasing bearing capacity of its layer. In addition, the total number of roadway layers can be reduced because of its higher bearing capacity, which effectively reduces the construction time and cost. The findings revealed that overall; the optimum value of Portland cement and bitumen emulsion utilized in base Soil stabilization method is 3% and 3% respectively.

S.M. Marandi et al., (2009) also undertook research to analyze the use of combined cement and bitumen emulsion in base course stabilization and found that the optimum values to eliminate the creation of shrinkage cracks in the whole project and minimize the execution period and construction costs were 3% for both binders in stabilization and its replacement with conventional pavement method. It was also found that this base modified method decreased the final road construction costs in comparision with earlier method.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

The objectives in the research work were achieved by following a particular methodology as given in fig.3.6. The first and foremost part of the work was literature review. On basis of this literature review, a case study was chosen which gave a direction to the research. Then based on all above information, objectives were setup for the research work. This chapter in particular describes the materials used and the testing methodology adopted for the work.

3.2 MATERIAL USED

Following materials were used for the research work:

3.2.1 EMULSION

Slow setting catioanic emulsion (Grade SS-2) was used that was procured from Ooms India Pvt. Ltd. The SS-2 grade emulsion was found acceptable as per Indian Standard (IS 8887: 2004).

TABLE 3.1: CATIONIC EMULSION

S.NO.	CHARACTERISTICS	VALUES	IS CODE
1	COAGULATION AT LOW TEMP.	NIL	NIL
2	STORAGE STABILITY	1.72	2
3	PARTICLE CHARGE	POSITIVE	POSITIVE
4	MISCIBILITY WITH WATER	NO COAGULATION	NO COAGULATION
5	TEST ON RESIDUE (PENETRATION)	77	60-120

6	COATING ABILITY	FAIR	FAIR
7	STABILITY TO MIXING WITH CEMENT	1.4	2(MAX.)
8	TEST ON RESIDUE (DUCTILITY),MIN	62	50
9	TEST ON RESIDUE (SOLUBILITY IN TRICHLOROETHYLENE)	98.6	98

3.2.2 CEMENT

Ordinary Portland cement with ACC brand and OPC 43 grade was used in the investigation. The properties of the cement were as follows:

TABLE 3.2: TEST RESULTS OF OPC43 CEMENT

S.NO.	CHARACTERISTICS	REPORTED	IS CODE
1.	CONSISTENCY	28	25-32
2.	INITIAL SETTING TIME(MIN)	45	30(MIN)
3.	FINAL SETTING TIME(MIN)	240	600(MAX.)
4.	COMPRESSIVE STRENGTH (MPa) 7/28DAYS	25/46	23/43

3.2.3 RAP aggregates

The rap aggregates were procured from Chhutmalpur area(Dehradun road)and reclaimed by milling process of a 5 year old flexible pavement. The tests on rap aggregates were conducted as per IS:2386. The material was considered satisfactory and its properties are as follows:

TABLE 3.3: SPECIFIC GRAVITY OF RAP

S.NO.	SIZE(mm)	SPECIFIC GRAVITY	WATER ABSORPTION
1.	GREATER THAN 4.75	2.508	0.943
2.	LESS THAN 4.75	2.262	2.776

TABLE 3.4: TEST RESULTS OF RAP

FLAKINESS & ELONGATION INDICES (As Per IS 2386, Part - I and MORTH Specifications)	
Flakiness Index (F.I.) = C/A x 100	13.8
Elongation Index (E.I.) = D/B x 100	14.4
FI & EI Combined	28.8
Specification Limit (Maximum %)	35

3.2.4 Virgin aggregates

The Virgin aggregates were procured from Bhadarabad quarry(Haridwar) and were found satisfactory as per IS: 109-2015. The properties were as follows:

TABLE 3.5: SPECIFIC GRAVITY OF VIRGIN AGGREGATES

S.NO.	SIZE(mm)	SPECIFIC GRAVITY	WATER ABSORPTION
1.	40	2.647	0.625
2.	20	2.622	0.91
3.	10	2.604	1.1

TABLE 3.6: TEST RESULTS OF VIRGIN AGGREGATES

FLAKINESS & ELONGATION INDICES	
(As Per IS 2386, Part - I and MORTH Specifications)	
Flakiness Index (F.I.) = C/A x 100	13.8
Elongation Index (E.I.) = D/B x 100	14.4
FI & EI Combined	28.8
Specification Limit (Maximum %)	35

3.3 Testing Program

The laboratory work for the research consisted mainly of three stages:

1. Testing of materials to be used in the research work.
2. Tests on WMM mix containing virgin aggregates, bitumen emulsion and cement.
3. Tests on WMM mix containing RAP aggregates, bitumen emulsion and cement.

In this work, the effect of bitumen emulsion and cement was investigated on WMM layer of the pavement. And this testing was carried out by varying percentages of bitumen emulsion (2, 3, 4 %) and cement (1, 2, 3 %) in the WMM mix. As stated in the objectives, the aggregates used in the testing were also varied, that is firstly the virgin aggregates were used in the mix and then the RAP aggregates.

So, after the testing of materials two stages ran parallel to each other. The stages being:

1. WMM mix testing of sample containing virgin aggregates, bitumen emulsion and cement.
2. WMM mix testing of sample containing RAP aggregates, bitumen emulsion and cement.

The tests conducted to check the suitability of emulsion in WMM layer were:

1. Modified Proctor Density Test
2. CBR test
3. Unconfined Compression Strength test
4. Constant Head Permeability test

3.3.1 Gradation

To initiate the tests first of all gradation of aggregates was done. Based on the gradation obtained and standard gradation as per IRC: 109-2015, job mix formula was obtained by using Rothfutch or Hit & Trial method both for virgin as well as Rap aggregates. As per the IS code, the achieved gradation should satisfy the following gradation:

TABLE 3.7: GRADATION AS PER IRC 109

IS sieve designation	Upper limit	Lower limit
53mm	100	100
45mm	100	95
22.40mm	80	60
11.20mm	60	40
4.75mm	40	25
2.36mm	30	15
600micron	18	6
75micron	8	4

FIG 3.1: SIEVING FOR GRADATION

3.3.2 Modified Proctor Density Test

The Proctor density test is one of the major tests to assess the suitability of emulsion and cement on base course layer that is Wet Mix Macadam in our case. It gives us the properties of the WMM mix. To carry out the tests IS 2720(Part 8): 1983 was followed. Proctor Compaction tests were carried out initially on various percentages of cement i.e. 1,2,3 % and then on the proposed percentages of bitumen emulsion and cement. This led to a total combination of 13 tests individually for Virgin and Rap aggregates. The combination is as given below:

1C	2C	3C	2 E+ 1C	2 E+ 2C
2 E+ 3C	3 E+ 1C	3 E+ 2C	3 E+ 3C	4 E+ 1C
	4 E+ 2C	4 E+ 3C	STANDARD WMM MIX	

FIG 3.2: Combinations of Emulsion and Cement

Where; C stands for cement and,

E stands for emulsion.

For carrying out the tests a mould of volume 2250 cm^3 with a diameter of 152.4 mm was used. The density was determined after the replacement of the aggregate sizes greater than 22.4 mm with the aggregates of sizes between 4.75mm and 22.40mm. The soil was compacted in five layers. Each layer was given 55 number of blows using a 4.9 Kg hammer dropped from a height of 450mm. To prepare the specimens, the required amount of cement and emulsion was added to the soil-aggregate and the resulting mixture was mixed thoroughly to achieve a uniform color .It was left for half an hour for letting the emulsion to break up. Water was then added to this aggregate cement emulsion mixture and specimens were prepared by compacting this mixture in the mold in five equal layers.

FIG 3.3: PROCTOR COMPACTION TEST

The masses and water contents were noted down. Then the Bulk Density of each compacted specimen was calculated. A curve was plotted between dry density and water content. The optimum moisture content (OMC) and maximum dry density (MDD) was determined using the compaction curve.

3.3.3 California Bearing Ratio Test

The CBR value is required for designing flexible pavement materials and thickness. It gives us an idea of the strength and stiffness properties of the pavement layer(WMM in this case). In this research IS 2720(Part16): 1987 was used to evaluate the strength of the cement-emulsion modified WMM layer of the pavement by using CBR values. The specimens were compacted in five layers into a cylindrical metal mold with an inside diameter of 152.4 mm and a height of 177.8 mm to the MDD at OMC. The tests were performed for both soaked condition. For it, samples attached to a 4.5 kg steel weight were immersed in a water bath for four days to achieve suitable saturation. The average CBR of the 4-day-cured specimens was determined using a hydraulic compressive strength testing machine by applying a load at a rate of 1.25 mm/min.

FIG 3.4: CBR TEST

To prevent the upheaval of soil into the hole of surcharge weight a 2.5 Kg annular weight was placed on the soil surface prior to seating of the penetration plunger. The load readings were recorded at a penetration of 2.5 mm, 5mm and upto a total penetration of 12.5 mm. Then the penetration load was calculated using a testing machine-calibrated equation and the load penetration curve was plotted. Finally, the CBR was calculated using corrected load values taken from the load penetration curves for 2.5 mm and 5 mm penetration by dividing the corrected load by the standard stresses of 7.0 MPa and 10.5 MPa. The corrected load value is taken from the load penetration curve and the CBR is calculated.

3.3.4 Unconfined Compression Strength Test

The primary purpose of the UCS test is to determine the approximate compressive strength of a mixture that has sufficient cohesion to permit testing in the unconfined state. It is the measure of the shearing resistance that the mix imparts to the pavement layer. For this test, the mixture was prepared according to ASTM D 1632 using a metal cylinder mould with an internal diameter of 152.40 mm and a height of 177.8 mm. The specimens were placed in the moulds in a moist room for 12 h for curing; subsequently, the specimens were removed using a sample extruder. Three specimens were fabricated for each percent of additive, resulting in 3 samples for Portland cement (1-3%) and 9 samples for the cement-bitumen emulsion mixture. An adequate amount of material was sieved through 50mm sieve, 19 mm sieve and 4.75mm sieve. The material of size greater than 19mm sieve was replaced by that of material with size ranging in between 4.75mm and 19mm sieve. The average UCS of the specimens cured for 7days was determined using a hydraulic compressive strength testing machine.

FIG 3.5: UCS TEST

3.3.5 Constant Head Permeability Test

The permeability test was carried out on the WMM mix to assess the drainage characteristics and find out how these characteristics change with the change in emulsion cement dosage. To carry out this test, IS 2720 (Part 17):1986 was followed. For a constant head test arrangement, the specimen is connected through the top inlet to the constant head water reservoir. The bottom outlet is opened and when the steady state of flow has been established. The quantity of flow for a convenient time interval is collected and weighed or measured.

The collection of the quantity of flow for the same time interval was repeated thrice. For determination of the coefficient of permeability of the WMM mixes, specimens of size 100 mm (diameter) and 127.3 mm (height) were cast and tested in accordance with IS: 2720-17 (1986). The dry density for remoulding of soil samples was the value of the maximum dry density estimated by the compaction tests [see IS: 2720 (Part 7)-1980: and IS :2720 (Part 8)-19833]. The moisture content used for compaction is the optimum moisture content or the field moisture as the case may be. After completion of compaction the collar, if attached, is removed and excess soil trimmed level with the top of the mould.

In case of soils of medium to high permeability the specimen is subjected to sufficient head, flow or immersion so as to obtain full saturation. Alternatively, in the case of soils of low permeability the specimen is subjected to a gradually increasing vacuum with bottom outlet closed so as to remove to form the soil voids. The evacuation shall be followed by a very slow saturation of the specimen with de-aired water from the bottom upwards under full vacuum. When the specimen is saturated both the top and bottom outlets are closed. The bottom outlet is opened and when the steady state of flow has been established, the quantity of flow for a convenient time interval is collected and weighed or measured.

FIG 3.6: CONSTANT HEAD PERMEABILITY TEST

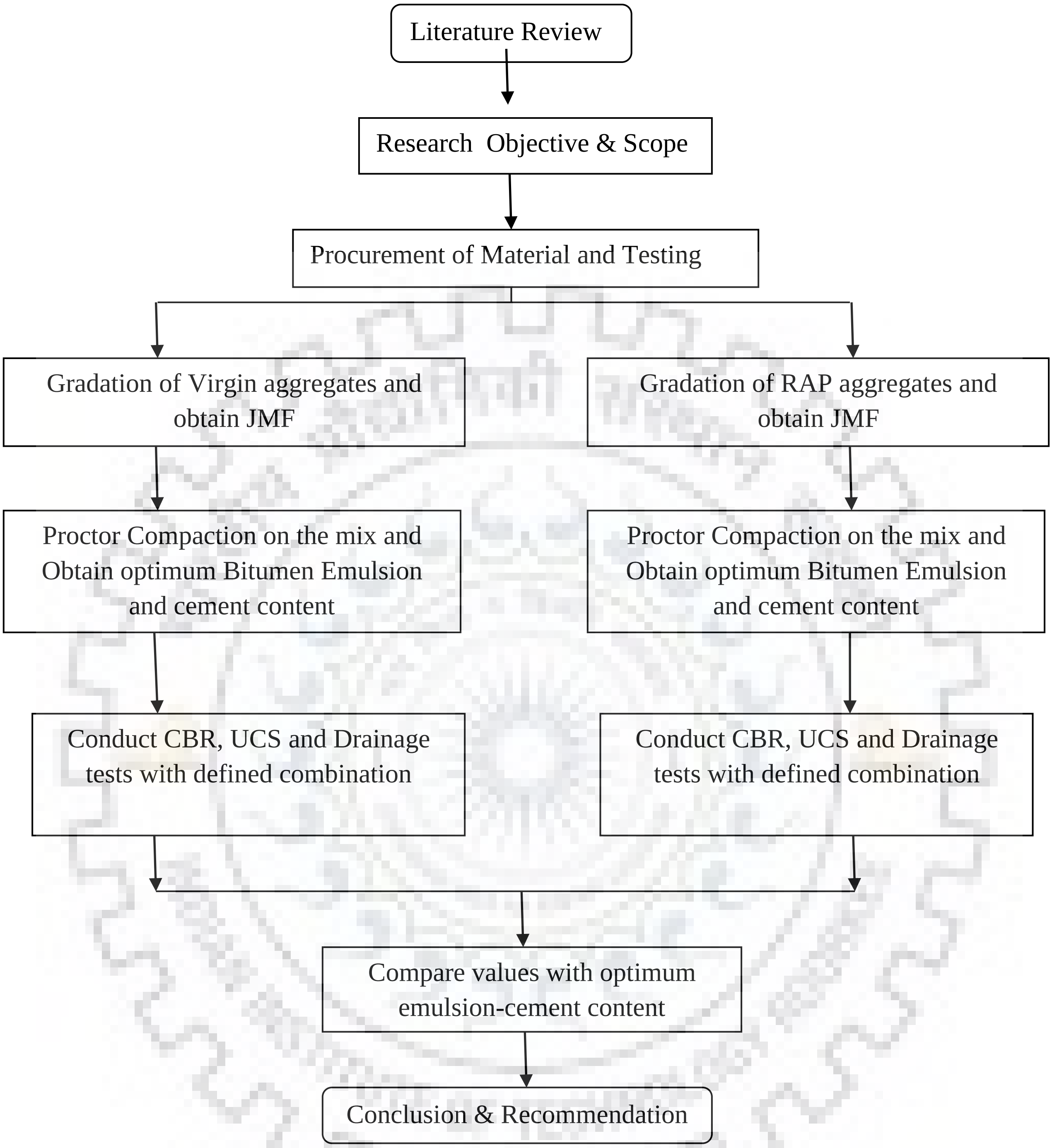

Fig. 3.7 METHODOLOGY FLOWCHART

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1. TESTS ON EMULSIONS

The emulsion used in the WMM mix is the cationic slow setting emulsion (SS-2). To validate its properties, tests were conducted on the emulsion as per the standard code IS 8887:2004. The test results were as follows:

TABLE 4.1: TEST RESULTS (CATIONIC EMULSION)

S.NO.	CHARACTERISTICS	VALUES	IS CODE
1	COAGULATION AT LOW TEMP.	NIL	NIL
2	STORAGE STABILITY	1.72	2
3	PARTICLE CHARGE	POSITIVE	POSITIVE
4	MISCIBILITY WITH WATER	NO COAGULATION	NO COAGULATION
5	TEST ON RESIDUE (PENETRATION)	77	60-120
6	COATING ABILITY	FAIR	FAIR
7	STABILITY TO MIXING WITH CEMENT	1.4	2(MAX.)
8	TEST ON RESIDUE (DUCTILITY),MIN	62	50
9	TEST ON RESIDUE (SOLUBILITY IN TRICHLOROETHYLENE)	98.6	98

All the tests conducted satisfied the codal provisions and hence the emulsion was found fit to be used in the research work.

4.2. TESTS ON VIRGIN AGGREGATES

4.2.1 SPECIFIC GRAVITY & WATER ABSORPTION TEST

TABLE 4.2: SPECIFIC GRAVITY & WATER ABSORPTION (40 mm)

SPECIFIC GRAVITY & WATER ABSORPTION (40 mm agg.)				
(As Per IS 2386, Part III)				
S. No.	Description	Unit	Sample-1	Sample-2
B	Weight of the oven dry sample in air	Kg	1.994	1.991
C	Weight of the sample in water(A)	Kg	1.253	1.252
D	Weight of the saturated surface dry sample(B)	Kg	2.007	2.003
E	Specific gravity = C/(B-A)	-	2.644	2.651
F	Apparent Specific Gravity = C/(C-A)	-	2.69	2.694
G	Water absorption (%) = 100x(B-C)/C	%	0.65	0.6
H	Average Bulk Specific Gravity	-	2.6475	
I	Average Apparent Specific Gravity	-	2.692	
J	Average Water Absorption	%	0.625	
Remarks : Hence water absorption is below the maximum value (i.e. 2%)				

The tests conducted on the aggregates were as per IS: 2386 . The tests conducted were :

1. Specific gravity & water absorption test.
2. Aggregate Impact Value test.
3. Flakiness & Elongation Index test.

All the tests conducted on aggregates are confirmed by IRC 109 (IS code for WMM).

TABLE 4.3: SPECIFIC GRAVITY & WATER ABSORPTION (20 mm)

SPECIFIC GRAVITY & WATER ABSORPTION (20 mm agg.)				
(As Per IS 2386, Part III)				
S. No.	Description	Unit	Sample-1	Sample-2
B	Weight of the oven dry sample in air	Kg	1.98	1.976
C	Weight of the sample in water(A)	Kg	1.243	1.241
D	Weight of the saturated surface dry sample(B)	Kg	1.997	1.995
E	Specific gravity = C/(B-A)	-	2.625	2.62
F	Apparent Specific Gravity = C/(C-A)	-	2.686	2.688
G	Water absorption (%) = 100x(B-C)/C	%	0.86	0.96
H	Average Bulk Specific Gravity	-	2.6225	
I	Average Apparent Specific Gravity	-	2.687	
J	Average Water Absorption	%	0.91	
Remarks : Hence water absorption is below the maximum value (i.e. 2%)				

TABLE 4.4: SPECIFIC GRAVITY & WATER ABSORPTION (10 mm)

SPECIFIC GRAVITY & WATER ABSORPTION (10 mm agg.)				
(As Per IS 2386, Part III)				
S. No.	Description	Unit	Sample-1	Sample-2
B	Weight of the oven dry sample in air	Kg	1.969	1.961
C	Weight of the sample in water(A)	Kg	1.234	1.23
D	Weight of the saturated surface dry sample(B)	Kg	1.987	1.986
E	Specific gravity = C/(B-A)	-	2.615	2.594

F	Apparent Specific Gravity = C/(C-A)	-	2.68	2.68
G	Water absorption (%) = 100x(B-C)/C	%	0.914	1.27
H	Average Bulk Specific Gravity	-	2.6045	
I	Average Apparent Specific Gravity	-	2.68	
J	Average Water Absorption	%	1.1	
Remarks : Hence water absorption is below the maximum value (i.e. 2%)				

4.2.2. AGGREGATE IMPACT VALUE TEST

TABLE 4.5: AGGREGATE IMPACT VALUE TEST(VIRGIN AGG.)

(As per IS 2386, Part - IV)				
S. No.	Description	Unit	Sample-1	Sample-2
A	Weight of surface dry sample passing 12.5mm and retained on 10mm IS sieves	(gm)	385	389
B	Weight of fraction passing on 2.36mm sieve after the test	(gm)	87	84.5
C	Weight of fraction retained on 2.36mm sieve after the test	(gm)	298	304.5
E	Aggregate Impact Value (A.I.V.) = (B/A) x 100	%	22.6	21.72
F	Average Value of A.I.V.	%	22.16	
Remarks : The calculated AIV is less than the maximum AIV (i.e. 30 %)				

So, as far as the virgin aggregates are concerned; they completely satisfy codal provisions as mentioned in the IS code IS 2386. The pattern that can be seen in specific gravity of aggregate size is that the value of specific gravity decreases with decrease in size. This is probably attributed to more voids present in the smaller size aggregates. This property also gives one more explanation for the higher value of water absorption in aggregates of smaller size. The impact value and FI& EI tests were conducted on all aggregates size and an aggregate result is shown here.

4.2.3 COMBINED FLAKINESS AND ELONGATION INDEX TEST

TABLE 4.6: COMBINED FI AND EI TEST(VIRGIN AGG.)

FLAKINESS & ELONGATION INDICES	
Flakiness Index (F.I.) = C/A x 100	13.8
Elongation Index (E.I.) = D/B x 100	14.4
FI & EI Combined	28.8
Specification Limit (Maximum %)	35

4.3.TEST ON RAP AGGREGATES

4.3.1. SPECIFIC GRAVITY & WATER ABSORPTION TEST

TABLE NO. 4.7: SPECIFIC GRAVITY AND WATER ABSORPTION(RAP I)

SPECIFIC GRAVITY & WATER ABSORPTION (greater than 4.75 mm agg.)				
(As Per IS 2386, Part III)				
S. No.	Description	Unit	Sample-1	Sample-2
B	Weight of the oven dry sample in air	Kg	2.010	2.015
C	Weight of the sample in water(A)	Kg	1.227	1.231
D	Weight of the saturated surface dry sample(B)	Kg	2.028	2.035
E	Specific gravity = C/(B-A)	-	2.509	2.506
F	Apparent Specific Gravity = C/(C-A)	-	2.567	2.57
G	Water absorption (%) = 100x(B-C)/C	%	0.896	0.99
H	Average Bulk Specific Gravity	-	2.5075	
I	Average Apparent Specific Gravity	-	2.5686	
J	Average Water Absorption	%	0.943	

TABLE NO. 4.8: SPECIFIC GRAVITY AND WATER ABSORPTIO(RAP II)

SPECIFIC GRAVITY & WATER ABSORPTION (BY PYCNOMETER)				
(As Per IS 2386, Part - III)				
S. No.	Description	Unit	Sample-1	Sample-2
B	Pycnometer Bottle Number	no	1	2
C	Wt of SSD sample	gm	500	500
D	Wt of Pycnometer Bottle + Water + Sample	gm	1805	1804
E	Wt of Pycnometer Bottle + Water	gm	1527	1524
F	Wt of oven dry sample	gm	488	485
G	Specific Gravity = F/ [C - (D - E)]	-	2.252	2.273
H	Apparent Specific Gravity = F / [F - (D - E)]	-	2.198198198	2.204545455
I	Water Absorption = 100 x (C - F) / F	%	2.46	3.09
J	Average Specific Gravity		2.262	
K	Average Apparent Specific Gravity		2.328	
L	Average Water Absorption	%	2.775	

4.3.2. AGGREGATE IMPACT VALUE TEST

TABLE 4.9: AGGREGATE IMPACT VALUE TEST(RAP)

(As per IS 2386, Part - IV)				
S. No.	Description	Unit	Sample-1	Sample-2
A	Weight of surface dry sample passing 12.5mm and retained on 10mm IS sieves	(gm)	354	389
B	Weight of fraction passing on 2.36mm sieve after the test	(gm)	55	64

C	Weight of fraction retained on 2.36mm sieve after the test	(gm)	299	328
E	Aggregate Impact Value (A.I.V.) = (B/A) x 100	%	15.53	16.45
F	Average Value of A.I.V.	%	15.99	
Remarks : The calculated AIV is less than the maximum AIV (i.e. 30 %)				

4.3.3 COMBINED FLAKINESS AND ELONGATION INDEX TEST

TABLE 4.10: COMBINED FI & EI TEST(RAP)

Flakiness and Elongation Index (Combinded)							
(As Per IS 2386, Part - I and MORTH Specifications)							
S. No.	Size range of aggregates, passing and retained IS sieve size, mm	Total Weight , g	Weight of flaky particles , g	Flakiness Index (FI)	Weight of Elongated Particles, g	Elongation Index (EIc)	Combined Flakiness and Elongation Index (FI+EIc)
1	20-16	944	72	7.62712	119	13.646789	21.27
2	16-12.5	833	56	6.72269	111	14.285714	21.01
3	12.5-10	412	58	14.0777	54	15.254237	29.33
4	10-6.3	169	29	17.1598	32	22.857143	40.02
						Average	**27.91**

The water absorption for rap aggregates greater than 4.75mm was satisfactory but for the aggregates of size less than 4.75mm it came out to be more than the standard value for aggregates that is 2 as per IS 2386. However, in case of using rap aggregates this codal provision is not followed because of higher water absorption characteristics of the rap than virgin aggregates. There was one more conclusion to draw and that is the rap aggregates used in the research have a better impact value than the virgin ones but are more flaky and elongated. So, these may prove as better substitute to the virgin ones if used in optimum quantity taking in consideration that they can absorb more water than the virgin ones.

4.4.TEST ON WMM MIX (VIRGIN AGG.)

4.4.1GRADATION

After conducting the tests on constituents materials, the gradation of the aggregates was determined as per IRC: 109-2015.

After sieving and finding the gradation, the standard gradation for WMM mix was referred and Job Mix formula (JMF) for the mix was obtained using Rothfutch method and Hit & Trial method. The percentages of aggregates obtained as per the JMF are as follows

1. 40 mm = 30%
2. 20 mm = 20%
3. 10 mm = 22%
4. Stone dust = 28%

TABLE 4.11: AGGREGATE GRADATION (IN WEIGHT)

GRADATION (AS PER IRC: 109-2015)				
	Weight passing (Kg)			
Sieve size(mm)	40 mm (5 Kg)	20 mm (5 Kg)	10 mm (5 Kg)	Stone Dust (1 Kg)
53	0	0	0	0
45	0	0	0	0
22.4	4.931	1.262	0	0
11.2	0.0609	3.734	1.017	0
4.75	-	0.004	3.929	0.006
2.36	-	-	0.028	0.054
0.6	-	-	0.003	0.354
0.075	-	-	-	0.429

TABLE 4.12: AGGREGATE GRADATION (IN PERCENT FINER)

TABLE NO. :PROPORTIONING OF AGGREGATES									
Size	**75 mm down**	**40 mm**	**20 mm**	**10 mm**	**S. Dust**	**LL**	**UL**	**MID**	**GRADATION**
53.00	0	100.00	100	100	100	100	100	100	100
45.00	0	100.00	100	100	100	95	100	98	100
22.40	0	1.38	74.76	100	100	60	80	70	69
11.20	0.0	0.00	0.08	79.66	100	40	60	50	45
4.75	0	0.00	0	1.08	99.4	25	40	33	25
2.36	0	0.00	0	0.52	94	15	30	23	24
0.6	0.000	0.00	0	0.46	58.6	6	18	15	15
0.075	0.000	0.00	0	0.46	15.7	4	8	3	4
0	0	0.00	0	0	0	0	0	0	0
Proportion	**0**	**0.30**	**0.20**	**0.22**	**0.28**				
Percent	**0**	**30**	**20**	**22**	**28**	Total Percent			

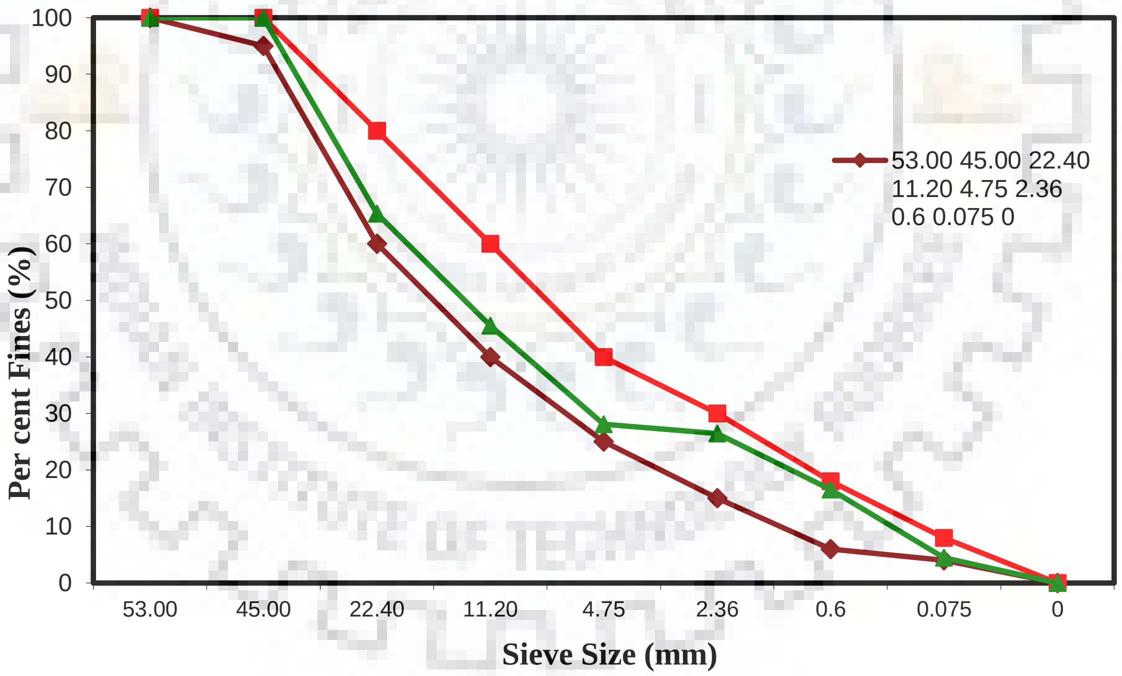

Fig. 4.1. GRAPH FOR GRADATION

The above displayed graph reveals that the percentages of material used for the mix are within the limits as mentioned in IRC 109.

4.4.2 PROCTOR COMPACTION TEST ON WMM

The JMF obtained from the previous result is of utmost importance as its lays the foundation of WMM mix. Using the JMF, Modified Proctor Compaction test (as per IS 2720) was conducted on the WMM mix devoid of bitumen emulsion and cement using the virgin aggregates and as well as alongwith these constituents. This test helps us in comparing the values of maxm. dry density with and without Emulsion-cement mixture.

The values of maxm. dry density (MDD) have been plotted on the graphs as shown in the figures down below. From the graph drawn MDD and OMC (optimum moisture content) values can be easily found which are as follows:

TABLE 4.13. MDD VALUES(VIRGIN AGGREGATES)

S.No.	Proportion	MDD(gm/cc)	OMC(%)
1.	0E0C	2.20	5.4
2.	2E1C	2.17	5.55
3.	3E1C	2.15	5.35
4.	4E1C	2.145	5.2
5.	2E2C	2.13	5.6
6.	3E2C	2.15	5.6
7.	4E2C	2.173	5.5
8.	2E3C	2.12	5.75
9.	3E3C	2.16	5.8
10.	4E3C	2.21	5.2
11.	0E1C	2.208	5.6
12.	0E2C	2.22	5.7
13.	0E3C	2.24	5.9

In total of 13 such tests were carried out (with combination of bitumen emulsion in percentages 2,3 & 4% and cement 1,2 & 3% and with cement alone). For all these combinations some abbreviations have been used in this chapter which are properly explained in the table given below.:

TABLE. 4.14. ABBREVATIONS

S.NO.	ABBREVATIONS	MEANING
1.	0E0C	0% emulsion and 0% cement
2.	2E1C	2% emulsion and 1% cement
3.	3E1C	3% emulsion and 1% cement
4.	4E1C	4% emulsion and 1% cement
5.	2E2C	2% emulsion and 2% cement
6.	3E2C	3% emulsion and 2% cement
7.	4E2C	4% emulsion and 2% cement
8.	2E3C	2% emulsion and 3% cement
9.	3E3C	3% emulsion and 3% cement
10.	4E3C	4% emulsion and 3% cement
11.	0E1C	0% emulsion and 1% cement
12.	0E2C	0% emulsion and 2% cement
13.	0E3C	0% emulsion and 3% cement

These Proctor Density tests are important for us to assess the properties of different combinations of WMM mixes. For a particular combination of cement and emulsion two tests were carried out. The average of the two readings have been mentioned in table 4.13. The calculation and graph for all the different combinations is almost similar.

Keeping this in mind the calculation and graph only for one combination out of 13 is shown in order to maintain the simplicity of the report.

As can be seen in table 4.13 the value of MDD has decreased by the usage of bitumen emulsion. However, this value of MDD increased if only cement was used . The values of MDD for only cement mixtures came out to be always higher than non cement mixture and increased with increase in cement percentage. Though this might not reflect upon the strength of the mix but it does tell about the characteristics. This suggests that emulsion just adds to the volume in the mix for the same given weight and thereby decreases the density.

Another thing that can be inferred is that for lower concentrations of the cement i.e. 1 & 2% if the emulsion percentage gets increasing, the MDD value of the mix keeps on decreasing. On the other hand, for a greater concentration of cement that is 3%, the MDD value increases on increasing the emulsion percentage. The higher percentage of cement is not advised as per the studies done before because they may induce cracks.

It can also be noted that on keeping the emulsion percentages same for a lower value of 2%, the addition of cement decreases the MDD value. On the contrary, if the percentage of emulsion is more and then the dosage of cement is increased, the value of MDD also increases. It may increase upto an extent that may cross the MDD value for non cement emulsion mix. In this case, only the 4% emulsion and 3 % cement proportion outweighs the non cement emulsion MDD value.

For OMC values it can be seen that cement mixes have got higher OMC whereas the emulsion cement mixes have shown a variation as the MDD changed from one dosage to the other. These MDD and OMC values may help in explaining the trend of tests to be discussed later, especially the drainage tests that are a result of the porosity and permeability of the mix.

1. **OC & 0E:**

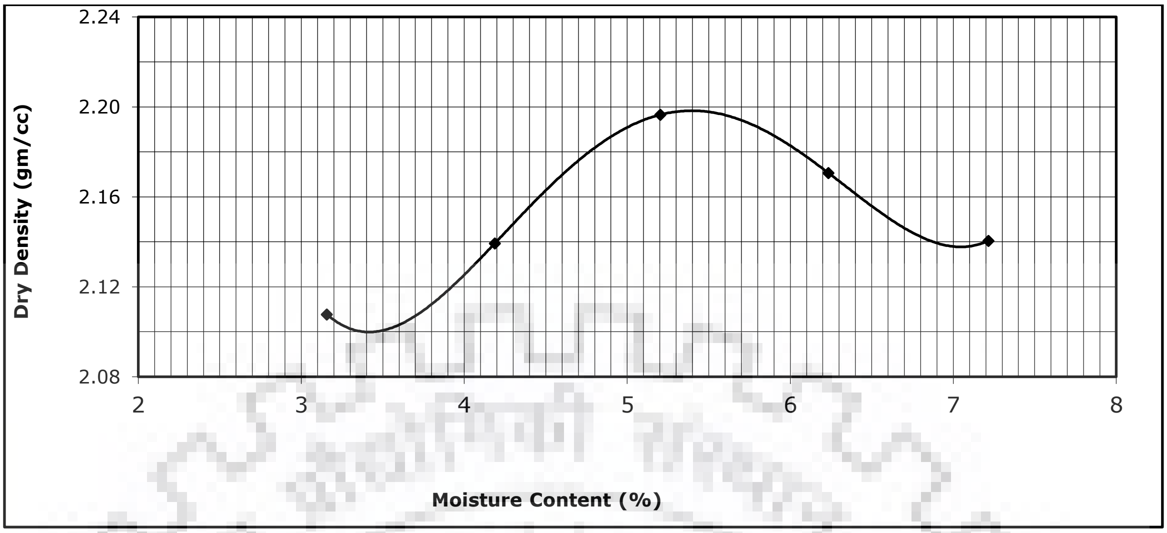

FIG 4.2: GRAPH FOR PROCTOR TEST (VIRGIN AGGREGATES)

TABLE 4.15: MODIFIED PROCTOR DENSITY TEST (VIRGIN AGGREGATES)

MODIFIED PROCTOR'S DENSITY TEST						
(As per IS 2720, Part-8)						
B	Mould:	Wt. (A) = 9490 gm			Volume (V)= 3092	
C	Trial No.	**1**	**2**	**3**	**4**	**5**
D	Wt.of wet sample + mould gm	16213	16382	16635	16620	16586
E	Wt.of wet sample (E = D-A) gm	6723	6892	7145	7130	7096
F	Wet density of sample (F = E/V) gm/cc	2.174	2.229	2.311	2.306	2.295
H	Wt.of container (gm)	171.34	174.14	167.83	133.21	139.94
K	Wt.of dry sample+Cont. gm	449.69	460.2	534.18	412.3	483.21
M	Wt.of dry sample(M=K-H) gm	278.35	286.06	366.35	279.09	343.27
N	Water content %	3	4	5	6	7
P	Dry density[P=100x(F/(100+N))] gm/cc	2.108	2.139	2.197	2.171	2.140
		M D D = 2.198 gm/cc		**O M C = 5.40**		

4.4.3. CBR TEST RESULT ON WMM:

For a particular proportion of cement and emulsion, three CBR tests were carried out and the average of the three values have been given in table 4.16. CBR gives the bearing value of the WMM mix. It is the penetration resistance value and is an indicator of the stiffness of the mix. The CBR values of WMM mix for various combinations is as follows:

TABLE 4.16: CBR VALUES(VIRGIN AGGREGATES)

S.No.	Proportion	CBR(%)
1.	0E0C	112.2
2.	2E1C	189
3.	3E1C	153
4.	4E1C	123.5
5.	2E2C	212
6.	3E2C	179.3
7.	4E2C	138.6
8.	2E3C	233.5
9.	3E3C	191
10.	4E3C	176.3
11.	0E1C	320
12.	0E2C	389.4
13.	0E3C	470.8

Generally in most of the tests conducted, the CBR value at 5mm penetration came out to be more than 2.5mm penetration and the test had to be conducted again. For this test also, the calculation and graph for all the different combinations is almost similar. Keeping this in mind the calculation and graph only for one combination out of 13 is shown in order to maintain the simplicity of the report.

If the trend in the CBR tests is discussed, then the usage of emulsion in the WMM mix has not been much satisfactory. Although the value of cement emulsion mix is has come out to be more than non cement emulsion mix, yet it can be that with increasing emulsion percentages the CBR value decreases. This is true for all the cases where cement percentages is kept fix and increase the emulsion proportion. Whereas, if emulsion proportion is kept fix and increase the cement percentage, then the value of CBR increases. Another thing that can be pointed out from Table 4.16 is that for only cement mixes if the cement percentage is increased then CBR value increases. Also, these CBR values of only cement mixes are quite higher than cement emulsion mixes. The highest CBR value for cement emulsion mix came out to for 2 %emulsion and 3% cement which is 208% of the CBR value without cement and emulsion. The overall highest CBR value came out for only cement mix with 3% cement proportion. This is about 420 % of the value without cement and emulsion

This may lead to a viewpoint to just use cement instead of cement emulsion mix in WMM but this just gives one property of the mix that is stiffness. So, other tests have also been carried out to assess the suitability of emulsion as cement emulsion mix in WMM layer of the flexible pavement. So, far the only positive that can be derived from the tests is that with inclusion of cement emulsion mix in WMM, the overall stiffness increases as compared to non cement mixes. The calculation and graph for 0% cement and 0% emulsion has been given below in table 4.17.

CBR TABLES AND GRAPHS:

1. **0E0C:**

TABLE NO. 17 :CBR TEST (VIRGIN AGGREGATES)

LOAD PENETRATION TEST DATA			
GENERAL INFORMATION	**Penetration (mm)**	**Proving ring reading**	**Corrected load(kg)**
Type of compaction used: Dynamic	0.0	0	0
	0.5	14	216.7
Period of soaking: 4 days	1.0	35	541.8
	1.5	50	774.0
Wt.of surcharge used (kg): 5	2.0	67	1037.2
	2.5	87.5	1354.5
Proving ring capacity (kN): 100	4.0	122	1888.6
	5.0	150	2322.0
Proving ring factor: 15.48	7.5	197	3049.6
	10.0	239	3699.7
	12.5	269	4164.1
	CBR at 2.5mm (%)	98.86861314	
	CBR at 5.0mm(%)	112.9927007	

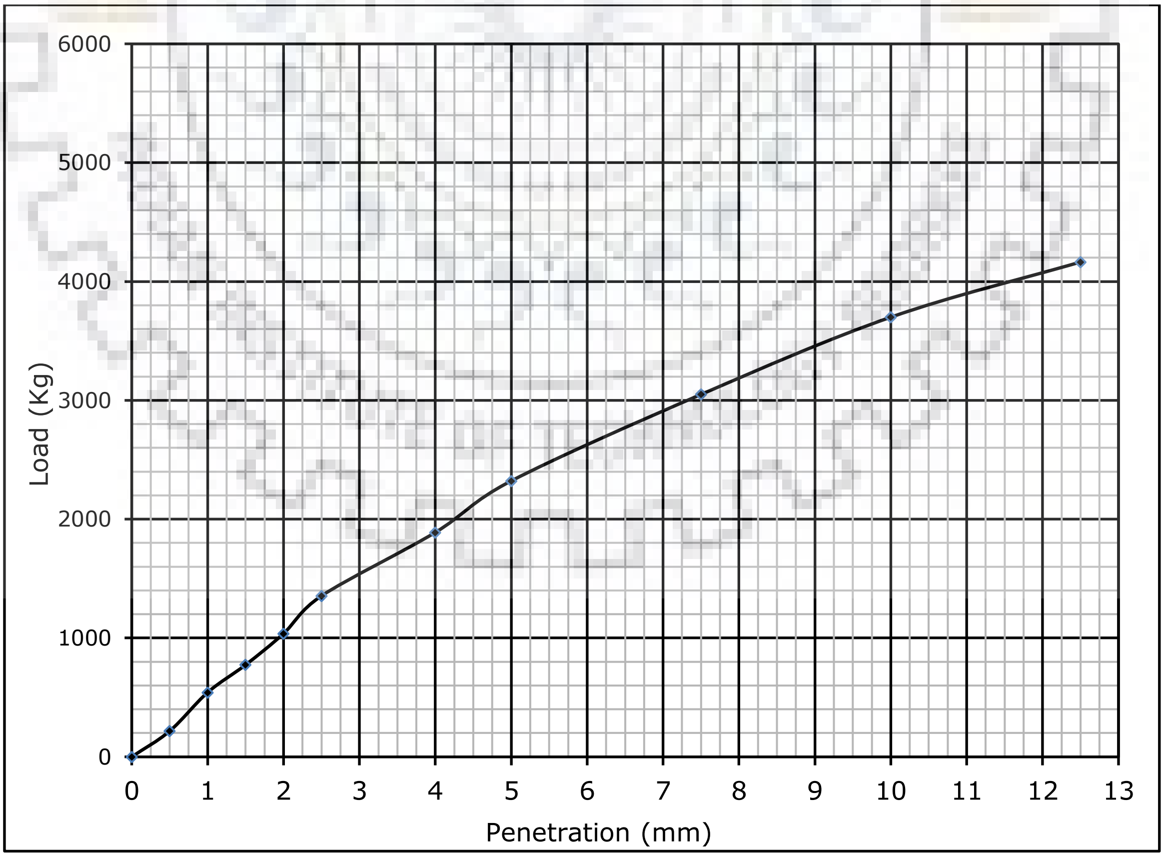

FIG. NO. 4.3 :GRAPH FOR CBR TEST (VIRGIN AGGREGATES)

4.4.4. UCS TEST RESULTS ON WMM:

The UCS value of WMM mix gives the amount of cohesion the mix possesses. It is an indicator of the shearing resistance of the mix. This test cannot be conducted for non cement emulsion mixes as they don't possess cohesion. The UCS values of WMM mixes are as given in table 4.18.

TABLE NO. 4.18 :UCS VALUES(VIRGIN AGGREGATES)

S.NO.	PROPORTION OF EMULSION AND CEMENT USED	DIAL GUAGE READING (LOAD FACTOR=2.77)	UCS (Kg)	UCS (Kg/cm^{2})
1.	2E1C	35	96.95	0.531757
2.	3E1C	47	130.19	0.714074
3.	4E1C	65	180.05	0.987549
4.	2E2C	92	254.84	1.397762
5.	3E2C	120	332.4	1.823168
6.	4E2C	141	390.57	2.142222
7.	2E3C	177	490.29	2.689173
8.	3E3C	205	567.85	3.11
9.	4E3C	280	775.6	4.25
10.	0E1C	225	623.25	3.41844
11.	0E2C	286	792.22	4.345217
12.	0E3C	340	941.8	5.165643

The above table shows that for a particular cement percentage if the emulsion dosage is increased then the UCS value increases. Also for only cement mixes, the UCS value increases with cement percentage. The increase in UCS can also be seen emulsion percent is kept constant and keep on increasing cement dosage. This increase happens as both cement and emulsion are cohesive substance and thus increase the cohesion in the mix. However, here also the UCS value for only cement mixes is greater than cement emulsion mixes. This may be because the emulsion also adds up some fluidity to the mix.

The highest value of UCS came at 4%emulsion and 3% cement dosage. By looking at these values, the role of cement emulsion can be debated over just cement mixes in the WMM layer. Still one more test is there to give a better picture on the same.

4.4.5. CONSTANT HEAD PERMEABILITY TEST RESULT ON WMM

The constant head permeability test give the drainage characteristics of the mix. It tells about the porosity and permeability. Three tests were carried out on all 13 proportions of cement and emulsion, whose average values are as given below.

TABLE NO. 4.19 :PERMEABILITY (VIRGIN AGGREGATES)

S.no	Proportion	Permeability (cm/s) *$10^{(-4)}$
1	0E0C	101.81
2	2E1C	102.76
3	3E1C	113.4
4	4E1C	129.4
5	2E2C	128.1
6	3E2C	138.43
7	4E2C	141
8	2E3C	134.2
9	3E3C	133.4
10	4E3C	152.3
11	0E1C	83.19
12	0E2C	73
13	0E3C	65.16

These test results give weight to the usage of emulsion in WMM mix as its incorporation increases the permeability of WMM. It may be helpful in high rainfall areas. Also the permeability of only cement mixes decreases drastically. This may be explained from density point of view as only cement mixes produce denser mix than cement emulsion mix which can be inferred from MDD values. The highest permeability came out at 4% emulsion and 3 % cement proportion which is 50 % more than non emulsion value. The calculation for constant head permeability test is given in table 4.20 for 0% emulsion and 0% cement proportion.

1. 0E0C: TABLE NO.4.20 :PERMEABILITY TEST(VIRGIN AGGREGATES)

Quantity(mL)	time(secs)	Permeability(cm/s)
50	6	0.010899
100	12	0.010899
150	19	0.010325
200	25	0.010463
250	32	0.010218
300	39	0.01006
350	46	0.009951
400	53	0.009871
450	61	0.009648
500	69	0.009477
Average permeability(cm/s)		0.010181

4.5.TEST ON WMM MIX (RAP AGG.)

4.5.1GRADATION

The gradation of the aggregates was determined as per IRC: 109-2015. The aggregates to be used in the mix are

1. 40 mm
2. 20 mm
3. 10 mm
4. Stone dust
5. RAP aggregates

After sieving and finding the gradation, the standard gradation for WMM mix was referred and Job Mix formula (JMF) for the mix was obtained using Rothfutch method and Hit & Trial method. From JMF it was inferred that RAP aggregates to be used were 60% of the total constituent materials. The percentages of aggregates obtained as per the JMF are as follows:

TABLE NO.4.21 :GRADATION(RAP)

PROPORTIONING OF AGGREGATES (WMM)										
Size	**75 mm down**	**40 mm**	**20 mm**	**10 mm**	**rap**	**S. Dust**	**LL**	**UL**	**MID**	**GRADATION**
53.00	0	100.00	100	100	100	100	100	100	100	100
45.00	0	100.00	100	100	100	100	95	100	98	100
22.40	0	1.38	74.76	100	98.94	100	60	80	70	75
11.20	0.0	0.00	0.08	79.66	73.42	100	40	60	50	59
4.75	0	0.00	0	1.08	22.4	99.4	25	40	33	28
2.36	0	0.00	0	0.52	9.18	94	15	30	23	20
0.6	0.000	0.00	0	0.46	3.04	58.6	8	22	15	11
0.075	0.000	0.00	0	0.46	1.46	15.7	0	5	3	3
0	0	0.00	0	0	0	0	0	0	0	0
Solution Bar										
Proportion	**0**	**0.25**	**0**	**0**	**0.6**	**0.15**				
Percent	**0**	**25.00**	**0**	**0.00**	**60.00**	**15**	Total Percent			

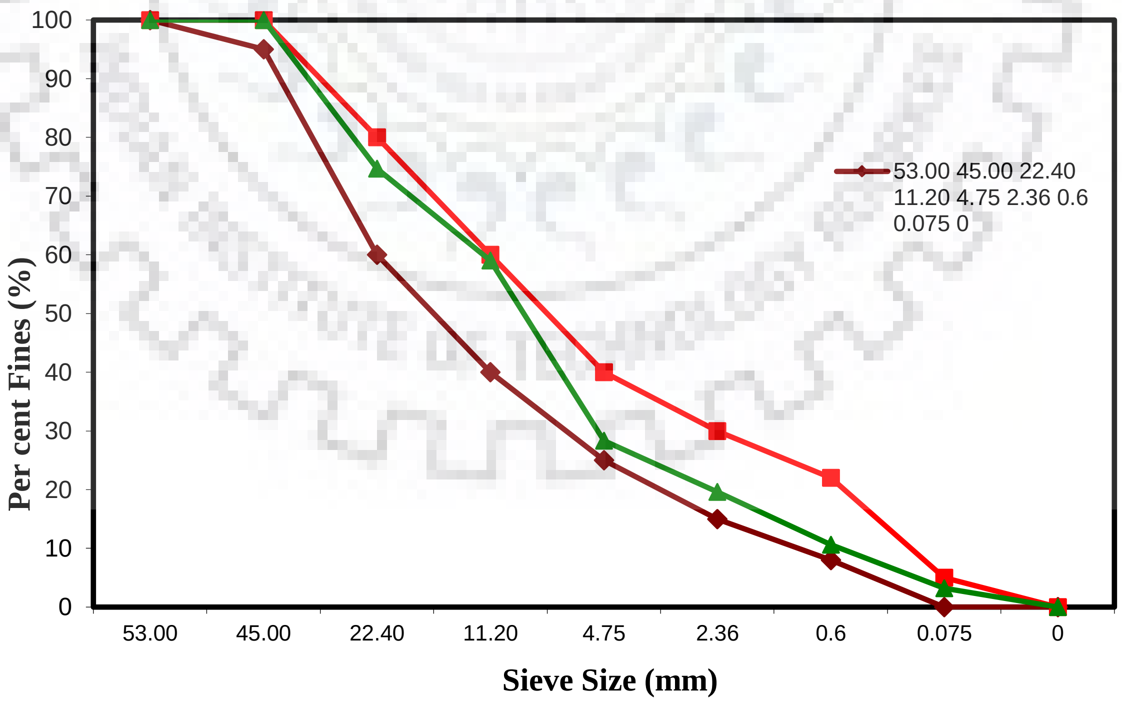

FIG. NO.4.4 :GRADATION CURVE(RAP)

The proportion of various constituents in WMM comes out to be as follows:

1. 40mm = 25%

2.Rap = 60%

3. Stone dust = 15%

4.5.2. PROCTOR COMPACTION TEST ON WMM

The final results for the density tests were as follows:

TABLE NO. 4.22 :PROCTOR TEST VALUES(RAP)

S.No.	Proportion	MDD(g/cc)	OMC(%)
1.	0E0C	2.19	5.8
2.	2E1C	2.125	7.2
3.	3E1C	2.105	7.3
4.	4E1C	2.09	7.5
5.	2E2C	2.14	6.3
6.	3E2C	2.13	6.4
7.	4E2C	2.11	6.6
8.	2E3C	2.19	5.7
9.	3E3C	2.17	5.8
10.	4E3C	2.16	5.9
11.	0E1C	2.196	7.2
12.	0E2C	2.202	7.25
13.	0E3C	2.21	7.5

The test on emulsion modified RAP mix will tell how the properties of the mix changes by changing the aggregates in the mix. In this case also, for a particular combination of cement and emulsion two tests were carried out. The average of the two readings have been mentioned in table 4.22. The calculation and graph for all the different combinations is almost similar. Keeping this in mind the calculation and graph only for one combination out of 13 is shown in order to maintain the simplicity of the report.

As can be seen in table 4.22 the value of MDD has decreased by the usage of bitumen emulsion. However, this value of MDD again increased if only cement was used . Here also, the values of MDD for only cement mixtures came out to be always higher than non cement mixture and increased with increase in cement percentage. This suggests that for the RAP case as well emulsion just adds to the volume in the mix for the same given weight and thereby decreases the density.

Another thing that can be inferred is that if the emulsion percentage gets on increasing the MDD value of the mix keeps on decreasing. This is true for all the cases tested. It can also be noted that on keeping the emulsion percentages same , the addition of cement increases the MDD value. The values of cement emulsion mix never cross the MDD value for non cement emulsion mix. In this case, the 3% emulsion and 3 % cement proportion gives the highest MDD value in cement emulsion mixtures.

For OMC values it can be seen that these values are much higher than the values with virgin aggregates. Here also the cement mixes have got higher OMC whereas the emulsion cement mixes have shown a variation as the MDD changed from one dosage to the other. For rap aggregates the values of MDD and OMC show a definite trend. These MDD and OMC values will again help in explaining the trend of tests to be discussed later, especially the drainage tests that are a result of the porosity and permeability of the mix. The calculation for 0% emulsion and 0% cement is shown below in table 4.6.

CALCULATION AND GRAPH FOR THE PROCTOR TESTS:

1. 0E0C:

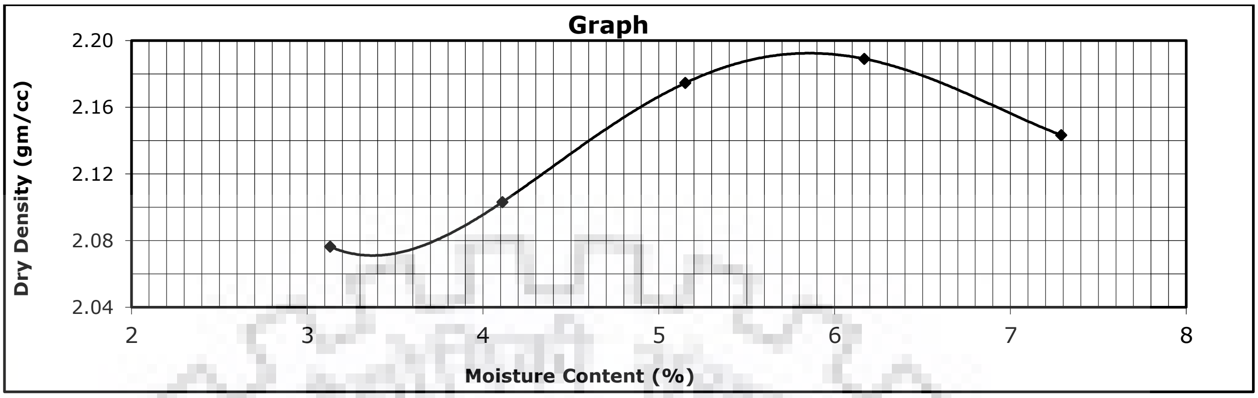

FIG. NO. 4.5 :GRAPH FOR PROCTOR TEST (RAP)

TABLE NO. 4.23 :PROCTOR TEST (RAP)

MODIFIED PROCTOR'S DENSITY TEST						
(As per IS 2720, Part-8)						
B	Mould:	(A) =9490 gm				(V)=3092
C	Trial No.	**1**	**2**	**3**	**4**	**5**
D	Wt.of wet sample + mould gm	16111	16260	16560	16676	16600
E	Wt.of wet sample (E = D-A) gm	6621	6770	7070	7186	7110
F	Wet density of sample (F = E/V) gm/cc	2.141	2.190	2.287	2.324	2.299
H	Wt.of container gm	171.34	174.14	167.83	133.21	139.94
K	Wt.of dry sample+Cont. gm	452.49	463.2	537.9	415.12	486.21
M	Wt.of dry sample(M=K-H) gm	281.15	289.06	370.07	281.91	346.27
N	Water content %	3.13	4.11	5.15	6.17	7.29
P	Dry density[P=100x(F/(100+N))] gm/cc	2.076	2.103	2.175	2.189	2.143
	M D D = 2.19 gm/cc			**O M C =** 5.80%		

4.5.3. CBR TEST RESULTS FOR WMM MIX (USING RAP)

For a particular proportion of cement and emulsion, three CBR tests were carried out and the average of the three values have been given in table 4.24.. The CBR values of WMM mix for various combinations is as follows:

TABLE NO. 4.24 :CBR VALUES (RAP)

S.No.	Proportion	CBR(%)
1.	0E0C	133
2.	2E1C	177
3.	3E1C	136
4.	4E1C	116
5.	2E2C	180
6.	3E2C	141
7.	4E2C	119
8.	2E3C	286.5
9.	3E3C	222
10.	4E3C	122
11.	0E1C	203
12.	0E2C	299
13.	0E3C	376.64

For this test also, the calculation and graph for all the different combinations is almost similar. Keeping this in mind the calculation and graph only for one combination out of 13 is shown in order to maintain the simplicity of the report.

The CBR value with rap aggregates without cement and emulsion is greater than with the virgin aggregates. In this case as well, the usage of emulsion in the WMM mix has not been much satisfactory. Again the value of cement emulsion mix has come out to be more than non cement emulsion mix. By increasing the emulsion percent and keeping cement constant the CBR value decreases. This is true for all the cases.

On the other hand, the emulsion proportion is kept fix and increase the cement percentage, then the value of CBR increases. Another thing that can be pointed out from Table 4.24 is that for only cement mixes if the cement percentage is increased then CBR value increases. The CBR values of only cement mixes in this case also are quite higher than cement emulsion mixes but less than in the case of virgin aggregates. The highest CBR value for cement emulsion mix came out to for 2%emulsion and 3% cement which is 215% of the CBR value without cement and emulsion. The overall highest CBR value came out for only cement mix with 3% cement proportion. This is about 282 % of the value without cement and emulsion

This again leads to a viewpoint to just use cement instead of cement emulsion mix in WMM. But, other test results need to be looked as well to assess the suitability of emulsion as cement emulsion mix in WMM layer of the flexible pavement. So, it can be stated that with inclusion of cement emulsion mix in WMM, the overall stiffness increases as compared to non cement mixes although it is less than CBR value for only cement case. The calculation and graph for 0% cement and 0% emulsion has been given below.

1. 0E0C:

TABLE NO. 25 :CBR TEST(RAP)

LOAD PENETRATION TEST DATA			
GENERAL INFORMATION	**Penetration (mm)**	**Proving ring reading**	**Corrected load(kg)**
Type of compaction used: Dynamic	0.0	0	0
	0.5	7	108.4
Period of soaking: 4 days	1.0	17	263.2
	1.5	35	541.8
Wt.of surcharge used (kg): 5	2.0	60	928.8
	2.5	87	1346.8
Proving ring capacity (kN): 100 KN	4.0	143	2213.6
	5.0	177	2740.0
Proving ring Identification:	7.5	248	3839.0
	10.0	307	4752.4
Proving ring factor: 15.48	12.5	332	5139.4
	CBR at 2.5mm (%)	98.30364964	
	CBR at 5.0mm(%)	133.3313869	

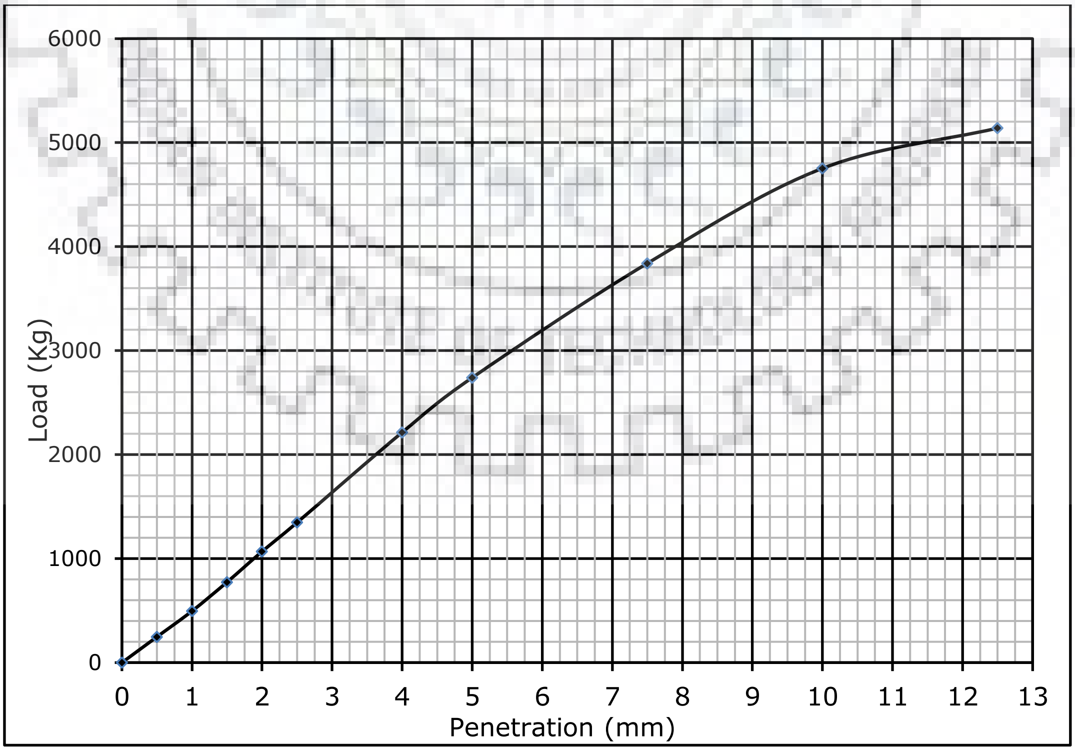

FIG.NO. 4.6 :GRAPH FOR CBR TEST(RAP)

4.5.4. UCS TEST RESULT ON WMM MIX(USING RAP)

As it is known that UCS is a test of cohesion. So, this test was not conducted for non cement emulsion mix as it doesn't possess cohesion The average UCS values of the rest 12 WMM mixes are as given in table 4.18.

TABLE NO. 26: :UCS TEST VALUE(RAP)

S.NO.	PROPORTION OF EMULSION AND CEMENT USED	DIAL GUAGE READING	UCS (Kg)	UCS (Kg/cm^2)
1.	2E1C	100	277	1.519307
2.	3E1C	202	559.54	3.069
3.	4E1C	286	792.22	4.345217
4.	2E2C	287	794.99	4.36041
5.	3E2C	301	833.77	4.573113
6.	4E2C	314	869.78	4.770623
7.	2E3C	260	720.2	3.950197
8.	3E3C	320	886.4	4.861781
9.	4E3C	375	1038.75	5.6974
10.	0E1C	280	775.6	4.254059
11.	0E2C	336	930.72	5.104871
12.	0E3C	410	1135.7	6.229158

From the above table it can be seen that for a particular cement percentage if the emulsion dosage is increased then the UCS value increases. For only cement mixes, the UCS value increases with cement percentage. Again the increase in UCS can also be seen if emulsion percent is kept constant and keep on increasing cement dosage. This increase can again be explained because of the cohesive nature of cement and emulsion. Here also the UCS value for only cement mixes is greater than cement emulsion mixes. We can also note that the UCS values with the usage of RAP aggregates has considerably increased if compared with the UCS values with virgin aggregates. The reason can be due higher of rap used or it can be debated that the weared out bitumen on rap aggregates is playing its part in imparting a better cohesion.

4.5.5. CONSTANT HEAD PERMEABILITY TEST RESULT (USING RAP)

The permeability test on rap was conducted on all 13 cement emulsion combinations. The average of 3 readings of these combinations is shown in the table 25. The calculation for one of the combinations i.e. 0%emulsion and 0 % cement is given in table 26.

TABLE NO. 27: :PERMEABILITY TEST VALUES(RAP)

S.no	Proportion	Permeability (cm/s) *10$^{(-4)}$
1	0E0C	102.55
2	2E1C	106.14
3	3E1C	138.19
4	4E1C	153.41
5	2E2C	135.1
6	3E2C	143.56
7	4E2C	148.1
8	2E3C	136
9	3E3C	134.5
10	4E3C	141
11	0E1C	97.6
12	0E2C	78.79
13	0E3C	69.5

It can be learnt from the table given above that the WMM mixes with rap are more permeable than the WMM mixes with virgin aggregates. This can be because of their lower density as obtained from the Proctor tests. It can be seen that for a fixed cement percent, the value of permeability increases with increase in emulsion percent. Another interesting point is that by keeping emulsion dosage constant, with the increase in cement percent the permeability again increases. But the permeability values for only cement mixes are fairly low .So, in rap case also the usage of emulsion WMM layer proves to be useful from the drainage aspect. This result might be helpful in high rainfall areas.

1. 0E0C: TABLE NO. 28 :PERMEABILITY TEST(RAP)

Quantity(mL)	time(secs)	Permeability(cm/s)
50	6	0.01089868
100	13	0.01006032
150	19	0.01032507
200	26	0.01006032
250	33	0.00990789
300	40	0.00980881
350	47	0.00973925
400	53	0.0098705
450	59	0.00997507
500	66	0.00990789
Average Permeability(cm/s)		0.01005538

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

To assess the suitability of emulsion cement mixture as a constituent in the WMM layer following tests were conducted :

1. Modified Proctor Density Test
2. CBR test
3. Unconfined Compression Strength test(7 days soaked)
4. Constant Head Permeability test

If divided in category, basically three types of test were run on WMM mixes:

1. Density test (Modified Proctor density test): the values for emulsion cement mixes came out to be less than only cement mixes for same cement percentage and were generally less than non cement emulsion mixes. It was not a satisfactory result. Only for 4% emulsion and 3% cement dosage alongwith using virgin aggregates a higher MDD value was obtained. The WMM mixes with rap gave lower MDD and higher OMC than with virgin aggregates.
2. Strength test (CBR test and UCS test) : Here also the results did not support the use of emulsion as the values for emulsion cement mixes came out to be less than only cement mixes for same cement percentage (although they were greater than WMM mix without emulsion and cement). The 2% emulsion and 3% cement dosage gave the highest CBR value for both type of mixes (i.e. with virgin an rap aggregates) .Whereas, 4% emulsion and 3%cement gave highest UCS value for mixes with virgin aggregates while 3%emulsion and 3% cement gave highest UCS value for mixes with rap aggregates. The WMM mixes with rap gave lower CBR values but higher UCS values than with virgin aggregates.
3. Drainage test (Permeability test): This test's results were in favour for using emulsion cement mixes as the values for emulsion cement mixes came out to be more than only cement mixes for same cement percentage. The permeability of only cement mixes reduced drastically. The permeability values for rap aggregates were higher than

values for virgin aggregates. The 4% emulsion and 3% cement value gave the best results both for mixes with virgin and 4% emulsion and 1% cement for mixes with rap aggregates.

5.2 RECOMMENDATIONS

Although the cement emulsion modified tests on WMM mixes did not produce satisfactory enough results in all the tests to call emulsion a supreme material to be used in all cases and conditions, yet there are many takeaways from it. Some of the points that could be concluded from the research work are:

1. The inclusion for emulsion in WMM surely does decrease the MDD values but gives overall higher values for CBR, UCS and Permeability tests than non modified WMM mixes.
2. If all the tests and properties of WMM mixes are taken then generally for a certain case i.e.4% emulsion and 3% cement in virgin aggregate mix and as well in rap aggregate mix better results can be seen. This can be an optimum dosage if used in the WMM mix.
3. Simply inclusion of cement emulsion in WMM layer with virgin aggregates may increase the cost of construction in normal areas but in high rainfall areas this may prove to be a boon.
4. Usage of rap aggregates in place of virgin aggregates is always an economical option and in this case using cement and emulsion would give the enhanced strength and drainage properties at lower cost. This can be a very good option for rural areas and also for high traffic conditions.