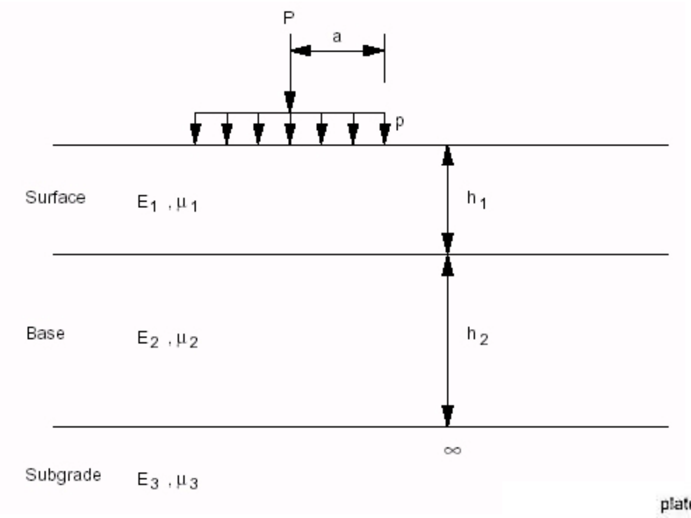
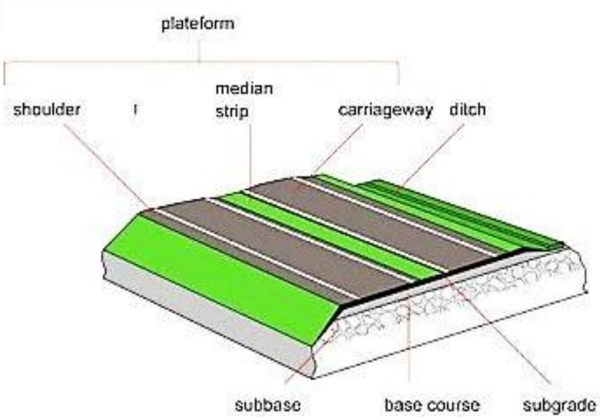
RBI Grade-81 Technology of Road Construction

Technical Manual





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जहाँ है हरियाली ।
सत्यमेव जयते वहाँ है खुशहाली ॥

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CHAPTER 1: TECHNICAL MANUAL

1.1 Introduction

This technical manual is a compilation of the field and laboratory techniques and execution practices adopted by experienced engineers and contractors in the soil stabilization industry using RBI GRADE-81. The manual includes three chapters , the first chapter discus the overall technical aspect of RBI GRADE-81 stabilizer, chapter two discuss the laboratory analysis of construction material with and without RBI Grade-81, and the third chapter gives an overview of construction methods. The basic purpose of this Manual is to highlight the detailed procedures involved in soil stabilization practice. The manual not only gives guidance for stabilization projects with RBI GRADE-81, but also provides a methodology for the applications that require unique solutions which are well within the scope of experienced consultants and contractors.

The manual is expected to recommend solutions to engineering and construction situations by gaining more understanding of the improved increased life cycle generated by the use of RBI GRADE-81. Users of the manual will observe significant "added life cycle cost" generated by the use of soil treatments with RBI GRADE-81. It provides complete engineering and construction solutions that scientifically address soil stabilization challenges using RBI GRADE-81.

The addition of various compounds such as lime and cement, into soils has been used for centuries throughout the world. The modern technique of stabilization is less than 40 years old, but considerable advances have been made in construction procedures during these past four decades. The modern method of stabilization which was improved as a result of the efforts of many engineers, contractors, and researchers is summarized as follows:

- Conventional approaches by numerous state PWD's, National Highway Authorities of different countries and applied research carried out by different Universities and Research Institutes around the world;
- Spread of Field and Research findings through international publication of research findings and construction reports of actual stabilization projects; and
- Improved Equipment Technologies after the realisation of the potential of stabilization and development of equipment tailor-made for specific needs of the project. The better equipment's improve the efficiency and quality of construction.

However, even at this stage, there is considerable lack of awareness as to what is the most durable and reliable product, and the best technology to be adopted for use for specific soil conditions and related life cycle cost economics. Very limited information is available that links up and consolidates theoretical and practical approaches about soil stabilization.

Soil stabilization or stabilization can be explained as a means of permanently consolidating soils and base materials while remarkably increasing their strength and load-bearing properties. In addition, soil stabilization will reduce the soil's water sensitivity and volume changes during wet/dry cycles in the field. To achieve the desired stability, a stabilizer must be properly incorporated into the soil. The most common methods of soil stabilization involve the use of lime, cement, or a natural soil stabilizer. However by treating the natural material (Soil) with RBI

Grade-81 resulted in a higher strength gain, greater degree of hardness, increase in bearing strength (CBR), compressive strength (UCS) and durability .Field and laboratory tests carried out indicated that changes in the physical characteristics of a soil by RBI -81 stabilization are permanent since the soil does not revert back to its original state, even after many cycles or years of weathering and service.

The manual may also be used as a training manual for civil contractors and engineers. As per most engineering and construction practices, the proper procedures have been improved through years of experience and reliable cost effective methods. The guidelines present the best construction management practices for site stabilization and soil modification using RBI GRADE-81, gained through experience.

1.2 Stabilization with RBI Grade-81

1.2.1 Purpose

A detailed criterion for improvement of the engineering properties of soils and granular materials used for pavement base courses, subbase courses and various types of subgrade and pavement layers with RBI GRADE-81 has been mentioned. When mixed with the soil / granular materials it improves the physical and engineering properties of these materials. This Manual is restricted to the use of RBI -81.

1.2.2 Scope:

The criteria for improving the engineering properties of different soil types and granular materials, procedures for determining a design treatment level for each type of soil through laboratory analysis and recommend construction practices for incorporating the RBI GRADE-81with the soil is suggested. These criteria are applicable for all types of roads and airfields where a stabilized layer is proposed to be included in pavement crust.

Note:

A. ***RBI GRADE-81 is a cementetious material suitable for stabilization of every type of soil, base and subbase layers confirming to the required gradation as per IRC specifications.***

B. ***Stabilization with RBI GRADE-81 can be carried out for pavement layer, although its use in wearing course is restricted to special cases and on approval of technology suppliers.***

1.3 Considerations for Design and Construction

1.3.1 Significance

The soil properties and their behavior should be of vital importance for construction consideration.

Soil modification and soil stabilization are basically different applications, which, although similar in technique, differ in purpose, design, and quantity of treatment required. The purpose of soil modification (the changing of soil behavior, principally through reduction in excess moisture), is to speed up construction. Stabilization is basically the improvement of a subgrade, subbase or base to withstand applied loads and to reduce its shrink/swell potential. Even though some stabilization inherently occurs in soil modification, the distinction is that soil modification is to expedite construction, whereas stabilization is part of the project design.

1.4 Soil Modification

Modification is the changing of soil behavior principally through the reduction of excess moisture to expedite construction by addition of organic and inorganic additives. Modification is commonly performed on subgrade and subbase in order to expedite compaction and subsequent paving. A wide range of problematic soils can be modified with addition of reduced quantity of the treatment product to improve its properties. Included in this category are also soils with high silt content where reduction of moisture sensitivity can be achieved. In addition to reducing excess moisture, the texture of clayey soils can be modified using a small percent of RBI GRADE-81, converting the clays into a non-plastic sand-like material that can be easily compacted. Unstable, fine-grained sand can also be treated to form a stable base. Modification may involve drying up construction sites and access roads regardless of the in-situ soil type. The common purpose for soil modification is the improvement of soil behavior, which permits other work to proceed without delay.

If drying is required in shallow depth, the subgrade soils can normally be treated in-situ. However caution should be exercised, in areas where water may have collected at greater depths. Such areas may require more additional quantities of the modifier to be mixed to greater depth, for effective bridging. The depth of modification needed to bridge a soft subgrade is generally equivalent to the depth required to stabilize the subgrade by excavation and placement of a geo-fabric, and backfilling with an aggregate material layer.

When high water table is encountered, an evaluation should be made to determine if water is infiltrating from an outside source. If the flow of water is continuous, then dewatering will be required prior to any treatment. Dewatering should be carried out to a depth of at least 300 mm below the bottom of treatment to allow for "wicking". If it is determined that the water is only perched, then areas containing any standing water should be pumped prior to treatment.

Soil modification is an effective and economical technique that expedites construction with generally modest engineering requirements. In most instances, soil modification with a proper treatment using RBI GRADE-81 will rectify adverse conditions immediately and permit construction activities to proceed as per schedule.

1.5 Soil Stabilization

Soil stabilization is the construction of a higher load-bearing subgrade or subbase/base for a strong base for a flexible or rigid pavement. The basic purpose based on a laboratory mix design, is to increase compressive strength and to reduce swell potential. Although the construction methods and techniques are similar to those used in soil modification, there are significant important factors which govern soil stabilization. In case the treatment is for the purpose of soil stabilization to increase soil strength or to lower plastic index, the consultant must develop a mix design by sampling and testing materials and percentages of RBI GRADE-81 required. Soil samples should be collected from the site location, taking into account the variable soil conditions. The mix design should be conducted well in advance of construction.

It is the job of Laboratory technicians to develop the mix design for a stabilization project based on established testing procedures. Laboratory testing will vary depending on the intended purpose of the treatment. For the purpose of pavement, the laboratory tests should be conducted to determine improvements in the unconfined compressive strength with different percentages of RBI GRADE-81. Soil stabilization has been established to provide substantial cost-saving for pavement design by way of reduction in pavement cost. This treatment will increase the load-bearing capabilities of marginal subgrade materials, therefore decreasing the amount of aggregate base required for the pavement. The stabilization process has proved to be a structural and economic solution, for correcting unexpected, poor pavement support conditions.

1.6 How does RBI GRADE-81 React?

- **Reaction Mechanism**

The use of RBI GRADE-81 in road projects is recognized as an extremely effective method of converting poor quality soil into a strong and relatively impermeable layer. It permits the construction of pavement layers, embankments and reinforced earth structures in areas where they were not previously viable, while saving significant good construction material and time.

RBI GRADE-81 is calcium driven, inorganic soil stabilizer patented worldwide. Its specific formulation allows for stabilization of a broad range of materials without compromising the quality of the result.

The main components that are used to formulate RBI GRADE-81 are a series of inorganic hydration activated powders. It is composed of a specific type of cement, a lime, several pozzolonas, rate governing additives, and a unique polypropylene fibre. The specific formulation allows for the individuality of the components to contribute to the reaction process, but also act holistically contributing of the stabilization process.

The theory behind their reactivity is quite simple, but the chemistry of each individual powder differs and the collaborative reaction is quite complex. Each component reacts individually while also contributing to the broader stabilization reaction. Each component contained in RBI GRADE-81 has its own series of reactions that occur at varying rates, which can be broken down into initial, short term and long term reactions.

A summary of the initial hydration reaction are as follows:

- *Additional of water initiates the hydration of all RBI GRADE-81 components,*
- *Lime mix dissolution creates excess Ca-ions and OH-ions,*
- *OH-ions increase the pH of the soil solution, in so doing activating the pH dependent sites on clays,*
- *Ca-ions interact with excangeable and pH dependent sites on clays, forming calcium silicates and calcium aluminates hydration products,*

- *hydration of calcium is very rapid,*
- *calcium will form from nucleation sites to cast the soil particles into an interconnected matrix,*
- *Ca-ions from the special cement mix hydration, along with Ca-ions from the lime mix hydration, will Activate the slang component,*
- *C_3A hydration is initiated,*
- *calcite formation will be limited due to the reduced nature of porosity,*
- *initial reaction will end with the final setting time of the lime mix approximately 120 minutes from addition of water.*

RBI GRADE-81 is mixed with the soil as a dry powder. Initiation of hydration will commence immediately upon addition of water. The importance of achieving the desired water content is required not only for hydration of the components contained in RBI GRADE-81, but also for wetting the reactive soil particles sufficiently to allow for exchange reactions to take place. Dissolution of $Ca(OH)_2$ will provide an excess of Ca-ions in the soil solution. These divalent ions will incorporate themselves into the clay structure, which provides a starting point for calcium silicate and calcium aluminate reaction products to form. Due to the cation effect, calcium is a difficult ion to replace on the exchangeable sites of clay. Therefore, it will remain in the clay structure. The presence of calcium in the crystal structure of clays allows for other clay particles to form bridging covalent bonds, forming insoluble calcium silicates and a starting point for alumina-silcate bridges. These bridges form an integral part of the inter-particle crystal matrix. Due to the phases contained in RBI GRADE-81, there is a considerable rise in the pH of the system. This increase in soil pH will activate the pH dependent sites on the surfaces and edges of clay particles. This will also provide a key site for combining with other soil particles creating a link between the micro and macro structure of the soil. One of the first reactions to take place is flocculation of the clay particles, which is associated with an immediate reduction (or elimination) in the plasticity (PI) of the soil. The 'aggregation' of the fine fraction leads to stability within the layer. Following flocculation, medium to long term reactions begin and secondary reaction products form as shown in Photo 1.1 and 1.2

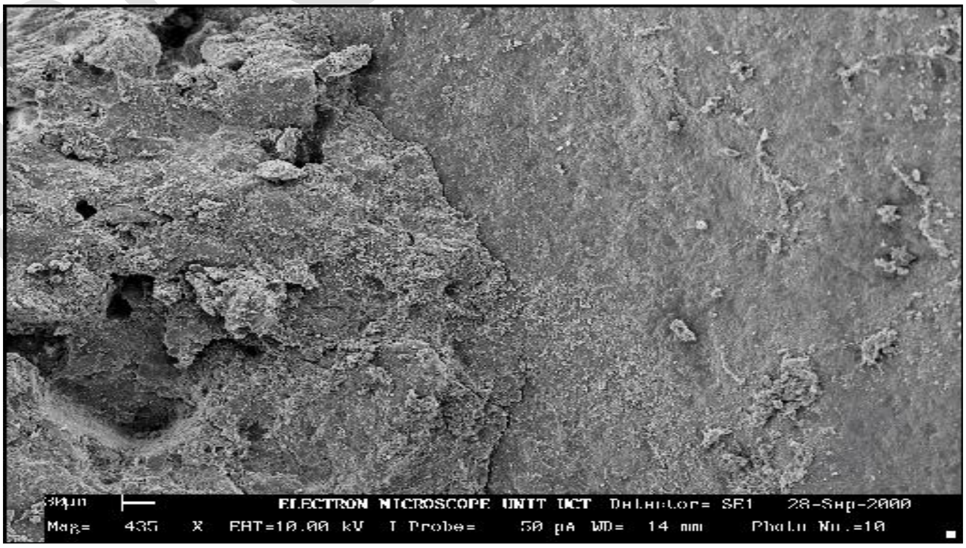


Photo 1.1: Low magnification SEM image of a silty soil and the intensive inter-particle matrix hat has been formed and its close binding to the lager sand-sized grain.

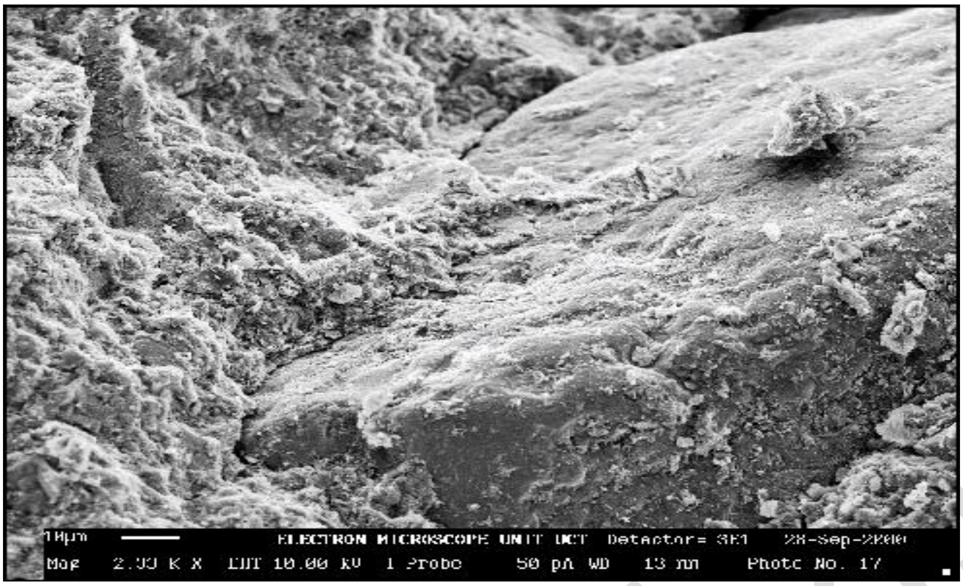


Photo 1.2: The matrix, which is composed of reacted clay particles and RBI Grade81, illustrates the linking of the microstructure to the macro-particle

The reaction mechanism of RBI GRADE-81 follows a hydration process, in characteristics to lime and cement. Water, or better put, moisture initiates the reaction process of RBI GRADE-81. The initial stages of reaction are very important to the success of RBI GRADE-81 soil stabilization; however, the strength of the stabilized layer is achieved over a long-term time frame. The strength gain within the initial stages is rapid which allows for the road to be opened shortly after final compaction. Upon completion of final compaction, the stabilized road can be opened/re-opened to traffic. Although the kind of traffic and the permission to ply on freshly stabilized pavements are subject to necessity and permission of engineer in charge. There are cases where certain stabilized surface demands more time to gain strength otherwise, in general the compaction induced by the load of traffic further enhances the compactive effort and the resultant strength of the surface. It is important to note that the strength results obtained in the laboratory often differ positively from those obtained in the field (in-situ). The logic behind is that in a laboratory the trial is performed on a cylinder of a specific dimension and allowed to cure. The lab core (unconfined) is exposed to atmospheric conditions from everywhere but the base of the core, allowing for rapid hydration due to the high evaporation rate. The more rapid rate of evaporation leads to suboptimal crystal growth (although sufficient enough under the conditions to stabilize the soil effectively) but, when soil is stabilized in-situ, only the surface is exposed to environmental conditions, allowing for slower hydration and optimal conditions for inter-particle matrix growth. Scanning electron microscope (SEM) studies of the stabilized soil reveal the effectiveness of RBI GRADE-81 in filling the pore spaces between soil particles in photo 1.3 below

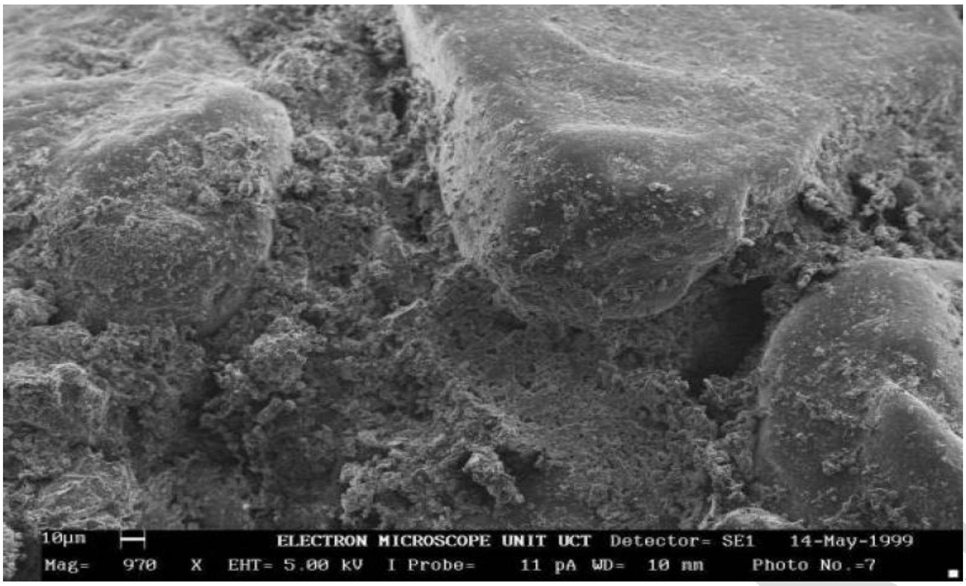


Photo 1.3: RBI Grade-81 in filling the pore spaces between soil particles

1.7 What Should a Stabilizer Do?

Amongst many requirements of stabilization the chief properties of a soil with which the construction engineer is concerned are volume stability, strength, permeability and durability. These factors, when taken into account, outline the potential of a soil stabilizer with respect to the success as well as cost effectiveness.

- **Volume stability :-**

Soil with a high content of clay can possess shrink-swell properties brought about by changes in moisture content. To overcome this negative aspect the stabilization alternative is to convert the soil to a rigid or granular mass by binding the soil particles sufficiently strongly to resist the internal swelling pressure of the clay. Alternatively, to reduce the shrink-swell potential, the movement of moisture within the soil must be retarded, which can be achieved through blocking the pores. Both aspects are achieved through stabilization with RBI Grade-81. The only means by which a clayey soil may be converted into a rigid mass is by chemical or thermal treatment. There is no suitable method to stabilization for overcoming the disruptive effects of moisture in an expansive soil and no better stabilization option than the use of RBI Grade-81. Intensive testing of RBI Grade-81, both within the laboratory and through project applications, has shown that through the addition of RBI Grade-81 the shrink-swell potential of the soil is reduced. Along with moisture sensitivity, RBI Grade-81 also makes the layer relatively impermeable.

- **Strength :-**

One of the most important aspects of road design is the strength of the layer, as this is essentially the backbone of the reason for road construction. Durability and strength of the soil are directly related; however inadequate strength is a soils problem, whereas the durability is the long-term solution. Methods for increasing soil strength are those that lead to transformation of the soil into a rigid mass. Through the addition of RBI Grade-81 the mechanical properties of a soil can be easily improved even at low dosages. The strength parameters majorly measured are CBR and UCS.

- **Durability :-**

Durability represents the long term resistance of the stabilized layer to the action of abrasion due to traffic yields, weather conditions and natural forces. Soil with a low durability requires upgrading to establish a system with a better longevity. Poor durability can result from many aspects of an inferior design, such as a wrong choice of stabilizer (i.e. the wrong response spectrum) or insufficient dosage of stabilizer. An example of poor durability often occurs with the addition of cement to stabilized soils with an abundance of soil sulphates. The addition of cement in the presence of a high concentration of sulphate ions produces detrimental sulphate salts that have large volumes that can lead to curing cracks. Detrimental salt creation includes tobomorite and ettringite, a calcium aluminium sulphate, which have very large and expansive volume due to the hydrated nature of the molecule. It is these salts that create cracking and eventual failure in cement stabilized systems. Further, because RBI Grade-81 does not have the same negative nature, cracking does not occur due to the fact that no ettringite creation is established. The addition of RBI Grade-81 increases the durability of soils over the entire response spectrum. The testing of in-situ cores taken from trafficable RBI Grade-81 roads have shown results appreciably lower than the most stringent requirements for road design.

1.8 Response spectrum and soil types

Portland cement is generally used on low PI soils when early strength is required. Cement is self-hardening, therefore when water is added it is effective in stabilizing soils such as sands and gravels due to the fact that OPC adds as filler and not directly forming chemical bonds with the quartz grains that are present in the system. In this regard, OPC is commonly used with soils that have a plasticity of 10 or less (preferably when used in stabilizing a soil with relatively high plasticity cement may cause a reduction in the PI after treatment, but full modification may not take place and will result in failure of the “stabilized” layer. One of the major problematic aspects of stabilizing soils with cement is during the compaction of soils that contain a higher PI than what should be complemented with such a product. It must be appreciated that a high PI soil will not be completely modified prior to the completion of compaction, which is detrimental due to the high importance on achieving a high level of compaction. Such a process will result in low strengths and undesirable cracking. The addition of cement to a soil with a high percentage of soil fines (clay) will result in, after hydration, expansive ettringite crystallization. Such formation will lead to expansion forces beyond the bearing capacity of the soil and inevitably resulting in cracking. Production of cracks is the beginning of the end for any stabilized layer, as water is able to penetrate the layer and cause irreparable damage. RBI Grade-81 has been tested on a suite of soils ranging from highly plastic to nonplastic sandy soils. All tests have shown commendable results and substantial initial strength gain due to the hardening of the soil that occurs through the formation of the inter-particle crystal matrix. Like cement, RBI Grade-81 does not necessarily need a fine component within the soil for stabilization to be achieved. This can be seen in the Scanning Electron Microscope (SEM) image in Photo 1.4 below

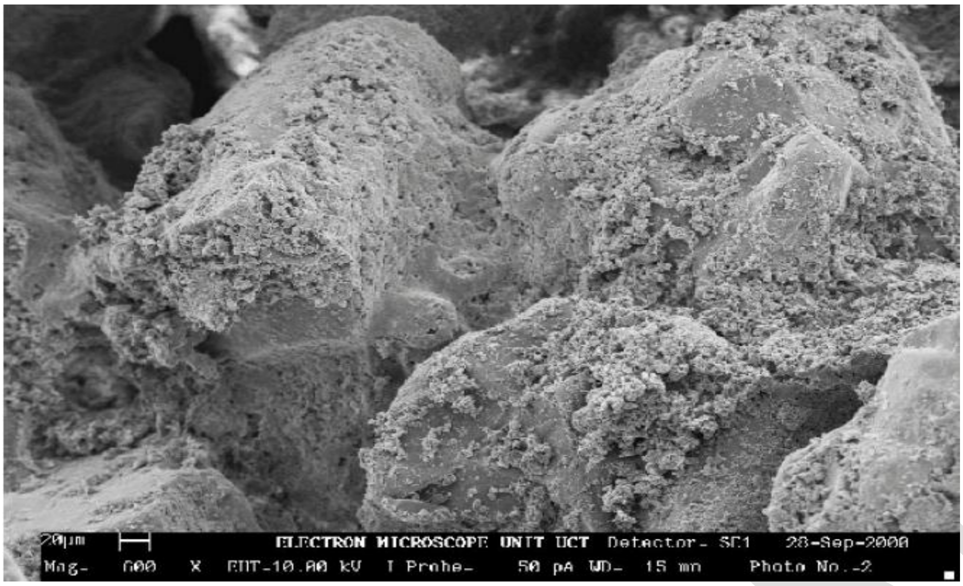


Photo 1.4: Non-plastic soil stabilized with RBI Grade-81

The extensive inter-particle matrix of the hydration products of RBI Grade-81 successfully links the inert sand grains to each other without the requirement of an extensive clay fraction. If a soil fine content is present, however, the stabilization reaction of RBI Grade-81 is not hindered and in fact can be accentuated to a level of increased reaction. Photo 1.5 below shows stabilization of Plastic soil with RBI Grade-81.

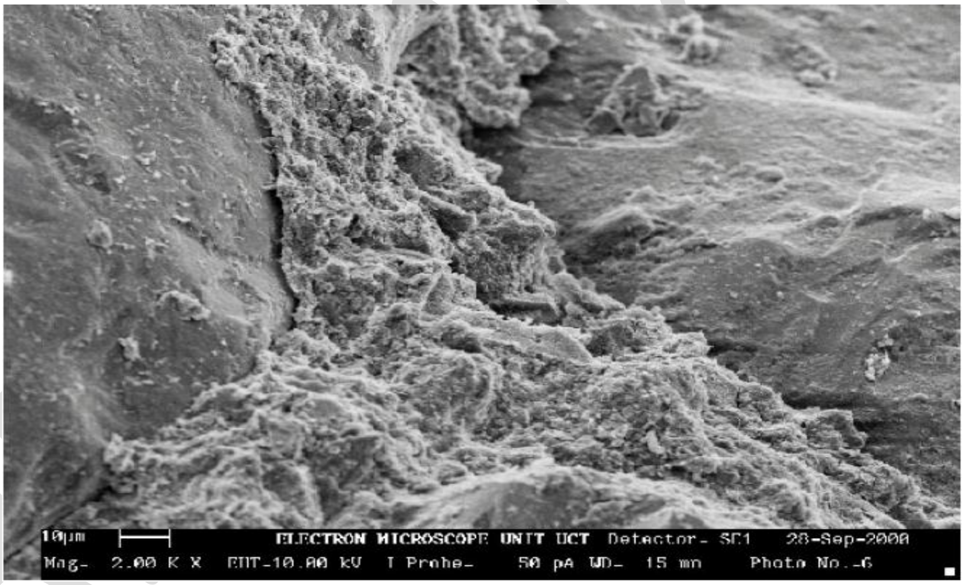


Photo 1.5: Plastic soil stabilized with RBI Grade-81

Due to the variable nature of soils, which can change within several meters of the same application, the selection of a soil stabiliser is governed by its “response spectrum”, the number and type of soil in which it has been effective in stabilizing. Soil stabilization with RBI Grade-81 provides the most opportune response spectrum, as it allows for the soil to undergo dramatic changes without the risk of limiting the success of the project at hand. Table 1.1 below displays the extent of maximum efficacy of a range of soil stabilizer’s, which highlights the advantage of using RBI Grade-81 because of the wide range of soil type to which it achieves success. Response spectrum for a range of soil stabilizers is the range over which a soil stabiliser can be used is not the only criteria for its acceptability, as the durability, cost, and ease of application also require consideration

Table 1.1: Response spectrum for a range of soil stabilizer's

Soil Type		Fine Clay	Coarse Clay	Fine Silt	Coarse Silt	Fine Sand	Coarse Sand
Particle Size (Microns)		< 1.5	1.5 - 2	2 - 10	10 - 60	60 - 500	500 - 2mm
Volume Stability		Very Poor	Fair	Fair	Good	Very Good	Very Good
Stabilizers	Cement						
	Lime						
	Bitumen						
	RBI Grade 81						

1.9 Research Study done Outside India

1.9.1 Report number SBF IN F08013, done by SINTEF in the year 2008, [3], reads "RBI GRADE-81 was tested for a common Norwegian material with 2%, 4% and 6%. The durability test results indicated very good resistance with 6%, good resistance with 4% and moderate /poor resistance with 2%.

1.9.2 The "TCLP and Modified Leaching Assessment of RBI Grade - 81 natural Soil Stabilizer and its Effect on the Environment" [4] report reads that the leaching report on RBI Grade-81 have shown that there is no risk involved or contamination of surrounding water bodies and soils from heavy metal leaching. As there is no addition to RBI Grade-81 layers of heavy metals there is zero risk of contamination to the surrounding soils, and in fact with the increased pH of the stabilized matrix the risk of movement of heavy metals from the material is lowered even further. Heavy metals that would be contained in the soil prior to addition of RBI Grade-81 would be immobilized as well through the increased pH of the soil environment. The amount of heavy metals to leach through a stabilized system (if leaching could occur) would most likely be less than that of the leached un-stabilized in-situ soil. Leaching test both modified and international, highlight the low environmental threat that RBI Grade-81poses. Result indicated that even if leaching was to occur, which is extremely unlikely, the leachate will be of such a low level of threat that it would not affect any surrounding body of water (groundwater) or cause toxicity to the surrounding ecosystem. Due to RBI Grade-81's non toxicity it was awarded the Green Label from the Ministry of Environment and the Standards institute is Israel.

1.9.3 The **"Interim Report on the first stage of laboratory tests for characteristics of soils used for road bases stabilized with RBI Grade-81 Stabilizer manufactured by Road Building International "tested by "DORSERVICE Testing Center, OJSS, St. Petersburg in the year 2008" [5]** that included the study of borrowed sandy soil with RBI Grade-81 stabilizer for compressive strength and frost resistance as per GOST. The outcome reads "the test combination of soil with 5 % and 7 % RBI GRADE-81 confirms to GOST 23558, grade M10 and M20, respectively. The same combinations also confirms to GOST 23558, grade F5 and F10 for frost resistance". It concludes that the stabilized material can be used in pavement base course to preserve flatness of the road surface.

1.9.4 Report on "The use of RBI Grade-81 material in virgin and secondary aggregate stabilization" by Pavement Technology Limited, [6] reads "the study can be classified into three categories, i. crushed rock aggregate and RBI GRADE-81, ii. Crushed rock aggregate, PFA (Pulverized fuel ash) and RBI Grade-81 and iii. Secondary Aggregate with RBI Grade-81, including dust, silty-sand and other aggregate. The report says "all the mixes made with RBI Grade-81 performed in a manner different from other well-known hydraulic binders such as cement such as cement or lime. The lime stabilization is a slow process and requires special soil (clay mineral) with a high pH value. The gain in strength with RBI Grade-81was reasonably quick enough to rank the material among the cement group, but that contradicts the tendency of the material to perform well with fine grained particles rather than crushed rock aggregate. Cement performs very well with graded crushed rock aggregate whilst the RBI Grade-81 performs better when PFA is present or silty material available within mixture. Such behavior is comparable to lime stabilization. In other words the RBI Grade-81has the combined effect of both cement and lime. Such combinations make the RBI Grade-81 capable of stabilizing a wide range of aggregate (virgin aggregate and the recycled material).

1.10 Research Study done in India

1.10.1 "Feasibility Study on the Use of RBI Grade-81 Cementation Material in Road Construction, year 2007" by Central Road Research Institute (CRRI) New Delhi [7]. In the study four type of soil classified as gravely, sandy, silty and clayey are combined with different dosage of RBI Grade-81 varying from 2% to 12% to test for CBR, UCS and Durability. The test were conducted as per prevailing IS and ASTM codes. The CBR of gravely soil improved from 30% to 234% at dosage of 6%, in case of silty soil the improvement at 6% RBI Grade-81 increased to 268% from 8%. The Clay and sand CBR improved from respective 4% and 22% to 129% and 79% at 12% RBI Grade-81. Gravel and silt soils sample also passed the durability test at 6 and 4% respectively, this dosage is recommended for construction of sub base and base .

1.10.2 "Laboratory Studies on Properties of Soil Treated with RBI Grade-81 Stabilizer" Done at RASTA, Center for Road Technology, under Prof. C.E.G Justo[8]. The involved four different kind of soils namely, black cotton, red loamy, silty sand and gravely soil. The study involved plasticity characteristics, CBR and UCS. The black cotton soil showed an improvement of 47% at 4 % when tested for PI. CBR increased by 1100% at 6% RBI Grade-81 and the UCS value raised by 353% with 4% RBI Grade-81. Similar and even better trends are observed with other three types of soils.

1.10.3 "Use of RBI Grade-81 for Soil Stabilization and Pavement Rehabilitation" done at IIT Kharagpur in 2008, Under Dr. M. Amaranatha Reddy, [9]. The study involves the characteristics of local soil found in IIT kharagpur campus with varying dosage of RBI Grade-81. The tests conducted in this study were mainly confined to CBR, UCS, Resilient modulus and durability. The CBR of soil improved from 3% to 102% with 6% RBI Grade-81. The UCS value improved from negligible to 9.13 MPa at 28 days curing with 8%RBI Grade-81. The Resilient modulus values obtained with 4% and 6% RBI Grade-81 are 2078 MPa and 2311MPa respectively. The durability test indicated similar results even with 2% RBI Grade-81. The study concluded that "RBI Grade-81 in general can be used for improving subgrade properties as well as for rehabilitation of damaged pavement by replacing some portion of aggregates with soil and RBI Grade-81".

1.10.4 "Stabilization of expansive soils using RBI Grade-81", by Dr. R. G. Robinson, IIT Madras, May 2007[10]. The major tests conducted in the study were mainly CBR and UCS. A highly expansive type soil was used to study its behavior using RBI Grade-81within the range 4% to 8%. The soil tested had a PI of 40 and FSI of 80%. The CBR value increased from 1.9% to 108% at 8% RBI Grade-81, at the same dosage the swell potential came down to 0. The unconfined compressive strength improved from 580kPa to 1520kPa at 28 days with 6% RBI Grade-81.

1.10.5 "Performance Evaluation of Cold Recycling Experimental Stretch Constructed with RBI Grade-81 at Bangalore University" IJRET, November, 2013[11]. The Study stretch selected is divided into three sections of length 50m, 100m and 100m treated with 4.5 and 6% RBI Grade-81 respectively. The analysis done after 1 year of construction is done using Geogauge, DCP and BBD. Geogauge showed the CBR % of 173 for section 1 and 400 for section 3. The CBR values with DCP are 435,646 and 715% in stretch 1, 2 and 3 respectively. The BBD values are less than 1 in all three sections. The study concludes that based strain analysis, the stretch can perform well for design life of 10 years. The study recommends adopting Cold in-situ recycling using RBI Grade-81, instead of reconstructing the damaged existing pavement by conventional construction practice.

1.10.6 "Study on Strength Characteristics of Soil Using Soil Stabilizer RBI Grade-81", IJERT, April 2014, pg.201 [12]. The study involves the analysis of two highly compressible clays with and without RBI Grade-81. The dosage of RBI GRADE-81 is restricted to 2, 4 and 6%. The unconfined compressive strength test and SEM analysis are conducted in this report. The UCS results with increased dosage and curing period showed better strength, the value at 6% improved by 4.37 times when compared with untreated soil . The SEM analysis showed formation of cementetious compounds C-A-H and C-S-H.

1.11 Benefits of RBI Grade-81

A. Engineering

- Increases the California Bearing Ratio (CBR) manifolds.
- Increases Unconfined Compressive Strength (UCS) considerably.
- Increases Modulus of Elasticity value, which results in reduction of pavement crust.
- Reduces Plasticity Index (PI) value.
- Reduces Free Swelling Index (FSI) value.

B. General Benefits of RBI Grade-81

- By strengthening the existing soil by 12 to 20 times the initial strength, it helps in replacing the conventional aggregate layers with soil stabilized layers, thus saving aggregate. It also reduces the quantity of bitumen in road construction.
- Since it reengineers any kind of soil and stabilizes it with increased strength, it eliminates removal and carriage of in-situ soil and replacing it with better soil suitable for construction.
- By using in-situ soil, it reduces the need to transport good soil & aggregate by about 40%-60%, thus reducing the carbon emission from the trucks.
- The treated areas are comparatively impermeable by water, thus preventing damage to the road foundation.
- Due to the reduced construction time, air pollution by heavy suspended particles is reduced considerably.
- Durability is increased thus the need for continuous maintenance is reduced.
- RBI Grade-81 technology is very simple and does not require skilled labor.
- RBI Grade-81 can also be used for cold recycling of existing pavement (flexible or rigid) layers, thus saving natural resources, as 90% of road material is being reused.

CHAPTER 2: TESTING MANUAL

2.1 Introduction

The main aim of these tests is to establish firstly, the type and engineering properties of the construction material (Soil/Aggregate/RAP) which is to be treated with RBI Grade-81, for the necessary improvement thereof in order to meet the specified requirements for its intended usage and secondly to achieve, by treating the construction material (Soil/Aggregate/RAP/Combination of Construction material) with RBI Grade-81, The test are performed primarily as per Indian standard. The international standards are also used whenever required.

The obtained engineering parameters are cross referred to Indian /international codes in practice for durable pavement design.

Annexure "2A" is for information purposes only and contains flow charts of procedures for testing the natural (untreated) soil, treated soil and relevant field tests to assist and guide the users.

Note: - In this Manual the various construction material such as aggregate, stone dust, RAP etc. will be referred as soil. The percentage of RBI grade- 81 is decided by the laboratory engineer based on soil classification and experience and it could be from 2 to 8%. The test procedures other than that of soil will be as per prevailing IS codes. All the test procedures must be followed as per the instructions of Engineers/Representative from Alchemist Touchnology Ltd.

2.2 Description of Engineering Properties to Be Tested and List of Test Methods

2.2.1 Grain-Size Analysis

It is a determination of the distribution of particles in a representative sample as a gravel, sand and silt & Clay. A lack of coarse or fine particles in the composition of a soil will produce an unbalanced grading or distorted grading curve resulting in poor mechanical stability due to insufficient packing of the particles, resulting in a high percentage of voids and thus unsatisfactory compaction. An improvement in the soils grading and the reduction of oversize material will enhance the stabilization effect by allowing more uniform strength development, higher density and a high mechanical stability. See "Annexure B" for the recommended grading envelope for Gravel Courses. By the Grain-Size Analysis we calculate the coefficient of uniformity.

Procedure: Soil sample as received from the field shall be dried in the air or in sun. In wet weather a drying apparatus may be used in which case the temperature of the sample should not exceed 60°C. The clods may be broken with a wooden-mallet to hasten drying. The organic matter, like tree roots and pieces of bark should be removed from the sample. Similarly, matter other than soil, like shells should also be separated from the main soil mass. A noting shall be made of such removals and their percentage of the total soil sample noted. The soil fractions retained on and passing 4.75-mm IS Sieve shall be taken separately for the analysis. The portion of the soil sample retained on 4.75-mm IS Sieve shall be weighed and the mass should recorded. The quantity of the soil sample taken depends on the maximum particle size contained in the soil.

The sample shall be separated into various fractions by sieving through the Indian Standard Sieves. While sieving through each sieve, the sieve shall be agitated so that the sample rolls in irregular motion over the Sieve. Any particles may be tested to see if it will fall through but it shall not be pushed through. The material from the sieve may be rubbed, if necessary, with the rubber pestle in the mortar, taking care to see that individual soil particles are not broken and re-sieved to make sure that only individual particles are retained. The quantity taken each time for sieving on each sieve shall be such that the maximum weight of material retained on each sieve at the completion of sieving does not exceed the specified values. The mass of the material retained on each sieve shall be recorded.

For further analysis a fresh portion of the fraction passing 4.75-mm IS Sieve shall be taken, the portion of the soil passing 4.75-mm IS Sieve obtained shall be oven-dried at 105 to 110°C. The riffled and weighed fraction shall be spread out in the large tray or bucket and covered with water. Two grams of sodium hexametaphosphate or one gram of sodium hydroxide and one gram of sodium carbonate per liter of water. The mix should be thoroughly stirred and left for soaking. The soil soaked specimen should be washed thoroughly over the nest of specified sieves as shown in Photo 2.1. Washing shall continue until the water passing each sieve is substantially clean. Care shall be taken to see that the sieves are not overloaded in the process. The fraction retained on each sieve should be emptied carefully without any loss of material in separate trays. Oven dried at 105 to 110°C and each fraction weighed separately and the masses recorded. The cumulative mass of soil fraction retained on each sieve shall be calculated. The percentage of soil fraction retained on each sieve shall be calculated by the total weight of sample.

Photo 2.1: Wet Sieving in Progress

Report: The results of the grain size analysis shall be reported in a suitable form. A recommended *proforma* is given in Annexure 2C. A grain size distribution curve shall be drawn on a semi-logarithmic chart, plotting particle size on the log scale against percentage finer than the corresponding size on the Ordinary scale. See the below given table 2.1 for grain size criteria.

Table 2.1: Acceptance Criteria

4.75mm	2mm		.425mm	0.075mm
Gravel	Sand			Silt & Clay
	Coarse	Medium	Fine	

2.2.2 Liquid and Plastic Limits

The liquid limit of a soil is the moisture content, expressed as a percentage of the weight of the oven-dried soil, at the boundary between the liquid and plastic states of consistency. The plastic limit of a soil is the moisture content, expressed as a percentage of the weight of the oven-dry soil, at the boundary between the plastic and semisolid states of consistency. Plasticity gives an indication of the soils clay reactivity (active clay content) and affinity to water (moisture content), which effects the variability in strength development and the possible need for determining optimum dosage of the RBI Grade-81 in order to neutralize the effect thereof. The Liquid Limit and Plastic Limit test are conducted in order to obtain the value of PI (Plasticity Index).

- **Liquid Limit:**

Procedure: There are two methods for determining the liquid limit.

i. **Mechanical Method:** A sample weighing about 120 g shall be taken from the thoroughly mixed portion of material passing 425-micron IS Sieve. Soil sample shall be mixed thoroughly with distilled water in the evaporating dish or on the flat glass plate to form a uniform paste. The paste shall have a consistency that will require 30 to 35 drops of the cup to cause the required closure of the standard groove. In the case of clayey soils, the soil paste shall be left to stand for a sufficient time (24 hours) so as to ensure uniform distribution of moisture throughout the soil mass. The soil should then be re-mixed thoroughly before the test. A portion of the paste shall be placed in the cup above the spot where the cup rests on the base, squeezed down and with as few strokes of the spatula as possible and at the same time trimmed to a depth of one centimeter at the point of maximum thickness, returning the excess soil to the dish. The soil in the cup shall be decided by firm strokes of the grooving tool along the diameter through the center line of the cam follower so that a clean, sharp groove of the proper dimensions is formed. In case where grooving tool, Type A does not give a clear groove as in sandy soils, grooving tool Type B or Type C should be used. The cup shall be fitted and dropped by turning the crank at the rate of two revolutions per second as shown in photo 2.2,until the two halves of the soil cake come in contact with bottom of the groove along a distance of about 12 mm. The number of drops required to cause the groove close for the length of 12 mm shall be recorded. A little extra of the soil mixture shall be added to the cup and mixed with the soil in the cup. The pat shall be made in the cup and the test repeated. The procedure shall be repeated until two consecutive runs give the same number of drops for closure of the groove. A representative slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right angle to the groove and including that portion of the groove in which the soil flowed together, shall be taken in a suitable container and its moisture content should be expressed as a percentage of the oven dry weight. The remaining soil in the cup shall be transferred to the evaporating dish and the cup and the grooving tool cleaned thoroughly. This procedure shall be repeated for at least three more trails on the soil collected in the evaporating dish or flat glass plate, to which sufficient water has been added to bring the soil to a more fluid condition. In each case the number of blows shall be recorded and the moisture content determined as before. The specimens shall be of such consistency that the number of drops required to close the groove shall be not less than 15 or more than 35 and the points on the flow curve are evenly distributed in this range.

Photo 2.2: Liquid Limit in Progress by Mechanical Method

'A flow curve' shall be plotted on a semi logarithmic graph representing water content on the arithmetical scale and the number of drops on the logarithmic scale. The flow curve is a straight line drawn as nearly as possible through the four or more plotted points. The moisture content corresponding to 25 drops as read from the curve shall be rounded off to the nearest whole number and reported as the liquid limit of the soil.

ii. **Cone Penetration Method**: A soil sample weighing about 150 g from thoroughly mixed portion of the soil passing 425 micron IS Sieve shall be worked well into a paste with addition of distilled water. The wet soil paste shall then be transferred to the cylindrical cup of cone penetrometer apparatus, ensuring that no air is trapped in this process. The wet soil shall be leveled up to the top of the cup and placed on the base of the cone penetrometer apparatus. The penetrometer shall be so adjusted that the cone point just touches the surface of the soil paste in the cup clamped in this position. The initial reading shall be either adjusted to zero or noted down as is on the graduated scale as shown in photo 2.3. The vertical clamp is then released allowing the cone to penetrate into the soil paste under its own weight. The penetration of the cone after 5 seconds shall be noted to the nearest millimeter. If the difference in penetration lies between 14 and 28 mm the test is repeated with suitable adjustments to moisture either by addition of more water or exposure of the spread paste on a glass plate for reduction in moisture content. The test shall then be repeated at least to have four sets of values of penetration in the range of 14 to 28 mm. The exact moisture content of each trial shall be determined.

Photo 2.3: Liquid Limit Test in Progress by Cone Penetrometer Apparatus

A graph representing water content on the y-axis and the cone penetration on the x-axis shall be prepared. The best fitting straight line shall then be drawn. The moisture content corresponding to cone penetration of 20 mm shall be taken as the liquid limit of the soil and shall be expressed to the nearest first decimal place.

- **Plastic Limit***:*

Procedure: A sample weighing about 20 g from the thoroughly mixed portion of the material passing 425-micron IS Sieve shall be taken. During the process of mixing of soil and water at which the mass becomes plastic enough to be easily shaped into a ball, a portion of the soil sample in the plastic state should be taken for the plastic limit test. A ball shall be formed with about 8 g. of this plastic soil mass and rolled between the fingers and the glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length as shown in photo 2.4. The rate of rolling shall be between 80 and 90 strokes/min. counting a stroke, as one complete motion of the hand, forward and back to the starting position again, . The rolling shall be done till the threads are of 3 mm diameter. The soil shall then be kneaded together to a uniform mass and rolled again. This process of alternate rolling and kneading shall be continued until the thread crumbles under the pressure required for rolling and the soil can *no* longer be rolled into a thread. The crumbling may occur when the thread has a diameter greater than 3 mm. This shall be considered a satisfactory end point, provided the soil has been rolled into a thread 3 mm in diameter immediately before. At no time shall an attempt be made to produce failure at exactly 3 mm diameter by allowing the thread to reach 3 mm, then reducing the rate of rolling or pressure or both, and continuing the rolling without further deformation until the thread falls apart. The pieces of crumbled soil thread shall be collected in an air-tight container and the moisture content shall be determined.

Photo 2.4: Plastic Limit Test in Progress

Report: The liquid limit should be reported to the nearest first decimal place. The plastic limit shall be determined for at least three portions of the soil passing 425-micron IS Sieve. The average of the results calculated to the nearest whole number shall be reported as the plastic limit of the soil. The plasticity index is calculated as the difference between its liquid limit and plastic limit.

The same test procedure shall be repeated with soil sample mixed with RBI Grade-81 in different percentage .See Annexure 2D for test sheet.

Note: the classification of soil is done as per IS: 1498-1970 and the detailed is mentioned in Annexure 2E.

2.2.3 Free Swell Index

Free swell is the increase in volume of a soil, without any external influence, on submergence in water. The possibility of damage to the pavement due to swelling of expansive clays need be identified, at the outset, by an investigation of those soils likely to possess undesirable expansion characteristics. It indicates the cracking behavior of plastic soils. The RBI Grade-81 content reduces FSI and hence reduction of crack generation in Pavement. See Annexure 2F for test sheet.

Procedure*:* Take two 10 g soil specimens of oven dry soil passing through 425-micron IS Sieve. Each soil specimen shall be poured in each of the two glass graduated cylinders of 100 ml capacity. One cylinder shall then be filled with kerosene oil and the other with distilled water up to the 100 ml mark. After removal of entrapped air, the soils in both the cylinders shall be allowed to settle. Sufficient time (not less than 24 h) shall be allowed for the soil sample to attain equilibrium state of volume without any further change in the volume of the soils. The final volume of soils in each of the cylinders shall be read. The level of the soil in the kerosene graduated cylinder shall be read as the original volume of the soil samples. The level of the soil in the distilled water cylinder shall be read as the free swell level. Refer photo 2.5

Photo 2.5: Free Swell Index Test in Progress

The free swell index of the soil shall be calculated as follows:

$$FSI = \{100 \times (V_d - V_k)/V_{k,}\}$$

Where,

V_d = the volume of soil specimen read from the graduated cylinder containing distilled water,

V_k = the volume of soil specimen read from the graduated cylinder containing kerosene.

The Same Test procedure shall be repeated with soil sample mixed with RBI Grade-81 in different percentage.

2.2.4 Water Content and Dry Density Relation

The Maximum Dry Density (MDD) of a material for a specific compactive effort is the highest density obtainable when the compaction is carried out on the material at varied moisture contents. The Optimum Moisture Content (OMC) for a specific compactive effort is the moisture content at which the maximum dry density is obtained.

Purpose of a laboratory compaction test is to determine the proper amount of mixing water to be used during compaction of the soil in the field and the resulting degree of denseness which can be expected from compaction at optimum moisture content. Thus soils used in fill of embankments, foundations and road beds, bases, etc. are compacted to a dense state in order to obtain satisfactory engineering properties. See Annexure 2G for test sheet.

Procedure:

Soil Not Susceptible to Crushing during Compaction: A 5-kg sample of air dried soil passing the 19mm IS test sieve shall be taken. The sample shall be mixed thoroughly with a suitable amount of water depending on the soil type. The mould, of 1000 cm^3 (V_m) capacity with baseplate attached, shall be weighed to the nearest 1g (m1). The mould shall be placed on a solid base, such as a concrete floor or plinth and the moist soil shall be compacted into the mould, with the extension attached, in five layers of approximately equal mass, each layer being given 25 blows from the 4.9-kg rammer dropped from a height of 450 mm. The blows shall be distributed uniformly over the surface of each layer, refer photo 2.6. The extension shall be removed and the compacted soil shall be leveled off carefully to the top of the mould by means of the straightedge. The mould and soil shall then be weighed nearest to 1 g (m2).

The compacted soil specimen shall be removed from the mould and placed on the mixing tray. The water content of a representative sample of the specimen shall be determined. The remainder of the soil specimen shall be broken up, rubbed through the 19-mm IS test sieve, and then mixed with the remainder of the original sample. Suitable increments of water shall be added successively and mixed into the sample, and the above procedure shall be repeated for each increment of water added. The total number of determinations made shall be at least five, and the moisture contents should be such that the optimum moisture content, at which the maximum dry density occurs, is within that range.

Soil Susceptible to Crushing during Compaction: Five or more 2.5 kg samples of air-dried soil passing the 19mm IS sieve, shall be taken. The samples shall each be mixed thoroughly with different amounts of water to give a suitable range of moisture contents. Each sample shall be tested as mentioned above.

Photo 2.6: Modified Proctor test in Progress

Compaction in Large Size Mould: For compaction of soil containing coarse material up to 37.5 mm size, the 2250 cm^3 (V_m) mould should be used. A sample weighing about 30 kg and passing the 37.5 mm IS sieve is used for the test. Soil shall be compacted in five layers, each layer being given 55 blows of the 4.9-kg rammer. The rest of the procedure is same as discussed above.

Calculation: Bulk density, Ym, in g/cm^3 of each compacted specimen shall be calculated from the equation:

$$Ym = (m1 - m2)/Vm$$

$$\text{And, Dry Density} = 100xYm/(100+w)$$

Where,

w = moister content of soil in percent.

The dry densities, obtained in a series of determinations shall be plotted against the corresponding moisture contents ‘w’. A smooth curve shall be drawn through the resulting points and the position of the maximum on this curve shall be determined.

Report: The experimental points and the smooth curve drawn through them showing the relationship between moisture content and dry density shall be reported. The dry density in g/cm^3 corresponding to the maximum point on the moisture content/dry density curve shall be reported as the maximum dry density to the nearest 0.01decimal. The percentage moisture content corresponding to the maximum dry density on the moisture content, ‘dry density curve shall be reported as the optimum moisture content and quoted to the nearest 0.2 decimal for values below 5 percent to the nearest 0.5 decimal for values from 5 to 10 percent, and to the nearest whole number for value exceeding 10 percent.

Procedure for Stabilized Sample: A representative sample weighing about 20 kg or more of the thoroughly mixed material shall be made to pass through 20-mm and 4.75-mm IS Sieves, separating the fractions retained and passing these sieves. Care shall be exercised so as not to break the aggregates while pulverizing. The percentage of each fraction shall be determined. The fraction retained on 20-mm IS Sieve shall not be used in the test. The percentage of soil coarser than 4.75-mm IS Sieve and the percentage of soil coarser than 20-mm IS Sieve shall be determined. The ratio of fraction passing 20-mm IS Sieve and retained on 4.75mm IS Sieve to the soil passing 4.75mm IS Sieve shall be determined. The material retained on and passing 4.75-mm IS Sieve shall be mixed thoroughly in the determined proportion to obtain about 16 kg of soil sample. Out of the soil sample obtained**,** eight 2-kg samples of stabilized soil shall be prepared. Water shall be mixed with each of the samples before compaction. Each of the samples of stabilized soil water mixture shall be compacted in the desired mould with the desired compactive efforts using the 4.89 kg rammer. Each layer of the compacted stabilized soil mixture shall be scratched with a spatula before putting the stabilized soil mixture for the succeeding layer. The amount of the stabilized soil mixture used shall be just sufficient to fill the mould leaving about 5 mm to be struck off when the collar is removed. The collar shall then be removed and the compacted stabilized soil mixture shall be carefully leveled off to the top of the mould by means of the straight edge. The mould with the compacted stabilized soil mixture shall then be weighed to the nearest one gram. The compacted specimen shall be ejected out of the mould, cut in the middle and a representative soil specimen shall be taken in an air-tight container from the cut surface. The moisture content of this representative specimen shall, be determined

Calculation: Wet density, Ym, in g/cm^3 of each compacted specimen shall be calculated from the equation:

$$Ym = (W - Wm)/1000$$

Where,

W = weight of mould with moist compacted stabilized soil in g
Wm= weight of empty mould in g

And, Dry Density = 100xYm/(100+w)

Where,

w = moister content of soil in percent.

Report: The dry densities of the compacted soil-RBI Grade-81 mixture obtained in a series of determinations shall be plotted against the corresponding moisture contents. A smooth curve shall be drawn through the resulting points. The dry density corresponding to the maximum point of the curve and the corresponding moisture content shall also be reported.

2.2.5 California Bearing Ratio

It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min.. The CBR determination is a penetration test which measures mainly the resistance of the soil to deformation by shearing. Its principle uses are:

i) The design of flexible road pavements with respect to subgrade.

ii) The prediction of settlements and bearing capacities under embankments and other layers.

Procedure: The material used in the remoulded specimen shall pass a 19-mm IS Sieve. Allowance for larger material shall be made by replacing it by an equal amount of material which passes a 19-mm IS Sieve but is retained on 4.75-mm IS Sieve. A representative sample of the soil weighing approximately 4.5 kg or more for fine-grained soils and 5.5 kg or more for granular soils shall be taken and mixed thoroughly with water. If the soil is to be compacted, to the maximum dry density, at the optimum water content. The exact mass of soil required shall be taken and the necessary quantity of water added so that the water content of the soil sample is equal to the determined optimum water content. The mould with the extension collar attached shall be clamped to the base plate. The spacer disc shall be inserted over the base plate and a disc of coarse filter paper placed on the top of the spacer disc. The soil-water mixture shall be compacted into the mould in accordance with the methods applicable to the 150 mm diameter mould specified in modified proctor test. The extension collar shall then be removed and the compacted soil carefully trimmed even with the top of the mould by means of a straight edge. Any hole that may then, develop on the surface of the compacted soil by the removal of coarse material, shall be patched with smaller size material; the perforated base plate and the spacer disc shall be removed, and the mass of the mould and the compacted soil specimen be recorded. A disc of coarse filter paper shall be placed on the perforated base plate, the mould and the compacted soil shall be inverted and the perforated base plate clamped to the mould with the compacted soil in contact with the filter paper. And by a representative sample its moisture content shall be determined and recorded. A filter paper shall be placed over the specimen and the adjustable stem and perforated plate shall be placed on the compacted soil specimen in the mould. Weights to produce a surcharge equal to the weight of base material and pavement to the nearest 2.5 kg shall be placed on the compact soil specimen. The whole mould and weights shall be immersed in a tank of water allowing free access of water to the top and bottom of the specimen. This set-up shall be kept undisturbed for 96 hours. A constant water level shall be maintained in the tank through-out the period. At the end of the soaking period, the mould is taken out of the water tank. The free water collected in the mould shall be removed and the specimen shall be allowed to drain downwards for 15 minutes. Care shall be taken not to disturb the surface of the specimen during the removal of the water. The weights, the perforated plate and the top filter paper shall be removed and the mould with the soaked soil sample shall be weighed and the mass shall be recorded.

The mould containing the specimen, with the base plate in position but the top face exposed, shall be placed on the lower plate of the testing machine. Surcharge weights, sufficient to produce an intensity of loading equal to the weight of the base material and pavement shall be placed on the specimen. The plunger shall be seated under a load of 4 kg so that full contact is established between the surface of the specimen and the plunger, refer photo 2.7. The load and deformation gauges shall then be set to zero. Load shall be applied to the plunger into the soil at the rate of 1.25 mm per minute. Reading of the load shall be taken at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.5, 10.0 and 12.5 mm. The plunger shall be raised and the mould detached from the loading equipment. About 20 to 50 g of soil shall be collected from the top 30 mm layer of the specimen and the water content shall be determined.

Photo 2.7: CBR Test in Progress

Calculation & Report: The specimen data shall be recorded on the data sheet as shown in Annexure 2H. The readings for the determination of the load penetration data shall be recorded in the data sheet. The load penetration curve shall be plotted. This curve is usually convex upwards although the initial portion of the curve may be convex downwards due to surface irregularities. A correction shall then be applied by drawing a tangent to the point of greatest slope and then transposing the axis of the load so that zero penetration is taken as the point where the tangent cuts the axis of penetration. The corrected load-penetration curve would then consist of the tangent from the new origin to the point of tangency on the re-sited curve and then the curve itself. The CBR values are usually calculated for penetrations of 2.5 and 5 mm. Corresponding to the penetration value at which the CBR values is desired, corrected load value shall be taken from the load penetration curve and the CBR calculated as follows:

$$\text{California Bearing Ratio} = (PT/P_S) \times 100$$

P_T = corrected unit test load corresponding to the chosen penetration from the load penetration curve,

P_S = unit standard load for the same depth of penetration

Generally, the CBR value at 2.5 mm penetration will be greater than that at 5 mm penetration and in such a case; the former shall be taken as the CBR value for design purposes. If the CBR value corresponding to a penetration of 5 mm exceeds that for 2.5 mm, the test shall be repeated. If identical results follow, the CBR corresponding to 5 mm penetration shall be taken for design.

The CBR test can be made on nearly all soils ranging from clay to fine gravel.

The Same Test procedure is repeated with soil sample mixed with RBI Grade-81 in different percentage the preparation of mould specimen with RBI grade-81 and curing is explained in section 3.1 and 3.2.

2.2.6 Unconfined Compressive Strength

This test is carried out on cylindrical or cubical specimens prepared by mixing the soil at a pre-determined moisture and RBI Grade-81 content and compacting the mixed material into a mould.. The choice of specimen size and shape depends on the grading of the soil. The UCS determination is a compression test which measures the resistance to increasing loads until failure (or up to 20 % axial strain for cylindrical specimen), which is the load required to crush a cylindrical soil specimen to total failure. See Annexure 2I for test sheet.

Procedure*:* The specimen for the test shall have a minimum diameter of 38 mm and the largest particle contained within the test specimen shall be smaller than l/8 of the specimen diameter. If after completion of test on undisturbed sample, it is found that larger particles than permitted for the particular specimen size tested are present, it shall be noted in the report of test data under remarks. The height to diameter ratio shall be within 2 to 2.5. Measurements of height and diameter shall be made with Vernier callipers or any other suitable measuring device to the nearest 0.1 mm. The specimen may be prepared either from a failed undisturbed specimen or from a disturbed soil sample. It shall be done using a mould of circular cross-section with dimensions corresponding to mention earlier. Compacted specimen may be prepared at any predetermined water content and density. After the specimen is formed, the ends shall be trimmed perpendicular to the long axis and removed from the mould. Representative sample cuttings shall be obtained or the entire specimen shall be used for the determination of water content after the test. The initial length, diameter and weight of the specimen shall be measured and the specimen placed on the bottom plate of the loading device. The upper plate shall be adjusted to make contact with the specimen. The deformation dial gauge shall be adjusted to a suitable reading, preferably in multiples of 100. Force shall be applied so as to produce axial strain at a rate of 0.5 to 2 percent per minute causing failure with 5 to 10 min. The force reading shall be taken at suitable intervals of the deformation dial reading. The specimen shall be compressed until failure surfaces have definitely developed, or the stress-strain curve is well past its peak, or until: axial strain of 20 present is reached. The failure pattern shall be sketched carefully and shown on the data sheet or on the sheet, showing the stress-strain plot. The angle between the failure surface and the horizontal may be measured, if possible, and reported.

Calculation: Stress-strain values shall be follows:

a) The axial strain, e, shall from the following relationship:

$$e = dl/L_o$$

Where,

dl = the change in the specimen length as read from the strain dial indicator, and

L_o= the initial length of the specimen

b) The average cross-sectional area, A, at a particular strain shall be determined from the following relationship:

$$A = A_o/(1-\varepsilon)$$

Where,

A_o = the initial average cross-sectional area of the specimen.

c) Compressive stress, σ, shall be determined from the relationship:

$$\sigma = P/A$$

Where,

P = the compressive force

Values of stress σ, and strain "ε" obtained from calculation shall be plotted. The maximum stress from this plot gives the value of the unconfined compressive strength q_u. In case no maximum occurs within 20 percent axial strain, the unconfined compressive strength shall be taken as the stress at 20 percent axial strain.

Procedure for Stabilized Sample: Using only material passing the 4.75 mm IS test sieve for fine-grained soils, and only material passing the 20 mm IS test sieve for medium-grained soils, the stabilized soil shall be prepared properly. The weight of the stabilized soil (W1***)*** required for moulding into a specimen of the required dry density shall be calculated in accordance with the mould used.

For Fine-Grained Soils- The appropriate plug shall be inserted into the bottom of the mould and a quantity of the material sufficient to give a specimen length of 100-115 mm after compaction shall be added to the mould, being tamped uniformly and gently with the tamping rod during the operation. The other plug shall be inserted into the mould, and the soil shall be compacted by 15 blows of the rammer dropped from a height of 310 mm into the plug (this plug should not be driven fully home at this stage; if it has, then there is insufficient material in the mould) refer photo 2.8 and 2.9. This mould containing the specimen shall then be inverted and the uppermost plug replaced by the plunger. The soil shall then be further compacted by 15 blows from the rammer applied to the plunger. The compacted specimen shall be rejected for subsequent testing if its length exceeds 115 mm. The plunger shall then be inserted into the end of the mould having the smaller diameter and the specimen released from the taper by gentle hammering or pressure. The specimen shall then be removed from the mould and weighed to the nearest 1 g (W2***).***

For Medium-Grained Soils- The appropriate plug shall be inserted into the bottom of the mould and a quantity of material sufficient to give a specimen of 200-215 mm after compaction shall be compacted into the mould in six equal layers, each layer being given 25 blows of the rammer dropped from a height of 310 mm above the stabilized soil. The blows shall be uniformly distributed over the surface of each layer, which shall be scarified with the palette knife before the next layer is added. The compacted specimen shall be rejected for subsequent testing if its length exceeds 215 mm. The plunger shall then be inserted into the end of the mould having the smaller diameter and the specimen released from the taper by gently hammering or pressure. Any length in excess of 200 mm shall be extruded beyond the mould. This length is gauged by placing the 200 mm long displacing collars on the plunger. The face of the specimen shall be carefully levelled off to the end of the mould using the straight edge, and any irregularities shall be filled with fine material from the same sample. The specimen shall then be removed from the mould and weighed to the nearest 1 g **(**W2***).***

After the completion of curing period, the length of the specimen (L) shall be measured to the nearest 0.25 mm by means of the calliper's, and recorded. The specimen shall then be placed centrally on the lower platen of the compression testing machine and the load shall be applied to the ends of the specimen. The load shall be applied so that the rate of deformation is uniform approximately 1.25 mm/min. The maximum load exerted by the machine during the test shall be recorded as, P kg.

Photo 2.8 & 2.9: UCS teat in Progress (For Fine Grain Soil)

The unconfined compressive strength (p) of the specimen shall be calculated from the formulae:

$$p = P/A,$$

Where,

A= Cross sectional area of the specimen.

The unconfined compressive strength of the specimen shall be reported as follows:

a) Values of compressive strength up to 2 MN/m^2 (20 kg/cm^2) report to the nearest 0.05 MN/m^2 (0.5 kg/sq.cm).
b) Values of compressive strength above 2 MN/m^2 (20 kg/cm^2) report to the nearest 0.1 MN/m^2 (1 kg/sq.cm).

Procedure for Coarse Grained Stabilized Soil: Using only material passing the 20-mm IS Test Sieve for medium-grained soils, and only material passing the 40-mm IS Test Sieve for coarse grained soils, the stabilized soil mix shall be prepared properly. The weight of stabilized soil (W1) required for moulding into a specimen of the required dry density shall be calculated. The material (W1) shall be divided into three equal parts by weight. One of the parts shall be placed in an assembled mould and the surface levelled off. Using a tamper fitted with a collar at the 10 cm mark and a vibrating hammer, the material shall be compacted uniformly until the collar comes into contact with the upper surface of the mould. The surface of the layer shall be scarified with the palette knife before adding the next layer, which shall be compacted in similar manner to the first layer, but using a tamper fitted with a collar at the 5 cm position. A 150 mm cube mould, less baseplate shall then be placed squarely on top of the mould, the compacted surface scarified with the palette knife, and the final layer added using the tamper with the collar at the 150 mm position. The upper mould shall then be removed and -the surface of the specimen carefully levelled off to the end of the mould using the trowel and vibrating tamper, care being taken not to spill any loose material during this final operation. The mould containing the specimen shall then be covered with a metal plate and stored at a temperature of $27 \pm 2^{o}C$ until the following day when the specimen shall be removed from the mould for further curing. The specimen shall then be weighed to the nearest 1 g (W_2).The specimen shall then be placed centrally on the lower platen of the compression testing machine, refer photo 2.10, in such a manner that the load shall be applied to opposite sides of the cube as cast, that is not to the top and bottom. The load shall be applied without shock and increased continuously at a rate of approximately 35 kg/cm/min. until the resistance of the cube to the increasing load breaks down and no greater load can be sustained. The maximum load exerted by the machine can be recorded (P kg). The moisture content shall be determined.

Photo 2.10: UCS Test in Progress (For Coarse Grain Soil)

The unconfined compressive strength (p) of the specimen shall be calculated from the formula:

$$p = P/A$$

Where,

P = maximum recorded load, and

A = area of cross section of specimen in mm^2.

The preparation of mould specimen with RBI grade-81 and curing is explained in section 2.3.1 and 2.3.2.

2.2.7 Durability

To determine the resistance of compacted stabilized soils to repeated adverse weather conditions. Therefore, one must determine the minimum amount of RBI Grade-81 required in a soil- RBI Grade-81 mixture to achieve a degree of hardness (strength gain) to resist field weathering. The test procedure is followed as per IS Code IS: 4332 (Part IV): Methods of test for stabilized soils: Wetting and drying, freezing and thawing tests for compacted soil-cement mixtures. See Annexure2 M for test sheet.

Procedure for Wetting and Drying: A representative sample weighing about 20 kg or more of the thoroughly mixed material shall be made to pass through 20-mm and 4.75-mm: IS Sieves, separating the fractions retained and passing these sieves. Care shall be exercised so as not to break the aggregates while pulverising. The percentage of each fraction shall be determined. The fraction retained on 20-mm IS Sieve shall not be used in the test. The percentage of soil coarser than 4.75-mm IS Sieve and the percentage of soil coarser than 20-mm IS Sieve shall be determined. The ratio of fraction passing 20-mm IS sieve and retained on 4.75mm IS Sieve to the soil passing 4.75mm IS Sieve shall be determined. The material retained on and passing 4.75mm IS Sieve shall be mixed thoroughly in the determined proportion to obtain about 16 kg of soil sample. A representative sample weighing approximately 16 kg of the thoroughly mixed material shall be taken. The soil, potable water and required amount of RBI Grade-81 shall be mixed properly. The mixture should be broken up without reducing the natural size of individual particles. The specimens shall be formed by immediately compacting the soil-cement mixture in the mould (with the collar attached) and later trimming the specimens In addition the tops of the first and second layers shall be scarified to remove smooth compaction planes before placing and compacting the succeeding layers. This scarification shall form groove at right angles to each other approximately 3 mm in width and 3 mm in depth and approximately 6 mm apart. During compaction, a representative sample of the soil-RBI Grade-81 mixture weighing not less than 100 g shall be taken from the batch for moisture content determination. The compacted specimens shall be weighed with the mould. The specimens shall then be removed from the mould. The oven-dry density in g/cm^3 shall be calculated. The specimens shall be identified suitably as No. 1 and 2. These specimens may be used to obtain data on moisture and volume changes during the test. Two more specimens shall be similarly formed and their moisture content and dry density be determined. These specimens shall be identified as No. 3 and 4 and used to obtain data on soil-RBI Grade-81 losses during the test. The average diameter and height of specimens No.1 and 2 shall be measured and their volume shall be determined. All the four specimens shall be placed on suitable carriers in the moist chamber and protected from free water for a period of seven days. Specimens No. 1 and 2 should be weighed and measured at the end of the seven-day period to provide data for calculating their moisture content and volume.

At the end of the storage in the moist room, the specimens shall be submerged in potable water at room temperature for a period of 5 h, refer photo 2.11 and removed. Specimens No. 1 and 2 shall be weighed and their dimensions measured. All four specimens shall then be placed in an oven at 70°C for 42 h and removed. Specimens No. 1 and 2 shall be weighed and their dimensions measured again. Specimens No. 3 and 4 shall be given two firm strokes on all areas with the wire-scratch brush. The brush shall be held with the long axis of the brush parallel to the longitudinal axis of the specimen or parallel to the ends as required for covering all areas of the specimen. These strokes shall be applied to full height and width of the specimen with a firm stroke corresponding to approximately 1.4 kg. 18 to 20 vertical brush strokes may be required to cover the sides of the specimen twice and four strokes may be required at each end, the above process constitute one cycle (48 h) of wetting and drying. The specimens shall again be submerged in water and the same procedure continued for 12 cycles. Testing of No. 1 and 2 specimens may be discontinued prior to 12 cycles should the measurements become inaccurate due to soil-RBI Grade-81 loss of the specimen. After 12 cycles of test, the specimens shall be dried to constant weight at 110°C and weighed to determine the oven-dry weight of the specimens. The data collected will permit calculations of volume and moisture changes of specimen's No. 1 and 2, and the soil-RBI Grade-81 losses of specimen's No. 3 and 4 after the prescribed 12 cycles of test.

For specimen's No. 1 and 2 the difference between the volumes of specimens, refer photo 2.12, at the time of moulding and subsequent volumes as a percentage of the original volume should be calculated. The moisture content of specimens No.1 and 2 at the time of moulding and subsequent moisture contents should be calculated as a percentage of the original oven-dry weight of the specimen. The oven-dry weight of specimen's No. 3 and 4 shall be corrected for water that has reacted with the RBI Grade-81 and soil during the test and is retained in the specimen at 110^{o}C, as follows:

$$\text{Corrected oven-dry weight} = W_d \text{ X } 100/(w+100)$$

Where,

W_d = oven-dry weight after drying at ll0^{0}C, and

w = percentage of water retained in specimen.

Photo 2.11& 2.12: Durability Test in Progress (Wetting and Drying)

The percentage of water retained in the specimens No. 3 and 4 after drying at 110°C for use in the above formula may be assumed to be equal to the average percentage of water retained in specimen No. 1 and 2. The soil cement loss of specimens MO. 3 and 4 shall be calculated as a percentage of the original oven-dry weight of the specimen as follows:

Soil cement loss, percent = A/B *x* 100

Where,

A = original calculated oven-dry weight minus final corrected oven-dry weight, and

B = original calculated oven-dry weight.

Procedure for Freezing and Thawing: The soil sample and specimens shall be prepared in accordance with the procedure given in wetting and drying.

At the end of the storage in the moist room, water saturated felts about 5 mm thick, blotters or similar absorptive material shall be placed between the specimens and the carriers. The assembly shall be placed in a freezing cabinet having a constant temperature not warmer than -23°C, refer photo 2.13 and 2.14 for 24 h and removed. The No. 1 and 2 specimens shall be weighed and measured. The assembly should then be placed in the moist chamber or suitably covered container having a temperature of 25^0C to 30°C and a relative humidity of 100 percent for 23 h and removed. Free potable water shall be made available to the absorbent pads under the specimens to permit the specimens to absorb water by capillary action during the thawing period. The No. 1 and 2 specimens shall be measured and weighed. Specimens No. 3 and 4 shall be given two firm strokes on all areas with the wire-scratch brush. The brush shall be held with the long axis of the brush parallel to the longitudinal axis of the specimen or parallel to the ends as required for covering all areas of the specimen. The strokes shall be applied to the full height and width of the specimen with a firm stroke corresponding to approximately 1.4 kg. Eighteen to twenty vertical brush strokes are required to cover the sides of the specimen twice and four strokes are required on each end. After being brushed, the specimens shall be turned over end for end before they are placed on the water saturated pads. The specimens shall be placed in the freezing cabinet and the procedure continued for 12 cycles. The No. 1 and 2 specimens may be discontinued prior to 12 cycles should the measurements become inaccurate due to soil- RBI

Grade-81 loss of the specimen. After 12 cycles of test, the specimens shall be dried to constant weight at 110°C and weighed to determine the oven-dry weight of the specimens. The data collected will permit calculations of volume and moisture changes of specimens No.1 and 2 and the soil-cement losses of specimens No.3 and 4 after the prescribed 12 cycles of test. The volume and moisture changes and the soil- RBI Grade-81 losses of the specimens should be calculated as given in wetting-drying procedure.

Photo 2.13 & 2.14: Durability Test in Progress (Freezing and Thawing)

Report: The report should include the following:
a) The designed optimum moisture and maximum density of the moulded specimens.
b) The moisture content and density obtained in moulded specimens
c) The designed RBI Grade-81 content, in percent, of the moulded specimens.
d) The RBI Grade-81 content, in percent, obtained in moulded specimens.
e) The maximum volume change, in percent, and maximum moisture content during test of specimen's No. 1 and 2.
f) The soil- RBI Grade-81 loss, in percent, of specimen's No. 3 and 4.

2.2.8 E-Value

Elastic Modulus test are conducted in order to check whether RBI Grade-81 stabilized mixture layer act as flexible or Rigid, so that if the Modulus of Elasticity is high, the pavement consisting of RBI Grade-81 stabilized layer and Bituminous layer will be considered as Semi-Rigid and then the suitability of RBI Grade-81 Stabilized layer as a base layer will be compared with respect to semi rigid pavement. The equipment shall be computerized cyclic beam loading set up.

To determine the flexural strength of casted beams, it consists of three points loading, and the test shall be conducted at different amplitude & frequencies for finding the maximum elasticity modulus. The recommended specimen sizes, to be used in Laboratory are, 500×100×100mm and 300×75×75mm.

Procedure: Soil- RBI Grade-81 shall be mixed either by hand or in a suitable laboratory mixer in batches of such size as to leave ten percent excess after moulding test specimens. This material shall be protected against loss of moisture, and a representative part of it shall be weighed and dried in the drying oven to constant weight to determine the actual moisture content of the soil-RBI Grade-81 mixture. When the soil- RBI Grade-81 mixture contains aggregate retained on the 4.75-mm sieve, the sample for moisture determination shall weigh at least 500 g and shall be weighed to the nearest gram. If the mixture does not contain aggregate retained on the 4.75-mm sieve, the sample shall weigh at least 100 g and shall be weighed to the nearest 0.1 g. The batch shall be mixed in a clean, damp, metal pan or on top of a steel table, with a blunt brick-layer's trowel, using the following procedures:

a) Calculated amount of water to give moisture content 2 percent less than the required final moisture content should be added to the soil passing 4.75mm IS Sieve, thoroughly mixed and kept in a sealed container to avoid moisture loss overnight for uniform distribution of moisture.
b) The additional water required for bringing the moisture to the required level should be calculated. The calculated weight of the moist soil and RBI Grade-81 required for making the specimens should be mixed thoroughly. The remaining quantity of water to make up the required moisture content of the soil- RBI Grade-81 mixture should be added and thoroughly mixed.
c) The saturated surface-dry coarse fraction of the soil shall be added and the entire batch mixed until the coarse fraction is uniformly distributed throughout the batch.
Divide it into three equal batches of predetermined weight of uniformly mixed soil- RBI Grade-81 to make a beam of the designed density. Place one batch of the material in the mould and level by hand. When the soil- RBI Grade-81 contains aggregate retained on the 4.75mm sieve, carefully spade the mix around the Sides of the mould with a thin spatula. Compact the soil- RBI Grade-81 initially from the bottom up by steadily and firmly forcing (with little impact) a square-end cut 12 mm diameter smooth steel rod repeatedly, through the mixture from the top down to the point of refusal. Approximately 90 rods distributed uniformly over the cross-section of the mould are required; take care so as not to leave holes in clayey soil- RBI Grade-81 mixtures. Level this layer of compacted soil- RBI Grade-81 by hand and place and compact layers two and three in an identical manner. The specimen at this time shall be approximately 95 mm high. Place the top plate of the mould in position and remove the spacer bars. Obtain. Final compaction with a static load applied by the compression machine or Compression frame until the height of 75 mm is: reached. Immediately after compaction, carefully dismantle the mould and remove the specimen onto a smooth, rigid wood or sheet metal pallet. Flexural test of moist cured specimens shall be made as soon as practicable after removing from the moist room, and during the period between removal from the ,moist room and testing, the specimens shall be kept, moist by the wet burlap or blanket covering.

Turn the specimen on its side with respect to its moulded position (with the original top and bottom surfaces as moulded perpendicular to the testing machine bed,) and centre it on the lower half-round steel supports, which shall have been spaced apart a distance of three times the depth of the beam. Place the load applying block assembly in contact with the upper surface of the beam at the third points between the supports refer photo 2.15. Carefully align the centre of the beam with the centre of thrust of the spherically seated head block of the machine. As this block is brought to bear on the beam-loading assembly, rotate its movable portion gently by hand so that uniform seating is obtained. Apply the load continuously and without shock. A screw power testing machine, with the moving head operating at approximately 1.2 mm/min. With hydraulic machines adjust the loading to such a constant -rate that the extreme fibre stress is within the limits of 7 ±0.4 kg/cm^2/min. Record the total load at failure of the specimen to the nearest 3 kg. Make measurements to the nearest 0.2 mm to determine the average width and depth of the specimens at the section of failure.

Photo 2.15: E-Value Test in Progress

Calculation and Report: If the fracture occurs within the middle third of the span length, calculate the modulus of rupture as follows:

$R = Pl/bd^2$ -- (weight of beam neglected)

$R = (P + 3W/4)\ l/bd^2$ (weight of beam taken into account)

Where,

R = modulus of rupture in kg/cm^2,

P = maximum applied load in kg,

l = span length in cm,

b = average width of specimen in cm,

d = average depth of specimen in cm, and

W = weight of the specimen in kg.

If the fracture occurs outside the middle third of-the span length by hot more than 5 percent of the span length, calculate the modulus of rupture as follows:

$$R = 3Pa/ bd^2$$

Where,

a = distance between line of fracture and the nearest support, measured along the center line of the bottom surface of the beam (as tested).

The report shall include the following:

a) Specimen preparation details;
b) Specimen identification number;
c) Average width and depth at section of failure to the nearest0.2 mm;
d) Maximum load, to the nearest 5 kg;
e) Modulus of rupture calculated to the nearest 0.5 kg/cm^2;
f) Defects, if any, in specimen;
g) Age of specimen; and
h) Moisture content at time of test.

For detail calculation refer annexure 2J

2.3 Amendments to Standard Test Methods

The following additional provisions and amendments shall apply to the test methods listed in 2.2.2, 2.2.3, 2.2.4, 2.2.5, 2.2.6, 2.2.7, and 2.2.8 when stabilizing with RBI Grade-81 and shall be strictly adhered to. The purpose of these provisions and amendments is to stimulate field conditions and most importantly to allow sufficient strength gain (degree of hardness) to take place to adequately resist field weathering and the effects of traffic loading.

2.3.1 Preparation of a Specimen

(1) Firstly, the calculated RBI Grade-81 content is mixed thoroughly with the dry untreated soil until a uniform color is achieved i.e. homogenous mixture.
(2) Thereafter the calculated percentage water is added to the soil- RBI Grade-81 mixture and mixed thoroughly, until the moisture is evenly distributed throughout the mixture.
(3) The mixture is then allowed to stand for not more than 30 minutes at room temperature for moisture equilibration to take place either in a sealed plastic bag or in a basin covered with a damp hessian sack or jute bag.
(4) Immediately thereafter the soil- RBI Grade-81 mixture is compacted into a mould as described in the standard test methods as listed.

Note: *All molded specimens are prepared individually so that no soil- RBI Grade-81* mixture *is allowed to stand for more than 30 minutes before proceeding with the compaction effort.*

(5) For the preparation of the next specimen proceed from steps (1) to (5).
(6) For test methods listed in paragraphs 2.2.5; 2.2.6, 2.2.7, and 2.2.8 place the molded and extruded specimens after compaction in a suitable curing room.

2.3.2 Curing of Molded (CBR) and Extruded specimens (UCS, E Value & Durability)

After completion of the compactive effort the specimens shall be damp-cured in a suitable curing room at 95 to 100% relative humidity if available in laboratory or under water proof wrap using suitable material i.e. Polythene sheet(The wrap should be done immediately after the sample is extruded from the mould), moist hessian sacks, jute bags or wood-shavings at a temperature of 22^0 C to 25^0 C until a sufficient strength gain has been achieved (degree of hardness) to withstand the tests as listed and described in 2.2.5, 2.2.6, 2.2.7 and 2.2.8

2.3.3 Determination of the curing period in order to achieve sufficient strength gain (hardness)

Once the maximum dry density (MDD) and optimum moisture content (O.M.C.) of the treated material at different laboratory contents has been established, for example at 2%,4% and 6%, compact further specimens at the different laboratory contents using the calculated optimum moisture content and maximum dry density determined from the compaction curve of each individual RBI Grade-81 content. See Table 2.2 as an example.

Table 2.2: Number Treated Material Samples

Number of compacted specimens for tests					
RBI Grade-81 Content (%)	M.D.D (g/cc)	O.M.C (%)	Compacted Specimens		
			CBR	UCS	Durability *
2	2.24	5.7	2	3	6
4	2.232	6.0	2	3	6
6	2.229	6.2	2	3	6

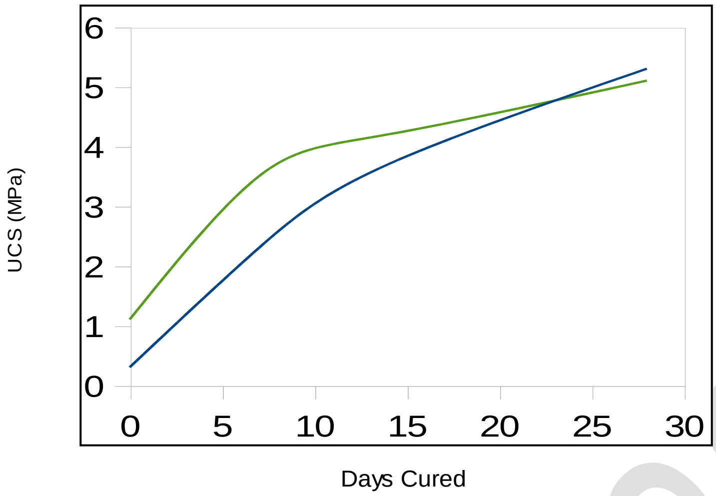
(1) 3 samples or wetting and drying tests and 3 for freeze and thaw tests.

(2) After compaction the specimens are cured as described in paragraph 2.3.2 but for a period of between 7 and 28 days in order to determine the actual hardening time or strength gain that gives the equivalent cement strength at 7 days as the RBI Grade-81 takes longer to reach the same strength as that of ordinary cement, see Graph 2.1 as an example.

Note: It is normal for stabilizing agents other than cement to take more than 7 days to produce strengths equivalent to that of cement. Thus to obtain significant results it would therefore be necessary for each case, first to determine the curing time that gives equivalent strengths and then adjust the curing time.

Therefore, deducing from Graph 2.1, strength gain equivalent to that of cement) at 7 days, was achieved after 14 days curing for the Laboratory RBI Grade-81. This result is one type of sample and may vary from sample to sample.

***Note**: For Practical purpose RBI Grade-81 specimen is kept in minimum 7 days for curing before conducting any test.*



Graph 2.1: UCS vs. Days Cured

2.3.4 Testing of compacted specimens

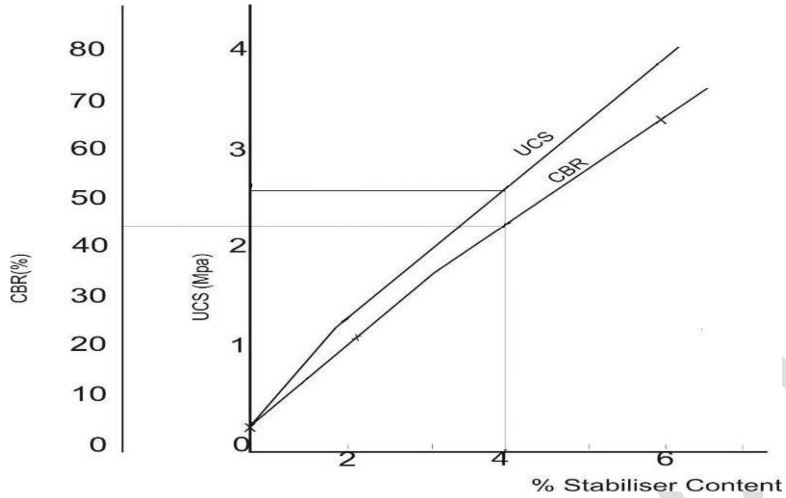
After the specimens have been cured for the actual determined hardening time as determined in Step (2) of 2.3.3, the specimens are handled as follows for the different tests.

(i) CBR determination (molded specimens).
The specimens are removed from the curing room and submerged in water for four days soaking period before proceeding with the penetration test as described in the Standard Test Methods.
(ii) UCS determination (extruded specimens)
The compacted UCS specimens are air dried before crushing to failure after the curing. The period of air drying is one to three days depends on soil type, which gave sufficient strength gain equivalent to that of cement in 7 days or crushed at 28 days plus.
(iii)Durability tests (extruded specimens)
Proceed as described in IS: 4332 (Part-IV): Methods of test for stabilized soils: Wetting and drying, freezing and thawing tests for compacted soil-cement mixtures.
(iv)E Value test (Unmolded Specimens)
Proceed as described in test method 2.2.8.

2.3.5 Determination of RBI Grade-81 Content

The following method is used to establish the required Laboratory content to produce a soil-RBI Grade-81 mixture that meets or confirms to the specific requirements as regards to load-bearing strength, compressive strength and durability as required.

A graph is plotted of RBI Grade-81 content versus strength test results which can be either the CBR test results or UCS test results or both. RBI Grade-81 content is then determined from the graph that meets the requirements, see Graph 2.2 of an example of typical fine silty gravel
.



Graph 2.2: UCS/CBR versus % Laboratory Content

Table 2.3: Test Results

RBI Grade-81 Content (%)	UCS (MPa)	CBR (%)
0	0.1	3
2	1.3	22
4	2.7	44
6	3.8	64

According to the requirement CBR value of 40% is required and a UCS of between 2 - 3 MPa. From the graph it can be shown that at RBI Grade-81 content of 4% the required specification is met with.

2.4 Field Tests - Quality Control

The following field tests shall be determined on the stabilized soil to ascertain if the requirements have been met with or achieved as specified.

2.4.1 Before compaction

2.4.1.1 Moister Content

Once the RBI Grade-81 and water has been thoroughly mixed in the field application and before compaction is commenced with, representative samples of sufficient quantity of the Soil-RBI Grade-81-water mixture shall be taken and tested for the moister content for the verification of optimum moister content.

Procedure for Oven Dry Method*:* Clean the container with lid, dry and weigh (W_1). Take the required quantity of the soil specimen in the container crumbled and placed loosely, and weigh with lid (W_2). Then keep it in an oven with the lid removed, and maintain the temperature of the oven at 110±5°C. Dry the specimen in the oven for 24 h. Every time the container is taken out for weighing. Replace the lid on the container and cool the container in a desiccator. Record the final mass (W_3) of the container with lid with dried soil sample. The percent of water content shall be calculated as follows:

$$w = (W_2 - W_3)/(W_3 - W_1) \times 100$$

Where,

w = water content percent,
W_2 = mass of container with lid with wet soil in g,
W_3 = mass of container with lid with dry soil in g, and
W_1 = mass of container with lid in g.

Procedure for Sand Bath Method: Clean the container with lid or the tray, as the case may be, dry and weigh (W_1). Take the required quantity of the soil specimen in the container crumbled and placed loosely and weigh (W_2). Add a few pieces .of white paper if necessary Place the container with the lid removed or the tray on the sand-bath and heat the sand-bath. Care shall be taken not to get the sand-bath too hot. During heating, the specimen shall be turned frequently and thoroughly with the palette knife to assist the evaporation of water, care being taken to see that no soil is lost in the process; Dry the specimen to constant mass indicated by the difference between two consecutive masses of the container with lid or the tray with the dried specimen taken at suitable intervals after initial drying, being a maximum of 0.1 percent of the original mass of the soil specimen. When drying is complete, remove the container or the tray from the sand bath, cool and weigh (W_3). The container should be weighed with lid. The percent of water content shall be calculated as follows:

$$w = (W_2 - W_3)/(W_3 - W_1) \times 100$$

Where,

w = water content percent,
W_2 = mass of container with lid (or Tray) with wet soil in g,
W_3 = mass of container with lid (or Tray) with dry soil in g, and
W_1 = mass of container with lid (or Tray) in g.

Procedure for Rapid Moisture Meter: Set up the balance. Place sample in pan till the mark on the balance arm mass lines up with the index mark. Unclamp the clamping screw of the instrument sufficiently to move the U-clamp off the cup. Lift off the cup. Check that cup and body are clean; otherwise clean it using a brush. Hold the body horizontal and gently deposit one level scoopful of absorbent (calcium carbide) refer photo 2.16, halfway inside the chamber. Then lay the chamber down without disturbing the absorbent charge. Transfer the soil weighed out as above from the pan to the cup. Holding cup and chamber approximately horizontal bring them together without disturbing sample or absorbent, bring the U-clamp round and clamp the cup tightly into place. With gauge downwards (except when the steel balls are used) shake the moisture meter up and down vigorously for 5 seconds, then quickly turn it so that the gauge is upwards, give a tap to the body of the moisture meter to ensure that all the contents fall into the cup. Hold the rapid moisture meter downwards, again shake for 5 seconds, then turn it with gauge upwards and tap. Hold for one minute. Repeat this for a third time. Once more invert the rapid moisture meter and shake up and down to cool the gas. Turn the rapid moisture meter with the gauge upwards and dial horizontal held at chest height. When the needle comes to rest take the reading. The readings on the meter are the percentages of water on the wet mass basis.

Finally release the pressure slowly (away from the operator) by opening the clamp screw and taking the cup out, empty the contents and clean the instrument with a brush.

Photo 2.16: Moisture Content Test in Progress

From the water content (m) obtained on the wet mass basis as the reading on the rapid moisture meter, the water content (w) on the dry mass *basis* shall be calculated as follows:

$$w = m \times 100/ (100-m)$$

Note:- RMM is not very accurate and is only indicative to assist field application.

2.4.2 After final compaction

2.4.2.1 Field density (compaction tests)

Once final compaction has taken place and within 24 hours thereafter, field densities should be determined on the compacted layer.

Procedure:

Calibration of Sand Pouring Cylinder and Unit Weight of Sand: The pouring cylinder shall be filled so that the level of the sand in the cylinder is within about 10 mm of the top. Its total initial weight (W1*)* shall be found and shall be maintained constant throughout the tests for which the calibration is used. A volume of sand equivalent to that of the excavated hole in the soil shall be allowed to run out of the cylinder under gravity. The shutter on the pouring cylinder shall then be closed and the cylinder placed on a plane surface, such as a glass plate. The shutter on the pouring cylinder shall be opened and sand allowed to move out. When no further movement of sand takes place in the cylinder the shutter shall be closed and the cylinder removed carefully. The sand that has filled the cone of the pouring cylinder shall be collected and weighed to the nearest gram. These measurements shall be repeated at least three times and the mean weight (W2*)* taken. The internal volume (V) in ml of the calibrating container shall be determined from the weight of water contained in the container when filled to the brim. The volume may also be calculated from the measured internal dimensions of the container. The pouring cylinder shall be placed concentrically on the top of the calibrating container after being filled to the constant weight (W1*)*. The shutter on the pouring cylinder shall be closed during this operation. The shutter shall be opened and sand allowed to move out. When no further movement of sand takes place in the cylinder the shutter shall be closed. The pouring cylinder shall be removed and weighed to the nearest gram. These measurements shall be repeated at least three times and the mean weight (W3) taken.

Calculation: The weight of sand (Wa) in g, required to fill the calibrating container shall be calculated from the following formula:

$$Wa = W1-W2-W3$$

The bulk density of the sand (Ys) in kg/m3 shall be calculated from the formula:

$$Ys = (Wa/V) \times 1000$$

Procedure for measurement of Soil Density: A flat area, approximately 450 mm square, of the soil to be tested shall be exposed and trimmed down to a level surface preferably with the aid of the scraper tool. The metal tray with a central hole shall be laid on the prepared surface of the soil with the hole over the portion of the soil to be tested. The hole in the soil shall then be excavated using the hole in the tray as a pattern, to the depth of the layer to be tested, refer photo 2.17. The excavated soil shall be carefully collected, leaving no loose material in the hole and weighed to the nearest gram (Ww). The metal tray shall be removed before the pouring cylinder *is* placed in position over the excavated hole. The water content (W) *of* the excavated soil shall be determined by the method specified. The pouring cylinder filled to the constant weight (W1) shall be so placed that the base of the cylinder covers the hole concentrically. The shutter on the pouring cylinder shall be closed during this operation. The shutter shall then be opened and sand allowed to move out into the hole. The pouring cylinder and the surrounding area shall not be vibrated during this period. When no further movement of sand takes place the shutter shall be closed. The cylinder shall be removed and weighed to the nearest gram (*W4)*.

Photo 2.17: FDD Test by Sand Replacement Method in Progress

Calculation: The weight of sand (W_b) in g, required to fill the excavated hole shall be calculated from the following formula:

$$W_b = W1-W4-W2$$

The bulk density Y_b, that is, the weight of the wet soil per cubic metre shall be calculated from the following formula:

$$Y_b = Ww \times Ys \times 100/Wb$$

The dry density Y_d, that is, the weight of the dry soil shall be calculated from the following formula:

$$Y_d = (100Y_b / (100 + w))$$

Dry density of soil, in kg/m^3, noted as the nearest whole number. The dry density may also be calculated and reported in g/cc correct to the second place of decimal. Water content of the soil in percent reported to two significant figures.

Alternative method by the Nuclear Density Apparatus (NDA)

2.4.2.2 Drilled-core specimens

Once the compacted constructed stabilized layer has achieved sufficient strength gain or a degree of hardness through sufficient curing, the drilling of core-specimens may be proceeded with. The time allowed for sufficient curing shall be determined by the officer in charge. In general it should be done after 28 days of compaction.

A minimum core diameter of 100mm is recommended, drilled to the full depth of the layer tested, refer photo 2.18. The following tests shall be determined on the prepared drilled-core specimens, see Table 2.4:

(i) Unconfined Compressive Strength (UCS)

Photo 2.18: Core Cutting in Progress

Table 2.4: Drilled-core Specimens

Drilled-core Specimens	
UCS	**3**

Notes:

(1) The method and mechanisms of drilling of core-specimens was designed for concrete and asphalt layers.

(2) Thus drilling of core-specimens of material stabilized with RBI Grade-81 is not always possible as it is a cementetious binder but not cement and also depends on its resistance to the

harsh mechanisms of the drilling operation. This resistance depends on the following factors:

(i) The composition of the stabilized material as to the course to fine material ratio.
(ii) The physical properties of the coarse aggregate particles as to texture (smooth or irregular), durability (hard or soft) and shape (round or angular),
(iii) The amount of fine material matrix in order to interlock the coarse aggregate particles and
(iv) The effectiveness of the compactive effort (amount of voids).

Thus if the drilling of core-specimens is unsuccessful then alternative non-destructive test methods must be implemented in the determination of performance criteria i.e. plate bearing test for instance.
(3) What do we want to achieve? We want to construct a strong, durable flexible/semi-rigid layer capable of withstanding the deflective loads without cracking etc., and thus enhancing the life-span of the road.

2.4.2.3 In-Situ CBR by DCP
Once the constructed stabilized layer has achieved sufficient strength gain or a degree of hardness through sufficient curing the DCP test may be conducted.

Procedure: One person stands on the stool and holds the apparatus by the handle while the second person lifts the drop weight and then observes the readings and records them on the appropriate form refer photo 2.19.

The steel scale attached to the guide foot is placed through the slot in the hand guard. The foot is placed on the surface to be tested and the cone tip passed through the guide hole. The entire apparatus is then held by the handle perpendicular to the surface. The technician observes the reading on the scale at the top of the hand guard and records this as the Zero Reading of DCP.
The drop weight is then raised to its maximum height and released. It is extremely important to gain maximum height for each drop.

The readings are taken with each blow of the weight. If the penetration rate is below 20 mm/blow, the frequency of readings may be decreased to:

- one for every two blows with readings from 10-20 mm
- one for every five blows with readings from 5-9 mm
- One for every ten blows with readings from 2-4 mm.

Penetration depth less than 1 mm and exceeding 20 blows is considered as refusal. The test depth is determined by the engineer. Upon reaching the desired depth or refusal, the instrument is withdrawn.

Photo 2.19: DCP Test in Progress

Calculations: The field data is reduced in terms of penetration versus corresponding number of blows. The number of blows is then plotted horizontally along the x-axis and the penetration reading plotted vertically along the y-axis.

Depending on the pavement structure and environmental conditions the plot is divided into "best fit" straight lines. The slope values are then calculated by the change in penetration versus the change in the number of blows observed over the range for that particular straight line section - expressed as mm/blow.

$$DCP = \text{penetration in mm/blow}$$

In Annexure 2K, the figure of DCP apparatus and calculation chart are shown. When we achieve the DCP value, we can find out the field CBR as per IRC SP-72:2007

2.4.2.4 Geo Gauge Test

At the time of DCP test we may also conduct the Geo Gauge test. Geo gauge works on electromechanical means of the in-place stiffness of soil or soil-aggregate mixtures so as to determine a Young's modulus based on certain assumptions. The apparatus and procedure provide a fairly rapid means of testing so as to minimize interference and delay of construction. The test procedure is intended for evaluating the stiffness or modulus of materials used in earthworks and road works. With the help of stiffness we may find the CBR value of the tested pavement.

Procedure: Before seating the foot, lightly brush any loose material away from the test location. The surface need not be levelled if the gauge can stand on its own. If levelling is required, scraping the surface with a square point shovel is sufficient. To provide for consistent stress on the ground for each measurement, at least 60 % of the foot's annular ring surface must seat or contact the ground. The amount of surface contact is visibly estimated from the footprint left by the foot when the apparatus is lifted off the ground after the measurement is taken. If the requirement of seating the foot, as given cannot be met because of a rough or irregular ground surface or if the surface is hard and smooth, apply a thin layer of clean, moist sand about 3.0 to 6.0 mm thick, on the test location. Pat it down firmly and seat the foot on top of the sand. Practice in seating the foot is suggested as described above at each site prior to any actual measurements or each time ground surface conditions change. In addition, follow the manufacturer's recommendations as appropriate. Assure that the foot is clean and free of soil and other debris. Turn on the apparatus, seat the foot as per the prescribed method. Assure that the external case of the apparatus does not come into contact with a trench wall, pipe or any other object. Initiate the measurement. The apparatus should dwell at each frequency. The shaker will impart a force to the foot of the apparatus. The stiffness is calculated at each frequency by measuring and comparing the velocities from the two sensors. When the stiffness is calculated at all frequencies, the average stiffness over frequency is calculated and displayed in MN/m. Using the radius of the foot and a user selected value of Poisson's ratio; a Young's modulus may be calculated and displayed. See photo 2.20.

Photo 2.20: Geo Gauge Test in Progress

Calculation and Report: For the calculating Young's modulus following formula can be used:

$$E = K_{gr}(1-v^2)/1.77R$$

Where,

E = Young's modulus

K_{gr}= Stiffness of the ground layer being measured

v = Poisson's ratio

R = Outside radius of the apparatus

And for CBR the relation between CBR and stiffness is:

$$CBR = 0.0039(8.672K_{gr})^2-5.75$$

For reporting, at least a visual classification of the soils or soil mixtures, as well as a visual description of the same, the test conditions, test locations and depth of measure shall be mentioned. A sketch showing and numerically recording the position of test locations relative to site stations shall be drawn. All stiffness measurements and modulus determinations with its assumed Poisson's ratio identified by test location, time and date must be recorded. Stiffness data shall be rounded and recorded to one decimal place.

The test should be conduct as per ASTM D6758 – 2008. Test result should be put in format as mentioned in Annexure 2L

2.4.2.5 Light Weight Deflectometer

The Light Weight Deflectometer can be used for measuring the bearing capacity (deflection), degree of compaction, in-situ CBR of subgrade/subsoil, unbound base layers, granular layers, backfilling materials, soil stabilisation, cold recycling materials and pavements.

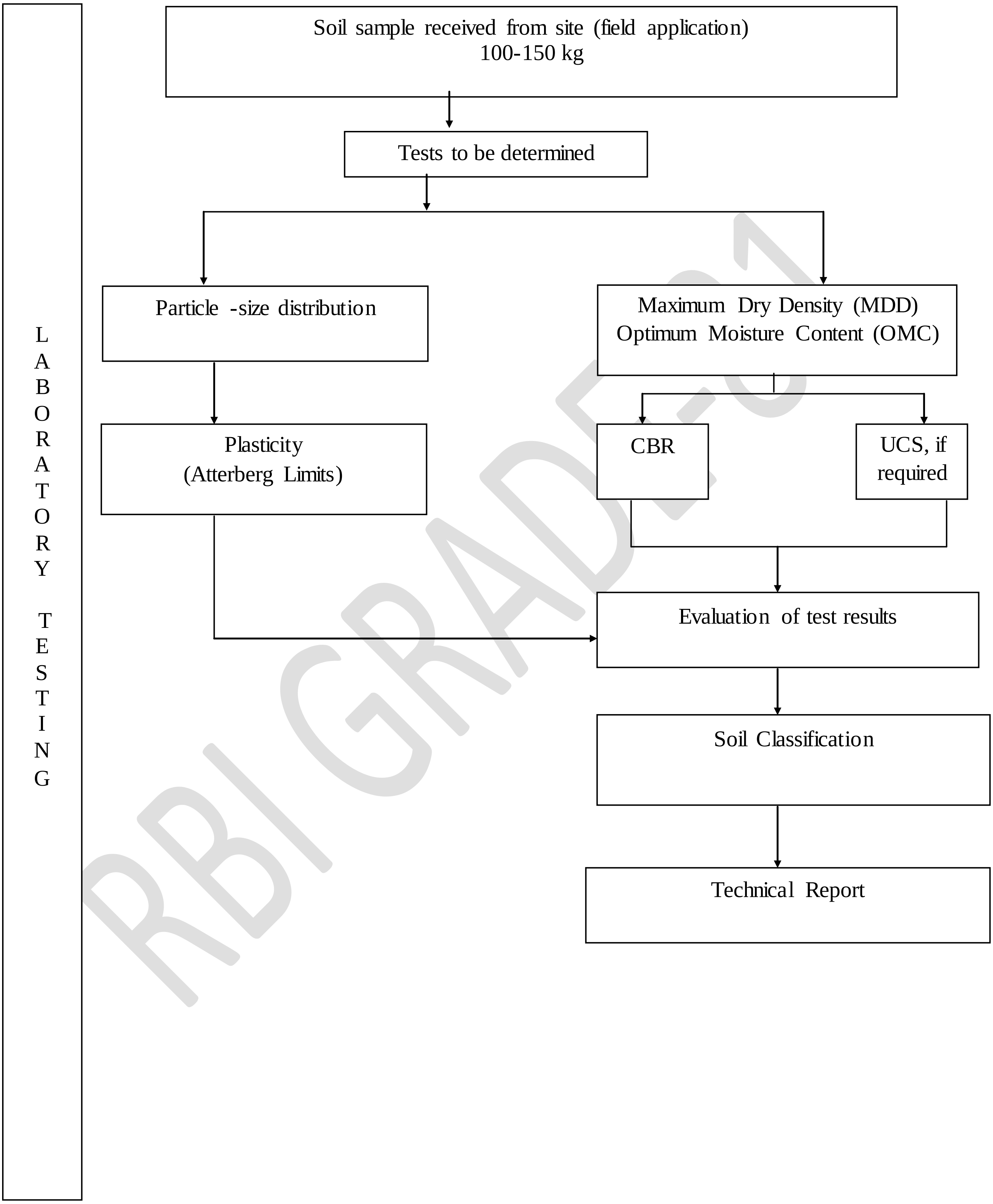
The soil receives an impact of maximum force Fs transmitted through the fall of the drop weight onto a circular plate of radius ‘r’, which is assumed to be rigid. When the device is calibrated, the force is selected such that the maximum normal stress under the load plate is 0.1MN/m2. A weight of 10 kg drops from a height of 72 cm on a load plate with a diameter of 300 mm. On the load plate, an acceleration sensor is arranged. From this acceleration signal will be calculated the dynamic deformation modulus Evd. On-site printouts complete with all information and simple data transmission to the PC with SD-Card is obtained through equipment. See Photo 2.21

Photo 2.21: LWD Test in Progress

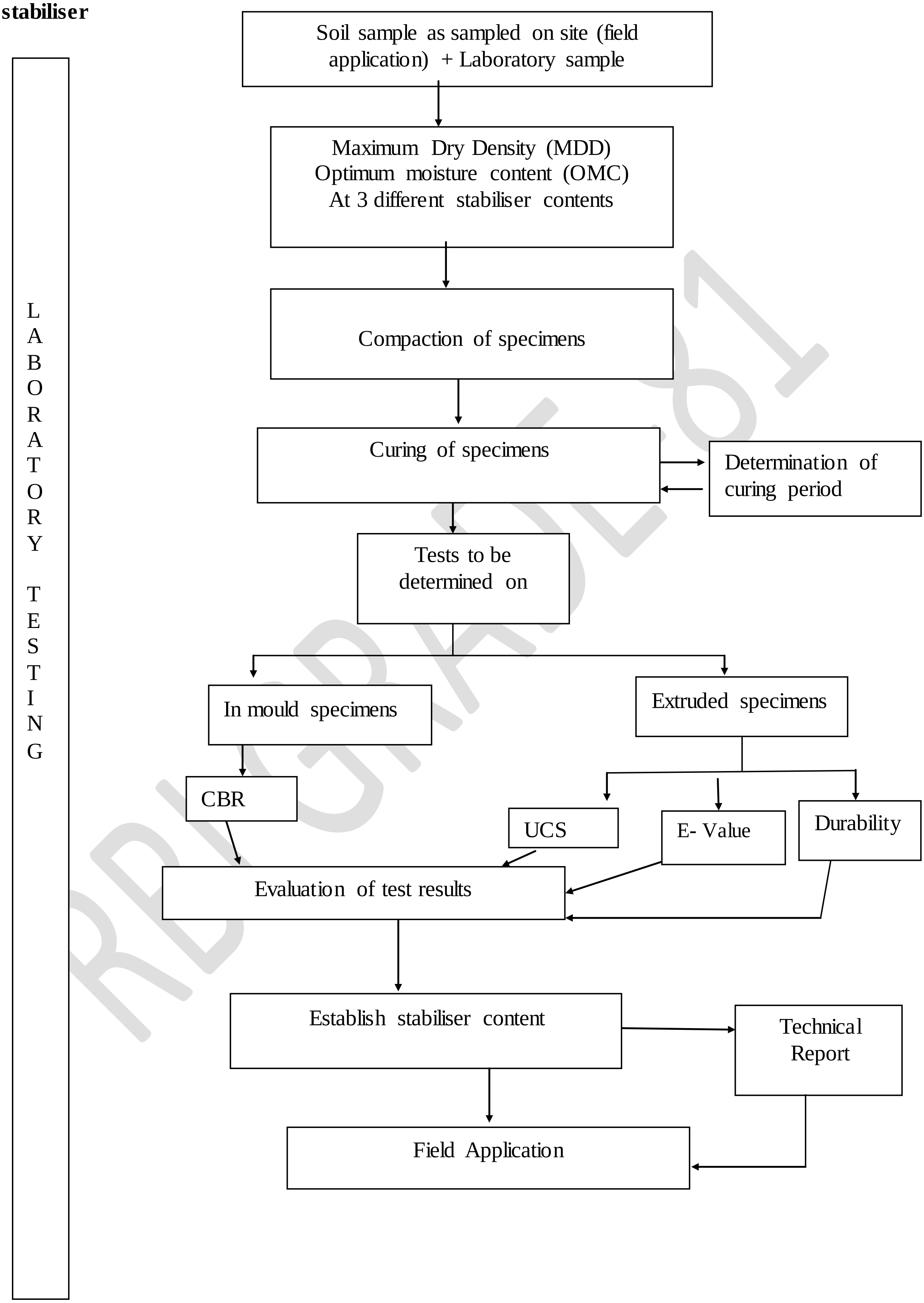
ANNEXURE 2A

FLOW CHARTS FOR TESTING PROCEDURES

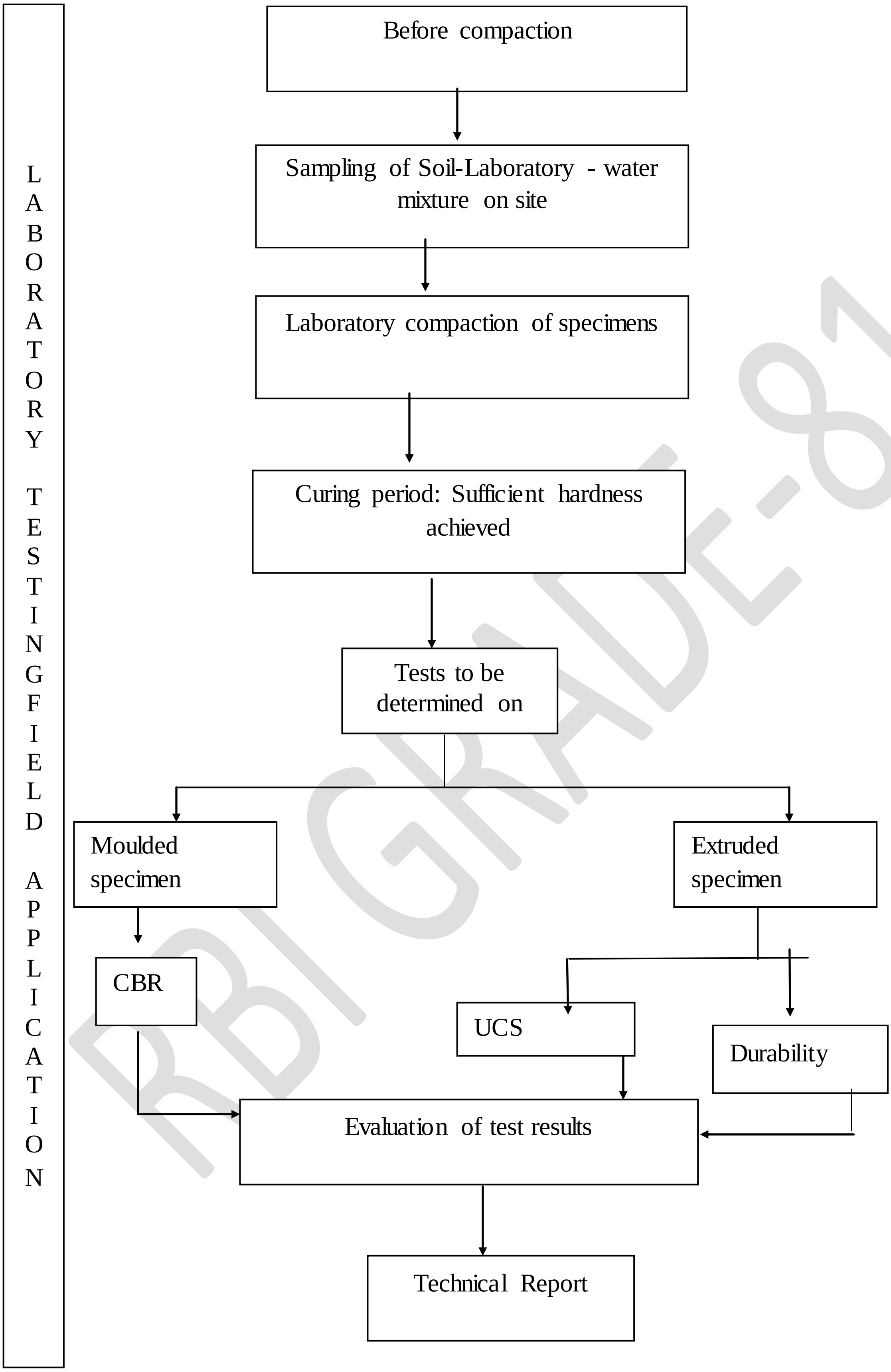
Flow Chart 1: Flow chart for the testing procedure of natural soil (untreated) before stabilization.



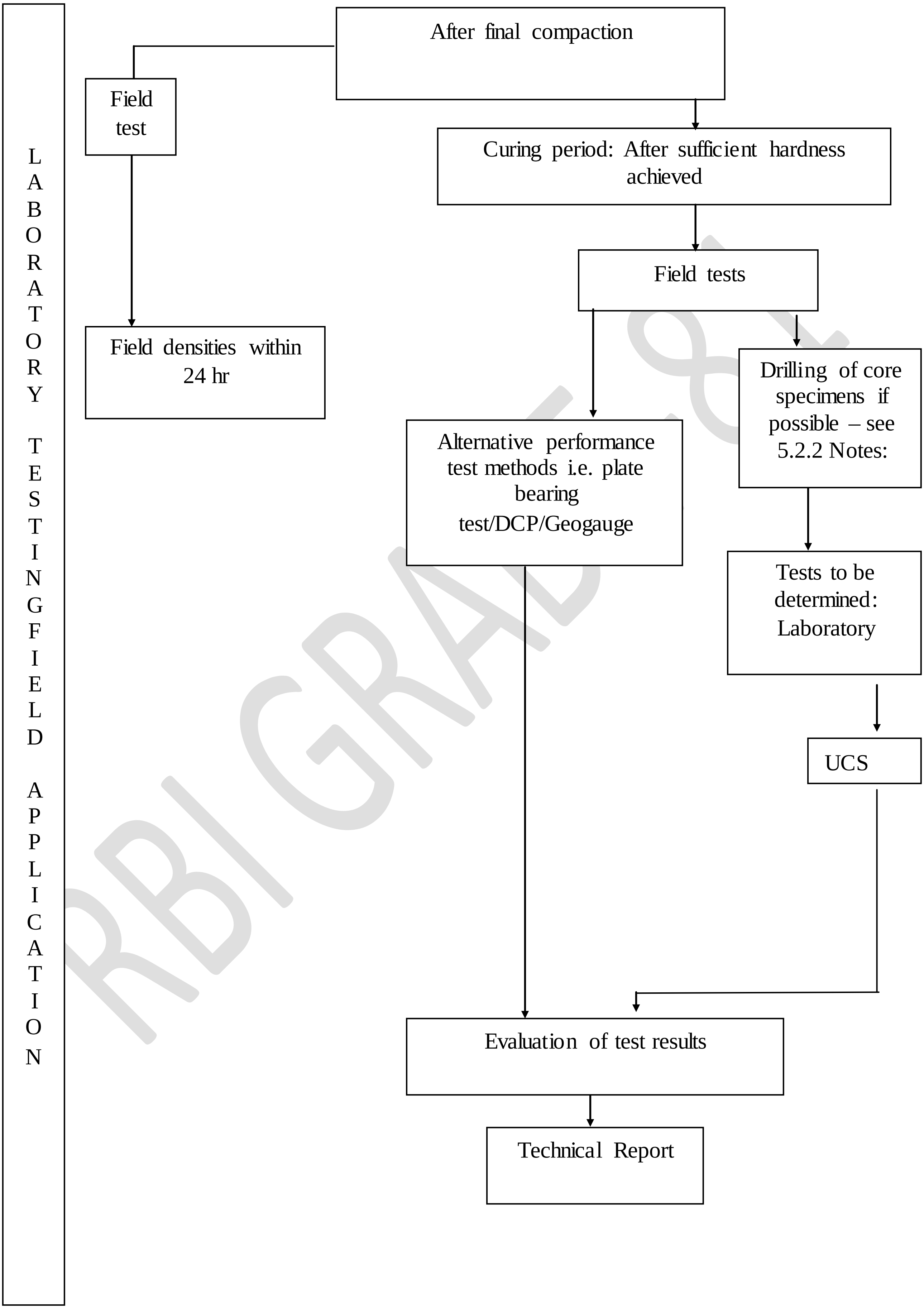
Flow chart 2: Flow chart for the testing procedure of treated soil with RBI Grade-81 stabiliser



Flow chart 3: Flow chart for field tests for quality control purposes



Flow Chart 4: Flow chart for field tests for quality control purposes



ANNEXURE 2B

RECOMMENDED GRADING ENVELOPE

FOR GRAVEL BASE/SUB-BASE COURSE

The following table is a recommended grading specification for material used as gravel course for roads stabilized with RBI Grade-81.

Recommended Grading Envelope

Sieve Size (mm)	% Passing sieves by mass	
	Sub-base	Base Course
26.5	95-100	90-100
19.0	45-100	75-90
13.0	-	60-90
9.5	35-100	-
4.75	25-100	40-60
2.0	-	30-50
0.6	8-65	-
0.425	-	12-25
0.3	5-40	-
0.075	0-10	0-5

The above recommended grading will achieve a high mechanical stability due to the preferred continuously smooth curve from the maximum particle size to the smallest particle size, consisting of a mixture of coarse and fine aggregate, silt and clay particles with no excess or lack in certain particle size. This will have a marked effect on the compatibility and bearing strength of the material and therein further enhancing the stabilization effort.

***Note*: 1**. Maximum nominal size of aggregate shall be 1/3rd of the layer depth/thickness**.**

ANNEXURE 2C

GRAIN-SIZE ANALYSIS TEST SHEET

Test sheet for Grain-Size Analysis

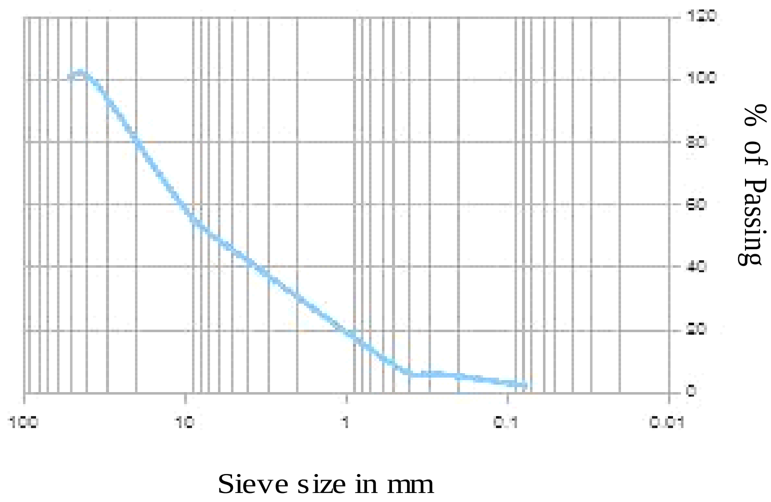
Project:	Client:
Sample ID:	Date of Sampling:
Source:	Date of Receiving:
Location:	Date of Testing:
Type of Material:	Layer: Sub-Base
Weight of Oven Dry Sample (g):15000	

IS Sieve (mm)	Wt. of Material Retained (g.)	Cumulative Wt. Retained (g.)	% Retained	% Passing	Limit	Remark
53	0	0	0	100	100	
37.5	0	0	0	100	95-100	
26.5	-	-	-	-	-	
19	3180	3180	21.2	78.8	45-100	C_u >5
13	-	-	-	-	-	
9.5	3225	6405	42.7	57.3	35-100	Gravel =55.4
4.75	1905	8310	55.4	44.6	25-100	Sand =42.5
2	-	-	-	-	-	Silt & Clay =2.1
0.6	4980	13290	88.6	11.4	8-65	
0.425	-	-	-	-	-	
0.3	810	14100	94	6.0	5-40	
0.075	585	14685	97.9	2.1	0-10	

Coefficient of Uniformity C_u:-

$Cu= D_{60}/D_{10}$

Where D_{60} is the diameter for which 60% of the sample is finer than D_{60}, and D_{10} is the diameter for which 10 % of the sample is finer than D10.



By the Graph:

Cu = 12/0.6

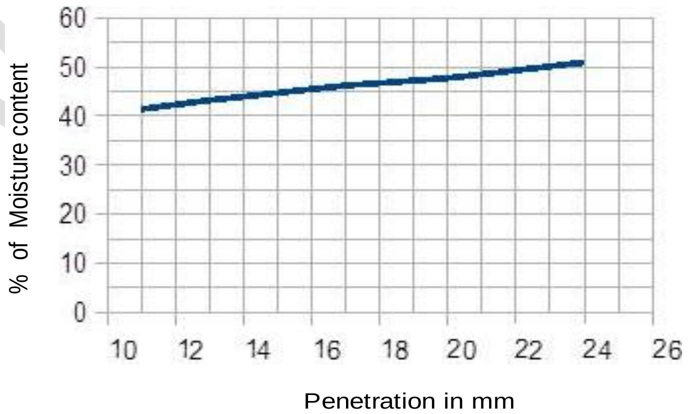
Cu = 20

ANNEXURE 2D

LIQUID AND PLASTIC LIMIT TEST SHEET

Test sheet for Liquid and Plastic Limit

Project:								Client: Alchemist
Sample ID:								Date of Sampling:
Source:								Date of Receiving:
Location:								Date of Testing:
Type of Material:								Layer:
Test Apparatus: Cone Penetrometer								
Description	Liquid Limit						Plastic Limit	
Observation No.	1	2	3	4	5	6	1	2
Penetration (mm)/No. Of Blow	11	13	17	20	24	-	-	-
Container No.	40	78	72	7	22	-	45	26
Wt. of Container (W_1)	13.12	13.99	10.97	17.03	14.84	-	13.86	13.48
Wt. of Container+ Wet Soil (W_2)	32.77	33.98	35.60	46.14	36.88	-	23.6	22.86
Wt. of Container+ Dry Soil (W_3)	27.02	27.95	27.82	36.74	29.45	-	21.19	20.58
Wt. of Water (W_2-W_3)	5.75	6.03	7.78	9.4	7.43	-	2.41	2.28
Wt. of Dried Soil (W_3-W_1)	13.9	13.96	16.85	19.71	14.61	-	7.33	7.1
Water Content = (W_2-W_3)/(W_3-W_1)X100	41.4	43.2	46.2	47.7	50.9	-	32.9	32.1



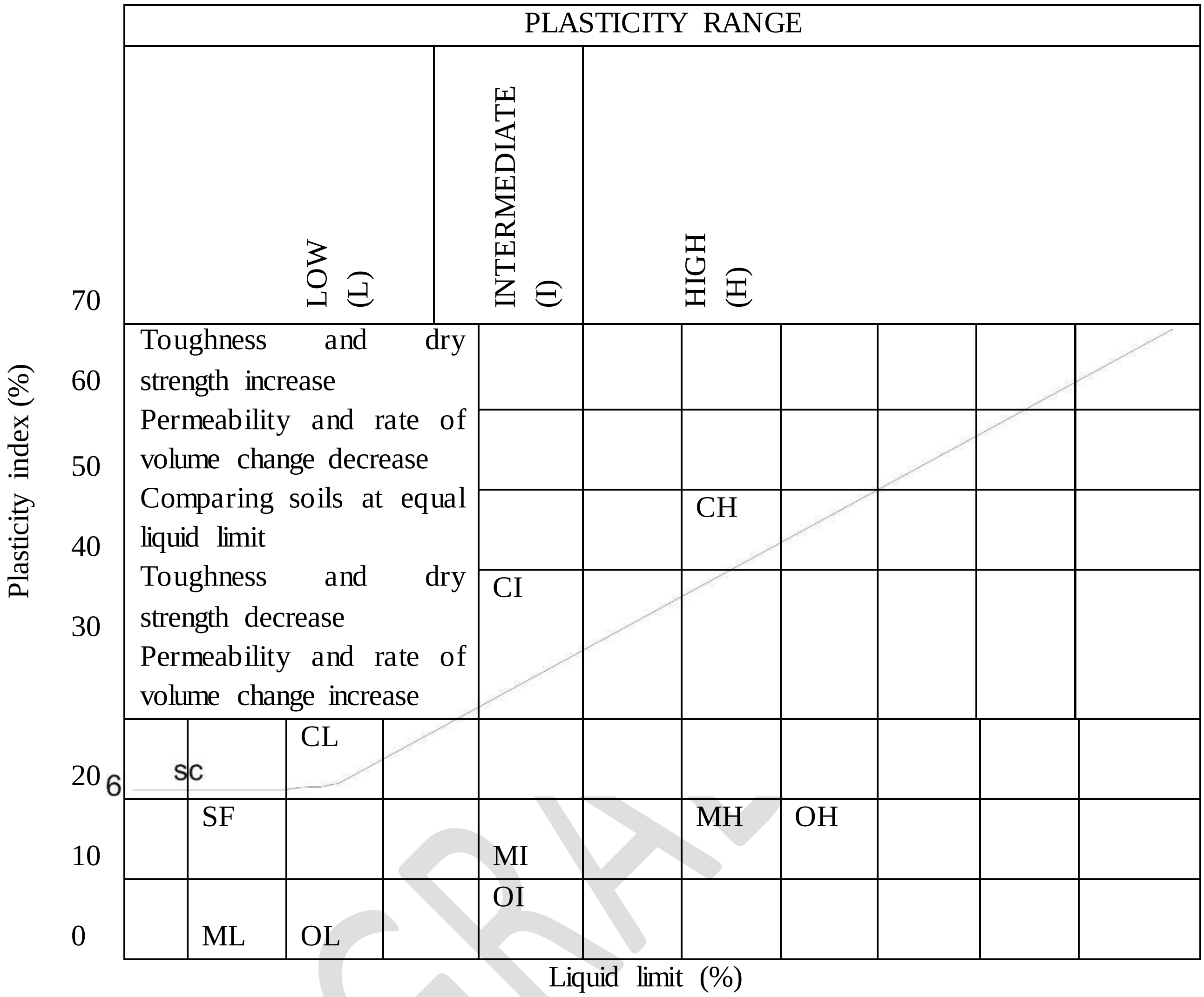
LL = 48, PL= 32.5, PI= 15.5

ANNEXURE 2E

CLASSIFICATION SYSTEMS

The Unified Soil Classification System

MAIN GROUPS			GROUP SYMBOLS	TYPICAL NAMES
Coarse-grained soils More than half of material is larger than No.200 sieve size 0,075mm (0.075mm)	Gravels More than half of coarse fraction is larger than No 4 sieve size (4.75mm_)	Clean gravels (Little or no fines)	GW	Well graded gravels, gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines
		Gravels with fines (Appreciabl e amount of fines)	GM	Silty gravels, poorly graded gravel – sand – silt mixtures
			GC	Clayey gravels, poorly graded gravel – sand – clay mixtures
	Sands More than than half of coarse fraction is smaller than No 4 sieve size (4.75mm)	Clean sands (Little or no fines)	SW	Well graded sands, gravely sands, little or no fines
			SP	Poorly graded sands, gravely sands, little or no fines
		Sands with fines (Appreciabl e amount of fines)	SM	Silty sands, poorly graded sand-silt mixtures
			SC	Clayey sands, poorly graded sand-clay mixtures
Fine-grained soils More than half of material is smaller than No. 200 sieve size (0.075mm	Silts and clay Liquid limit less than 50		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity
			CL	Inorganic clays of low to medium plasticity, gravely clays, sandy clays, silty clays, lean clays
			OL	Organic silts and organic silt-clays of low plasticity
	Silts and clays Liquid limit greater than 50		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
			CH	Inorganic clays of high plasticity, fat clays
			OH	Organic clays of medium to high plasticity
Highly organic soils			Pt	Peat and other highly organic soils



Graph 3: LL versus PI

(The letter O is added to any material containing a significant proportion of organic matter e.g. MIO)

ANNEXURE 2F

TEST SHEET FOR FREE SWELL INDEX

Test sheet for Free Swell Index

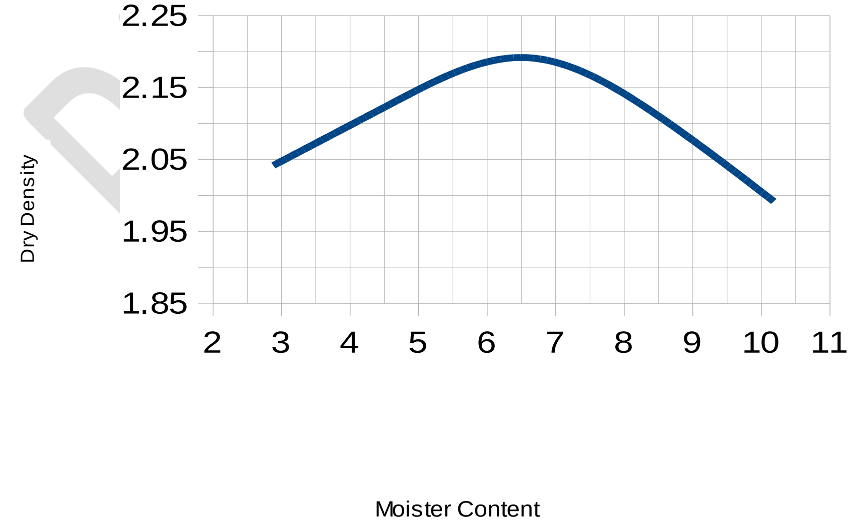
Project:		Client:	
Sample ID:		Date of Sampling:	
Source:		Date of Receiving:	
Location:		Date of Testing:	
Type of Material:		Layer: Sub-base	
Determination		Soil	Soil + RBI Grade-81
Volume of specimen in graduated cylinder containing kerosene, after 24 hrs. (ml)	V_k	10	10
Volume of specimen in graduated cylinder containing distilled water, after 24 hr (ml)	V_d	12.5	11
Volume difference of specimen in water and kerosene (ml)	V_d-V_k	2.5	1
Free Swell Index (%)	$(V_d-V_k)/V_k$	25	10

ANNEXURE 2G

TEST SHEET FOR WATER CONTENT AND DRY DENSITY RELATION

Test sheet for Water Content-Dry Density Relation

Project:				Client:		
Sample ID:				Date of Sampling:		
Source:				Date of Receiving:		
Location:				Date of Testing:		
Type of Material:				Layer:		
Mould No:-	**Mould Weight (g):-5890**			**Mould Volume (cc):-2250**		
Description	Unit	1	2	3	4	5
Volume of water used	%	2	4	6	8	10
Wt. of mould + Wet soil	g	10613	10908	11143	11041	10824
Wt. of wet soil	g	4723	5018	5253	5151	4934
Wet Density of soil	g/cc	2.10	2.23	2.33	2.29	2.19
Container number	-	38	78	61	40	08
Wt. of Container	g	15.35	13.97	16.29	13.18	12.69
Wt. of wet soil+ Container	g	120.86	125.11	141.05	132.31	154.99
Wt. of dry soil +Container	g	117.89	120.12	133.33	122.98	143.48
Wt. of water	g	2.97	4.99	7.72	9.33	11.51
Wt. of dry soil	g	102.54	106.15	117.04	109.8	130.79
Moisture content	%	2.9	4.7	6.6	8.5	0.2
Dry density of soil	g/cc	2.04	2.13	2.19	2.11	1.99



Rammer Wt. =4.89 Kg.
No. of Blows =55
No. of Layers =5

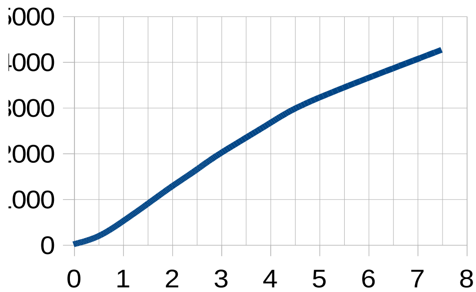
M.D.D = 2.19 g/cc
O.M.C = 6.6 %

ANNEXURE 2H

TEST SHEET FOR CALIFORNIA BEARING RATIO

Test sheet for California Bearing Ratio

Project:		Client:	
Sample ID:		Date of Sampling/Receiving:	
Source:		Date of Casting:29.04.13	
Location:		Date of Soaking:06.05.13	
Type of Material:		Date of Testing:10.05.13	
Description	Unit	Before Soaking	After Soaking
Mould No.	-	25	
Volume of Mould (V)	(cc)	2250	
Wt. of empty Mould	(g)	6503	
Wt. of Mould + Compacted Soil	(g)	11780	11858
Wt. of Compacted Soil	(g)	5277	5355
Wet Density	(g/cc)	2.35	2.38
Container No.	-	85	62
Wt. of container	(g)	14.98	16.47
Wt. of container + wet soil	(g)	89.96	101.53
Wt. of container + dry soil	(g)	82.71	92.62
Wt. of Water	(g)	7.25	8.91
Wt. of dry soil	(g)	67.73	76.15
Moisture content	(%)	10.7	11.7
Dry Density	(g/cc)	2.12	2.13

Proving Ring Dial Gauge Reading					Proving Ring Capacity: 50 kN	
Sl. No.	**Penetration (mm)**	**Proving ring reading (Divisions)**	**Unit Load (kg)**	**Corrected Load (kg)**	**CBR Result** **(Please Refer Attached Graph)**	
1	0	0	4.33	0	CBR at 2.5 mm (%)	133
2	0.5	40		173	CBR at 5.0 mm (%)	164
3	1.0	115		498	 Graph:	
4	1.5	202		875		
5	2.0	291		1260		
6	2.5	375		1624		
7	3.0	460		1992		
8	4.0	611		2646		
9	5.0	740		3204		
10	7.5	982		4252		
11	10.0					
12	12.5					

ANNEXURE 2I

TEST SHEET FOR UNCONFINED COMPRESSIVE STRENGTH

Test sheet for Unconfined Compressive Strength

Project:				Client:		
Sample ID:				Date of Sampling:		
Source:				Date of Receiving:		
Location:				Date of Testing:		
Type of Material:				Layer:		
Dial Gauge Reading	**Axial deformation (mm)**	**Axial strain, ε (%)**	**Corrected area (cm^2)**	**P. Ring dial Reading**	**Axial force (kgf)**	**Compressive stress (kgf/cm^2)**
0	0	0	19.63	0	0	0
50	0.5	0.5	19.73	26	122	6.2
100	1	1	19.83	55	257	13.0
150	1.5	1.5	19.93	93	435	21.8
200	2	2	20.03	108	505	25.2
250	2.5					
300	3					
350	3.5					
400	4					
450	4.5					
500	5					
600	6					
700	7					
800	8					
900	9					
1000	10					
Unconfined Compressive Strength: 25.2kgf/cm^2						

ANNEXURE 2J

CALCULATION SHEET FOR E-VALUE

Sample Calculation

<Sample Description> 50%soil + 50%20mm+4%RBI GRADE-81

Test Type: Flexure

Sample Id:

Test Date:

Sample TypeId:0

Sample Height:100(mm)

Sample Width:100(mm)

Sample Length:500(mm)

Sample Diameter:0(mm)

Sample Area:50000(Sq mm)

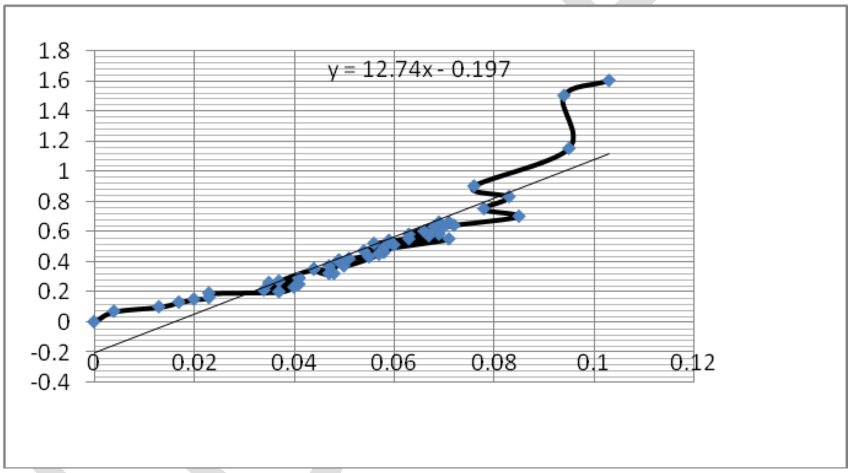
Sample Weight: .... (Kg)

Sample Age:28 days Cured

<Test Data>

Rate Of Loading:0.01 ((KN/Sec))

Testing Person :



Graph 2.3:Load versus Displacement Graph

Table 2.5 : Calculation of E-Value

Calculation of E-Value				
1	Failure Load (P)			KN
2	Corresponding Disp. (d)			Mm
3	Dimension of Beam	Length (L)	500	Mm
		Breadth (B)	100	Mm
		Width (D)	100	Mm
4	Avg. P'=P/d (from graph)		12.74	KN/mm
5	Failure Load (P)			N
6	Effective Length of Beam (L)		400	Mm
7	Moment of Inertia = I= $(B*D^3/12)$		8333333.333	mm^4
8	L/3=a		133.333	Mm
9	E= $Pa(3L^2-4a^2)/24*I$			MPa

ANNEXURE 2K

FIGURE OF DYNAMIC CONE PENETROMETER

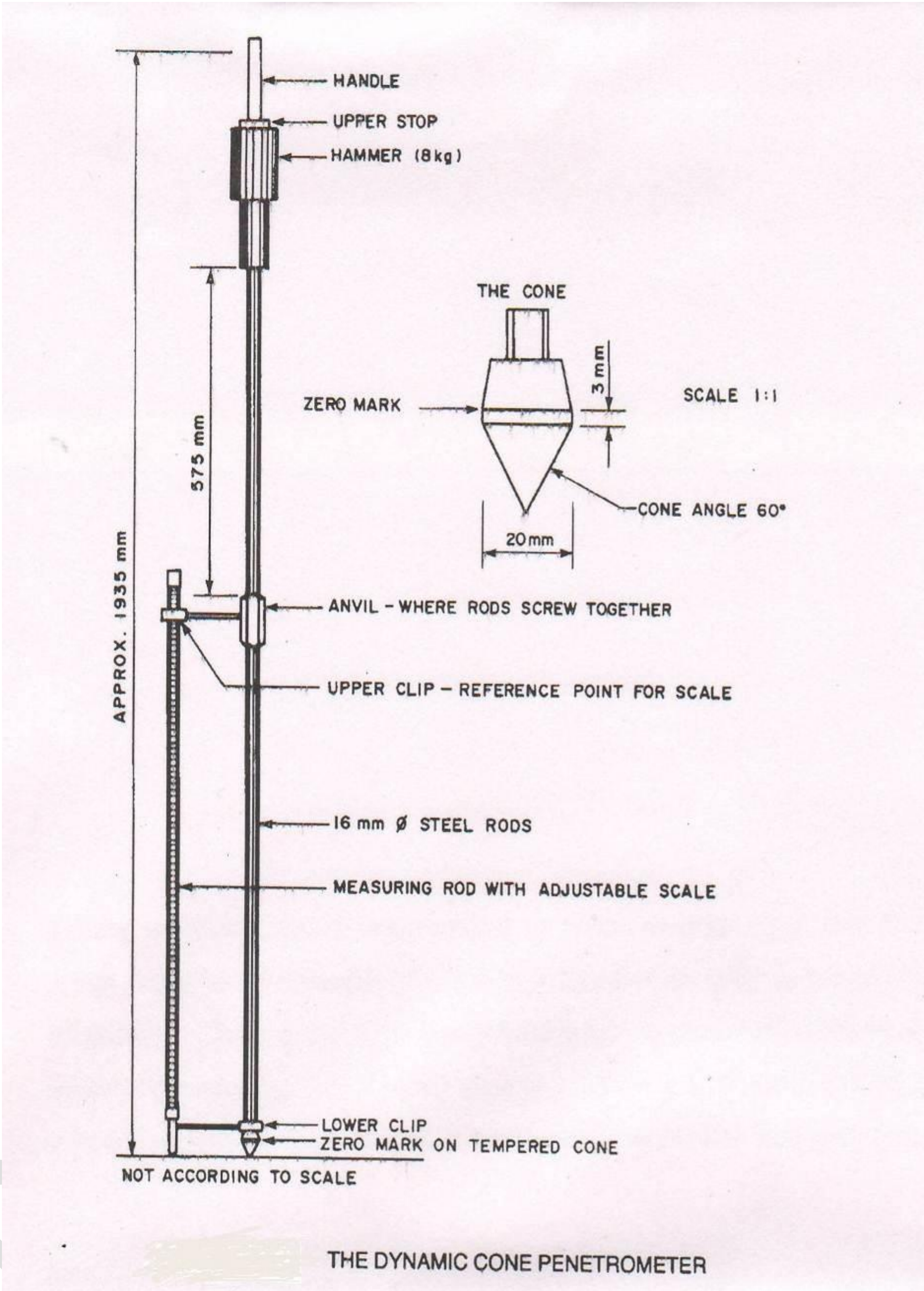


Fig 2.1 : Dynamic Cone Penetrometer

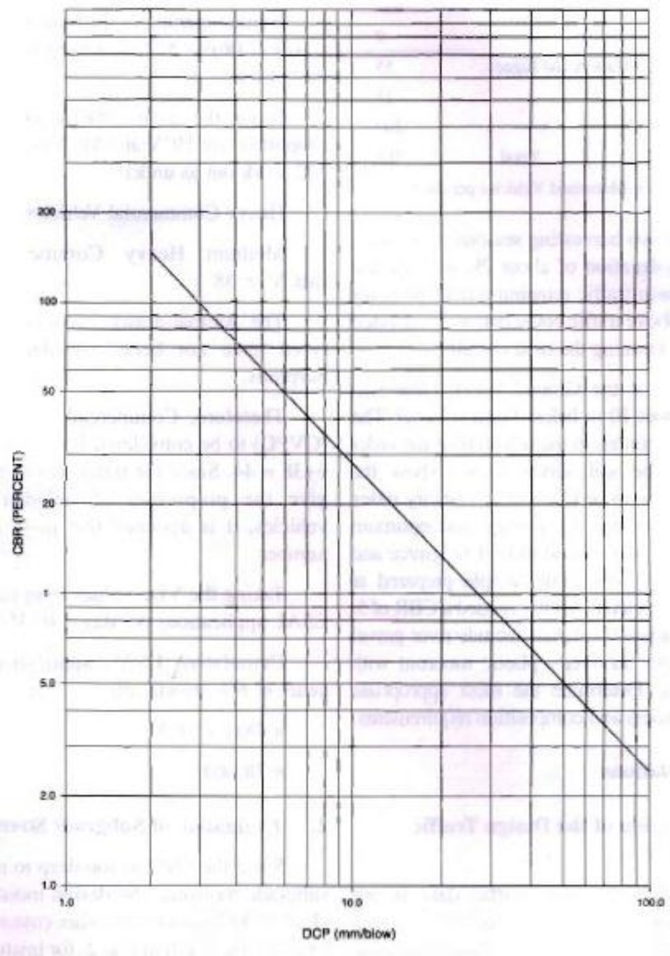


Fig 2.2 : Dynamic Cone Penetrometer Graph

ANNEXURE 2L

FORMAT FOR GEOGAUGE TEST

Geogauge Test Format

In-Situ CBR by GEO GAUGE									
Project :				Client:					
Location:				Date of Laying					
Layer composition:				Date of Testing:					
Pavement Composition:									
Chainage (KM)	LEFT SIDE OFFSET			CENTER			RIGHT SIDE OFFSET		
	Stiffness, K (MN/m)	Elastic Modulus (MPa)	CBR (%)	Stiffness, K (MN/m)	Elastic Modulus (MPa)	CBR (%)	Stiffness, K (MN/m)	Elastic Modulus (MPa)	CBR (%)
Average									

Remarks:

Stiffness CBR Relation : **CBR= 0.0039(8.672*K)^2-5.75**

ANNEXURE 2M

TEST SHEET FOR DURABILITY

Test sheet for Durability

Durability Wetting And Drying (As Per IS :4332,Part-4)					
Project :			Client:		
Sample ID			Date of Receiving		
Source			Date of Casting:		
Location			Final Testing Date		
Material Description					
Sample-1			Sample-2		
Initial Weight : 2164 g.			Initial Weight : 2169 g.		
Cycle No.	Weight Loss After Each Cycle (g.)	% Loss	Cycle No.	Weight Loss After Each Cycle (g.)	% Loss
1	2029	6.2	1	2036	6.1
2	2022	6.6	2	2033	6.3
3	2022	6.6	3	2032	6.3
4	2020	6.7	4	2028	6.5
5	2020	6.7	5	2027	6.5
6	2019	6.7	6	2023	6.7
7	2017	6.8	7	2020	6.9
8	2015	6.9	8	2018	7.0
9	2013	7.0	9	2015	7.1
10	2013	7.0	10	2012	7.2
11	2009	7.2	11	2008	7.4
12	2004	7.4	12	1992	8.2
Remarks:					

CHAPTER 3: CONSTRUCTION MANUAL

3.1 Introduction

This chapter covers the stabilization of materials used in the construction of the roadbed, fill and pavement layers by the addition of RBI Grade-81 stabilizer. It includes the preparation of the base, application of stabilizer, compaction and curing of the stabilized layer. Stabilization with RBI Grade-81 stabilizer improves the engineering properties of substandard, readily available material, where such stabilizations is a cheaper alternative to the procurement of materials complying with the relevant specifications with an outcome in reduction of construction costs, or where layers with substantial higher tensile strength are required to withstand the onslaught of the expected high increase in heavy traffic and environment. The success of the stabilization requires technical input and engineering and not merely equipment and powder. A good technique used successfully will guarantee a high degree of stabilization success even in extreme conditions which entails the following:

- a thorough investigation of existing road pavement and borrow pit materials,
- the right technical knowledge,
- proper and adequate design parameters,
- the use of appropriate equipment and product and
- Sufficient quality control testing before and during application.

Thus the use of a good technique, efficient planning and capable method in combination with RBI Grade-81 stabilizer will guarantee a successful stabilization every time.

The following chapter which includes project specifications has been written to cover all phases of construction work normally required for the stabilization of materials or pavement layers using RBI Grade-81. The objective is to produce uniform results confirming to relevant specifications. The manual is intended as a guide for practicing engineers and at the same time permits engineering judgment to be administered.

Annexure 3A is for information purposes only and contains a flow chart for the construction procedure to assist and guide the users.

3.2 Foundation and Drainage

Before commencement with the stabilization of pavement layers, thorough assessment of the foundation and drainage should be carried out.

3.2.1 Foundation

The stabilized layer should be constructed on a stable, durable, adequately compacted foundation layer or underlying pavement structures, depending on the type and amount of traffic load. The following problems should be addressed and eliminated before any stabilization of a material or pavement layer is initiated:

i) Excessive volume changes which occur in some soils as a result of moisture change (eg. expansive soils and soils with a collapsible structure).

ii) Flaws in structural support (eg. sinkholes and slope stability).
iii) Non-uniform supports those results from wide variations in soil types or states.
iv) Biological activity (eg. moles, termites etc.).
v) Organic material (eg. humus, vegetation etc.)
vi) Non-compaction of underlying layers.
vii) Low and insufficient bearing capacity of the underlying layers.

3.2.2 Drainage

The compacted layers should be adequately drained and shaped (maintaining a 2-3% camber) to prevent standing water from scouring the completed work. Windrows should be removed to facilitate the drainage of water from the surface.

a) Open drains should be excavated within the road prism (medium drains and side drains) either by hand or special excavating equipment (brackets, draglines or similar equipment) to control the free water by effective drainage. Open drains will prevent damage to the stabilized layer and its foundation from free water.

b) All existing open drains shall be cleared out, and where necessary, shaped by removing the sediment and trimming the floors and sides.

c) All backfilling that is required for excavation of open drains and concrete linings, should be of suitable material and compacted to at least 90% of Mod. AASHTO density or higher.

All reasonable precautions should be implemented to prevent the material or the road from becoming excessively wet as a result of rain, groundwater or storm-water.

Where material or existing layers are too wet to comply with the requirements in regard to moisture content during construction, the material shall be dried out until it is suitable for compaction, stabilization, and all other aspects associated with RBI Grade-81 application. See Figure 3.1(a): Illustrating a typical cross-section of an unpaved side drain.

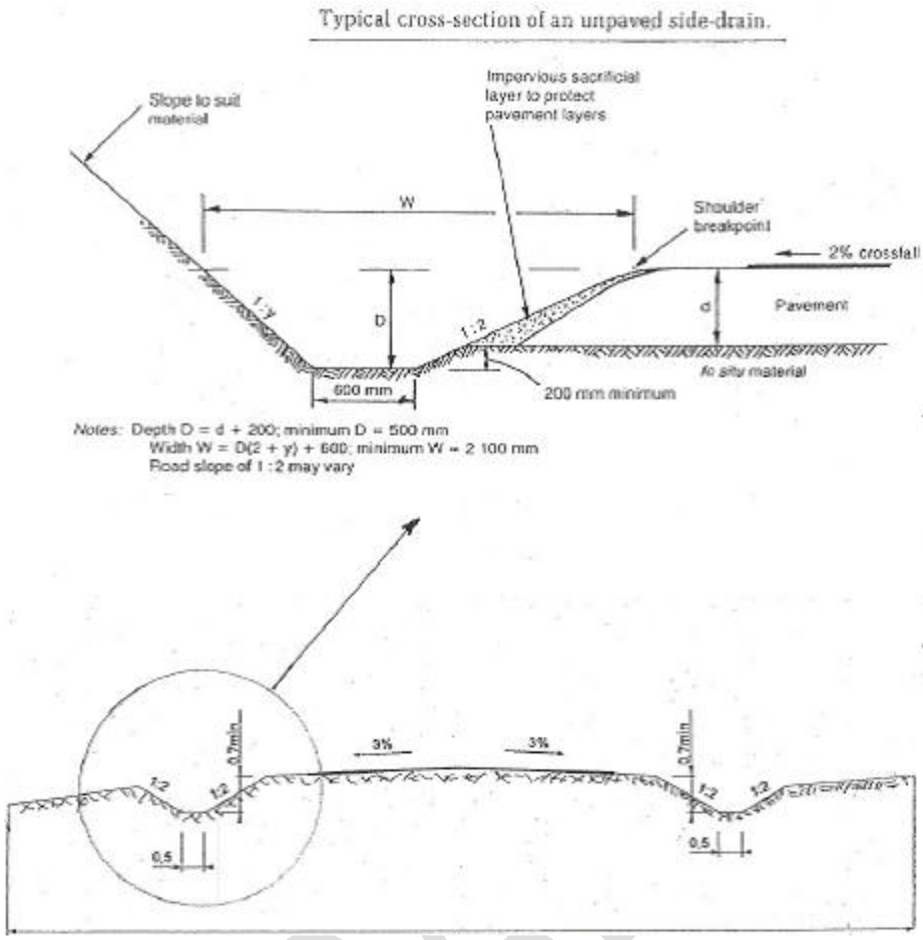


Figure 3.1(a): Illustrating a typical cross-section of an unpaved side drain.

3.3 Stabilization using RBI Grade-81

Stabilization using RBI Grade-81 (the process of improving the engineering properties of a material by means of the addition of RBI Grade-81) is subject to the quality of materials available and the impact of the environment (traffic, climate, etc.) on the structural design. Stabilization with RBI Grade-81 endeavors to increase the quality of the project and reduce construction costs by improving the properties of substandard, readily available material to comply with the relevant specifications.

3.3.1 Materials

a) Stabilizer agent, RBI Grade-81

Should be kept under cover and protected from moisture from the time of purchase to the time of use. If material has been left exposed to environmental elements, consult a RBI Grade-81 representative.

b) Soil or Gravel

It is preferable to stabilize a soil with a continuously smooth gradation curve from the maximum particle size to the smallest particle size with no excess or lack in certain particles. This will ensure better interlocking capabilities of the soil particles resulting in increased density and strength of the soil. It is recommended that the soil material have sufficient fine material (< 2.00 mm) to effectively stabilize the material with RBI Grade-81.

3.3.2 Water

Water used should be free from harmful substances that may affect the setting and hardening process of the stabilizer. Water that is thought to encourage adverse reactions should be tested for compatibility with RBI Grade-81. Potable water is most preferred.

3.3.3 Construction procedures

There are three methods for construction with RBI GRADE-81:-

1. Manual Method
2. Semi-Automatic Method
3. Automatic Method by WMM Plant/Batch Mix Plant

- **List of Machinery Required for Manual Method**
  a. Back Hoe Loader (JCB)
  b. Single Drum Soil Compactor/ Earth Vibratory Compactor
  c. Water Tanker with sprikler
  d. Tractor with Rotary tiller (rotavator)
  e. Motor Grader
  f. Tractor trolley/Tipper

- **List of Machinery Required for Semi-Automatic Method**
  a. Back Hoe Loader (JCB)
  b. Single Drum Soil Compactor/ Earth Vibratory Compactor
  c. Water Tanker with and without sprinkler
  d. Automatic Stabilizing Machine
  e. Motor Grader
  f. Tractor trolley/Tipper

- **List of Machinery Required for Automatic Method**
  a. Back Hoe Loader (JCB)
  b. Single Drum Soil Compactor/ Earth Vibratory Compactor
  c. Water Tanker with and without sprinkler
  d. WMM Plant/Batch Mix Plant
  e. Paver Finisher
  f. Motor Grader
  g. Tractor trolley/Tipper

3.3.3.1 Construction Methodology-Manual Method

a. Preparing the Layer: Before construction of any stabilized layer and before any transported material for stabilization is dumped on the road, the underlying layer should be investigated to establish whether there is any damage, voids, wet spots or other defects. Any defects to the layer should be rectified with the material of having similar properties with the native material before the stabilized layer is constructed. Where the stabilized layer is constructed on the floor of a pavement excavation or on the top of an existing pavement layer i.e. where the underlying layer has not been reworked or reconstructed, the floor of the excavation or top of the existing pavement layer should first be watered and the compaction of the layer should be carried when layer become moist or comes at OMC. The material to be stabilized should be placed, or in the case of existing pavement layer, scarified to the full depth specified, broken down and watered if necessary and mixed to achieve a homogenous layer. Any oversize material (> 1/3 the thickness of the layer to be stabilized) should be removed. Normally Maximum size of aggregate is 30mm.

Photo 3.1: Initial view of site

Photo 3.2: View of Bed Preparation in Progress

Photo 3.1 to 3.4 shows a stabilization site observed, tested and prepared for stabilization.

Photo 3.3: View of Checking of Existing Subgrade compaction by DCP

Photo 3.4: View of Spreading of Construction Material for Stabilized Layer

b. Applying the Stabilizing agent, RBI Grade-81: Dosage of Product (RBI Grade-81) should be determined during the design before the product application. The product should be spread uniformly over the layer to be stabilized by means of an approved type of mechanical spreader or by hand. Material that has been exposed to the open air for the period of 4 hours or more should not be used. The Bags of RBI Grade-81 should be accurately spaced at equal intervals, see photo 3.5, along the section to be stabilized to ensure uniform application of RBI Grade-81. The stabilizing agent should be spread as evenly as possible over the entire surface, see photo 3.6. RBI Grade-81 should not be applied in windy conditions otherwise it will lead to a situation where the stabilizer becomes airborne and is wasted in such a manner that it becomes hazardous to traffic, workmen, adjacent workers or adjacent property.

Photo 3.5: View of RBI Grade-81 bags laying

Photo 3.6: View of RBI Grade-81 Spreading

c. **Dry Mixing:** Immediately after the product has been spread it should be mixed with the soil/material to the full depth of treatment. Special attention should be taken not to disturb the compacted layer underneath and especially not to mix the stabilizing agent in below the desired depth. Mixing should continue for as long as necessary and repeated as often as required to ensure homogeneity and through mixing of the soil/material with RBI Grade-81 over the full area of the application site. Mixing should be done using a rotary tiller (rotavator), see photo 3.7 or equivalent equipment over successive passes of the layer. Specific attention should be made to ensure that the mixing device does not cycle RBI Grade-81 and shift the majority of the powder at the bottom of the layer to be constructed.

Photo 3.7: View of Dry Mixing with Rotavator

d. Watering: Watering equipment should be adequate to ensure that all the water required is added and mixed with the soil/material being treated within the prescribed period to enable compaction, see photo 3.8. Uniform mixing of the product and water is paramount to the success of the stabilized layer. Particular care should be taken to ensure satisfactory moisture distribution over the full depth, width and length of the section being stabilized and to prevent any portion of the work from getting excessively wet after the stabilizing agent has been added. It should be ensured that the moisture content of the mixture is not below the specified optimum moisture or more than 2 percent above the specified optimum moisture content. If any portion of the section becomes too wet during application of water as during rain or downpour, the application shall be rejected. These portions should be allowed to dry out to the required moisture content and then be scarified, re-stabilized and re-compacted.

Photo 3.8: View of water addition

Photo 3.9: View of RMM test in progress

e. Wet Mixing: As soon as the watering is done over the whole section, the wet mixing should start with rotavator. In case of any problem faced during construction it should be kept in mind that the time gap between the watering and wet mixing should not get more than prescribed. The wet mixing, see photo 3.10, should be done in such a way that the moisture distribution must be uniform along the surface as well as depth. . Mixing should continue for as long as necessary and repeated as often as required to ensure homogeneity and through mixing at OMC. To check OMC in the field, wet RBI Grade-81 and soil mix should be rolled into a ball, subject to the condition that it should not break or split. Rapid Moisture meter as shown in photo 3.9 can also be used for more accuracy.

Photo 3.10: View of Wet Mixing by Rotavator

f. Grading in Proper Profile: After the wet mixing is over, grading should be done with motor grader to achieve the required profile, see photo 3.11. The surface should be smooth and any big size stone or unbroken clumps if present on the surface should be removed. Once the grading is done and proper profile is achieved, the stabilized surface is ready for compaction.

Photo 3.11: View of Grading in progress

g. Compaction: Compaction of the material in the pavement layer should be carried out within 4 hours after watering is done. The type of compaction equipment to be used and amount of rolling to be done should be such as to ensure that specified densities are obtained without damage being done to lower layer structures. Selection of correct compaction equipment should be carried out by the contractor. Preferably Single Drum Soil Compactor/ Earth Vibratory Compactor should be used, see photo 3.12. Compaction should be carried out in a series of continuous operations covering the full width of the layer concerned. During compaction, the layer should be maintained to the required shape and cross-section, and holes, ruts and laminations should be removed. Loss of moisture from evaporation should be corrected by further light applications of water over the surface. During final compaction, field density determinations should be done to determine accurately the applied compaction effort and to ensure the minimum compaction requirement has been obtained. Final density test should be carried out within 24 hours of compaction completion or as suggested by EIC.

Photo 3.12: View of Compaction in progress

Photo 3.13 is showing the view of compacted surface.

Photo 3.13: View of Final surface

h. Curing: The existing moisture of the stabilized layer should not be allowed to evaporate. The water shall be sprinkled, see photo 3.14, twice or thrice a day (the frequency of sprinkling of water will also depend on the weather condition).

Curing period:-

i). Minimum 7 days.

or

ii). Till the next layer is laid, whichever is earlier

No traffic shall be allowed on the partially constructed pavement, even in case where it is necessary to ply traffic on the stabilized surface the curing must continue.

Photo 3.14: View of Curing of Stabilized Layer

3.3.3.2 Construction Methodology-Semi-Automatic Method

Two options in Semi- Automatic Method:-

- **i.** Stabilization (New Layer)
- **ii.** Cold Recycling

i. Stabilization

a. Preparing the Layer: The Subgrade or layer on which the stabilized layer is to be laid must be made free of Wet/ loose spots unevenness/ surface irregularities. The surface shall be compacted, see photo 3.15. Within the 24 hr. of final compaction, the compaction ratio shall be obtained with Sand Replacement or other suitable Method. The compaction ratio must satisfy the MORT&H specification, which requires the Sub Grade/layer compaction to be not less than 97/98%. The difference in crust thickness shall be compensated by adding an equal thickness of subgrade layer only if required.

Photo 3.15: View of Preparing Subgrade

b. Spreading of Construction Material: After the preparation of the layer generally Subgrade/GSB the quantity of construction material (complying with the design Submitted by Alchemist Touchnology Limited) required should be spread on site, see photo 3.16. The construction material i.e., soil & aggregate shall be transported to the site. The dumped material should be spread evenly over the entire area of treatment using grader, see photo 3.17.

Photo 3.16: View of Dumping of Construction Material

Photo 3.17: View of Spreading of Construction Material

c. **Initial Grading of Construction Material:** The construction material should be spread (as discussed above) and be graded to desired levels as per site requirement and the thickness of layer. After the grading the 10-12 T compactor shall apply one plain pass **to provide consistent thickness to Stabilizing Machine.** See photo 3.18

Photo 3.18: View of Initial Compaction of Construction Material

d. **Mixing of RBI Grade-81 and Water:** The Stabilizing machine is in general provided with the basic inputs and connections as listed below:-

1. The rate of dispense of RBI GRADE-81. (this is measured in per square meter)
2. Density of RBI GRADE-81
3. Speed of the machine
4. Water flow/discharge rate of water
5. The hopper of the machine that can be filled with RBI GRADE-81 regularly as per construction requirement. See photo 3.20
6. The water hose that can be connected to the water tanker.

Note: The field moisture content is determined with Rapid Moisture Meter and only the balance amount to OMC is added, see photo 3.19.

After the relevant inputs are fed into the control panel and the necessary connections made, the stabilizing machine shall be aligned; the depth shall be adjusted and subsequently physically verified by doing a small 5-10m trial at the start of the work. On actual site, operator shall start the functions as required with provided input to the machine and move forward. The spreading of RBI GRADE-81, water and mixing to the desired depth will all happen at the same time. The section where the grinder moves gets raised in between the two rear wheels, see photo 3.21, **this upheaval shall be compacted using plain pass of 10-12T roller.**

The machine meanwhile shall be shifted to the adjoining lane and the process shall be repeated as per the site requirement.

Photo 3.19: View of Checking of Existing OMC

Photo 3.20: View of Filling of RBI Grade-81 in Stabilizing Machine

Photo 3.21: View of Stabilization by Stabilizing Machine of RBI Grade-81 layer

e. Grading and Compaction: - The finished product where the construction material, RBI GRADE-81 and water are mixed should be graded to desired levels, see photo 3.22, and compacted using a 10-12t vibratory roller, see photo 3.23. The density of the layer shall comply with the prevailing IS codes in practice. The number of passes shall be determined by the engineer in charge.

The compaction at no point in time shall get delayed by more than 4 hours since the water is added in the mix. Photo 3.24 shows view of compacted surface

Photo 3.22: View of Grading of Stabilized Layer

Photo 3.23: View of Compaction of Stabilized Layer

Photo 3.24: View of Final Compacted Stabilized Layer

f. **Curing:** The existing moisture of the stabilized layer should not be allowed to evaporate. The water shall be sprinkled, see photo 3.33, twice or thrice a day (the frequency of sprinkling of water will also depend on the weather condition).

Curing period:-

i). Minimum 7 days.

or

ii). Till the next layer is laid, whichever is earlier. No traffic shall be allowed on the partially constructed pavement, even in case where it is necessary to ply traffic on the stabilized surface the curing must continue.

ii. Cold Recycling

Photo 3.25: Initial view of distressed pavement

a. Dumping and Spreading of Missing Component to achieve the required Gradation: Based on the design the desired quantity of Missing component for achieving the required gradation like 20mm/10mm/Stone dust should be placed on site and spread with the help of grader at predefined average depth. See photo 3.26.

Photo 3.26: View of Spread Stone Dust on Existing Pavement

b. Applying the Stabilizing agent, RBI Grade-81: Once the desired depth, levels and markings are established, the RBI Grade-81 bags should be placed as per the design dosage. The bags should be placed as evenly as possible, see photo 3.27, for the even spread of stabilizer. The bags should then be cut open and the powder should be spread evenly over entire area of treatment, see photo 3.28.

Photo 3.27: View of Laying of RBI Grade-81 bags

Photo 3.28: View of Spreading of RBI Grade-81

c. Milling & Mixing of Existing Pavement, Missing Component & RBI GRADE-81 at OMC with Stabilizing Machine: The mixing of Existing Pavement, Stone Dust (can be other aggregate size, as per mix design) & RBI GRADE-81 should be done with stabilizing machine , see photo 3.29. The water should be added through the inbuilt water sprinkle system in the machine. The field moisture content should be determined with Rapid Moisture Meter on site at different places and only the balance amount to OMC should be added during mixing.

Photo 3.29: View of Milling & Mixing with Stabilizing Machine

d. Grading and Compaction: The grades and slopes should then be maintained with the motor grader, see photo 3.30, and the compaction shall be done with 12 T Single drum Vibratory Roller, see photo 3.31. The density of the layer shall comply with the prevailing IS codes in practice. The number of passes shall be determined by the engineer in charge.

The compaction at no point in time shall get delayed by more than 4 hours since the water is added in the mix.

Photo 3.30: View of Grading of Recycled layer in progress

Photo 3.31: View of Compaction in Progress

The photo 3.33 below is showing view of completed cold recycled stabilized surface with RBI GRrade-81.

Photo 3.32: view of Completed Cold Recycling

e. Curing of Stabilized Base Layer: Curing: The existing moisture of the stabilized layer should not be allowed to evaporate. The water shall be sprinkled, see photo 3.33, twice or thrice a day (the frequency of sprinkling of water will also depend on the weather condition).
Curing period:-

i). Minimum 7 days.
or

ii). Till the next layer is laid, whichever is earlier. No traffic shall be allowed on the partially constructed pavement, even in case where it is necessary to ply traffic on the stabilized surface the curing must continue.

Photo 3.33: View of Curing in progress

On top of stabilized base a wearing course shall be laid as per design, as shown in photo 3.34

Photo 3.34: View of finished surface of Cold Recycling

3.3.3.3 Automatic Method by WMM Plant/Batch Mix Plant

a. **Preparing the Stabilized Layer:** Before construction of any stabilized layer and before any transported material for stabilization is dumped on the road, the underlying layer should be investigated to establish whether there is any damage, voids, wet spots or other defects. Any defects to the layer should be rectified with the material of having similar properties with the native material before the stabilized layer is constructed. Where the stabilized layer is constructed on the floor of a pavement excavation or on the top of an existing pavement layer i.e., where the underlying layer has not been reworked or reconstructed, the floor of the excavation or top of the existing pavement layer should first be watered and the compaction of the layer should be carried at OMC, ±2%. The material to be stabilized should be placed, or in the case of existing pavement layer, scarified to the full depth specified, broken down and watered if necessary and mixed to achieve a homogenous layer. Any oversize material (> 1/3 the thickness of the layer to be stabilized) should be removed. Normally Maximum size of aggregate is 30mm.

b. **Calibration of WMM/Batch Mix plant:** All the components of design that are like 20 mm aggregate, 10mm aggregate, stone dust and RBI GRADE-81 shall be filled in the hoppers, as suited for the type of material. The calibration shall be done, as is done for WMM/Batch Mix. The special care must be taken to ensure the delivery of RBI GRADE-81 to the mixing unit, in desired quantity and the optimized water content, Once the calibration is done, the actual mix should be prepared

Note: For WMM plant the gate opening must be suitably adjusted.

c. **Mixing:** Only after the calibration is done, the Mixing of design component, see photo 3.35, shall be done. Special care shall be taken to mix right amount of water to attain OMC, the moisture should not be less than OMC, though +2% of OMC is preferred as some moisture gets lost during transit. The mixed material shall be transported in tippers to site, immediately

Photo 3.35: View of WMM Plant

d. Laying: Laying shall be done with WMM paver, see photo 3.36. The proper thickness and levels shall be maintained through regular check during laying.

Photo 3.36: View of Laying of RBI Grade-81 layer by Paver

e. Compaction: Compaction of the material in the pavement layer should be carried out within 4 hours after watering is mixed. The type of compaction equipment to be used and amount of rolling to be done should be such as to ensure that specified densities are obtained without damage being done to lower layer structures. The right compaction equipment that is vibratory roller, see photo 3.37, is used. Compaction shall be carried out in a series of continuous operations covering the full width of the layer concerned. During compaction, the layer shall be maintained to the required shape and cross-section, and holes, ruts and laminations should be removed. Loss of moisture from evaporation should be corrected by further light applications of water over the surface. During final compaction, field density determinations should be done to determine accurately the applied compaction effort and to ensure the minimum compaction requirement is attained. Final density test shall be carried out within 24 hours of compaction completion or as suggested by EIC. Photo 3.38 shows the finished stabilized surface

Photo 3.37: View of Compaction

Photo 3.38: View of Final Surface

f. Curing: The existing moisture of the stabilized layer should not be allowed to evaporate. The water shall be sprinkled twice or thrice a day (the frequency of sprinkling of water will also depend on the weather condition).

Curing period:-

i). Minimum 7 days.

or

ii). Till the next layer is laid, whichever is earlier. No traffic shall be allowed on the partially constructed pavement, even in case where it is necessary to ply traffic on the stabilized surface the curing must continue.

Note:-Suitable and economical method out of the above discussed method can be selected.

3.3.3.4 Construction limitations

i) RBI Grade-81 should be applied only to a surface area ,the size of which will permit all process, watering, compacting and finishing to be completed within a single working day.

ii) No stabilization shall be done during wet weather or windy conditions.

iii) Any rain falling on the working area during the process of stabilization may be sufficient to damage area being constructed.

iv) No material for the stabilized layer may be placed if the underlying layer has been softened by excessive moisture.

v) The minimum and maximum depths that should be stabilized in one section on a stable and compacted sub-base or underlying layer are as follows:

- minimum: 75 mm
- maximum: 150 mm

Depths in excess of 150 mm can be completed provided that the correct mixing equipment and compactor is utilized that can achieve an effort large enough to compact the lower regions of the layer. Commonly, depths of more than the maximum of 150 mm should be constructed in two separate layers in order to ensure that the minimum compaction requirement is obtained.

See figure 3.1(b): "Vibratory Compactors".

3.4 Quality Control

The following are some of the important factors that can influence the outcome of an application ,

(1) Grading: During the production of the aggregate at the plant and depending on the aggregate's porosity or hardness the production of fine material may differ from batch to batch even though the grading overall is still in the grading envelope (specification) by either being on the higher or lower limit.

(2) Moisture: The moisture can differ from application to application due to the following factors which can render the final product drier than others.

i) Grading, if much finer than the control test samples grading, the water demand will be higher than the O.M.C. water.
ii) Hygroscopic moisture or in-situ water of a material will also influence the amount of water required in achieving OMC.
iii) Break-down of material especially the coarser aggregate particles under compaction. If the aggregate has a large percentage of porous material it will result in the increase in fine material and if the aggregate is very hard the material will become coarser due to the production of coarser particles in relationship with the finer particles in the material i.e. a higher percentage of coarser aggregate.
iv) Porosity of the aggregate will also influence the amount of water added (O.M.C.) in that the aggregate will absorb a certain percentage of the water and therein reducing the amount of water needed for the chemical reaction and compactive effort.
v) Mixing techniques, where, if the aggregate is not mixed thoroughly enough, that is, (1) aggregate are not homogenous, (2) the water is not evenly distributed throughout the aggregate and (3) the stabilizer does not effectively cover all the aggregate particles, one will get streakiness, patches of wet and dry material and

v) Laboratory O.M.C., if the incorrect O.M.C. was used during the application that is the O.M.C. of the natural material was used instead of that of the treated material. Depending on the type of material and percentage stabilizer content it could differ between 0.5 to 2%. The O.M.C. during its determination in the laboratory can be influenced by the following factors in either lessening or increasing the O.M.C.

a) How representative was the sample,
b) Preparation of the sample,
c) The method of compaction and compaction effort and
d) The interpretation of the test data.

(3) Shaping: If the aggregate is on the coarser side and the water added is not sufficient the intention shall be to get a coarser surface during final shaping and leveling by the grader as the finer material tends to filter to the bottom of layer during grading effort. In order to correct this, one need to water-roll the surface that will bring the fines back up to the surface. By doing so it, close-up the voids in the surface as well as lock-in and bound the coarser particles.

(4) Spreader: Problems could arise in the use of computerized cement spreaders where the stabilizer and the fiber content due to their fineness could clog-up the nozzles resulting in under application of stabilizer and thus be easily eroded by traffic actions resulting in loose material on the surface which will deteriorate further over time. Thus the spreading by hand still remains the preference method in ensuring that the correct stabilizer content has been added. Therefore when using high tech spreaders adequate methods of testing the application of the stabilizer and control therefore must be exercised during the spreading phase to ensure that there is no blockage of the nozzles and that the correct dosage has been applied.

(5) Over-compaction: Vibratory rollers should not be used for any length of time but up to 3 to 4 passes at the most and thereafter followed by heavy static rollers. This will prevent (1) excess water and fine material from being drawn to the surface rendering insufficient water for the chemical process and 2) the loosening up of the layer from the bottom upwards and therein decreasing the density of the layer.

(6) Roller pick-up: If material during the final compaction phase starts to cling to the steel Drum of the roller causing raveling of the surface it can be due to the following reasons:

(i) The steel drum is too dry due to it either not being fitted with water nozzles (sprinklers) or the nozzles are blocked and are not functioning correctly,
(ii) The steel drum is not fitted with scrapers
(iii) Too much fine material on the surface and
(iv) Surface too dry
(v) Plasticity of the material is too high (sticky effect)

(7) Mixing-in: There are two very important criteria which must be met at all times in order to obtain a successful stabilization, that is:

a) All aggregate particles during the mixing of the stabilizer must be coated with stabilizer to prevent the formation of streakiness and clear patches and
b) The aggregate particles or material must be sufficiently wet leaving no dry streaks or dry patches or signs of stabilizer.

Thus once the stabilizer and water has been added and thoroughly mixed in a wet homogenous material must be the result, free of dry and streaky patches and signs of unmixed stabilizer.

Therefore the following must be controlled before and during the stabilization process in order to ensure at all times a successful application:
(i) The grading of the aggregate during the production thereof,
(ii) The method of stockpiling the aggregate and the loading technique used in transporting the aggregate from the stockpile to the site,
(iii) The mixing of the aggregate on site in order to obtain a homogenous mixture,
(iv) The hygroscopic moisture or in-situ moisture of the aggregate at the time of application,
(v) The type of mixing equipment and technique used,
(vi) The percentage break-down of the aggregate during compaction,
(vii) The percentage porous aggregate in the material and
(viii) The use of the correct laboratory O.M.C.

3.5 Testing of materials and workmanship

Sufficient tests should be conducted by the contractor carrying out the application, both before and during the progress of the work to ensure compliance with the requirements of the project specification outlined by a competent consulting engineering firm experienced in the aspects of pavement layer design. Results of the testing are the responsibility of the client's lab and the client's consulting engineer.

a) All samples of soil and general materials should be taken in accordance with the standard methods specified. The standard methods to be utilized for testing which may differ from country to country are:

i) The specifications of the American Society of Testing and Materials (ASTM)
ii) Bureau of Indian Standards (BIS)
iii) The specifications of the American Association of State Highway and Transportation Officials (AASHTO)
iv) British Standards Institute Specifications (BS)
v) South African Bureau of Standard Specifications (SABS), test methods, codes of practice and co-ordination specifications (CKS)
vi) Standard methods for testing road construction materials (TMH1 and TMH6) and for calibration (TMH2), compiled by the Committee of Land Transport Officials (COLTO).

In addition to the above standard methods of testing, standard specifications or test methods of other bodies may also be referred to in these specifications, or test methods may be described where no acceptable standard method exists but must be brought to the attention of the technical division of RBI Grade-81 before implementation thereof.

b) Samples for laboratory testing should be fully representative of the material to be stabilized with RBI Grade-81 stabilizer. For the necessary laboratory tests on the natural (untreated) soil, the treated soil with RBI Grade-81 stabilizer and field tests refer to the Testing Manual.

3.6 Minor applications

These minor applications comprise construction of domestic driveways, pedestrian or bicycle pathways, backfilling's and/or pothole repairs, other than pavement layers of newly constructed or existing major works, airport-runways and large parking areas etc. The material used in these minor works can either be in-situ or imported material either from nearby local sources or from commercial sources.

3.7 Foundation layer or roadbed

All stabilized material must be constructed on a stable, durable and adequately compacted foundation layer or roadbed. The minimum percentage compaction shall be greater than 97% of modified AASHTO density.

3.8 Drainage

Adequate surface drainage and/or side-drains shall be provided where necessary in order to protect the minor works, including the stabilized material. The drainage must prevent the minor works from becoming excessively wet, leading to unwanted weaknesses and deformation.

3.9 Stabilization using RBI Grade-81

The stabilization should be as per this manual or prevailing standards.

3.10 Testing of materials and workmanship

The amount of testing *is **"left to the discretion"*** of the Officer-in-Charge but shall adequately

address the improvement through stabilizing with RBI Grade-81, of all the necessary engineering properties in order that the correct decision can be derived at, to what dosage of stabilizer the material shall be stabilized, in order to obtain optimum results.
For the necessary testing refer to chapter 2 in this manual.

3.11 Construction Equipment

For an application to be successful the appropriate equipment together with experienced operators must be planned for in advance and be readily available on site before any stabilization of the road is commenced with. The appropriate construction equipment required for the following:

i) A road-grader,
ii) A rotary tiller,
iii) A grid-roller,
iv) A water-bowser or tanker,
v) Compactors and
vi) Laborers.

- **Road-grader:** With attachable ripper to i) loosen up the in-situ soil by ripping and ii) to, shape the road to final road level.

- **Rotavator:** To i) mix the soil into a homogenous mixture, ii) mix in the stabilizer and iii) mix in the water content

- **Grid-roller:** To break-down any large, oversized rocks and aggregations that may be present in the loosened or transported soil.

- **Water-bowser or tanker:** Must be fitted with a suitable sprinkler system to evenly apply the water to the soil-stabilizer mixture without creating unnecessary wet spots. The force of the sprinkler must also be controlled to be able to apply a light sprinkle of water for curing purposes.

- **Compactors:** To compact the stabilizer layer to the specified compaction. The compaction rollers can consist of 6-10 tons static, steel-drum rollers or 8-12 tons vibratory rollers. The steel drums of the rollers shall be equipped with water-sprinklers and brush- scrappers to prevent the pick-up of surface material and in order to scrape-off any material that is sitting fast to the steel drums.

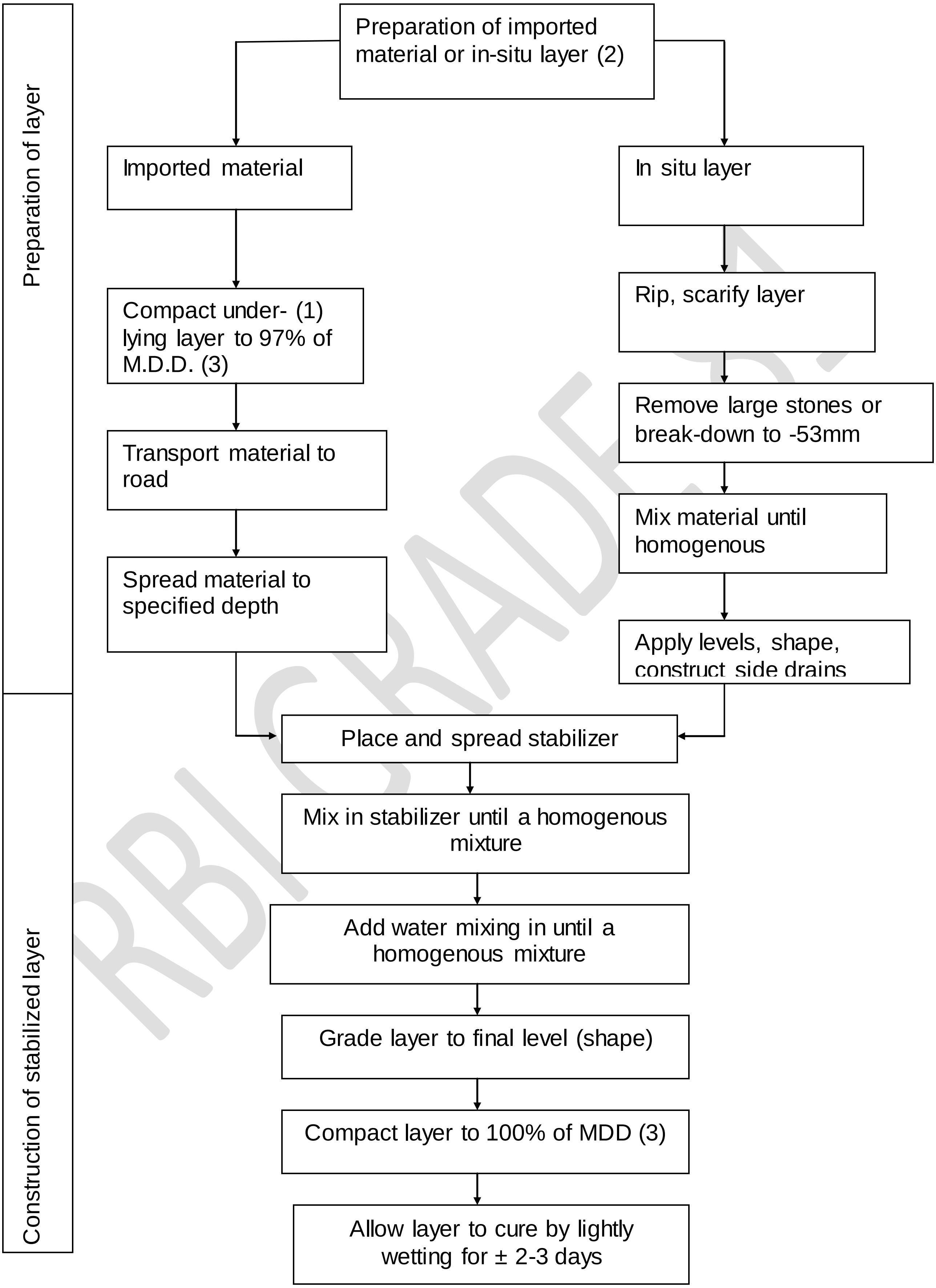
- **Laborers:** Sufficient laborers to carry out the following tasks:

  a. Unloading of the stabilizer bags,
  b. Placing and opening of the bags,
  c. Spreading of the stabilizer,
  d. The initial setting-up of levels and placing of level-pegs,
  e. During the preparation stage of the layer to be stabilized, the removal by hand of over-sized stones, boulders or large rocks,
  f. The removal of the empty stabilizer bags and
  g. All trimming works such as side-drains, road shoulders and fill slopes.

ANNEXURE 3A

FLOW CHART OF CONSTRUCTION PROCEDURES

Flow Chart 5: Flow Chart of Construction Procedures



Note:

(1) An underlying layer is the layer or loose layer immediately under the layer to be stabilized and could be i) the roadbed, ii) the foundation layer or iii) any existing pavement layer such as the subbase or selected subgrade layers

(2) An in-situ layer will consist of any existing pavement layer to be stabilized without the import of material.

(3) The M.D.D., maximum dry density, of the material is the standard density of that material determined in the laboratory.

ANNEXURE 3B

STABILIZER BAG SPACINGS

- **Calculation of the amount of stabilizer in mass and bag spacing**

The calculation of the mass of stabilizer to be added is based on the assumption that the soil is dry as shown in calculation 1 of the example. If the soil is moist i.e. has in-situ moisture content then calculation 2 of the example must be used.

- **Requirements**
    1) Length of road or layer to be stabilized in meters = L
    2) Width of the road in meters = W
    3) Depth of stabilization in meters = D
    4) Maximum dry density of material to be stabilized in kg/m^3 = MDD
    5) Stabilizer content in percentage (%) = C
    6) Mass of stabilizer bag in kg = b

- **Calculation formula:**
    1) Volume of material (V_m) = (L x W x D) m^3
    2) Mass of material (M_m) = (V_m x MDD) kg
    3) Mass of stabilizer (M_s) = (M_m x C) kg
    4) Amount of bags (B) = (M_s / b) bags
    5) Bag spacing (S) = (B / L) bags / M

- **Example:**

Given:
L = 100 m
W = 6 m
D = 0.150 m
MDD = 2200 kg/m^3
C = 4%
b = 20kg bags

- **Calculation 1**

$V = L \times W \times D = 100 \times 6 \times 0.15 = 90\ m^3$
$M_m = V \times MDD = 90 \times 2200 = 198\ 000$ kg
$M_s = M_m \times C = 109\ 000 \times 4/100 = 7920$ kg
$B = M_s / b = 7920/20 = 396$ bags
$S = B / L = 396/100 = 3.96$ bags/m

- **Calculation 2**

If the material to be stabilized is moist, that is, has an in situ moisture content of 2% then the mass of stabilizer to be added and bag spacing would be calculated as follows:

$$M_D = M_M - (2.0\% \times M_M) = 194\ 040\text{kg}$$

Where,

M_D = dry mass of material in kg

$$M_S = M_D \times C = 194\ 040 \times 4/100 = 7762\ \text{kg}$$

$$B = M_S/b = 7762/20 = 388 \text{ bags}$$

$$S = B/L = 388/100 = 3.88 \text{ bags/m}$$

As can be seen by the calculations the difference is .08 bags of which the cost is minimal compared to the cost of the laboratory tests in determining the in-situ moisture content of the material in the field. Thus the material is always assumed dry, unless at optimum or over optimum and cannot be dried out sufficiently before stabilization, when calculating the mass of stabilizer to be used.

ANNEXURE 3C

ADDITION OF WATER

- **Addition of Water**

Calculation of the amount of water to be added using the O.M.C. of the treated material:

- **Requirements:**

1) Capacity of water-bowser or tanker in litre
2) Laboratory test results: Natural materials MDD and HMC or in-situ moisture content and O.M.C. of tested material
3) Section of road to be stabilized in length (L), width (W) and depth (D) of the layer

- **Calculations:**
  1) Volume of material (V_M) = (L x B x D) m^3
  2) Mass of material (M_M) = (V_M x MDD) kg
  3) Volume of water (V_W) = M_M[(OMC + 1.0%) – HMC]/100

- **Example**

Given: A section of road, 100m long, and 6m wide with a gravel wearing course with thickness of 100mm.
A water-bowser of 10 000 liters capacity was used and the following laboratory test results supplied:

- MDD of natural material = 2110kg/m^3
- OMC of treated material = 8.2%
- HMC of natural material = 1,2%

V_M = L x W x D = 100 x 6 x 0.1 = 60m^3

M_M = V_M x MDD = 60 x 2110 = 126 600 kg

V_W = M_M [(OMC + 1.0%) – HMC)]

= 126 600 [(8,2 + 1,0) – 1,2]/100
= (126 600 x 8)/100
= 10128 litres

Therefore 1 water bowser emptied onto the stabilized material would be sufficient in achieving optimum

(10128/10000) = 1.0128, a full water tank.

Note:
(1) The addition of 2.0% in the calculation of V_W is to allow for evaporation during the construction of the stabilized layer.
(2) HMC is the hydroscopic moisture content or in-situ moisture content of the natural material.

(3) The OMC of the treated material is taken to compensate the water required by the stabilizer as well as that needed for compaction purposes.

(4) Special care should be taken for material containing a high percentage of porous aggregates such as calcirites and therein a high degree of water absorption. These materials should be pre-wetted the evening before application to cater for the extra water demand due to the materials porosity.

FREQUENTLY ASKED QUSETIONS

1. Is RBI Grade-81 a liquid or a powder?

RBI Grade-81 is a powder-based product that is composed of a suite of natural inorganic materials.

2. What is the dosage of RBI Grade 81?

The percentage of RBI Grade-81 added to the soil is dependent on several factors, namely the traffic requirements of the road, the type of road, the type of soil, the underlying sub-base and the desired result. Typical application rates range from 2- 5% by mass, although not limited to this range. The amount of material in kilograms per square meter to be applied to a road is dependent on the thickness to be stabilised. A road stabilised to 10 cm will have less material per square meter than a road stabilised to a depth of 15 cm, however the relative concentration remains the same. Typical application rates to a depth of 10 cm range from 6-12 kg of RBI-81,
Same, this is dependent on the soil type and design requirements of the road.

3. What kind of soils can be stabilised?

Extensive in-situ and laboratory testing has defined the application limits of RBI Grade-81.The grading of the soil (particles size distribution) helps to define these limits, however they are very broad. RBI Grade-81 has a wide response spectrum of soil types ranging from sandy soils (an achievement of RBI Grade-81 that separates it from other conventional soil stabilisers) to highly plastic soils.

4. Is RBI Grade-81 limited to stabilising soil?

No, RBI Grade-81 is not limited to soils. As part of our company's initiative to maintain a high standard of research and development we are continually seeking alternative application opportunities. Therefore, we have successfully treated waste material in both liquid and solid form, as well as fly ash and other industrial dusts.

5. How is RBI Grade-81 packaged?

RBI-81 is packaged in 25 Kg bags as well as 1-ton bulk bags for larger application projects. All of our packaging is met with rigorous quality control testing to ensure that the standard of material is kept constant.

6. What is the shelf-life of RBI Grade-81?

The product must be kept contained in a dry storage area to ensure its 12 month storage life is maintained.

7. How is RBI-81 applied and what machinery is required?

The application procedure for RBI Grade-81 is very simple. Firstly, the soil to which RBI Grade - 81 is being applied must be scarified and rotavated to ensure a homogenous mixture. This also breaks up any large lumps or conglomerates and allows for overly moist soils to dry. RBI Grade-81 is then added and rotavated into the soil to ensure thorough mixing. Water is then added to the calculated requirement to achieve Optimum Moisture Content (OMC) and to initiate the comprehensive chemical reaction. One of the most crucial aspects is the compaction, which must be performed thoroughly and with the proper equipment to ensure maximum compaction is achieved.

8. When will the results of the RBI Grade-81 application be visible?

Even before the application is finished are visible as the addition of RBI Grade-81 to the soil acts as a compacting aid. Therefore, after final compaction the results are already visible, however the reaction is still in the introductory phases. Within the first 24 hours a substantial amount of the reaction of RBI Grade-81 with the soil has been completed and after the first 7 days a substantial proportion of the reaction has been established. Because of the nature of RBI Grade-81 and the fact that it is based on hydration, the reaction continues for a 365 days period.

9. When can tests be performed on the roads?

To achieve the most substantial benefit from your road project, core removal should not be performed earlier than 28 days. The removal of cores is a very stressful procedure and requires the stabilised material to have reached a state of advanced curing. It is advisable to consult with a member of the RBIGrade-81 technical team prior to such a procedure.

10. What are the benefits of using RBI Grade-81?

RBI-81 serves to increase the quality of road construction while at the same time eliminating much of the excessive costs associated with this field. RBI Grade-81, through its comprehensive inter-particle matrix due to the complex hydration reactions, irreversibly binds the soil particles into a rigid framework that contributes to the high strength of the stabilised layer. Using RBI Grade-81 decreases the cost of road construction through using in-situ soils at the site of construction, eliminating the requirement to transport masses of soil to the site for use within the road design and decreasing the time required for the project. An RBI Grade-81 stabilised in-situ road eliminates the harmful creation of dust, while producing water resistant all weather surface.