Subgrades and subbases for concrete pavements pdf

Analysis of the Federal Highway Administration's Long-Term Pavement Performance (FHWA) data reveals that the basis of the pavement (basic or subbase and subgrade) is one of the most critical design factors in achieving excellent performance for any type of pavement.* For concrete pavements, design and construction requires the mentsment of the road structure or base may vary, pending. However, the main objective of building a road or foundation for a concrete pavement is to gain uniform support conditions for the pavement to be applied throughout the life of its services. Drainage consideration is also important in the design and construction of the right roads or foundations for the pavement of concrete. It is important not to build a support layer system that holds water under the slab of pavement. This is a common mistake in the design of the concrete pavement structure, which has led to poor field performance of some parts of the concrete pavement. It is equally important for no more design ability of the subbase layer. Excessive engineering of exemplary subbases will most likely lead to a foundation that does not provide the necessary stability for long-term pavement performance. Where stability has been sacrificed for drainage, concrete pavements have done poorly and have suffered a de damaged number of joints and cracked slabs in a relatively short period. Free drainage and daytime subbases are a reasonable alternative to draining subabets that are easily consumed with a edge drainage system that often lacks stability for human long-term perfor or causes other compliance problems. * The use of highly open or exemplary subbases for concrete pavements is not recommended. This conclusion is achieved through experience with less prescient pavements built on a permeable layer of subbase. It is supported by a national performance evaluation study that concludes that the system has no significant influence on the performance of pavement, positive or negative (NCHRP 2002). However, the cost of this system can be quite significant, sometimes as much as twenty-five percent of the section's cost compared to a more conventional subbase (Cole and Hall 1996). For these reasons, and others described in this publication, the following subbase layer categories are not recommended: cement-treated subbases, subbases treated with asphalt and open-scred subbases that are not stabilized with an cement-treated subbase more than about 350 feet/day (107 m) In the northern or cold climate, the influence is Certain subgrade soils are particularly vulnerable to frozen action, which gives rise to the foundation and layers of vertical concrete pavement during the freezing period (commonly referred to as or frozen weight). Generally, frozen lids are limited to freezing climate areas with quiet soil. If the weight is uniform along the pavement part it is not harmful to mental, but if the weight is accelerated, it interferes with the uniform support mity given to the surface pavement. Removing or treating these materials is necessary to ensure that the route is carried out as expected. For almost every pavement design there are many different subbases to choose from (that is, the aggregate of unmatched recycled concrete, treated cement, lean concrete, etc.), as well as natural or treated subgrade results. In some cases, for most clay and some silky soils, it is probably the most economical and advanta to treat subgrade soil and then to provide a subbase (granular) that is not stabilized as a construction platform. In the case of roads for relatively low traffic levels, the likelihood of a natural subgrade may be sufficient, as long as it is assessed to be accepted as a road. The optimal subbase and design or selection of subgrades must offset both the cost and performance of considy erations. The same combination of subbase and subgrade treatments used for heavily traded highways may not be necessary for low volume roads, even in the same area and subject to the same climate. Finally, it is likely that because this document is printed and distributed, some new and emerging technologies advance in the edging and opening industry. This guide captures basic parameters, recommendations, and considerations for subgrades and subbases for concrete pavements. Emerging technologies, such as smart compaction tions and grading/placing GPS-guided equipment, are likely to become more common in the future. These improvements to existing methods are not replacements for judgments that need to be basic. With the same token, we encourage agencies and contractors to advance their construction methods and improve the quality of their work using advanced technology. The introduction and Terminology of Design and road construction of any pavement structure is key to its long-term performance and smoothness over time. Roadblocks are characterized by layers that provide the basis for riding surfaces. For concrete pavements, the foundation usually consists of a subbase layer on subgrade soil. Various engineering subbase materials and subgrade treatment methods exist for use with concrete pavements. Careful attention to the design and construction of subgrades and subbases is essential to ensure the capacity of the structure, stability, uniformity, durability, and smoothness of any concrete pavement throughout the life of the pavement. The most important is basic erpity. The publication of this bulletin discusses every important factor and background information required for proper selection and application of subbas and appropriate subgrade considerations for the concrete pavement used for roads, roads, and highways. Because the term for the engineering roadmap is unique and sometimes unfamiliar to the pavement design engineer, the vast glossary of the term is included as this publishing Attachment. (Refer tabs on the edge of this publication for quick reference.) Therefore, this section does not tend to be a comprehensive glossary, but a way of distinguishing between the basic components for the structure of concrete and asphalt pavements. The main terms required to distinguish between concrete and asphalt pavement structures are: Pavement structures - a combination of asphani/concrete surface courses and basic/subbase courses placed on subgrades provided to support traffic load. Basic — Layer in asphalt pavement structure; usually granular or stable material, whether previously placed and hardened or newly placed, where the surface of the pavement was placed in the operation later. Basic Courses - An instant layer of asphalt hot mixtures under the surface course, generally consisting of less asphalf and aggregate larger than surface courses. Also known as binding courses (AI 2007). Subbase — A layer of selected material or a planned thickness engineering is placed between a subgrade and a concrete pavement that serves one or more functions such as preventing pumping, distributing loads, providing drainage, minimizing frost action, or facilitating the construction of pavements. Common types of subbases include unstable subbases (granular), cement-treated subbases, lean concrete subbases (econocrete) and apshalt-treated subbase. Subgrade - Natural, graded and compact soil, where the pavement structure is built. File:Sub01.png Figure 1. Illustration of cross-sectional differences is relative in the term design and layout between asphalt and the structure of concrete pavement. In practice, the subbase layer is usually referred to as a basic course. Strictly, however, the basic course is a layer of material below the surface of the asphalt; Therefore, basic courses exist only under the pavement of asphalt and subbase exists only under concrete pavements. The pressure imposed on basic courses under the asphalt pavement is dramatically different from those imposed on subbases under concrete pathways. Due to these differences, the quality requirements of the material for subbase can be relaxed compared to what is needed for the foundation. The difference in terms (fundamental versus subbase) recognizes these fundamental differences. The publication discusses the subbase of concrete pavements, and readers are encouraged to adopt this term into their usual or local terms. Figure 1 depicts the structure of concrete and asphalt pavements. Design Principles Understanding the basic premises and basic design principles for concrete pavements require knowledge of how concrete slabs transfer loads from vehicles to subgrades. Compared to asphalt pavements, concrete dissemination in larger areas of the road or base which, in turn, reduce the pressure on the supporting layer material and subgrade. The important thing is that the underlying strength is not important to the performance of concrete as it is for the pavement asphalt, even when considering pavements for heavy loads. Although subbase and subgrade strength are important factors in the design of the pavement, other fundamental properties besides strength should be considered in the basic design for concrete pavements. Each foundation for use in the structure of concrete pavements should provide the following features: Ethics; there are no diluting changes in the characters of the materials (i.e., weak spots or stbing spots). Extensive subgrade material control to ensure uniform support through wet and dry seasons. Resistance to frozen lids during winter and cold temperatures. Resistance to eerity by slabs that disappear under heavy loads. From these features, uniform support is very important. Providing equality is also one of the biggest challenges in the design and construction of any pavement structure. Because every basic design begins with the natural soil in-situ, the challenge always begins with a subgrade. In practical terms, the subgrade must, at least, provide a stable working platform to build a layer of subsequent pavement structure. The potential for weight and/or shrinking and swelling of subgrade material must be assessed by engineers during the design phase. The methods available to deal with extensive subgrade materials are selective grading and/or chemical modification (commonly referred to as land stabilization) of the land in-situ. These two subgrade conditions (e.g. frost weight and shrinking/swelling) should be considered separately from providing pavement support, but indeed part of the ultimate goal of providing a uniform foundation. In other words, although the subgrade can be compact and willing to provide adequate support for construction activities and loading future traffic, it may be a weak foundation for concrete pavements if subgrade is exposed to volume changes from swelling, shrinking, or weighting. Therefore, the vast potential of the subgrade must be evaluated and controlled. Subgrade preparation includes: Compact soil on moisture and density content that will ensure uniform and stable pavement support. Whenever possible, set a grade profile at a height that will allow sufficient depth in the side drains to protect the structure of the pavement from the water table. Improves extensive or weak soil with treatment with portland cement, flying ash, kiln cement dust (CKD), chalk, or alternatively, importing better soil. Cross-transportation and land mixing to achieve uniform conditions in areas where there are horrity changes hoaxing in the soil type. Using selected crediting in the area and filling to put better ground closer to the top of the final subgrade Finely grade the top of the subgrade to meet certain grade tolerance in specifications and for subbase thickness control and/or concrete pavement. Perfect subgrade material- those that will meet all design criteria- are rarely found in nature. This is especially true of the ingredients that will be used in many traded pavements. For this reason, the subbase layer provides an additional measure of assurance that both uniform support and a layer cannot be erode available for slabs of concrete pavements. Subbas consists of engineering materials or materials produced and controlled to specifications. The most commonly used subbase falls into one of the following categories: Unstable subbases (granular). Stable subbases, including: stable subbases of cement (cement-treated subbases or lean concrete subbases, both of which may include flying ash and/or slag) and subbases treated with asphalt. For light traffic pavements, such as residential roads, secondary roads, parking lots, and airports of light duty, subbase may not be required if the correct subgrade preparation techniques will minimize potential shrinkage, swelling, and/or weight, provide adequate construction platforms and provide adequate pavement support. When the use of subbase is considered appropriate, the best results are obtained by: Choosing subbase material and an adequate combination of layers prevents the absorption of subgrade soil for the life of the pavement. Determining grit controls that will ensure ongoing subbase crediting for individual projects. Determine the minimum density of 95 per cent AASHTO T99 (ASTM D698) for non-based subbases. Determining the need for stable subbase materials (treated cement, lean concrete, or asphalt-treated) that considers the delicate balance between uniform support requirements and the risk of cracks associated with high strength subbases due to loading unsupported edges (due to arrangement and war). Design the width of the subbase to accommodate opening equipment. Subbase should extend beyond the width of the pavement with at least 3 feet (1 m) on both sides to provide a stable of all weather work platforms for equipment to open paving or fixed side shapes. The additional width of this subbase is a critical feature to help ensure a smoother pavement. Secondary benefits over a lifetime of pavement include better load transfers at the edge of concrete slabs. To determine the thickness of the minimum subbase of 4 in. (100 mm) for the unstable subbase (granular), 4 in. (100 mm) for stable subbases of cement and 2 in. (50 mm) for asfaphalt-treated subbases. UNIFORM SUPPORT Opens concrete usually has a flexible strength of 28 days between 550 to 750 psi (3.8 to 5.2 MPa), or greater, and eternity modules between 4 to 6 million psi (28,000 to MPa), helps provide a high level of kink. This kink allows concrete turapan to circulate the load upwards support layer area, as shown in Figure 2. As a result, the pressure on the base layer is very low and the extremists are relatively small. Therefore, concrete pavement does not necessarily require very strong basic support. Figure 2.Concrete safeguard helps concrete pavements distribute wheel load in large areas, keeping subbase/subgrade pressure low. Children and Kapernick (1958) show that heavier loads are distributed over large areas of the subgrade and, therefore, do not cause high subgrade pressure. Figure 3 provides test conditions and subgrade pressure for a load of 12,000 lb (5,400 kg). The applied pressure of 106 psi

(0.73 MPa) is reduced to subgration pressure of only 3 to 7 psi (0.02 to 0.05 MPa) as the applied load is distributed above 20 feet (6 m). Other studies (Children, Colley, Kapernick 1957; Children and Nussbaum 1962; Children and Kapernick 1963) confirm that subgrade pressure under the concrete pavement structure is relatively low and, in fact, far less than the bearing strength of almost all subgrades. For the structure of the concrete pavement, it is very important that the support is reasonably uniform without abrupt changes or weak or stitching spots in the basic character. This is in contrast to the principle of design for asphalt pavements, where a stronger base layer in a row is needed closer to the surface layer to distribute the higher pressure that is transmitted by wheel load through each layer and ultimately to the subgrade. Figure 3. Subgrade pressure for a load of 12,000 lb (5,400 kg) used in some posts on the slab. The importance of uniform subgrade support principles is best explained by an anomaly in pavement performance from the field. Performance surveys were conducted on many old concrete pavement stones built without proper subgrade payment control and without subpass. Where the subgrade is naturally uniform, many of these old pavements are still in excellent condition. Hardships are limited to cut filling shifts and other locations where there are sneak changes in subgrade materials and moisture conditions. Surveys showed that low strength soil where construction methods provided reasonable uniform support showed better performance than stronger soil lack of uniformity (ACPA 1995). FUNDAMENTAL STRENGTH STRENGTH INTEGRATION OF CONCRETE TURAPAN Although subbase is used to increase the strength of composite support and protect the subgrade, it is a subgrade that must ultimately bear the load, making it the starting point for the characterisation of support and design. As mentioned, the main requirement of the subgrade under the structure of the concrete pavement is that it is uniform. This is the cause of the mental funda for specifications on subgrade delegation. Although the uniform subgrade, good quality, and properly compact will improve the performance of the pavement, it does not true that stronger will do the same; most of the capacity of the concrete pavement structure is supplied by concrete slabs and not by the foundation (subgrade and/or subbase). The fundamental strength of the concrete pavement structure is often quantified as a subgrade reaction modulus (k-value). Subgrade reaction modulus is determined by the plate load test (AASHTO T222 or ASTM D1196). The subgrade plate load test models as spring beds, with k-value being analogue to constant spring; in fact, k is sometimes referred to as a constant spring subgrade. The test involves placing a diameter plate of 30 in. (762 mm) on the subgrade and loading it with a very heavy load. The plate distributes the load to the subgrade through the pressure on the face of the plate. K-value is met by dividing the pressure of the plate by the plate auctioneer under load. Units for k-value are psi/in. (MPa/m). K-exact value subgrade is usually not required; k-value subgrade measured a lot depending on season, humidity conditions, location, etc. Furthermore, when the subbase system is used, there is a significant increase in the composite k-value and the exact value of the subgrade is less of a concern. K-value composite can be measured by recurring static plate load tests (AASHTO T221 or ASTM D1195) for design use or evaluation of concrete pavement components. This test, widely used in Europe, is a modification of the standard plate load test used on subgrades (AASHTO T222 or ASTM D1196). It includes recurring loading and bearing the diameter of the plate to 6 in. (150 mm), to more accurately vehicular load models. The magnitude of the k-value increase from the inclusion of subbase in the design of the pavement system depends on the subbase material and whether the subbase is treated or untreated. Normal variations of subgrade or k-value composite will not affect the thickness of the pavement within the typical k-value range, as shown in Figure 4. Note that it does not save on using subbase systems that are too designed for purposes of simply increasing composite k-value; increasing the thickness of the slab, concrete strength, edge support and many other variables often proved more economical. Figure 4 shows an increase in k-value from 100 psi/in. (27 MPa/m) to 500 psi/in. (135 MPa/m), which will only reduce the thickness of the required concrete slab by about 20 percent. Figure 4. K-value sensitivity to residential streets and main arteries. Assumptions for residential roads include: shared distance of 12 feet (3.7 m), no dowelbars, 20-year design life, ADTT 3, and flexural strength of 600 psi (4.1 MPa). Assumptions for the main arteries include: 15 feet (4.6 m) of joint distance, 1.25 in. (32 mm) diameter dowelbars, 20 years of design life, ADTT 10,000, and flexible strength of 600 psi (4.1 MPa). FUNDAMENTAL WOKEN INFLUENCE ON STRESS TENSIONS IN SLABS CONCRETE PAVEMENT Although concrete pathways are commonly referred to as 'rigid,' because the modulus of eternal eternity is relatively high when compared to pavement asphalt (commonly referred to as 'flexible'), the concrete elongation modulus is not so high that the concrete pavement does not stick under heavy load. In fact, once the cracks are started in a concrete pavement (top down in the corner or mid-slab, bottom on the middle slab, etc.), the immediate zone around the cracked end is more suitable modelled as pseudoelastic than fragile as hardcore terms might suggest. The opening and spread of the next cracked end are the origins of concrete pavement fatigue, which can lead to distress such as cracking across the middle slab. When the pavement of the concrete is placed either on the subgrade or on any number of layers of subbase, the properties of this base layer will directly affect the pressure and tension of the concrete slab and, in turn, have several bearings on the long-term performance of the system. The most commonly used substance property used in measuring this inter action between the foundation and the concrete slab is the modulus of erodity, often measured indirectly by the compressive strength in the stable subbase. Figure 5 illustrates how concrete pavements, subbase layers of composite and composite subgrades may be modelled in modern design analysis, showing a combination of support modules (stirrings) in layers under concrete pavements. The counter for intuition, the stronger and stirring the foundation becomes, the more problematic it is possible to perform the concrete pavement. If the concrete slab is fully in contact with the foundation, the stiffer support system will reduce the charm and, accordingly, the pressure under heavy loads. If the concrete pavement can be built on a perfectly rigid foundation (infinished fatigue modulus) and remains the perfect plan, there will be zero dissent and zero flexible pressure, the main mode of fatigue failure in the concrete pavement. The stiffer support system, however, will increase adhesives and pressure under environmental unloading (heat healing and moisture warfare); if the concrete pavement is built on a very rigid foundation, the foundation cannot adhere to the shape of the slab so that the support of the foundation may disappear when loading the environment. The opposite is true for concrete pavements built on a very flexible foundation, with higher pressure caused by applied load due to free depletion and lower pressure under environmental easing due to the basis of adhering to the shape of the slab. Both outrageous support of this foundation are reflected in Figure 6. The balance of strength and flexibility in the underlying system is necessary for excellent long-term pavement performance, putting the best basic support conditions between Case 1 and Case 2. Figure 5. Structural models for concrete pavement structures Calculation. Figure 6. Illustration of the basic effects on applied and environmental loads in the concrete pavement system. The best basic conditions for concrete pavements are somewhere between Case 1 and Case 2. Higher curved pressure has a more damaging effect when concrete is quite young, when the slab has not yet developed the strength and fractured chaos needed to withstand cracks. Strength is essential to prevent the onset of cracked and hard fractures it is important to prevent crack separation. If the stable hardship of the subbase becomes too large, not only the curved pressure in the pavement slab increases, but the probability of cracking reflecting from a stable subbase will also increase (assuming the shrinkage of cracks has occurred in the subbase). Also, the thicker layers of subbase are built, the greater the increase in supporting clutch. The pavement design engineer must realize that the thickness and stowage of the subbase (by way of compressive strength) is essential on the basic system of concrete pavements. The recommended minimum subbase thickness is 4 in. (100 mm) for unbilled subbases, 4 in. (100 mm) for stable subbases of cement and 2 in. (50 mm) for asfaphalt-treated subbases. Unstable subabs and cement-treated subabs are best controlled using precious and/or density requirements. Cement-treated subbases should be within the target range of strengths of 300 to 800 psi (2.1 to 5.5 MPa) (PCA 2006), while lean concrete subbases require a maximum strength limit of 1,200 psi (8.3 MPa). The method for reducing prob lem due to excessive strength is discussed through this publication. DRAINAGE PAVEMENT SYSTEM It is important for readers not to overlook drainage as insignicant in the design of concrete pavements. The opposite is true. Drainage, however, must be put in the right perspective because only one much element is needed to optimize the performance of the concrete pavement structure. Uniform support is the main driver of good performance and the most important basis in engineering and choosing ing subgrade and subbase combinations for concrete pavement. In many respects, drainage should be addressed in providing subgrade and forming road templates with sufficient drains and crushing and vertical slopes; However, considerations of drainage in the subbase layer are also important. Moisture Resources in The Moisture Resource Pavement Structure to the pavement structure are shown in Figure 7. The importance of moisture influence on pavement performance should not be ignored. However, an engineer must also recognize that while there may be some possible controls, drainage systems such as subsurface ditches, side drains, and culverts have never been an absolute control to prevent moisture from gaining access to the pavement. On the other hand, the drainage system is a tool for moisture variation within the limits of the structure into reasonable limits (maintaining balance). Outrage in intuition variations (not inconsistencies) contributes more to the distress of the pavement and problems than the presence of sheer humidity. Figure 7. Source of moisture of the pavement structure. Precidence and entry from the edge of the Kapillary Suction pavement from the drainage waterways from natural highland vapor movements through the table of groundwater rises in height capillarity is an action in which the liquid (water) rises or wicks on the ducts on top of the aircraft free water supply (water table). The number and size of channels in the soil determines the distribution of pore size and therefore its capabilities. This land property is measured as tance dec (from zero to 30 yards (9.1 m) or more) moisture will rise on the water table with this action. Moisture in clay can be raised by capillarity for a vertical distance of 30 feet (9.1 m), which is considered by the highway en gineers to be high-calorious substances. However, long periods of time are often required for water to increase the maximum possible distance in clay due to very small and frequently interrupted channels. The stool also has a high capsule, but the maximum capilary increase occurs over a longer period of time than clay because the pores on the silk soil are large enough to reduce capilary action. Capilary increases in pebbles and coarse sand vary from zero to a maximum of several inches because the pores are large enough to eliminate almost all capilary action. The water table under the route will increase and fall due to seasonal and annual rainfall differences (i.e., number 5 in Figure 7 depending on number 1). Higher water tables will cause greater driving force for capilary suction and steam movement near the subgrade (that is, numbers 2 and 4 depending on number 5). Therefore, the design of the pavement structure must assume the highest water table expected during the pavement life, becoming the cause that is when the subgrade and subbase will contain moisture and be the weakest. The highest water table during the pavement life should be expected around the most primary rainfall events, making a run from the higher elevation area most detrimental to the local water table (so number 3 depends on number 1). In order to minimize moisture levels in the pavement structure, road engineers often concentrate on the easiest source of humidity to isolate, i.e. numbers 1, 3, and 5. Most often, highways are raised with respect to their surroundings, configurations that force water to run downhill to the trenches (mitigation numbers 1 and 3) while, at the same time, increase the distance between the pavement structure and the water table (reduce numbers 5 and, in turn, minimize numbers 2 and 4). Due to roads usually not possible for road or road applications, edge trenches and pembetung pembetung to collect any surface runoff (insulation numbers 1, 3, and 5). The subbase of free draining subtasks is prioritised on subbases which are exemplary due to its more durable and more stable nature (Figure 8). The recommended target reliability (k) for independent draining subbase materials is between 50 and 150 feet/day (15 and 46 m/day) in laboratory tests. The ingredients providing as much as 350 feet/day (107 m/day) in laboratory tests can also provide adequate long-term stability for the pavement base. Figure 8. Independent draining, a subbase that cannot be billed with a pretty stable fine during constructionbut still provides a reliability of about 200 feet/day (60 m/day) in laboratory tests. Note that truck tires do not cause excess carpets or subbase material shifts. Older recommendations for unstable subbases suggest target reliability in the range of 500 to 3,000 feet/day (150 to 315 m/day) in laboratory tests (FHWA 1992). However, substances with this high level of vameability (above about 350 feet/day (107 m/day)) also have a high level of invalid space, which reduces stability. Field reports from contractors showed difficulty in building pavements on these open grade materials. Trucks, paving machines, and other heavy equipment displaced unstable materials open in their grading (made up mostly one aggregate size). The cone tractor has used a description of it like opening a marble to describe opening an exemplary subbase. While free-draining subbases drain the drains slower than exemplary subbases (due to the increase in fine content) they still flow faster than conventional, compact subbases. Stability is enhanced by the use of aggregate angles and does not degrade prestigious under repeated loads. The aggregate of recycled concrete (either from existing concrete pavements or other resources) produces good results in an independent draining subbase; However, it should be noted that the recycled aggregate subbase has lower permeability, strength, and resistance to particle deterioration than limestone or gravel subbases. Edge Drainage System The edge drainage system can consist of a collector pipe system and outlets with excess stores, or daytime subbase systems where ex subbase tends to and bring water to the side drains. A common application for a side drainage system is for road applications or high-volume highways, such as major state and interstate roads. Despite this, its consumption is not always required or proposed. The use of edge drainage systems for low volume applications such as rural roads, district roads, etc., is not recommended. This type of pavement will provide services excellent with basic road considerations, such as suitable trenches and height design. In addition, the unlocking on this path may be such that pumping is not a concern. In these situations, a subbase or granular granular construction is prepared accordingly will be enough. Edge Drain Piping Where edge drains are used, the hydraulic capacity of the longitulating edge drain and lateral outlets must be high enough to drain free water within the pavement structure within 2 hours of rain removal (FHWA 1990). Drainage pipes usually range from a diameter of 4 to 6 in. (100 to 150 mm) flexible, corrosive polyetylene tubes (perforated) meeting AASHTO M252. Rigid PVC pipe (slotted) meeting AASHTO M278 - PC50 has also been used, but it is much more expensive. The drain is filled with very exemplary material to easily pull moisture from the subbase. Filter fabric (geotextile) trench line to prevent fine particles from trespassing into the trench area; The filter cloth is extended across the pavement section to prevent fine particles in the subgrade from trespassing into the free draining subbase. Recommended details for filter fabric protectors are found in Figure 9. Lateral pipe is made of rigid or metal PVC. Rigid pipes provide more protection than destroying due to construction or maintenance operations. Although the distance between stores is 300 to 500 feet (90 to 150 m) in practice, a maximum of 250 feet (75 m) is prioritised to ensure proper drainage. Outlets should also be placed at the bottom of all vertical curves. Pipes should be placed at 3 per cent grade with outlets of at least 6 in. (150 mm) exceeding the design flow of 10 years in the trenches. Concrete heads are essential to protect the pipeline. Stores should be equipped with a rat screen. Figure 9. Detailed for the edge drain pipe. Note that the filter fabric (geotextile) does not completely surround the trenches, that prevents fabric from being clogged by leachates or other fine particles carried by water flowing through the subbase, and a balancing drain of at least 3 feet (1 m) from the edges opening whenever possible, which protects it from construction For crowned pavements, the edge drains are installed along the edges of the internal and outer pavements. This shortens the age route of the drain and reduces the time for the subbase to drain. However, for the pavement lane built as an unmatched part, only one edge drain is installed, on the low side, which is much cheaper. It is important to put a longituming edge drain outside the line of the paver runway or any location expected to receive loads by heavy construction equipment. The minimum distance offset 3 feet (1 m) is recommended whenever possible. Daytime subbases Though are often overlooked in the past because excessive thoughts along the trench lines will clogg the system, daytime realizing directly into the side drains can produce better long-term performance than a side drain, since it does not depend on the periodic maintenance required for the pipe drain system. Furthermore, studies that flexible pavement part with daylight foundation (without side drains) performed as well as (or (or from) any flexible pavement section (NCHRP 2002). Similar performance should be expected with concrete pavements. The recommended details for the daytime subbase are shown in Figure 10. Figure 10. Details for the daytime subbase. Note that there is no filter fabric (geotextile) or filter layer as there is for side drainage. On the other hand, it is accepted that some local clogged of persistent layers will occur, but the overall drainage will not disappear because the overall depth of the layer is exposed to the whole length of the pavement. Separatist separation is a geotextile fabric or filter layer that prevents the migration of fines from subgrade into an independent draining subbase. Geotextile fabrics are usually used (and highly recommended) directly under the free-draining subbase layer to prevent fines from infiltrating and installing subbases. Some agencies also layer filter layers (4 to 6 in. (100 to 150 mm) thick layers of unstable dense granular material) under a subbase that can be drained. This is not considered a necessity when free-draining subbase materials are used in design. Where used, the filter layer serves as a construction platform and as a barrier to prevent water from entering the subgrade as it flows through the subbase into a ditch or side drain pipe. The following criteria for the filter layer are recommended. It is necessary to evaluate both the filter/subgrade layer and the subbase/filter layer interface (FHWA 1990, US ACoE 1941): Size 15 percent (D15) subbase should not be more than 5 times larger than the size of 85 percent (D85) filters. The size of 50 percent (D50) of the subbase should not exceed 25 times greater than the size of 50 percent (D50) filters. The size of 15 per cent (D15) filter should not exceed 5 times greater than the size of 85 percent (D85) of subgrade soil. The size of 50 percent (D50) the filter should not exceed 25 times greater than the size of 50 percent (D50) of subgrade soil. Note: Dx size means that x percentage of particles is smaller than this size. Filter materials cannot be placed in a way to prevent drainage through subbases or edge pipes. The size of 85 per cent of subbase should be at least 11/2 to 2 times the size of slotted pipe openings. Various filter design criteria for aggregates and fabrics are available elsewhere (FHWA 1990, US ACoE 1991). SUBgrades LAND FOUNDATION FOR CONSTRUCTION PAVEMENT Note: This section, Land Base for Pavement Construction, taken primarily from the EB007 Portland PCA Soil Primary Cement Association. Soil is formed when rocks, marine shells, corals, etc. break down particles of smaller and smaller sizes through the abrasion process and/or fractures (physical weather). Events that contribute or accelerate this breakup process include wind weather, erosion, freezing, rock effects, root growth, wet and drying, heating and cooling, action and man of man Far more important for delicate soils, although less intuitive than the physical fractional process, is modification by chemical processes (chemical weather), the addition of plants and animals, and human effects as the soil is transported by water flowing or subjected to wet-to-wet conditions in place. The recognition of the process of land formation (fractions and modifications) is valuable for both the initial site survey and the extension of limited subgrade sample information throughout the project. Close to mountain or highland sources, the soil will be stronger and more closely related to the source rocks; downstream or at lower altitude, the soil will be refined, renovated and subject to the process of sorting (i.e., wind and water transportation). Also, the break-up process will apply more directly in arctic areas, while chemical renovations of the soil will be greatest in tropical areas. Regardless of the method of formation or soil resources, the performance of the long-term subgrade depends heavily on three factors depending on: Humidity and density content. The following section provides an overview of the test methods used to measure the performance factors mentioned earlier. Knowledge of these attributes and their dependence is necessary to understand the classification system presented at the end of this section. Moisture and Density Content As mentioned, the equality of support is the best concern to the pavement engineer. Also the importance is the strength of the land. Because the soil consists of solid particles, water and air, moisture conditions and, to a lesser extent, the density or weight of the units also becomes a concern because they directly influence the strength. This section describes the various properties associated with moisture and density of soil. Soil Mass Water is a swimming material containing solid particles that are alternately alternate with pores or voids. These vomps can be filled with air, with water or with air and water. There are several terms used to determine the relative amount of soil, air, and water in soil mass: Density - Weight of total units of soil. It can be stated either as wet density (including both soil and water) or as dry density (soil only). Porosity - The ratio of total voids to total mass regardless of the amount of air or water contained in voids. Porosity is usually expressed as a percentage. Invalid ratio — Volume ratio of voids to soil particles. The ratio of porosity and invalidity of the soil depends on the level of computing or consolidation. Therefore, for certain soils in different circumstances, the ratio of porosity and illegality will vary and can be used to assess relative stability and the load carries capacity with these factors increasing as porosity and invalidity ratio decreases. Saturated - The ratio of water volume to total voids, usually expressed as a percentage. Moisture or groundwater content is usually usually as a percentage of the weight of the dry oven of the soil. It is determined by first taking the difference in weight between damp soil samples and the same dry samples in the oven at 230 deg F (110 deg C) until it reaches a constant weight. These differences divided by the weight of the oven dry soil (expressed as a percentage) are the content of moisture. AASHTO T265 or ASTM D2216 describes this test method. In normal use, the term moisture content and water content are synonymous. Moisture or water that make up a measurable difference between the state of in-situ moisture and the dry condition of the oven are three different types: Gravity Water - Free water moves under the influence of gravity. This is water that will flow from the ground. For the land in-situ it is water inside and under the groundwater table and is often termed groundwater. Groundwater is water that is uncrovelled or free. Capriary Water - Water held in land pores or capilies by capilary action. This is the result of an attraction between liquid and solid surfaces, which, due to a stronger attraction to water than air, result in curves over meniscus on the edge of the water and the actual rise of water in a narrow tube. Water pressure is zero at groundwater levels or freatic surfaces; it is under pressure below this surface and in the tension above. Note that capilary water cannot exist directly in front of gravity water. The effect of gravity on water mass results in stress or compression from the weight of water. This overcomes tension and relieves capilary attraction. Capilary water is usually not considered as free water as it is, at least weakened, tied to the action of surface tension. However, since it is not bound by direct land particles, sometimes it has been grabbed as free water on older ones and especially in the reference of agricultural-oriented soils. Hygroscopic Water - Humidity maintained by the soil after the moisture of gravity and capilary is removed. It is held by every ground cereal in the form of a very thin film that is inducted on the surface by molecular attraction involving both physical and chemical affinity. The film is in balance with the moisture content of the air and increases or decreases with the change in humidity; it can be described as water associated with dry moisture content of the air. The equivalent humidity of both capilary water and hygroscriric water are, degree, bound and represent the capacity for the soil to hold water against the force that tends to remove it. These water holding capacity measures are moisture-equivalent moisture content. Low value is associated with coarse soil, which is not moisture-sensitive and very exemplary. High value is associated with plastic clay, which is very moisture sensitive and low. The tests used to measure humidity at the same time are: Equivalent Terrain Humidity - Equivalent terrain humidity (FME) is the content of moisture where the surface of the soil is smooth will absorb no more water within 30 seconds when the water is added in individual drops. It shows the moisture content needed to fill all the pores in the sand, when the capillity of soil that does not develop unity is completely satisfied and when the ground unites approach saturn. These tests are no longer common and both standard procedures used to run them, AASHTO T93 and ASTM D426, were discontinued. Centrifuge Equivalent Humidity - The equivalent centrifuge moisture (CME) is the content of soil moisture after a saturated sample is collected for an hour under the force equivalent to 1,000 times the force of gravity. The test, ASTM D425, was used to assist in the classification of soil structures. Low values, such as 12 or less, show exemplary sand and slacks; high value, like 25, shows inevitable clay. High value indicates high capitality soil, and low value indicates low capitality soil. When both the FME and CME are more than 30 and FME larger than the CME, the soil may develop when releasing loads and classified as elastic. The Soil Moisture (Capilary Action) FME and CME suctions had origins in agricultural land technology, but they found early applications in relation to highway subgrade assessments and senior road land surveys. They continue in some uses, but the technology concerning the strength of subgrade moisture in place is now more focused on a puff of soil moisture. This is a strain of moisture associated with caloriarity, and accordingly, it is often called capillarity or capillary action. Water in the ground on the water table has less pressure than atmosphere. It rises on the water table due to surface tension (capillary force) and adsorption forces where water is bound or held in the soil. For the soil with a puff of measurable soil moisture, the caloric ranges from zero to saturation to large enough values when the soil is quite dry. Therefore, a puff of soil moisture depends not only on the overall driving power of the soil but also the current moisture situation. This suction can be expressed in the stress unit (negative). The relationship between suction and humidity content depends heavily on the type of soil. Test standards for suction measurement of land are presented as AASHTO T273 and ASTM D3152. Plastic soil Most lands include fine breakdowns of stools or clay, or a combination of both. The consistency of this soil can range from dry and solid conditions to wet and liquid conditions with water repellent. Introducing water into the matrix of soil, air and water particles allows empty pore space (space currently occupied by air) to fill water. Finally, all empty pores will be occupied by water and more additions will cause the system to grow. If the addition of water occurs in small enough measures, the consistency of stools and clay can be seen passing from solid to semisolid to plastic and liquid, as in Figure 11. Shrinkage limits (SL) separate solids from semisolids, plastic limits (PL) separate semisolids from plastic conditions and liquid limits (LL) separating plastic from liquid conditions. The plastic index (PI) is the width of the plastic condition (LL minus PL), expressed in terms of moisture content. PI is an important indicator the ground plastic behavior will showcase; Low PI shows very sensitive soil moisture. Standard procedures have been developed so that consistent determination to set distribution limits can be made by anyone using this procedure. Since it is a more plastic or finer soil that reflects this pattern of reactions to moisture variations, standard testing is performed on the part of the soil that will pass the siege of mesh No. 40 (425 μm). Figure 11. State of land and consistency limits (Atterberg limits) with evidence. Non-plantation land Lands considered in previous sections have compositions including fine fractions of sacks and clay, which gives them plastic consistency. The soil consists of almost entirely the size of sand, pebbles or coarse stops, or any of these combinations, has a non-elastic consistency. Coarse sand and fine gravel, which includes little or no particle size passing the siege of No. 40 (425 μm), is clearly nonplastic (NP). This shows no significant variation of consistency with variations of moisture. Dry sand has no element of solidarity to join the cereal together. Individual particles react with only mass, shape and gravity. When excavated or placed in hemorrhoids, they will show the maximum slope of the characteristics at the angle of the repose. Damp sand is tied to a capilary moisture film in the place of contact between cereals. Therefore, the bond is zero when dry, increases through the maximum as the humidity increases, and returns to zero at complete saturation. Variations of this humidity do not cause swelling or shrinkage in uninterrupted sand, but when moist sand is moved or disrupted by construction operations, the capilary fringe will compete with gravity forces. The result was increased by vouch and density was reduced. This phenomenon is termed as bulking, and it can lead to problems of solutions, especially in mild construction when not properly considered and treated. Bearing Capacity Load Historically, the complexity of pavement design prevents the direct use of soil rip strength to design. Design methods are created based on tests that give index numbers related to the most common soil strength, but not always, are considered to represent the strength of the narrh. Some of the tests and methods still used in modern design include: Testing of the California Bearing Ratio (CBR) – This is a test that measures the force needed to penetrate the soil surface by a round piston with an area of 3 in.2 (19 cm2) End. The value of the index (CBR) is a percentage of the robust reference value for 0.1 in. (2.5 mm) and 0.2 in. (5.0 mm) of penetration. References of the 100 originally thought to represent the crushed stone resistance that was crushed well. The usual CBR value may range from 2 to 8 to clay and 70 to 90 for crushed stone. The U.S. Military Engineers Corps and several highway departments used CBR principles in conducting tests to assess the bearing value of materials. The methods of preparing the specimen and conducting these tests are given at AASHTO T193 and ASTM D1883. Some agencies have their own CBR test modifications. R-value value - This is basically a measure of the hardship of the material by means of resistance to plastic flow. The test was developed as a better CBR test and must be carried out in the laboratory. Samples are provided so that they will represent the worst-case scenario during testing and confined on all sides in testing tools, causing triaxial stress conditions. Value R is a vertical load ratio applied to the resulting lateral pressure. The typical R values for heavy clay are 0 to 5, for high plastic slippers are 15 to 30 and for graded crushed stones are 80 or more. Standard R-value test methods are provided at AASHTO T190 and ASTM D2844. Subgrade Soil-resilient modulus (MRSGor MR or ESG) - This test measures stowage as an estimated modulus of eternity (E) material; Employability modulus is a pressure divided by tension for loads used slowly and resilient modulus is pressure divided by tension for fast-to-use loads. There are several methods of estimating resilient modulus, both in the laboratory and in the field, and with that, they are excluded here for habit. Standard resilient modulus testing is given at AASHTO T307. Subgrade Response Modulus (k-value) – This is a bearing test, conducted in the field, which provides an index for assessing the support provided by the ground layer or subbase directly under the concrete slab. Almost all concrete pavement designs are based on subgrade reaction modulus, k, as used in the Westergaard formula. K-value is defined as a subgrade response per unit of deformation area and is usually given in psi/in. (MPa/m). The determination of k for the design of the concrete pavement is made in the field in the subgrade in place, or on the subbase, if used, under conditions that would approach a reasonable mean service situation. The 30 in. (760 mm) diameter plate is recommended standard, although test variations with smaller plates have been introduced to facilitate testing. Plate size influences the results of bearing tests because the resisting force of decompile consists of shear around the perimeter of the plate as well as consolidation under the plate area. With a diameter plate of 30 in. (760 mm) and larger, the shear-shearing force around the perimeter is ignored. Figure 12 shows a plate bearing test. Details for plate bearing field test at AASHTO T221 and T222 or in ASTM D1195 and D1196. K-value (to) as specified from the Testing bearing recurring plate (ASTM D1195) is of higher value as most inelastic de formations are eliminated in unauthorized testing (ASTM D1196). When performing a plate-bearing test on a stable subbases, loading equipment may not be able to produce adhesives of 0.05 in. (1.3 mm). Although it can, the resulting pressure on the subbase may far exceed the pressures inflicted under the concrete slab by the traffic load, not to accurately represent the state of service. As a result, a maximum pressure of 10 psi (0.7 MPa) is recommended for all plate load tests and, for realistic test results, both limits (0.05 in. (1.3 mm) deployment or 10 psi (0.7 MPa)pressure) should exceed. Cone Penetrometers - Cone Penetrometers, such as wes Cone Penetrometer and Dynamic Conetrometer (DCP), is a device used to measure ground strength. Test results can be used to estimate the strength of soil shear, CBR and k-value. Due to the rapid testing and basically not building, they are ideal for evaluation and construction testing on site and can be used in large areas to assess the eergetion. Penetrometers consist of a small cone with an apex angle of between 30 degrees and 60 degrees, attached to the steel rod (Fig. 13). The projected area of the cone base is approximately 0.5 in.2 (320 mm2). Penetrometers are driven into the ground either at a constant rate (WES) or by dropping a certain hammer weight at a certain distance (DCP). A measured value is the load required for driving a penetreter or a blow count per unit of depth. These values are then associated with CBR, shear strength or soil modulus value. Also, by plotting a load or blow count against depth, one can get a profile changing the strength of the ground across the project area. This can be used for things like checking the depth of stabilization and finding a soft or stirring layer. Figure 13. Penetrometertesting cone (Minnesota Department of Transportation). Correlational equations exist that attempt to estimate any one of the measurements of the aforementioned load bearing capacity from the other (i.e., k-value of CBR, CBR from R value, etc.). Because there is no general consensus where the best equations, none of them are included here, but the proposed correlational equation should be available in any design procedure or design software documentation. It should be noted that although steam is often summed up through measurements of strength, tredness and strength are not synonymous and, therefore, should not be considered as in the mechanics of the soil. The deterioration of both material properties can help a person understand how a stronger foundation may slightly reduce the thickness of the necessary pavement, but if the foundation becomes too stubruck, it may be in the wrinkles of stress in the concrete slab. This concept is discussed more in chapter the Principles of Design of this publication. Volume Stability It is necessary measuring expansion and shrinking the age of the soil, since these overall volume changes (or changes in the volume of differential from point to point along the route) can cause serious damage to the pavement structure, especially in areas where the soil remains relatively dry until wet by a rare period of rainfall. Tests used to measure potential volume stability problems by shrinking and swelling means include: Index Testing for Expansion and Ground Shrinkage - a number of simple tests showing potential ground volume changes are given in ASTM D427. ASTM D4829 gives its broad ground index and, based on test results, rates land from very low to very high expansion potential. California Bearing Ratio (CBR) and Resistance (R-Value) tests — Expansion tests are usually conducted in conjunction with CBR (AASHTO T193 or ASTM D1883) and R-Value (AASHTO T190 or ASTM D2844) tests. In both instances, test specimens are compact to the density that has been determined on the correct moisture content in mold and water supply prepared. The surcharge, equal to the weight of the covering material that will overlap the soil in the ultimate pavement structure, is used at the top of the specimen. The expansion that occurs during several soaking periods is measured as a real change in the length of the specimen, or the pressure imposed by expanded soil can be measured by way of stemming the specified gage. The same specimen was then used for the determination of CBR or the value of R. Sand Equivalent Test — A rapid field method, known as sand equivalent testing, was developed to detect the presence of unwanted clay materials in the soil and aggregate materials. This method tends to enlarge the amount of clay found in samples that are somewhat prosired by its adverse effects. Sand equivalent testing is a silence-type test in which samples of test material, in prepared solu tion, are completely angry in the 100ml glass cylinder. After setting for 20 minutes, the breakdown of sand and clay settles into layers. The height of this layer is measured by taking a reading with a specially calibrated trunk. The equivalents of sand (SE) are calculated as follows: SE = sand/clay readings read x 100 Concrete Sand and crushed stones have SE value of about 80; Very spacious clay has a value of ZERO to 5. Details of the test procedure are given at AASHTO T176 and ASTM D2419. The Classification System The size of the soil particles ranges from kubikel/stone, pebbles, pebbles, sand, cruelty, clay and, ultimately, for colloids. It has become a practice to determine the various ranges of particle size for the purpose of describing moisture characteristics and for the overall identification and classification of materials. The Integrated Land Classification System (USCS) and the United States State Highway and Transport Officer System (AASHTO) are two engineering classifications widely used. Other classification systems exist, such as the index system is presented in ASTM D3282, but it is not widely accepted. The AASHTO (AASHTO M145) method grew from the needs and developments in the field of highway engineering and the USCS (ASTM D2487) method was formulated to support the development of soil engineering technology (geotechnology). The USCS began, however, with a system created for use in material classifications for military airfields. It has been subjected to minor adjustments and has been adopted by many other organisations around the world. A clear understanding of the relationship between soil identification and soil classification is necessary to prevent confusion about the many factors involved in earthworks. For example, grading tests may be used to identify certain soil samples in the laboratory, but the classification of such samples depends on which classification system (AASHTO, USCS, soil texture method, etc.) is used. Once the soil samples are classified in a classification system, it is likely difficult to classify that the soil in different systems without the knowledge of soil properties. There are 11 classifications in the AASHTO system and 15 in the USCS system, so if the soil is classified in the USCS system in a group that has no clear corre link to the group in the AASHTO system, the nature of the material will be required to classify it in the AASHTO system. Therefore, the pavement design engineer must be aware of the preferred classification method for each project. Although soil classification using the AASHTO or USCS method may help pavement design engineers in mining factors that prevent such as the Wild Bearing Ratio (CBR) value or subgrade response modulus (k-value), some land will definitely exist in areas that are not easily classified within the limits of this method. For such soils, or for soils where such design variables are unsuitable, soils can be classified using soil texture methods. AASHTO Land Classification System The AASHTO system classifies land is an engineering property classification system based on highway field performance. The system compiled comparable load storage capacity land and service levels produced in seven basic groups, designated A-1 through A-7. The best land for road subgrades is classified as the next best A-1, A-2, etc., with the poorest land classified as A-7. The soil in each classification group has the same characteristics. However, there are various in carrying capacity of load inside each group, as well as overlapping capacity carrying loads between groups. For example, A-2 land borders may contain materials with a capacity to carry a larger load than A-1 soil and, under unusual circumstances, perhaps lower than the ingredients classified in the A-6 or A-7 land group. Therefore, if the AASHTO land group is the only known fact about the soil, only the limits of capacity carrying a wide load can be stated. As a result, seven basic land groups divided into subgroups, with a group index created to approach assessments within the group. The charts and tables used to classify soil in the AASHTO land classification system (AASHTO M145) are shown in Figures 14 and 15 and Table 1. The classification of materials in various groups of AASHTO M145 applies only to fractions that passed the filtration of 3 in. (75 mm). Therefore, any specifications regarding the use of A-1, A-2 and A-3 materials in construction shall state whether the stone, maintained on a filter of 3 in. (75 mm), is allowed. Figure 14. Plastic indexers limit liquid for AASHTO soil classes. See the section entitled, Plastic Soil, earlier in this chapter for more on liquid limit plastic indexes. Figure 15. Group index chart. Table 1. AASHTO Classification of AASHTO Highway Subgrade Materials AASHTO Land Classification System (from AASHTO M145) General Classification of Granular Materials 35% or less pass no. 200 (75 μm) Material Clay-Clay >35% pass no. 200 (75 μm) bears the Group Classification A-1 A-3 3 A-2 A-4 A-5 A-6 A-7 A-1-a-1-b A-2-4 A-2-5 A-2-6 A-2-7-7-7-5A-7 S6 Sie-6% pass no. 10 (2.00 mm) No. 40 (0.425 mm) No. 200 (75 μm) 50 max 30 max 15 max — 50 max 25 max — 51 max 10 max — 35 max — 35 max — — 35 max — 35 max — 35 max — 36 min — — 36 min — 36 min Fractional features pass No. 40 (0.425 mm)Liquid Limit Plastic Index — 6 maximum — N.P. 40 max 10 max 41 max 10 max 40 max 11 min 41 min 11 min 40 max 10 max 41 min 40 max 11 min 41 min 41 min * Common type of constituent material , gravel and sand finely Silk or clay gravel and Clay sand silk ground Excellence for Good Fair to Poor ASTM (United) U.S. Military Engineer Corps Land Classification System develops classification systems that use texture as desktiptive terms (see Table 2), such as GW: pebbles, GC: credits and GP: pebbles, less graded. Since its inception, the classification system has been expanded in collaboration with the United States Bureau of Reclamation (USBR) and the Tennessee Valley Board (TVA). It is now referred to as the Integrated Land Classification System (ASTM D2487). The ASTM Land Classification System identifies soil according to the quality of textures and plastics and their groups with respect to their presentation as engineering construction materials. The following properties form the basis of soil identification: The percentage of pebbles, sand, and fines (fractions surpass the siege of No. 200 (75 μm). Form of cereal-sized distribution curve. Plastic characteristics. Each land is classified into the most suitable group identifying its main characteristics. ASTM system groups are easily identifiable by descriptive names and letter symbols, as shown in Table 3. Table 2. ASTM D2487 Information. First Letter of Description G Gravel M Kelodak C Clay O Organic PT 2nd Peat Description Of Symbol W Bergred Good P Bad-grade M Silty fine C Clayey fine H High plastic L Low plastic Table 3. ASTM (United) Land Classification System Main Part of the Group's Typical Gross Land Forecast More than 50% is maintained at No. 200 (75 μm) steaming * Pebbles 50% or more gross breakdown is maintained at No. 200 (75 μm) steaming * Gravel 50% or more gross breakdown is maintained at No. 4 (4.75 mm) shrink the Good graded Gravel GW Gravel and gravel mixture, little or no poor graded Gravel GP fine and gravel sand mixture, little or no fine gravel with GM Silty's Fines gravel , sand-sand gravel mixture GC Clayey gravel, sand clay mixture 50% or more of gross breakdown passes at No. 4 (4.75 mm) siege to the good grade Sand SW Sand, and gravel, little or no SP fine or no Sand fine with SM Fine Silk Sand, a mixture of SC Clayey sand sacks, a mixture of fine Sand clay 50% or more Pass No. 200 (75 μm) filters * Skull and Liquid Clay Limit less than 50 ML Inorganic , very delicate sand, stone flour, silk fine sand or low to medium-to-medium CL Inorganic clay, pebbles, sandy clay, silk clay, lean clay OL Organic sagging and low-placing organic silk clay- sagging sagging and Clays Liquid Limit 50 or over MH Inorganic clue, fine sand rat or diatomaceous, fat clay OH Soil organic coat , muck, and other highly organic soils - Based on materials that pass filtration 3 in. (75 mm). Soil Texture Methods Although the AASHTO and USCS methods are used to set the size range of soil particles, the soil found in the field is too different to be limited to the size range of these particular particles. Sand soil, for instance, can include limited quantities of stools, clay, or pebbles size, or this combination, and is still classified solely as sand. The same goes for scoots, clay or pebbles. The size range is standardized so that the size of other particles may be present, but soil classes (sand, sacks, clay, or gravel) can be set. When larger quantities of other sizes are present, the type of base soil has a combined fixation, such as clay sand, sandy pebbles, clay clumsy, etc. The determination and designation of such mixtures in the soil classification is referred to as the texture of the soil. Texture-related terms used for various separate soil combinations are defined by several agencies. The amount of each separate amount of land in the soil, which will determine the texture or feel of the soil, is determined by laboratory tests. These test results were then compared to the texture definition used to determine the texture name. The texture of the soil is given to tell as much about the land in just a few words. With the texture specified, and estimates of the properties of the soil can be made, such as bearing values, water holding capacity, marketability to be frozen frozen and adapt to the construction of soil cement. To allow for texture classification estimates, many practical shortcuts can be created to determine the amount of satiety and clay in the soil. However, because the range in clay content for texture groups is not large, an accurate sample weight is required, which requires some laboratory facilities. ASTM D2488 describes procedures for identification and description of land for engineering purposes based on visual inspections and simple manual testing. Soil texture types are listed in Table 4. Table 4. Land Texture Method Of Classification Of Sand Description Texture Includes only a small amount of fines or no fines. These are available on the beach, in the dunes or in flow bar deposits. Individual cereals can be seen and felt easily. Squeezed on hand when dry, this soil will fall apart when the pressure is released. Squeezed when sluggish, it will form an actor who will hold his shape when the pres- surely released but will collapse when touched. Silk sand consists of sand, but has enough sausions and clay present to provide some stability. Individual sand grains can be seen and felt easily. Squeezed on hand when dry, this soil will fall apart when pre-definitely released. Squeezed when sluggish, it forms an actor who will not only hold his shape when the pressure is released but will also withstand cautious submission without breaking. The stability of the damp cast distinguishes this land from the sand. The stool consists of a large number of stool particles with no small amount of sand and clay. Lumps in dry, unsuitable conditions look a bit cloddy, but they can be greeted easily; the soil then feels soft and floured. When wet, the stool loam runs together and puddles. Whether the actor is dry or damp can be handled freely without breaking. When a wetland ball is pressed between the thumb and the finger, the moisture of its surface will disappear, and it will not press into a smooth ribbon, uncrocked but will have a broken appearance. Silk clay consists of plastic (solid) fines mixed with significant quantities of stools. It's a fine ground that breaks into hard clods or lumps when dry. When a wetland ball is pressed between the thumb and the finger, it will form a thin ribbon that will break easily, barely maintaining its own weight. Wetlands are plastic and will form an actor who will endure great handling. Fine clay that breaks into clods or very hard lumps when dry and plastic and unusually sticky when wet. When a wetland ball is pressed between the thumb and the finger, it will form a long ribbon. Fat or Ground Heavy Clay Plastic Clay; very exhibit indicated for clay. Lean Clay or Simple Lightweight Clay plastic; shows the characteristics shown for clay, but to a lower stage. The taste and appearance of the texture set describes the factors used in determining the texture of the soil in the field as well as in the field classification work. Note: forming two ground actors, dry and humid, on hand and pressing or rolling wetballs of thumb and finger tweens is two important field tests to assess the texture of the ground. STRENGTH SUBGRADE AND WORK PLATFORM Because of the ability of concrete pavements to spread loads in large areas, the highest subgrade pressure will usually occur during the construction phase of the concrete pavement or subbase layer. Once in place, subbase and concrete pavements protect the subgrade from high pressure relations by load. Therefore, the required subgrade strength is usually coordinated by providing a stable working platform to build successive layers of countries. Research conducted by Wisconsin Depart ment of Trans por tation has concluded that the California Bearing Ratio is minimum (CBR) 6 in the top 24. (610 mm) subgrade provides an adequate working platform, while limiting rutting devaluation under construction traffic to 1/2 in. (13 mm) or less (Crovetti and Schabelski 2001). Compressing subgrades to density that provides an adequate working platform for construction equipment will provide sufficient subgrade strength for the pavement of concrete in service. AASHTO T99 field testing (standard proctor) is recommended to characterize subgrade for acceptance. The percentage of heating targets will vary by land type and local conditions. State transportation departments recommend values between 84 to 100 percent standard proctors, but the value of 95 percent is by far the most prescribed and, therefore, is the recommended value for most applications (ACPA 2005). The species cautions against arbitrary determining high levels of maturation as this can contribute to an increase in the construction period due to the necessary additional heating efforts and unnecessary project costs, all without any associated benefits. Keep in mind that subgrade strength is a function of both density and moisture content. Compact soil with density given on dryers from the optimal moisture content will lose strength if the soil becomes saturated over time. Under normal circumstances, losing this strength is not an issue to support pavements, but may be an issue to provide a stable working platform. When sub-grade is compact and received weeks or months ahead of subbase or pavement construction, a once-stable working platform may not be enough to support construction equipment due to saturation. Depending on the soil that occurs on the project and the requirements of density in specifications, strict adherence to certain density can be inefficient. For example, if a stable working platform can be achieved at a density of 90 per cent, further maturation efforts to meet arbitrary density are set by 95 per cent wasteful; This additional density is not necessary for uniform support of the pavement. OBTAIN UNIFORM SUPPORT To obtain a subgraduate uniform support, the four main causes of inconsistencies must be addressed: Soil exposed to frost (frost slaves). Pumping (from a layer that can be eroded under the slab of pavement). Effective control of frozen soils is the most economical achieved through appropriate subgrade preparation techniques; the inclusion of a thick subbase layer in an attempt to control extensive soil and frost weight is expensive and ineffective as the proper preparation of the subgrade. In cases where the potential for pumping exists, a subbase layer is always required. Where subgrade conditions are not reasonably uniform, the most economical and effective correction is achieved by proper subgrade preparation techniques, such as selected grading, cross-transportation, mixing on soil type and cut/filling shifts, and control of subgrade compaction slowdown. Regardless of which technique is used, special attention is necessary to control extensive soils and excessive differential frost weight. The subbase layer also helps provide uniform support, but its main purpose is to prevent pumping or erosting it. Whether or not a subbase is used in the structure of concrete pavements, the preparation of the right sub-grade is the best way to get uniform support. The selection of suitable ways to reduce extensive land, soil exposed to frost and pumping depends heavily on the conditions of the subgrade in-situ land, the extent of the necessary improvements, environmental concerns and construction requirements [MNDOT 2003]. A certain concern, because of its difficulty estimating before construction, is the moisture content of the soil in-situ. If wet soil is found during construction, the mitigation method may not be as effective as planned. The following sections provide a detailed explanation on design and construction issues on extensive soil, exposed land to frost and wet soil; the pump is dealt with in Chapter 4. Vast land Land changes the volume with changes in moisture content. Extensive land that may swell enough to cause pavement problems generally clay falls into the AASHTO group A-6 or A-7, or is classified as CH, MH, or OH by the Integrated Classification System, and with the Plastic Index larger than about 25 by ASTM D4318. Knowledge of potential changes in soil volume and the resulting effects of pavement performance have been obtained through experience and research. Simple testing provides indicators that serve as useful guidance to identify potential land estimate volume changes (Snethen 1984; Wisemen, Komornik, Greenstein 1985). For example, Table 5 shows the estimated contact. Keep in mind that the percent expansion data listed in Table 5 represents changes from dry to saturated conditions. In reality, approximately the expansion will be because variations of this extreme humidity will not occur and the subgrade will be compacted to a suitable density. Experience shows that the Clay changes with medium or low expansion levels (Plastic Index below 25) are not an important concern for the pavement of concrete, especially if selective grading operations such as cross-transportation and soil-type blending minimize or eliminate sharp changes in soil characters along the alignment. However, experience also shows that uncontrolled shrinkage and extensive ground swelling can lead to increased pressure in concrete pavements due to non-uniform support, which accelerates the deterioration of the ment and negatively affects the smoothness of the pavement. Although changes in soil moisture content are inevitable throughout the life of the pavement, extensive soils can be handled effectively through selective grinding operations or chemical modifications (stabilization). Table 5. Soil Index Properties and Possible Volume Changes for High Plastic Land (after the Earth Manual 1985) Data from the Estimated Index1 Test of a possible expansion estimate,2 percent total changes (dry to saturated conditions) Levels of expansion Colloid content (percentage less 0.00004 in. (0.001 mm)) (ASTM D422) Plastic Index (ASTM D4318) Percentage Shrinkage Limit (ASTM D427) > 28 > 35 & lt; 11 > Very high 20 – 31 24 – 41 7 – 12 20 – 30 Highs 13 – 23 15 – 28 10 – 16 10 – 20 Medium & lt; 15 & lt; 08 >

15 & lt; 10 Low 1 All three index tests should be considered in estimating vast properties. 2 Based on vertical loading of 1.0 psi (0.007 MPa). To fit higher the amount of expansion is reduced, depending on the load and characteristic of clay. Construction factors that can exacerpt performance issues related to vast soil include: Compressing soil while too dry, causing the possibility that the soil will absorb moisture and grow after preparing the subgrade. Placing the pavement on a subgrade with varying moisture content, allowing for different volume changes of soil to occur along the road alignment. Creating uniform support by ignoring sharp changes between soil types and different capacities for volume changes along the road alignment. Certain expansion test procedures such as ASTM D4546, ASTM D4829, Caltrans Test Method No. 3548 (CALTRANS 1978) and ground suction test (AASHTO T273 or ASTM D3152) are ideal for evaluating subgrade soil volume changes. Some of the important factors determined by this test, which are not indicated by simple index tests, are: Effects of compaction, humidity and density on the swelling characteristics of the soil. Effects of surcharge load. Expansion for total crediting samples and not just for finer grit fractions of the soil. Possible volume changes with potentially wide ground depending on a number of factors: Climate - the level of humidity variation that will occur in subgrade year or year to year. It is generally true that the pavement will protect the grade to a certain extent and reduce the humidity level of moisture in the basic subgrade as long as the soil cannot afford to paint moisture from the bottom through capilary action. Surcharge — effects of soil weight, subbase, and pavement on extensive ground; Tests showed that soil swelling could be reduced by surcharge load (Holtz and Gibbs 1956). Moisture and wide density of soil at paved time. The knowledge of the conversion of these factors leads to the selection of economical and effective control methods. Erasure and Moisture of Broad Ground Control To reduce very wide ground volume changes, it is important to compress it at 1 to 3 percent above the optimal humidity content (AASHTO T99). Research has shown that compact soil on moisture content exceeds the optimal AASHTO T99 will produce a subgrade that absorbs less water, provides slightly higher strength, and will not grow or swell as much as the dry soil of optimal humidity at the time of preparation (Dubose 1952; Felt 1953; Holtz 1959; Parcher and Lie 1965; McDowell 1959). Figure 16 shows the strong influence of the computing mois ture and density of changing volume. Lower compactive efforts (lower dry density) will result in significantly lower expansion, but this is not recommended in practice. At lower comactive efforts there may be practical difficulties in achieving a reasonable level of computing uniform and there is a high risk of secondary computing from the subgrade once the pavement structure is placed on it. Therefore, properly grouped subgrades are best achieved by increasing moisture content and comactive efforts near AASHTO T99. It is also important not to assume that higher degrees of computing produce better subgrade when dealing with good and wide ground. The U.S. Military Engineers Corps and various other agencies used a modified slowdown test, the AASHTO T180, which was developed to represent a higher level of compaction from AASHTO T99. The test was created for a compact granular subbase and it produces higher density and lower optimal humidity content than the standard test method, AASHTO T99. It is also used for subgrade soil with low plastic indicators and, while it is acceptable for this purpose, as a result of higher comactive effort in too low humidity content for pan ground containers. In addition, these higher compactive efforts do not need for subgrades and subbase under concrete pavements because uniform support is more im portant than support strength. Figure 16. The volume changes for different computing conditions. To better reflect the difference between the AASHTO T99 and T180 test methods, consider Figure 17. To get density approximately 114 lb/ft3 (1,830 kg/m3) for AASHTO T180 testing, the moisture content during commencement must be less than 15 percent. If the soil moisture content is then increased to the percentage due to the increase in water tables, the predicted density of soil is about 98 lb/ft3 (1,570 kg/m3), a decrease of more than 14 percent. However, for the AASHTO T99 test, the change from maximum density of 101 lb/ft3 (1,620 kg/m3) on the humidity content of 21 per cent to 95.5 lb/ft3 (1,530 kg/m3) at 25 per cent was only a decrease of 5.5 per cent. Any decrease in density will lead to an increase in procided volume; Thus, wide ground extinguishment on the lower optimal moisture content (as required in the AASHTO T180) results in a swelling container scissoring. Furthermore, the correct deletion of the optimal moisture content of the AASHTO T180 requires a more compact effort. Figure 17. Moisture density relations (AASHTO T99 and T180) for extensive A-6 land. To describe the effects of moisture content on the swelling of the soil, Figure 18 shows that, when compared to the high expansion obtained when the AASHTO T180 dry density with additional erasure efforts, the expansion of A-6 land is reduced when it is collected a little wet AASHTO T99im optum. Research results also show that, for the wet compact soil AASHTO T99, greater strength and lower humidity absorption occurs after soaking. Field experience also shows the best extinguishing moisture content for use with extensive land (Felt 1953 and McDonald 1986). Unpleasant disturbances do not occur in the pavement placed on plastic ground uni form with moisture content near the plastic limit (slightly larger that AASHTO T99 is optimal). Figure 18. Strength, humidity gets and swells the AASHTO T180 dry ground and wets the optimal moisture of the AASHTO T99. On the other hand, pavement disorders have occurred for pavements placed on subgrade soil the broad content of lower humidity. Experience also shows that slightly wet subgrade soil offers greater resistance to water gain by absorption or loss of water with eroding than doing dense soil under any other condition. After the pavement is placed in service, most sub-grades reach the moisture content approaching their plastic limits, which are slightly above the standard optimum. When the content of this moisture is obtained during construction, the swelling of any subsequent humidity changes will be less, and the subgrade will maintain reasonable uniform stability required for excellent pavement performance. If a spacious subgrade of soil is prepared and properly compact, but a significant time passes before laying the sub-base or pavement layer, the soil can dry out. Therefore, the soil should be retried before the placement of the subbase or open and, if necessary, is recalected at the recommended moisture content (above optimal). Depth requires reprocessing can be determined from a field moisture test. There are additional considerations for great height embankments. Because too many (mass) embankments, lower soil layers in embankment do not require the same curtain as near the surface. The optimal humidity content of deletion can be increased from slightly below the optimum at the bottom of the embankment upwards optimal in the top 1 to 3 feet (0.3 to 1.0 m). Selected gradation If extensive land is not the mainland type along the road alignment, selected grading is usually the most cost-effective method of treatment. Selective grading operations may also be sufficient to control shrinkage and swell potential when profile grades can be designed to keep the ground wide from the top of the subgrade. Tests showed that ground swelling was reduced by surcharge loads (Holtz and Gibbs 1956). Field measurements indicate that excess swelling at a depth of 1 to 2 feet (0.3 to 0.6 m) gradually decreases to the amount ignored at a depth of 15 feet (5 m) or more. Therefore, excess swelling can be controlled by placing wider ground at the bottom of the embankments. Cross-grading or selective grading operations that combine or mix soil types effectively, causing less extensive soil to be placed at the top of the subgrade, can provide reasonable uniform conditions that will minimize the change in the volume of broad soil. Similarly, this operation should also be used on cut filling shifts to eliminate sedimentary changes in soil types. In deep parts of the very wide soil, large expansion may occur due to the removal of natural surcharge loads and the subsequent absorption of additional humidity. Since this expansion occurs slowly, it is important to dig these deep wounds well before other grading work, whenever possible. When excavation and embankment operations do not lend themselves to this initial excavation, these parts should be chemically modified to control shrinkage and swelling. Many projects no longer lend themselves to selective grade operations because phrase and scheduling projects require ments. However, selected crediting is usually more economical than chemical modifications. Therefore, engineers are encouraged to carefully evaluate the soil conditions along the project alignment before choosing which method to choose. Selective crediting is an excellent technique to control extensive soil volume changes for the isolated pockets of these materials that occur on projects. Chemical Modification When subgrade soil consists mainly of pancific clay containers and does not save on importing unbroad soil, chemical modification is an optional technique. Soil can be modified by chalk, portland cement, kiln cement dust (CKD), Class C flying ashes or Class Flying ashes in conjunction with chalk. Renovations provide a positive way to control the potential of swelling of the soil. In addition, sub-grade soil modified provides an ideal work platform, and time-saving related to subgrade modifications can prove more economical than selective grading operations. Each ordinary stabilization material provides chemicals and/or/or mechanisms that alter the properties of the soil. An important contributor to the effects of stabilizing material is calcium. Stabilization material responds with extensive clay in two ways (Bhatty, Bhattacharja, Todres 1996; FHWA 2003): Stabilization of Ion Exchange (chemical mechanism) — flocculation and agglomeration of clay particles resulted in granular particles with lower PI and lower sensitivity to humidity fluctuations. Pozzolanic stabilization (physical mechanism) - the direct cement effect of bonding grains together. Each material used for subgrade modifications described in this document (chalk, portland cement, CKD, Abu flying Class C and ash flying Class F with chalk) reacts with clay material in both ways, but to different levels. The chemical composition of the soil charac renovation and theistics of the soil determines the type of reaction that is the main stabilization mechanism. In general, chalk, CKD, and Class Fly ash renovations depend mainly on exchange of ions, while class C flying ash modifications occur mainly through pozzolanic reactions. The stabilization of clay with portland cement is a combination of both types of reactions. Ash flying Class F is not self-cement, so it requires chalk as an activation; Together, Class F flying ash and lime creates cementitious products through a pozzolanic reaction (ACAA 2006). Laboratory Selection and Material Dosage Testing should be done to determine the appropriate dosage rate for each modification material under consideration. Laboratory procedures proposed for each material are shown in Table 6. Table 6. Common Laboratory Procedure for Land Renovation Assessment Atterberg Limits (PI) (ASTM D4318) Land Expansion Index (ASTM D4829) CBR (ASTM D1883) Uncensored Compression Strength (UCS) (ASTM D1633) Lime X X Portland Cement X X Cement Kiln Dust X X X Class C Fly Ash X X Class Fly Ash with Lime X X X X Any modification material can be used to control extensive ground volume changes. However, the effectiveness of each modification material is a function of soil properties and dosage rates. Selection of soil modification materials should be based on laboratory test results and economic factors. For example, the results of the ASTM D4318 laboratory test may indicate that a 4 percent lemon modification would reduce the soil PI to 10 and that 16 percent of flying ash renovations would reduce the expansion index to 30 when tested according to ASTM D4829. Based on these results, a comparison between the estimated cost of lime and flying ash materials can be made to determine which material is the most cost-effective. In cases where the cost of materials for each alternative is the same, one can assume that the cost of construction for a subgrade that is modified lemon will be slightly higher than that of other ingredients due to the soil mixture must be manipulated twice (see Figure 19). This document is not intended to determine the appropriate dosage rate for soil Materials. These results are special projects/soils and should be based on laboratory testing procedures using soil samples that are expected to be available in the top layer of the subgrade. A geotechnical engineer should provide guidance on the dosage rate of material that will control the change in the amount of subgrade soil wide. Reference documents published by cement, chalk, and ash flying industry organizations often include a normal range for dosage rates. This recommended dosage range should not be used in lieu of ground laboratory tests for modification. For most types of soil, more than one type of modification material will adequately control the volume changes. Therefore, the cost of each ingredient available in the laboratory tested the dosage rate should be estimated and rather than optimizing the design. NOTE: Modifying sulfate bearing soil with any of the above materials can result in a loss of volume harmful to the soil. Soil with sulfate levels above 0.3 percent can react with calcium in modification materials (NLA 2000). Consult with geo technical engineers for projects that may potentially have land containing sulfate. Build Modified/Stable Subgrades Processes to build modified sub-grades with lime slightly different from portland cement, CKD and modified subgrades with flying ash. Lem needs a period of mellowing to respond with the ground. On the other hand, cementitious ingredients must be fully incorporated into natural soil and matched completely as soon as reasonably possible to take full advantage of the pozzolanic reaction. The pozzolanic reaction of particle soil bonds together, which blocks their potential to change the volume. Disrupting portland cement, CKD, Abu flying Class C or Ash flying Class F with a mixture of lemon and soil after ground particles have tied together basically breaking those tie-ups and reducing the ability of modification materials to control extensive soil. The requirement that a fully modified soil mixture is met within 1 hour of the process of mixing ash flying ground is common in specifications for the modification of class C. Although portland flying ash, the ashes of flying CKD and Class F with chalk did not respond as fast as the ashes flying class C, it is advisable that the time of quitting com Details of the subgrade preparation process, with special considerations and measures for chemical modification, are shown in Figure 19. Special methods for Controlling Broad Land Where potential exists for changes in extreme amounts of land, some special treatments have been used with success. These include ponds (pre-swelling), membrane encapsulation, horror geomembrane, and vertical moisture barriers (Gordon and 1984 Waters; Luttrell and Reeves 1984; Picornell and Lytton 1987 and 1989; Ramaswamy Aziz 1987; Reed 1987; Snethen 1979; Steinberg 1981; Watt and Steinberg 1972; Weston 1980). Electroosmotic electroosmotic chemicals and chemical pressure injections have also been used, with mixed results (TRB 1990, Petry and Armstrong 1989). Information on the specific treating of this particular treat is beyond the scope of this publication; details of the techniques given in the quoted reference. Figure 19. Construction process for subgrades, with special considerations for lime soil and modified cement. Action Frost Action Frost is a phenomenon that takes place in winter and early spring in the northern climate. Almost all surface soil undergoes some frost action, a magnitude that depends on the local climate and rainfall. Frost action divides into two phases: 1) freezing groundwater and 2) diluting ground water. For the pavement, frost action becomes critical when either: The freezing phase is accompanied by a significant weight of road surfaces, or the melt phase is accompanied by significant road cladding. It is important to understand that the consideration of the design to control the frost pavement is not necessarily the same as those to control subgrade survival. For example, a soil that has a high potential weight of variables will not necessarily exhibit a maximum level of subgrade calmness. Although both mechanisms are usually present on the ground exposed to frost, it is important to recognize how their effects on the performance of concrete pavements differ. Field experience with concrete pavements has shown that frost action damage due to frost weight, in the form of an sharp differential weight, has affected performance more than softening the subgrade. Typical cracks from the weight of the frost are shown in Figure 20. Subgrade connectivity because frost action is not a major concern for subgrade design because uniform support from subgrade is more important than its strength. However, the softening of the subgrade can pump the aggra-vate in a pavement built without addressing the potential of pumping adequately. In short, the slowness of the subgrade because frost action is not a concern if the pavement has been designed to avoid pumping. The frost design for concrete pavement is concerned with providing uniform subgrade conditions. This is achieved by eliminating the humidity conditions that lead to an unpleasant weight of differential frost: Where subgrade soil varies suddenly from non-frost sand -exposed to very vulnerable cruelty. On the transition of cut filling or in the pockets of the stoils. Where ground water is close to the surface. Where water bearing strata is found. Frost Heave Heaving's way from the frost action is termed frost weight. Frost pavements, especially when in remote areas, drive uneveiled support of the pavement. When the heavy load passes an unequal support area, a crack can form in the surface layer of the pavement. There are at least three conditions that must exist before the weight of the variable can occur. They are: A climate that is to allow freezing temperatures to penetrate below the road surface and into the subbase and and Water supply from below, above and/or later to the freezing zone. Soil materials are exposed to frozen and sightseeing in the freezing zone. The areas of the United States most vulnerable to freezing weight are those identified as wet freezing (WF) in Figure 21, as two of the three conditions listed above (cold climate and water supply) are common during winter in these areas. It should be noted that, since the water supply needed for the freezing weight occurs, the weight of the frost is not generally a concern if the water table is more than 10 feet (3 m) below the surface of the pavement structure. Figure 21. Four climate zones as identified in the Long-Term Pavement Performance (NCHRP 2004) programme. Weight due to the formation of ice lenses in the soil under the pavement (Fig. 22). Water grew 9 percent by volume when frozen. When freezing temperatures penetrate the subgrade soil, water from the unfrozen subgrade part is attracted to the freezing zone. If the soil is exposed to capilary action, water migrates to previously formed ice crystals and freezing. The size of the ice lens depends on the quantity of free water found in the soil and from the water table, and time. As the soil freezes, free water freely freezes and grows. Once started, ice lenses continue to grow as long as free water sources are provided. Free water migrates through the ground to the ice lens formation by capsilary action. This water migration can be 30 feet (9 m) for certain soils exposed to frost. If the rate of frozen penetration into the subgrade is slow, a thicker ice lens will be developed as there is more time for water to migrate from the unfrozen zone before all the water is free in subgrade freezing. Eliminating water supply to the ground under the pavement is almost impossible. However, good drainage can partially reduce the quantity of water available to feed the ice lenses and cause frozen weight. Most of the water supply from below can be cut with a combination of sand blankets and tile drains. Some soils are more susceptible to the formation of ice lenses than others. Silk crows or clay (AASHTO A-4 and A-6 groups or Classifi Consolidation cation ML and MH) are considered among the most susceptible to the formation of lens ice (NMDOT 2006, ASTM M145). The stool encourages water flow by the capsule action through its pores because the distribution of pore size is small enough to induce capilary action but large enough to allow the migration of pores. Therefore, crows supply the water needed to promote the formation of ice lenses in the freezing zone. Other soils considered vulnerable to frost will also encourage the formation of ice lenses. Figure 22. The formation of ice lenses, causing frozen lids. Performance program (NCHRP 2004). Frost heave most frequently found on site The transition from the cut to filling. Where the trenches are insufficient or nonexistent. Next to the that dams by the side of the drain road and/or collect water. Where there are changes to dilute in subgrade material. Not all furry weights are detrimental to the pavement. Uniform weight may not be noticeable on the eyes or to vehicle passengers. If uniform weight occurs, there is no bruises or rolls on the surface of the pavement and therefore, uniform weight does not indicate maintenance problems. The weight is damaging and troublesuiting only during the freezing or frozen phase, when it varies sharply, causing uneven support to the pavement. To prevent frozen lids, highly exposed soil should be replaced or stabilized. Exposed areas should be drained with tiles drains and/or drains should be kept clean and free of chaos preventing water flow from the route. The Frost-Susceptible Land Criteria and land classification to identify land exposed to frost usually reflect the susceptibility to melt as well as weight (Army 1985, ASCE 1984, Chamberlain 1981, and TRB 1953 and 1974). For concrete pavement, the main concern is to lose weight; Spring softening control is not much consideration. Therefore, differentiation should be made in the classification between soils exposed to lashes and those exposed to softening calmness. There is broad diversity in frost reliability determination methods; almost all methods are unique to individual countries, territories, and federal agencies. Most methods are based on determination of the size of the soil particles, and some have criteria similar to that of Casagrande (1931) - more than 3% smaller than 0.8 miles (0.02 mm) in uniform soil. However, this method rarely distinguishes between frost turap and melts. A method that distinguishes both factors is the frozen testing of the U.S. Military Engineers Corps (Chamberlain 1987), but testing and equipment are not easy. In general, the level of suspicion of frost can be explained by two hydraulic properties of the soil: Kapillarity - the soil's ability to attract moisture by capillary force. The smaller the distribution of the pores network size, the greater the driving force (capillary action) and the greater the calories. Perseverance — the soil's ability to transmit water through its voums. The accuracy of any material depends heavily on the connectivity of the pore network. For example, if the material contains many tohorous pores that suddenly end, it will have less persorability than material with very open pores that pass completely and directly through the substance. The more connected and the larger the pore network, the greater the reliability. Figure 23. The relationship between frost action and soil hydraulic properties. The relationship of these properties for frost reliability is flashed visualization in Figure 23. Heavy clay has very high capility but they are practical can be seeded. Therefore, heavy clay will not allow sufficient water to be transported to the ais for excessive weight occurs (Fredrickson). Pebbles and sand, however, have very high permeability, allowing water to be easily diverted through their pores network, but they do not have a conducive distribution of pores of capilary action, so they cannot lift enough moisture to heavy occur. When proper combinations of capitality and perseverance occur in the soil, such as with silk materials, severe frost weight may occur. Low plastic, fine soil with a high percentage of stool-sized particles (in the range of 0.02 to 2 miles (0.0005 to 0.05 mm)) is particularly vulnerable to frozen weight. Other soils considered frost-sus-ceptible include loam, sandy loam, clay loam, fine sand, clay gravel, and stone flour. Moderately exposed frost-susceptible soils include dirty sand and pebbles and glaciers up to this day. The only soil that can be considered as unsealed to sand turmoil and very clean pebbles. Spring Subgrade Softens Except in the permafrost area, the frozen subgrade melts both from the surface down and from the ground up. As a result, dilution is usually faster than freezing. When dilution begins, the moisture content of the subgrade may be high due to the increase in previous humidity during freezing and infiltrating of surface water. This water in the upper layer diluted cannot flow down because of the frozen zone below. In addition, the expansion of weight consequences has led to temporary loss in density. Under these conditions, there was a sharp reduction in subgrade support during the liquid period. A review by the Material Committee of the Highway Research Board shows that the largest loss period of strength is brief - usually two to three weeks — followed by a recovery period after the dilution is completed and the subgrade material is redeemed. Figure 24 shows a typical increase in subgrade strength at freezing and loss of subgrade strength at dilution over the course of a year. Figure 24. Normal loss in bearing value on the liquid. The reduced subgrade support period accompanied by dilution has little effect on concrete pavement. This is because concrete reduces pressure to safe limits by distributing loads in large areas and because the ments of concrete pavements are designed for fatigue pressure due to repetition of the load. The effect of fatigue in a period of reduced subgrade strength is offset by reduced fatigue over a longer period of time that the subgrade is frozen and offers very high support. Concrete pavements designed based on the strength of the normal weather subgrade have sufficient reserve capacity for reduced support periods during spring twists. Tests on concrete airfields and highway pavements in frost areas show maximum reduction in subgrade support 25 to 45 percent during the spring melt period (PCA 1975). When these reduced values are used in design analysis, results indicate that additional pavement thickness is not required. Because their existing load carries capacity and ability to distribute in larger areas, concrete pavements are excluded from load restrictions during the spring melt period, unlike many asphalt pavements. Field experience and flowing design confirm that subgrade solids are not a factor in design considerations to control frost action for concrete pavement. On the other hand, it is an sharp frost weight, a differentiation that must be controlled. Frost Heave Control The performance of older concrete pavements in areas exposed to frost under today's traffic is gaining weight indicating that extensive, expensive controls are not necessary to prevent frost damage. This pavement survey shows that control is needed only to regain excess weight and, more critically, to avoid the weight of the differentiation by achieving a reasonable uniform subgrade state. As in the case of former reverse ground pans, large levels of frost pavement control are achieved most economically by appropriate grading operations and by controlling the erasure and humidity of the subgrade. Water Table Grade and Height The most basic design aspect of controlling the potential weight of the frost is to set a pretty high grade line and build a trench side deep enough so that the very exposed soil frost is always above the capilary range of groundwater tables. If possible, where the groundwater is near the surface, the grade should be kept 4 or 5 feet (1.2 or 1.5 m) above the bottom of the trench at the cut and natural soil in the fill (embankment part). Since grade height is usually not possible for roads and roads, as it is with highways, other frost hero mitigation techniques should be considered for this app. Selective grading and Grading operations benefit to laying the ground very vulnerable to frost-exposed at the bottom of the embankments, and to cross the less frost-suscep-tible land haul form the bottom of the subgrade towards the top. Cross-sectional transport and mixing are also useful on full-cut shifts to correct abrupt changes in characters and soil types. Where the soil varies widely or frequently in character, mixing them effectively in preventing the weight of differential frosts. Figure 25 describes the usual section filling the cut; the transition part is removed and mixed with the contents only to promote the inconformity of the finished subgrade surface. With modern construction equipment, uniform mixing of soil to form a uniform subgrade is often more economical than importing selected materials from borrowing holes. Chemical modifications will also deliver some benefits towards subgrade consensual goals, but it may also be less economical than choosing grading and mixing. Pocket Removal Of Satiety When grades include only a few pockets of stoils or other frost-susceptible soil, the best option is to and back up these pockets with land similar to the surrounding subgrade. To ensure that uniform support conditions will be created for pavements, it is important to compress the backfill backfill to the same moisture and density conditions of those found on adjacent soils. Replacement soil should be mixed with the soil around to form a filtered transition zone on the edge of the pocket, similar to in cut-content transitions. Erasure and Moisture Control Once reasonable soil equality is established through grading operations, deletion at controlled humidity levels will increase subgrade further. As discussed earlier, subgrade equality can be obtained by compressing the subgraduate material slightly wet the moisture content of the optimal AASHTO T99. Treating the most delicate soils in this way significantly reduces soil permeability, which records the humidity flow rate to the freezing zone. Research confirms that less weight frost occurs when the soil compacts on higher humidity content (Beskow 1947, Springenschmid 1965). Figure 25. The transitions used when embankment material differs from natural subgrades in the cut side. Furthermore, commencement of the slightly wet moisture optimal AASHTO T99 makes the subgrade less vulnerable to nonuniform moisture changes (changes due to saturation and drying) on the edge of the pavement and joints. Experience shows that, over time, subgrade moisture will naturally increase slightly above the optimal humidity for soil exposed to frost-exposed in climate where frost action is a problem. Resistance to weight variables is enhanced when subgrades are initially compact on the moisture content above the optimum, rather than when in dry compact and then saturated by natural power. Drainage Where raising pavement grades is not practical, underdrain can be used to lower groundwater tables. Drains must be placed so that the groundwater level is lowered beyond the capture range of subgrade soil because the capilary water cannot be drained effectively. Where wet spots are found in grades, as looking through the exemplary stratum below by bad material, bypassing the drain can be considered. Backfill placed around and on top of pipes underdrains should be open graded to allow quick flows into slotted pipes. Underdrain drains should be packed with geotechstile fabrics to prevent infirtation and clogged by adjacent soil. Protection for Utilities Located in Subgrade Puts utilities such as culverts, drains or ducts under concrete pavements with frost-susceptible subgrade can be problematic and should be avoided if possible. However, if it is necessary to put the utility into the pavement structure then special consideration should be taken to protect the utility and the pavement structure on it. Figure 26 shows several examples of frozen sneaking protection methods for culverts on various depths with respect to frozen lines (boundaries of freezing zones). If culvert above freezing zones (cases a and b in Figure 26), measures should be taken to isolate the culvert from potential expansion around frost-exposed frost-exposed frost-exposed Materials. As the depth of the culvert increases with respect to the freezing zone, less protection is required. If the culvert is placed entirely in an unfrozen zone, no isolation is required because all land expansion exposed to frozen will occur on the culvert, in the freezing and frozen zones. Figure 26. Freezing sequence in typical pavement profiles and for example frozen protection methods for culverts on various depths. Non-Frost-Susceptible closing layers of clean gravel and sand will reduce the weight of the frost, but they are not required for this purpose if the weight of the frost can be reduced by proper grading operations. When an unstable layer of granular subbase is used to prevent pumping, it also provides some protection against frost action. However, the coverage is minimal because rough soil allows deeper frost penetration than doing fine ground due to the difference in heat properties due to the moisture content in higher places of fine soil. Examples of the effects of subbase thickness on frozen pavements for roads in Minnesota are shown in Figure 27 (Nowlen 1959). Although the amount is not good, the data shows that it is not eliminated on subbase thicknesses up to 18 in. (460 mm). The subbase layer is more effective in preventing the loss of subgrade support on the melt, which is not a major design consideration for concrete pavement. Proper grade design, selective grading and erasure control will result in uniform support and resistance to fast humidity flows to the top of the subgrade. This is an effective method to prevent excessive differentiation or weight. If the subbase layer is used, it is not necessary to be thicker than the nominal thickness needed to prevent pumping because it is not an effective way to prevent frozen heroes and should not be considered as such. Figure 27. The effects of subbasethickness (granular) are not stabilized on the frozen lid. Wet soil wet soil may be encountered during construction for reasons ranging from naturally high water tables to seasonal rainfall, as well as changes in drainage conditions due to construction. Regardless of the cause, wet soil in-situ must be addressed before building a subbase or concrete pavement on the subgrade. The easiest way to reduce problems caused by wet soils is to build a ditch before construction or let the subgrade dry before building a subbase or concrete pathway on a subgrade. However, construction scheduling and costs can make this solution ineffective [Burak 2007]. Other usable procedures fall into three categories: Improvement – Methods eliminate excess moisture in wet soil by providing drainage through drains or toe drains at the lowest point; compress subgrade using heavy equipment, which forces moisture excessively from sub-grade due to high applied pressure; or adjust moisture content through chemical modifications (soil (soil) (See the section entitled Chemical Modification at the beginning of this chapter for more discussions on chemical modifications.) Strengthening / separation - Methods of eliminating excess moisture in wet soils using geosynthesis. Geosynthesis is thin, reliable sheets of textile material vary in reliability. Geosynthesis ranges include geotechnical, geogrid, geonet, geocells, and geommembrane. The use and effectiveness of geosynthesis directly depends on the type of geosynthesis, the intended function (filtration, separation and/or reinforcement), the soil conditions of the in-situ, and installation techniques. Replacement - Methods of eliminating excess moisture in wet soils emit inappropriate soils, unstable or excessively wet and replacing them with selected loan materials or, alternatively, covering wet soil with suitable materials to develop the necessary incompatiency and stability. (See section entitled Selective Gradingand Selective Gradingand Selective Gradingand and Mixingearlier in this chapter for more discussion on cross grading and selective grading.) More detailed information on special considerations of wet soil can be found elsewhere [MNDOT 2003]. SPECIAL CONSIDERATION OF SUBGRADE DURING RECONSTRUCTION DUE TO REPLACEMENT OF INTERSECTIONS, UTILITY CUTS OR reasonable uniform Subgrade INLAIS, without a sharp change of support, is suitable for any concrete pavement. Achieving this situation after the pavement disposal operation will require some effort especially in the relatively confined working areas of the intersection. The first step is to ensure that subgrade soil is uniform material and density. Adequately dense subgrade surfaces require compact enough weight to reach 95 percent of AASHTO T99 density, similar to other pavement construction. However, it may be difficult to climb a large compactor in a trench created by removing older pavements for parts between. More effective strategies in confined areas are likely to use more compression efforts using smaller equipment. Because final tearing interferes with the surface of the subgrade a little, rolling computing tional addi is usually required after the installation. The content of soil moisture should be uniformly uniform during deletion; Excessive wet or dry patches require correction to produce reasonable segregation. For many soils, erasure should be done on moisture content on or slightly above the optimum, as discussed earlier. Soft spots in subgrade often become visible after removing the old pavement. It is unacceptable simply placing granular layers in these soft areas; excavation is necessary to remove the soil of the suspect. Ideally, replacement soil should be kind of just like in the surrounding subgrade to develop uniform support. Contractors should pay special attention to too many parts of the subgrade installation of utilities such as sewers, telephones and power conduits and water lines. Negligent negligent contents compression this drain often causes soft spots in sub-grade. Low strength-controlled filling ingredients (flowable-fill) are economical alternatives for these areas. Flower-filled ingredients do not require computing and flowing easily to fill the trenches. The mixture contains portland cement, sand, flying ash and water and usually develops a comma newspaper strength of 28 days about 50 to 100 psi (0.35 to 0.70 MPa). Flower-filled ingredients provide enough strength to prevent solutions, but it is easy to remove using buckets on the rear hoe or front-end loader if future excavations are required. Subbases A subbase provides benefits to design and construction. From a design perspective, the important function of the subbase is to avoid pumping fine ground. From a construction perspective, the subbase function is to provide a stable working platform for construction equipment, which allows contractors to provide smoother pavements and achieve a more consistent pavement thickness than is possible if building only subgrade. The secondary benefit of the subbase is that they help in controlling volume changes for vast or vulnerable subgrade soils to frost, and they can reduce excessive differential frost weight. However, these factors can most likely become more economical and better controlled through proper subgrade preparation treatments. Subbas can also be used as a layer of drainage; However, when doing this, the right balance of drainage and stability must be obtained. Pump Pump is defined as a strong displacing of the soil and water mixture through the slab joints, cracks and edges of the pavement. Continue, the uncontrolled pump ultimately replaces enough so that the equality of support is lost, leaving the slab angle and ending uns supported. These uniform support conditions often result in premature fractures in the corners of the slab and the roacity of the pavement, generally in the form of the wrong reverse joint. In the worst case, loads of concrete slabs are enough to pump water and fine ground particles through the joints and onto the surface of the pavement, where the visible dirt becomes apparent. Figures of 28 and 29 show the pump joints in action and the next deposit of subbase/subgrade material to the shoulder. A cooperative study by the state highway departments and the Portland Cement Association in the 1930s and 1940s first determined the basic factors needed for pumping occurred. Further experience determines that all the following ing conditions must be present: Fast moving, heavy load to remove slabs (trucks, not cars). Untidy joints or joints with poor load transplants. The presence of water between the pavement and the subgraduate or subbase. Fine subgrade or erodable subbase material. Figure 30 depicts a pumping mechanic. First, wheel load force the slab leaves down as it approaches the joints or cracks. When a wheel load crosses the joint or cracks, the holiday slab rebounds quickly Slabs of the approach are forced quickly, causing rapid distinguishing adhesives in the joints or cracks. These rapid lashing adhesives push water and soil from under the slab of an approach towards the slab of the holidays and can evict a mixture of soil and water out from under the slab. Finally, after thousands of heavy load applications, voums can develop under the slab, causing uneveilable, non-uniform support. The most common hardships due to this action are breaks of damaged angles and joints (Fig.s 31 and 32). The subgrade materials that are most susceptible to ing pumps are high plastic slicks and clay. Unstable subbase material (granular) is prone to bombing is generally considered to be those with 15% or more fines surpassing filtration No. 200 (75 µm). Pumping can be reduced by using subbases that cannot be eroded or stable. Unstable subbases (granular) meet the requirements of AASHTO M155 will effectively prevent bombing in pavements that carry even the highest traffic volume, assuming that other design features are chosen accordingly. Figure 30. The mechanics are pumping. Regardless of the selection of subbases, experience has shown that the most influential design factor to prevent pumping using dowelled lubricant pavement joints. However, any measures that can be taken to eliminate any one or more of the causative factors required to pump are advised. Using the correct (unstable or stable) subbase eliminates fines in the soil that will enter the suspension, while using the intestines eliminates rapid differential adhesives caused by frequent heavy wheel loads; This combination of mitigation strategies is most often used because it isolates both the simplest and most reliable wretched wrea factors to deal with by options in the design of pavement. Figure 31. Angle breaks from invalid under the corner of a concrete slab. Figure 32. The joints are blamed. WHEN TO USE SUBBASE Engineering subbases it is appropriate when a stable and uniform construction platform will benefit construction and/or when the combination of subgrade soil type, water availability, and high speed, heavy vehicle traffic is at a conducive level to cause pumps and any related distress. Therefore, the subbase is a necessary element to the concrete pavement designed for the main pavement that many travel, especially those that carry a large number of trucks. Pavements for slow-moving trucks or light traffic pavements, such as residential roads, secondary roads, parking lots, and high-speed roads automatically only, are not exposed to pump development. Subbase is not guaranteed to pump protection in such applications as these facilities are not subject to pavement stickers and rebound high speed, heavy wheel load causes. In particular, there are some exceptions to advice using subbase to avoid pumps as previously presented in this chapter: Traffic* - Pavements that are expected to carry 200 trucks† a day or less generally do not requires a subbase to avoid pumping. Also, the pavement designed to carry less than 1,000,000 18-kip (80 kN) ESAL over the life of their service does not require subbase to avoid pump damage. Natural drainage - Subgrade soil that naturally drains free usually won't pump because of water percolates through subgrades and does not remain under the route where it can transport refined ingredients in suspension. Pavements can be built directly on natural subgrade soils with this character as long as the soil is satisfactory in other critical matters (for example, frost action and expansion). Qualified Subgrade Soil - Subgrade soil with less than 45% passing No. 200 (75 µm) spices and with PI 6 or less is sufficient for a moderate amount of heavy truck traffic without using the subbase layer. In this case, it is advisable to use dowelled joints - even in slabs less than 8 in. (200 mm) — to avoid differential adhesives in the slab joints. Keep in mind that these exclusions, which allow concrete pavements to be placed directly on the subgrade, rely heavily on the estimated number of heavy truck traffic over the life of the pavement. In no case, increase the thickness of the concrete pavement slab an acceptable step to avoid pumping. Without proper preventive measures, the pump occurs at even the thickest of pamper paddles if the correct combination of factors exists. A non-erodable subbase and dowel transfer load on the joint crossing is necessary when the number of heavy trucks is expected. To further define when the subbase is warranted, Table 7 provides service data and pumping factors from the AASHO Road Test for sections that do not have a subbase compared to 6 in. (150 mm) of the subbase. In this data, loops of 2 and 3 are typical of many city roads, district roads, and light traffic highways. As can be seen, under the conditions of this low volume, the subbase-free pavement provides the same performance as the pavement with subbase. Table 7 also shows that a subbase of 6 in. (150 mm) provides adequate protection against pumping for very heavy loads. * These guidelines have been developed from AASHO Road Testing and cooperative surveys with state agencies covering more than 2,000 miles of concrete pavements in ten states representing various climate, soil, traffic conditions. Despite being developed many years ago, these guidelines remain applicable today. Included in the study are pavements with and without joint load transfer devices and projects carrying as many as 700 axes per day more than 18,000 lb (80 kN) and projects with a semi-trailer tractor count of 1,000 to 2,000 per day. † use bilateral traffic, excluding panel trucks and pickups, and another four-tyre single unit. Table 7. Performance Factors and Pumps for No subbase and 6 in. (150 mm) Subbase Section, Concrete Design Level 3 - All Loops of Traffic Loops. Axletype Axle load[kips (kN)] Thick slab. [in. (mm)] (mm)] Thick. [in. (mm)] P at the end of the Repetitions test at P=1.5 (in 1,000s) Factors of the heavy pump 1 22 Singles 2 (9) 5.0 (130) 0 (0) 6 (150) 4.1 4.1 — 0 0 2 Singles 6 (27) 5.0 (130) 0 (0) 6 (150) 4.1 4.0 — 0 0 33 Single 12 (53) 6.5 (165) 0 (0) 6 (150) 4.2 4.1 — 0 0 4 Single 18 (80) 8.0 (200) (0) 6 (1 50) 4.5 4.4 — 0 0 5 Single 22.4 (100) 9.5 (240) 0 (0) 6 (150) 3.9 3.7 — 25 15 6 Single 30 (130) 11.0 (280) 0 (0) 6 (150) 4.2 4.2 — 0 0 33 Tandem 24 (110) 6.5 (165) 0 (0) 6 (150) 4.0 4.1 — 0 0 4 Tandem 32 (140) 8.0 (200) 0 (0) 6 (150) 2.4 4.2 — 100 12 5 Tandem 40 (180) 9.5 (240) 0 (0) 6 (150) — 40 658 — 907 148 6 Tandem 48 (210) 11.0 (280) 0 (0) 6 (150) — 43 907 — 925 0 1 Pump data obtained from AASHO System Road Test Data 4243, Hardcore Pavement Pump Survey 2 Loop 2 data for Design 1 section 3 Loop 3 – 6 data for Design 3 parts Also of interest in the decision to use the subbase is an influence that may have on the construction of surface pavement. Subbases provide a stable, smooth track line or pad-line for paving machines and stable support for the construction of fixed forms. The track or pad line for a slipform paving machine is about 3 mal (1 m) for either the width edge of the pavement. This is the route where the slipform paving machine track will ride while placing the pavement (Fig. 33). Many agencies recognize constructive value on a stable, uniform track, so they need an extension of the subbase beyond the edge of the pavement in their concrete pavement design template. Expanding the layers of subgrades and subbase provided beyond the edges of the pavement slab also contributes to edge support, which reduces edge pressure and prevents shoulder-and-gutter solutions of parts. Figure 33. Trackline for slipform paving machines. SUBBASE TYPES Several types of subbas have been successfully used under concrete pavements. These include: Unstable subbase (granular) . Stable subbases, including: stable subbases of cement (cement-treated subbases or lean concrete subbases, both of which may include flying ash) and subbases treated with asphalt. With any subbase, it is possible to use recycled concrete (either from existing concrete pavements or other sources) or various waste as aggregate. Regardless of the consideration of certain subbases, the best results are obtained by: Choosing subbase material and adequate combination of layers prevents the absorption of sub-grade soil for the life of the pavement. Choosing a subbase material that will not contribute to excessive pavements under the traffic load, and will remain stable over time. Treat the surface of the subbase to ensure that it does not cause excessive friction or induces bonds to the slab of pavement. Determine the grading or control of materials that will ensure consistent quality of subbase materials across individual projects. Build for control grades that foster nurture consistent thickness and smoothness. The Non-Stabilized Subbase (Granular), also known as the granular subbase, is the most common type of subbase for applications such as roads, roads and highways. Various types of soil and aggregate make excellent constituents for an instable sub base. The types of materials that have been used successfully include crushed stones, banks carrying out sand gravel, sand, ground stable gravel, lower ash, crush or scar slabs, and local ingredients such as crushed wine waste and sand bell mixtures. Any number of combinations of all these ingredients that will provide the right subbase can alter openly be used. Crushed concrete re is also a source material of celloner containers for unbilable subbases. Unstable subbases have long been the most common type of subbase, but they fall out of favour with some highway agencies at a time when together climbing reinforced concrete (JRC) and undowelled (usual) concrete pavements (normal) are moss. These two pavement designs are subject to deterioration by pumping and blaming - on the cracks that occur by the design between the dowelled joints in the JRC's mensmen and in each joint lubricate on a normal undowelled path. The blame, cracked angles and roacity developed on a pavement designed in this era are mainly due to a lack of positive joints (or cracks in the case of JRC load transfer) and the unconscionable increase in truck traffic experienced on the road network, and not due to any general negative characteristics of the unsustable subbase. Since the 1980s, dowelling lubricants have become a moss for regular concrete pavements and the use of JRC pavement designs for road or highway means has fallen out of favour. Therefore, an inbilizable subbase is once again an optional way to reduce pumps for most highway agencies. When designed and properly constructed, unstable subbases make an excellent layer of support for concrete pavements for all kinds of roads and highways. Their main advantage is the relatively low cost when compared to stable subbases. Material Requirements As minimal, unstable subbase material must meet the requirements of AASHTO M147 (alternatively, AASHTO M155 may be used if pumping is an important concern). The following factors usually define materials that make the subbase unstable: The maximum particle size is no more than a third of the subbase thickness. Less than 15% passed filter No. 200 (75 µm). Plastic Index 6 or less. Liquid limits 25 or less. Abrasion resistance to Los Angeles (AASHTO T96 or ASTM C131) by 50% or less. Target reliability of about 150 feet /day (45 m/day), but more than 350 feet / day (107 m/day), in laboratory tests. The main † to creating a well-stabilized subbase is to limit the amount of fines passing the siege of No. 200 (75 µm). If there is too much unstable subbase can hold water more easily and will be exposed to erosion, pumping and boring action. If the climate and local soil determine that it is necessary to prevent damage by frost action, it is better to use the material on or near the minimum fine content defined by the specifications of the material. Soft aggregate material is also unsatisfactory for subbases that cannot be billed because additional fines can be established under abrasion or crushing action of heating equipment and construction traffic. This fine will reduce the eergity in layers and can contribute to frost action and other problems. Grinding Controls Although various substances (and editing) have performed well as unstable subabs under concrete pavements, it is important that each project for subbases has continuous editing that allows packaging equipment to produce uniform and stable support that is essential for excellent pavement performance. Like sub-grade, any sharp change in subbase character can lead to reduced performance of concrete pavements. As a guide, Table 8, taken from AASHTO M147, shows the grading of typical unstable subbase materials (ASTM D1241 is the same). AASHTO M147 divides various subbase materials that are not stabilized into six separate gradings that all allow different types in percentages past various sieges. As a result, all grading includes an unstable granular subbase that can either be open-grated and slightly-medium-to-exemplary, or compact-graded and somewhat undeniable. All gradations included in the AASHTO M147 will perform satisfactorily if properly credited to allow minimal density marketing to increase in density will occur after the pavement in service. On the other hand, subbases that cannot be billed with sudden or uncontrolled variations between open and compact grading — even in bands specifications - can cause pavement performance to vary because of the uniform character resulting along the project grade. Table 8. Grading Requirements for Soil Aggregate Materials (ASTM M147) Grading Size Percent pass Grading B Grading C Grading E Grading F 2. 50 mm 100 100 — — — 1 in. 25 mm — 75 – 95 100 100 100 100 3/8 in. 9.5 mm 30 – 65 40 – 75 50 – 85 60 – 100 — — No. 4 4.75 mm 25 – 55 30 – 60 35 – 65 50 – 85 55 – 100 70 – 100 No. 10 2.00 mm 15 – 40 20 – 45 25 – 50 40 – 70 40 – 100 55 – 100 No. 40 425 µm 8 – 20 15 – 30 15 – 30 25 – 45 20 – 50 – 30 15 – 30 25 – 30 25 – 45 20 – 50 – 30 15 – 30 25 – 30 25 – 45 20 – 50 – 503 – 503 – 503 – 30 15 – 30 25 – 45 20 – 503 – 503 – 30 15 – 30 25 – 45 20 – 5033 – 50 30 – 30 25 – 45 20 – 50 – 50 – 30 30 – 30 25 – 45 20 – 50 – 50 30 – 30 25 – 45 – 570 No. 200* 75 µm 2 – 8 5 – 20 5 – 15 5 – 20 6 – 8 – 25 * Limit passing material No. 200 (75µm) down to 15% maximum for all Grading (A– F) for uninspired subbaes (granular). † It is important to understand that it is possible for subbase material that cannot be billed to pump if it is a less merged substance that erodes easily and/or it contains an overrun of fine material. Unstable subbase material pumps can also occur on the structure of the structure pavement is caused by excessive adhesives caused by frequent loads on inadequate thickness slabs. This was observed at the AASHO Road Test (HRB 1962) and recommendations in this publication are predicted on adequate structural design. A cautious examination of the percentage allowed to pass each filtering for grading A via F in Table 8 reveals that only Grading A and C limits the maximum percentage beyond no. 200 (75 µm) decreased to less than 15%. It is important to remember that the grading of the AASHTO M147 is developed for the construction of general pavements including both concrete and asphalt routes. Therefore, the use of AASHTO M147 to be used with concrete pavement may require more thorough development of a combination of granular materials to limit the passing percentage of no. 200 (75 µm) bending up lower requirements (again, the maximum recommended percentage pass no. 200 (75 µm) filter is 15%). Discussion on Unstabilized Subbase Drainage (Granular) It is important to draw the difference between open-haired subbases and independent draining. In this publication, the term independent draining prescribes materials similar to those indicated as grading A in Table 8, where the percentage of fines passing the siege of No. 200 (75 µm) is well below 15%, but the fine is not eliminated at all. The recommended reliability of targets for independent draining subbases is around 150 feet/day (45 m/day) in laboratory tests, all of which are required for effective draining subbases. Although the ingredients as rough and open-graded as ASTM No. 57 stones have been used as drainage layers, they are not recommended to ment concrete pavement due to the lack of sufficient stability for their constructive tion operation and insanity for long-term solutions under heavy truck traffic. It is better to design granular subbase grading that is not stabilized to include more fines for the sake of stability than to ignore fines for the sake of drainage. The term 'independent draining' used to be synonymous with older terms - open-wired - continues in literature and specifications. However, readers caution that, in practice, unstable subbases set as 'open-graded' are also often associated with 'transparent' or 'drainable' subbases, a very angled subbase that became an element of popular design through the 1990s. Enableable subbase — subbases that are not stabilized by the amount of fines reduced to levels that increase subbase reliability to 500 to 20,000 feet/day (152 to 6,6, 6,000 square feet (152 to 6,6,000 100 m/day) in laboratory tests - no longer recommended for concrete pavements because these subbases are unstable over time and violate requirements funds to maintain a uniform, stable basis for pavement life. See the section entitled Per meableSubbases: Reasons to Avoid their Uselater in this publication or the section entitled Drainageearlier Pavement System in this publication for more discussion on exemplary subbases. Example. Control Project Specifications should clearly identify the choice of crediting for any particular project, or allow contractors to choose an indisbilable subbase resource that complies with any grading in the AASHTO M147 that also meets specific criteria (such as the passing percentage of No. 200 (75 µm) An effective way to ensure grading control is to allow for a wide latitude in the selection of subbase that cannot be billed from the grading limit. Prior to construction, contractors are required to submit appropriate target grades in the designated grade group. For quality control, added and minus tolerance should be created from the target grinder submitted. Common occupational control tolerance from target editing is: ±10% for materials 1 in. (25 mm) and larger. ±8% for materials between 1 in. and No. 4 (25 mm and 4.75 mm). ±5% for material No. 4 (4.75 mm) and smaller. Consolidation of granular material is subject to a number of consolidation from heavy traffic action once the pavement is placed into service. The comprehensive maturation of unstable subbases will minimize post-construction consolidation, keeping them within an acceptable range (less than about 10 percent). Figure 34 shows local failures from insufficient commencement.

Figure 34. Examples of concrete pavement failure due to insufficient subbase maturation. The results of the research document the need for high levels of heating for subbs that are not based on heavy duty pavements, as shown in Figure 35 (Colley and Nowlen 1958). Research shows that as many as 50,000 repetition loads can produce excessive consolidation where density is very low (less than 85 percent). According to the research, density approaching 95 percent of AASHTO T99 density will prevent the consolidation of densely granular subbase (non-integrity). Note that standard laboratory tests do not provide adequate density control for some subbase materials without unity or almost unity. In such cases, the equivalent of a com axis should be created by testing for the density of land without unity (ASTM D4253 and D4254). Thickness and shyness Since the primary purpose of the subbase is to prevent ing pumps, no need or save to use thick subbases in an attempt to improve support or increase grades with respect to the water table. Experimental projects have shown that 3 in. (75 mm) of unstable sub-bases thick will prevent pumping under very heavy traffic. Similarly, excavations of crevice trenches made on the edge of the pavement reveal that the thickness of the unstable subbase of only 2 in. (50 mm) can prevent the exferment, even on projects that have brought heavy traffic for 10 years or Therefore, the maximum recommended subbase thickness is 4 in. (100 mm) for normal construction projects. This proposal is a practical way to get the necessary thickness of 2 to 3 in. (50 to 75 mm) as necessary Pumping. Another worrying point in considering the necessary subbase thickness is the potential for consolidation under traffic. Given the thickness of the unstable subbase increase, the same consolidation rate from recurring loads will result in a greater amount of consolidation (i.e., a 10 percent post-construction consolidation of 6 in. (150 mm) of unstable subbase is 50% higher than the unstable subbase 4 in. (100 mm) subbase. Figure 36 shows the results of recurring load tests on unstable subbases of 4, 6 and 12 in. (100, 150 and 300 mm) thick, placed on clay subgrade and compact to 100 per cent AASHTO T99 density. After 450,000 repetition loads, there are more than twice as much consolidation at 12 in. (300 mm) of unstable subbases as per the basis of 4 or 6 in. (100 or 150 mm). The amount of at least a solid combination of subgrade-subbase occurs at 4 in. (100 mm) of unstable subbases. Full-scale static load tests of slabs on various types and thicknesses of unstable subbase also reveal that tension and prostitution were not significantly affected by the unsustainable thickness of the subbase (Children, Colley, Kapernick 1957). For loads placed on the edges of the traveling joints, this test shows only a slight reduction in strain and adhesive when the unbilable thickness of the subbase is more than 4 to 6 in. (100 to 150 mm). Recurring load tests also show that a slight reduction in strains and possible perversion from the use of 9 to 15 in. (225 to 450 mm) of thick subbase that is not stabilized will be offset by excessive consolidation of this thick layer (Colley 1958). For these reasons, the following two guidelines should be followed with respect to subbases not stabilized for concrete pavements: At least 95 percent of the AASHTO T99 density should be developed for subbase material that is not stabilized. On projects that will bring large amounts of heavy traffic, the minimum density set by 98 per cent of the AASHTO T180 is warranted. The thickness of the unstable subbase should not exceed about 4 in. (100 mm). The cost of additional materials and construction to provide a non-stabilized subset is more thicker. When the thickness of the billable subbase increased by more than 4 in. (100 mm), there was an increased risk of poor pavement performance due to post-struction consolidation due to heavy traffic. Unstable Subbase 37 Construction Diagram (Granular) 37. Construction Processing for Unstable Suburbs. Figure 37 shows the basic steps in building an unstable subbase (granular). The construction of non-principal subbases can be achieved in many ways. Key to consolidation right, however, is to ensure homogeneous stirring of subbase materials that are not stabilized and have all materials that are uniformly damp before and during rape. Ingredients can be mixed whether mixer or pugmill mixer, both of which must have the right control mechanism for the proportion of water and aggregate. An alternative method is to place and mix aggregate on the road using a motor grader or other similar equipment and add water during mixing operations. Once mixed, it is acceptable for subbase material that cannot be billed to be placed in the following way: Placed from the truck, spread with blades on motor graders, and then cut into grades and cross-slopes with auto-trimmer. Placed and cut with hopper-converted auto-clinchers. Placed for height with a paved machine. After placing unstable subbase material, the contractor must form a layer to the desired part of the cross, conditions with water to develop the optimal and dense moisture content of the subbase to the prescribed density. Free-draining subbase materials can also be placed with a jersey spreader, nude or motor grader. Regardless of equipment, it is important to disseminate and form a thickness material specified in the usual section so that adequate density can be caused by minimal compaction efforts. One to three roller passes 4 to 10 tons (4 to 10.2 metric tons) of steel wheel roller in static mode will usually be enough. Over-rolling can cause deterioration of the material, with the resulting loss of reliability. Heating operations appear to contribute the most to the aggregate isolation of the unstable subbase, leading to spatial variations. The rotation adds to the problem of isolation in some way: they shake the aggregate, causing fine particles to migrate to the bottom of the layer, and they remove the top, rather aggregate and leave behind a finer aggregate. Aggregate placement and dispersal operations may also be contributors to fine isolation and therefore, the consistency of contractor operations is key to producing layers with consistent properties (White 2004). The surface of the last unstable subbase should be smooth and uniform, free of ruts, humps, or other abrupt height changes and graded to the desired cross slope. Tolerance finished subbase that ±1/2 in. (± 12 mm) grade design profile. It is common practice to initially put unstable subbases thicker than designed and then end the surface grade with an automatic trillor or motor grader. The materials released during the finishing process are suitable for rescue and reuse. Opening the contractor's precautionary measures should wet unstable subbases before opening. Dry, non-stabilizable subbase can contribute to an early age, an uncontrollable crack in the concrete pavement. Dry subbase draws moisture from concrete, can dry the bottom of the slab before the middle or top. This condition prompts the shrinkage of the differentiation (warping) similar to the drying surface from high winds except at the bottom of the slab and not the upper part of the slab. Any potential subbase to absorb water from should be moisturized before opening. Moisturizing efforts are very important with the subbase materials of slab concrete and recycling due to the high absorption capacity of this aggregate. Stable subbase of Stable Subbases usually refers to subbase material bound either by cement or asphalt binding. Stable subbase falls into three common categories: treated cement, lean concrete, and treated asphalt. The main benefit of a stable subbase is that they provide relatively strong, uniform and resistant support to ebirion (pumping). Table 9 lists the potential erosion of various subbase substances under an undowelled joint. Compared to unstable subbases, stable subbases provide higher levels of support to pavement slabs (i.e., higher k-value). Although this does not alter the thickness of the pause required for a given load significantly (see the section entitled FoundationStrength of Concrete Pavement Thicknessearlier's influence in this publication), it strengthens the overall pavement structure. The plate-bearing test on a stable subbase produces very high k-value and this high k-value reduces pressure, tension and adhesives from the load of the vehicle in exorspective concrete slabs. As an ex ample, Figure 38 shows tension measured in concrete slabs under a load of 9,000-lb (40-kN) on clay subgrades, unstable subbases and cement-treated subbases, and k-values calculated from this data. The calculated K-value is in close agreement with those determined by the test bearing the plate made directly on subgrades and subbases. It should be borne in mind that while increasing fundamental stirring through increased strength is ficial bene from a applied load point of view, it could potentially negatively affect the stress and tension caused by the environment. (See section, InfluenceFoundationStiffness on Strain Stressesand in concrete Papak Turapan, for more information on this concept.) Table 9. Erosion Potential Subbase Materials (after Ray and Christory 1989) Erosion Potential Substances Type Highly Resistant To Lean Concrete with 7-8% cement. Subbase treated with asphalt 6% or greater. The cement-treated subbase is resistant to 5% cement. Hold under certain conditions of the cement-treated subbase with 3-5% cement. The subbase treated with asphalt about 3%. The rather eroded cement-treated subbase with less than 3% of cement. Unstable subbase of granulars. Untreated granular ingredients are highly eroded. Subbase is not stabilized. Another benefit of the structure of the stable subbase is that they increase the transplantation of loads in pavement joints, especially for pavements with undowelled joints and regular concrete slabs (Colley and Nowlen 1967; Henrichs, et al. 1989; Ionnides and Korovesis 1990). Research results regular concrete papaks discarded on ordinary subgrades, unstabilized subbases and simen-treated subbases are shown in Rajah 39. When the load application is gathered on the slabs supported by regular subgrades or unstable subbases, load transfers (co-efficacy) gradually de creases. However, at a cement-treated subbase, losses occur at a slower pace and stabilize around one and a half million load applications; even after 1 million loads, co-efficacy remained at almost 80 percent (Figure 39). These results indicate that cement-treated subbases will contribute more to maintain effective load transfer over a longer period of time than would a normal subgrade or unstable subbase, when all other factors are the same.* The same results will be expected for lean concrete subbases and subbases treated with asphalt, although donation levels may differ from those indicated for the lean concrete subbase and subbase treated with asphalt, although contribution levels may differ from those indicated for the lean concrete subbase and subbase treated with asphalt, although contribution levels may differ from those indicated for the lean concrete subbase and subbase treated with asphalt, although contribution levels may differ from those indicated for the lean concrete subbase and subbase treated with asphalt, although contribution levels may differ from those indicated for the lean concrete subbase and subbase treated with asphalt, although contribution levels may differ from those indicated for the lean concrete subbase and subbase treated with asphalt, al , modulus of emptiness and resistance to erosion. Figure 38. Measured calculated strains and k-values, a 9-kip (4,100 kg) plate load. Figure 39. Joint efficacy for ordinary subgrades, unstable subbases, and cement-treated subbases (based on 9 in. concrete slabs (250 mm). The stable subbase provides an excellent construction platform for building concrete paths. The subbase-bound surface drains water quickly, providing an all-weather work platform that accelerates construction operations after rain. Stable subbase also helps in increasing the smoothness of the final pavement as they provide strong and stable support for concrete forms or slipform pavement tracks. Other benefits of a stable subbase include: minimizing the consolidation of post construction subbases under traffic; minimize hard disturbances into the bottom of the pavement joint; provide more overflowing subbase materials; and allow the greater use of local materials, aggregate substandard, and recycled materials (recycled concrete from either existing concrete pavements or other sources, reclaimed asphani pavements, etc.), which can result in aggregate conservation and savings of materials and transportation costs (FHWA 2004, PCA 2003, Yrjanson 19). * Regardless of the benefits of better support and contribution to load transfer, stable subbase is not an alternative to dowelling joints. Any expected pavement has significant truck traffic requiring dowelled travelling joints. The thickness of the concrete pavement slab, as required by thickness design procedures such as streetPave ACPA or the Mechanical Empiric Pavement Design Guide (MEPDG), is the most rational factor for determining whether dowels are guaranteed. Generally, slabs larger than 8 in. (200 mm) thicker require dowels because of expectations of loading trucks. The design of the mixture for a stable layer of material is driven by the desired nature or properties. Sometimes, subbase required solely to provide a coaching platform, and does not aim to provide additional long-term strength. When this happens, it applies, the minimum active percentage that will result in the required performance is determined and does not need to test the strength or endurance requirements (FAA 1999). Cement-leveled subbases stable with portland cement fall into two common categories: cement-treated subbases (CTB) and lean concrete subbases (LCB). Flying ash can also be inserted into either CTB (giving the subbase treated with cement-plus ash) or LCB (giving subbase without concrete-plus-ash), and slabs can be used in CTB. Cement-treated ingredients are distinguished from lean concrete (also referred to as econocrete) because they have a drier consistency, contain less cement, and are best controlled using compaction requirements and/or density rather than strength requirements. Each ingredient also requires different placement techniques. CTB placement is equal to other subbase materials that are not stabilized. Contractors can choose to mix cement with granular material using pugmill or standard central mixing factory and then unemployed it to a paved site. To achieve sufficient final results, CTB material, due to their dry consistency, requires a compac tion by roller for density. LCB materials, how ever, are placed with slipform pavements or modified concrete spreaders basically similar to a conventional concrete mixture, do not require additional heating efforts. As a result of these fundamental differences, the requirements of specifi ca tion ca for each material are also different. For lean concrete, typical specifications require a 7-day com press strength from 750 to 1.20 psi (5.2 to 8.3 MPa) and air content from 4.0 to 12.0%. LCB air content can be used to avoid exceeding maximum strength, as well as for frozen-liquid durability. 100 Because the CTB layer is best controlled using shy and/or density requirements, the joint requirements are heating levels between 96 and 100 percent of the maximum density. The maximum density (determined by AASHTO T134 or ASTM D558) is determined by a representative field sample taken from the damp mixture at the time the compression begins. Although there is usually no strength requirement on CTB materials, targeting compressive strength of 7 days from 300 to 800 percent percent passing Filtration Size (2.1 to 5.5 MPa) guarantees long-term durability (PCA 2006). Contractors may choose to build test strips to show that their construction methodology meets the required density specifications and that the resulting compressive strength falls within the desired target strength range. The Requirements OF SUBBASES TREATED Subbase CEMENT (CTB) usually require about 2 to 5% of cement with weights. Granular materials, as described in AASHTO M147 or Land Class Fixation Group A-1, A-2-4, A-2-5, and A-3 work well for CTB. Granular material usually does not more than about 35 percent passed the no. 200 (75 µm) of filtration, the Plastic Index 10 or less, and perhaps either or produced. The maximum particle size of 3/4 to 1 in. (19 to 25 mm) is better to allow accurate subbase gridding. In many instances, dirty granular materials or recycled concrete aggregates may not be acceptable for non-refundable subbase specifications due to excessive fines or plastics, but such materials are acceptable for use as subbase if it is treated with cement (PCA 2003). These cheap ingredients often require less cement than cleaner and more expensive aggregates. Falling grit in a wide group shown in Figure 40 usually requires minimal cement content. Also, the use of materials in the group will result in lower cost savings due to lower cost of materials and cement. Figure 40. Crediting of minimum cement requirements treated (from PCA IS029). To determine the optimal cement content for CTB requires a standard laboratory of wet-dry and frozen testing and PCA weight loss criteria or laboratory-bound commo newspaper strength results (PCA EB052). Regardless of the issuance of cement content, CTB acceptance tests should be based on fields measured percentage of maximum density. When determined, the compressive strength of 7 days 300 to 800 psi (2.1 to 5.5 MPa) (PCA 2006) is the usual target strength range for the CTB layer. At this strength, the long-term durability of the CTB is subject to wet recycling and drying or freezing and dilution is almost assured (i.e., Figure 41 shows that about 97 percent of test specimens are passed ASTM D559 and frozen tests D560 and wet with strength of 750 psi (5.2 MPa)). Figure 41. The relationship between strength and durability for CTB. (PCA EB052). Construction Figures 42 shows fundamental measures in building cement-treated subbase. Contractors can choose to use either a road mix or central mix to build CTB. In road mixing, material is processed in subgrade. The correct quantity of cement is transmitted to the ground/aggregate with the cement spreader and mixed either with a multi-pass mixer or a one-pass mixer. Multiple pass mixers require one pass to dry mix cement and soil/aggregate and a second pass to damp mixing ingredients. A single-pass mixer completes the operation simultaneously, in one pass. In central mixing operations, cement and soil/aggregate for CTB are mixed in pugmill or central factory mixers. After mixing, a damp mixture is brought into a garbage pile truck, where the tractor throws it into grade and then spreads it with a mechanical conveyor. Subgrade should be damp when cement of the treated substance is placed and the operator should remove and spread the mixture in a way that will minimize isolation. Shortly after granular material, cement and water are blended uniformly and spread to the thickness of the target and width, contractors solid material with a grinder, followed tightly by pruning, which will finish the material for grade. Any surface moisture that is lost through through during the finishing operation must be repentanced by a spray of light fog. Reasonable surface grading tolerance for cement-treated subbases after heating is ±0.5 in. (±12 mm), tudinally longi or traveling, as measured by a straightedge of 10 feet (3 m). The method for ending CTB to the right grade is the same as those who to terminate the unstable subbase material. However, due to the nature of CTB cement, time affects the finishing and slightly adjusting. To gain the full advantage of the benefits given by cement, about 4 hours of working time is available to place and end the CTB once the cement is in contact with the water. High winds and extreme heat can reduce the available working hours, so contractors are encouraged to be careful with working conditions. Figure 42. Construction process for cement-treated subbase. CTB requires application for repair once the finishing operation is completed. Water fluffy spray and bituminous repair applications help contain moisture so that cement can hydrate properly. The normal application rate for bituminous regregation agents is from 0.15 to 0.25 gal/yd2 (0.68 to 1.1 l/m2). In some cases, cut the CTB subbase before opening the character turbs of the subbase surface. After the rotation, the surface may be rough in a particular location, creating unwanted conditions that promote the bond between CTB and the route. One of the following methods will minimize bonding in a cut area: Reuse of asphalt healing agents and the spread of thin layers of sand before opening. Application of two coats of candlestick-based repair compounds before being paved. LEAN CONCRETE SUBBASES Lean Material Requirements concrete mixture contains more cement and water than cement-treated subbase substances, but it contains less cement than conventional concrete. Lean con crete has the same appearance and consistency as conventional concrete, and it also requires consolidation by vibrations such as conventional concrete. It is acceptable to relax some limited requirements for conventional concrete in specifications for lean concrete. Certain requirements associated with concrete performance characteristics as exposed pavement surfaces are not very critical for lean concrete subbases, such as minimal cement content or aggregate abrasion resistance. Loss of surface texture or aggregate polish, lack of abrasion resistance, popouts, surface scaling, or other unwanted qualities for pavement surfaces are acceptable for lean concrete as a lower course in the pavement structure. Lean concrete is signed for use as a subbase only and, in general, uses aggregates that do not necessarily meet quality standards* for non-levelal subbases or concrete tional convenes, therefore some has adopted the term econ ocrete when referring to non-stop concrete (ACPA 1975). Data from laboratory testing programs and lean concrete construction projects show that various aggregates will work well in the LCB mix (ACPA 1975). Some of these aggregates are substances that are not processed to the same level as normal concrete aggregates. Most have more fine ingredients that pass No. 100 (150 µm) and No. 200 (75 µm) filters than accepted for regular concrete, but this is not necessarily unpleasant for lean concrete because additional fine supplies require resurability. On some projects, existing concrete and asphalt pavements have been recycled and used as aggregate for lean concrete subbases. In fact, a slight decrease in flexible and compressive strength, as is usually observed when using aggregate recycling over virginity, is not a concern for lean concrete subbases. Special precautions may be warranted, however, for recycled aggregate grading because recycled fines have a higher absorption capacity than normal fine aggregates; if anxiety, fines from recycling aggregates can be issued during the crushing and sorting process and replaced with delicate aggregate virgins (Cho and Yeo 2004). * To reduce pavement costs and preserve high-quality aggregates, the U.S. Federal Highway Administration issued a Notice of N5080.34, which says: Lower aggregate, local use available is encouraged to econ ocrete (lean concrete). The use of recycled pavement materials that serve as aggregate is recommended. Limits for lowering aggregate quality should be determined by the state, based on local experience, or through econocrete design tests (lean concrete). (FHWA 1975) Common procedures and tests for the concrete mixture apply to lean concrete, with the following exceptions: A single aggregate can be used rather than the aggregate combination of coarse and fine aggregate, stock separately. The content of cement may be much lower than that for conventional concrete, and must be controlled to maintain lean concrete compression strength between 750 and 1,200 psi (5.2 and 8.3 MPa), as detailed later. The combination of the material must produce workable lean concrete, capable of adequate consolidation by vibration and solid enough to resist excessive deterioration when placed with slipform pavement. Reliability can be enhanced by the existence of additional fines in aggregate; higher than the normal amount of air triggered; the addition of flying ash, adventures reduce water or functional agents; or any combination of these additions. Past proposals limit the maximum strength of LCB to 1,500 psi (10.3 MPa) while the current proposal limits strength to 1,200 psi (8.3 MPa) (ACPA 1975). The aim of limiting strength is to avoid problems related to high curves and pressure drops in the pavement slab. Di Stiffness or strength of the LCB subbase into excessive, interlayer fabric can be used to alleviate problems associated with additional stiffness. The strength of the Properties Laboratory investigation and field installation indicates that the The lean concrete characteristics used as subbase courses were achieved with cement factors in the range of 200 to 350 lb/yd3 (119 to 208 kg/m3), deteriorating from 1 to 3 in. (25 to 75 mm), the average compressive strength of 7 days between 750 and 1,200 psi (5.2 and 8.3 MPa) and air content is quite larger than regular concrete (6% to 8% of air for conte made with aggregate maximum size 1 to 2 deep. (25 to 50 mm) in the frozen-liquid area). The strength of the LCB layer is also important to mance perfor pavement over time. The counter for intuition, the stronger the LCB layer becomes, the more problematic it may become for the performance of the pavement. Long-term mance perfor study revealed increased levels of cracks at LCB layers versus unstable subbags. This decision is due to the hardship of the LCB, which becomes excessive if the strength of lean concrete is not stored in check. Also, cracks can reflect from the LCB subbase into the pawn if LCB's strength becomes an excessive shrinkage crack and drying exists in LCB. Higher LCB strength generally increases the stiffness of the layer and, although this may lower stress and tension due to the applied load, this usually leads to higher curved pressure in the pavement slab. The same increase in supporting cliffness was attributed to the thickness of the LCB layer. Therefore, it is also important for the LCB layer not too thick. Higher environmental pressures (curves and wars) have a more damaging effect when concrete is relatively young, when the slab has not yet developed the strength and fractured chaos needed to counter fractures. For more information, see section, Influencers of the FoundationStiffness on Strain Stressesand in the Slab of Concrete Papapan, earlier in this publication or part, The Stable Subbase of Measures, later in this chapter. Engineers must acknowledge that targeting compression strength ranges such as 750 to 1,200 psi (5.2 to 8.3 MPa) may be difficult to achieve by contractors due to the usual variations in project materials. Contractors must recognize the importance of not becoming too much by achieving strength in the LCB subbase for the purpose of expediting struc cone tions or other causes. In some cases, higher propagation is not from the abuse of specifications, but only as a matter of passage of time. The sequencing of projects and strength development must be properly factored into the design of the LCB mix. Construction Figure 43 shows the basic steps in building lean concrete subbases. Lean concrete subbase allows contractors to concrete paving to use mixing equipment and put themselves up for subbases, thereat spreading the cost of moving in (mobilizing) over larger amounts of work. Scheduling of contractor work opening paving will be more certain than when a subbase of the type (for example, asphalt-treated) is a sublet to another contractor. In some cases, work schedules maintained by subbase subcontractors inappropriately with the con-tractor table that opens up, may cause delays. Lean concrete subbase is built essentially in the same way and with the same equipment as normal concrete pavements. The only two differences are joint practice and lean concrete subbase surface treatment. Installing joints is generally unnecessary in lean concrete subbases. Shrinkage cracks will grow, but experience has shown that, for LCB strength - 750 to 1,200 psi (5.2 to 8.3 MPa) - and with interlayer treatments discesed below, the cracks usually won't reflect through too much concrete pathways. If the strength of the LCB is a concern (that is, the strength of the LCB is too high), the joints can be scored or seen to the surface of the lean concrete subbase in the location where the joints will be placed in the concrete pavement. If the cracks reflect anxiety, tar paper or any other such substance may be placed on any shrinkage crack before the bond-breaker application to further reduce the likelihood of reflective cracking. The recommended interlayer treatment is to leave the surface of unlimited concrete to avoid mechanical ties to the surface of the concrete. The further step to prevent the bond is to apply two heavy coats of candles based on com pounds as a bond breaker. The first coat is used with dignity, as a cure coat, and a second coat is used shortly before the surface concrete is placed, to refresh the coverage. Figure 43. Construction process for lean concrete suburbs. In Germany, the current practice is to use non-thick non-wofe geotechnical fabrics to separate the pavement of concrete and lean concrete subbases. The practice has great merit and is now used in parts of the United States and elsewhere in the world. Surface finishing tolerance for lean concrete subbases is better on average than any other type of subbase due to placement techniques; Tolerance is often expressed as low as ±0.25 in. (±6 mm), longitching or crossing, with straightedge 10 feet (3 m). This minimizes the occurrence of crete cone overruns (yield losses) due to the need for con-tractors to meet the depth requirements of mini mother pavement (ACPA 1975). The treated Asphalt-Treated Asphalt subbase (ATB) provides other options as a layer of soup port for concrete pavement. &Design Material Requirements The design criteria for soil treated with asphalt and aggregate combination focus almost exclusively on the erasure/stability and parameters of grading. The asphalt coat on the granular ingredients provides brane mem, which prevents or prevents water penetrification and thereto reduces the tendency of the substance to lose strength in front of the water. Because the asphalt-treated subbase relies on adhesion to tie the aggregate par ticles together, stripping is Main. Stripping is a burst of bonding between asphalt cement and aggregate by action or water vapor (SHRP 1993). Stripping result is a breakdown of the asphalt of the hot mixture into particles without any binding medium. Although there are many reasons identified for stripping, the most reasonable cause in the subbase layer is from the decreased asphate content in the asphalt mix, which reduces the thickness of the binding film. Anti-stripping agents can prevent these potential problems. The humidity test used to assess asphalt for stripping was AASHTO T283. The test works two purposes: to identify whether a combination of asphallic and aggregate fasteners is moisture exposed and to measure the effectiveness of anti-stripping additive substances. The thickness requirements for a stable subbase of asphalt depend on support from sub-grade. Thicker subbases are required for poor soil conditions to prevent construction equipment from changing the aspharak layer, especially on softer or more producing subgrades. A 2 in. (50 mm) subbase of thick asphate stabilizers may be sufficient for stiffer bases, as modified by chalk, flying ash or cement, or if an ATB is placed on a subbase that cannot be billed. The following considerations and stipulations are advised to use subbas treated with asphalt under concrete pavement: The asphalt mixture for the subbase can use lower asphani cement grade than necessary for the asphalt surface. The content of asphile cement about 4 to 4.5% is considered typical for sub-steamed with asphalt. Durable aggregate remains an essential requirement that does not affect the asphalt-treated subbase and its appropriate size depending on the thickness of the subbase. Aggregate maximum size is usually 3/4 in. (19 mm). Aggregate meets the needs of moderate sounds performing satisfactorily in the subbase treated asphalt. Maximum frozen-liquid losses in 10 water and frozen-tin losses in water alcohol solutions as high as 45 according to AASHTO T103 are considered sufficient. Some agencies do not require frozen-thawed and wet endurance tests to mix subbases treated with asphalt (1994 Army). The density requirements of the determining agency must be maintained for a mixture of asphalt-treated subbase. The surface of the subbase treated with asfaphalt may range from rough to smooth. Rougher surfaces can drive high levels of friction with concrete pavements and require additional techniques to reduce this friction. Because the surface of the subbase treated with asfaphalt can reach 140°F (60°C) or more, it should be sprinkled with water or whitewashed with a water chalk solution before opening the concrete to reduce surface temperature (IPRF 2003). The construction method for subbase treated with asphalt is the same as to build any layer of asphalt. Contractors put materials using asphaltive paving machines compact layers to specified density with rollers. Layers must adhere to the usual parts of the plan, and provide uniform support and resistance to closeness or stripping. stripping. control with subbase treated with asphalt is also a major factor in construction. Surface deviations that do not exceed ±0.25 in. (±6 mm), longitude or travel, with straightedge 10 feet (3 m) acceptable for asphalt-treated subbases. Most often, it is more difficult to put subbase treated with asphalt close to the desired grade than the cement-treated subbase, causing unnecessary costs to overcome concrete parts of work. More details about building subbas treated with asphalt can be found at other sources. Stable Subbase Precautions Despite the stable subbase advantage, one cannot simply replace a stable subbase for an unstable subbase and expect enhanced performance. There have been uncontrolled incidents on projects with lean concrete, treated cement, subbases treated with asphalt and exemplary known to have been tied to concrete pavements (Halm, Yrjanson, Lokken 1985; Voigt 1992 and 1994). The core of the examined from these projects usually reveals that the cracks travel around the aggregate particles of coarse, indicating a very early formation. These cracks are usually caused by two factors: High friction between pavement and subbase - Shrinking concrete plastic due to drying concrete and/or temperature contraction causes concrete pavements to slide along the subbase. As subbase hardship increases, the friction coating between the subbase and the slab increases, which drives higher tense pressure and increases the risk of cracking. Table 10 shows a typical friction fed alkali for various subbase materials. Increased curved pressure on the pavement - Stable subbase substances increase the pressure in concrete slabs as it causes the radius value of relative hardship* decreased pavement. This reduces the ability of slabs to spread pressure from the load and, for the equivalent panel size, it increases the pressure state on the path. Due to this effect, curved pressure on a stable subbase may be up to twice as high as curved pressure on subbases that cannot be billed conventionally. For more information, see the section entitled The Influence of Stiffness of the Foundation on Stress and Strain in the Slabsearlier Concrete Pavement in this publication. Table 10. Friction Coeftuary for Various Subbase Substances Subbase Subbase Subbase Coeffill Natural Friction Friction 1.0 Clay modified chemically 1.5 Gran not stabilized subbaseular 1.5 Bituminous surface treatment 3.0 Subbase crushed 6.0 Subbase 0 Cement-treated subbase 10.0 Subbase treated by Asfad (gross) 15.0 Asfart treated open graded subbase 15.0 Subbase open cement 15.0 Lean concrete subbase (econocrete) 15.0 * Leace Radius ̃ affected by the modulus of concrete emptiness (Ec), the thickness of the pavement (h), the ratio of Poisson (.), and and subgrade response (k-value). As the strength and thickness of subbase increases, k-value increases, and the relative stirring radius decreases. The lower relative stirring radius causes higher pressure on the pavement. By itself, the above factors may not be significant enough to cause random, uncontrolled fracctions on new construction projects. However, when combined with other factors such as the incorrect selection of ingredients, poor concrete mixed design and/or too much distance between lubricant joints, the risk for unwanted cracking increases. To minimize the potential for random, uncontrolled cracks, the following three factors must be considered in choosing materials for stable subbases, and to design concrete pavements with stable subbases: A bond of potential plastic concrete to the surface of the subbase. The strength of the subbase material is stable. Shared distance (dimensions of panel size). The potential bond between concrete and subbase can be minimized by wearing a bond-breaking medium. For lean concrete subbases, current practice includes two applications of heavy spray-based spray curing compounds on the surface of the subbase. Although there are no recommendations of ordinary bond-breakers for cement-treated subbase or asphalt-treated subbase, Table 11 provides several alternatives to reduce friction and prevent the bonds of concrete pavement to a stable subbase. Alternative Subbase Materials In some cases, aggregate virgin subtitle clippings are not easily available near concrete paving projects. In other cases, the aggregate virgin subtitle may not be the most eco-nom ical option. When such cases arise, recycled concrete (either from existing concrete pavements or other sources) or other waste may be used as aggregates in the subbase layer. Recycled concrete Uses recycled concrete as an unstable subbase or in a stable subbase of cement is common practice. There are many benefits to using recycled concrete, many of which fall into areas of sustainability, including: Performance: Angularity aggregate recycled concrete, coupled with potential waste cement, providing a powerful and durable platform for construction and increasing the carrying capacity of the load over a lifetime of pavements. Furthermore, crushing operations and sizes can be modified to accommodate any desired aggregate grading (FHWA 2004). Economy: Savings are realized in the cost of trans new aggregate portings, and in the cost of estimating and disposing of old pavements. Table 11. Alternatives to Reducing Friction or Bonds Between Concrete Pavement and Subbase Materials Stable Substances Subbase Materials Compound Two coats of white candlestick-based compounds work well. Sand dust about 12 lb/yd2 (5.5 kg/m2) works well. Fines that are grossed recycled working materials as well as thin layers. Emulsion Works well on a smoother subbase surface. Must be coriander. Non-woven geotecstile good for CTB and LCB. Must be 0.2 in. (5 mm) thick, tied to the surface. Polyethyte sheets work well but are difficult to use when resorting; can pose a danger of traffic in urban areas. The tar paper works as well as smashing the medium directly over the shrinkage cracks in the subbase. Did not reclaim applications throughout the sub-base area. Penctic Stone For stable open-only open-gated material — chip-sized material to fill nearby surface voids and minimize concrete penetration into the subbase. Resource Conservation: Reuse of existing materials helps where quality aggregate supplies are difficult (Yrjanson 1989). Also, using the aggregate of recycled concrete either in the subbase or in the concrete mixture conquers the aggregate of virgins. Environmental Consideration: Recycling of existing pavement materials as aggregate subbase reduces dumping and disposal of land (FHWA 2004). Using the valuable landfill space for concrete disposal will be questioned when it can be easily recycled. The cost of using recycled aggregate for subbase materials includes only devastating operating costs. The cost of breaking down, get rid of, steel separation, and transportation is an inch of dentistry to any reconstruction project. Although the aforementioned construction process used for unstable or stable subbases has not changed, there are several precautions that must be considered when using recycled concrete as an aggregate. Aggregate Research Features and experiences have established various aggregate physical properties together and finely made by recycling mentsing concrete pave in place. Properties have also been confirmed through agency testing where recycled concrete aggregates have been determined for reuse. Generally, tests performed on ingredients made of recycled concrete pavements are the same as for virgin aggregates, with only a few exceptions. Contractors can produce almost any desired grass dation using crushed, recycled concrete. Table 12 provides the grading of specially unstable subbase layers (ACPA 1993). Lower yields than recycled gross materials will cause when target grading requires a smaller high-sized material. Aggregate cladding are particles that are at least 3/8 in. (9.5 mm) on their narrowest width. The grass dissolution of the fine aggregate part depends on the type of crushing operation used. This material will be very angular, requiring more effort to put than virgin-based granular materials. A small number of fine particles cling to rough aggregates while crushing and targeting operations. The study of this condition concludes that, for most cases, aggregate does not need to wash it to eliminate finely this. However, some agencies require detergents to reduce the potential of calcium leaching carbonate or calcium oxide when aggregate is used for subbases that cannot be billed. Recycling aggregates generated from all but the poorest quality material should be able to meet L.A. AASHTO T96 or ASTM C131) test requirements of 50% or less subbase material. Typically, on highway projects that use recycled concrete into subbases, the source material is an old pavement at the project site, which is processed without any contaminants or entry. In urban areas, the concrete to be recycled may be from a variety of sources and can include materials such as plaster, soil, wood, gypsum, plastic and vinyl, or rubber. Testing for contaminants is very important for generally recycled source materials. Agencies should apply the percentage limit of pollution that is usually allowed for virgin subtitle aggregates as a way to control the amount of these contaminants in recycled concrete subbase material. Table 12. Typical Recycling Subbase Gradations SieveSizes Percent Pass Sieve 2 in. 50 mm 100 100 1 in. 25 mm - - 3/8 in. 9.5 mm 40 – 75 - No. 4.75 mm 25 - 60 35 – 60 35 - No. 35 - No. 4.75 mm 25 – 60 35 – 60 35 – 60 35 – No. 30 35 – No. 4.75 mm 25 – 60 35 – 60 35 – 60 35 – No. 35 4 4.75 mm 25 – 60 35 – 60 35 – 35 – No. 4 4.75 mm 25 – 60 35 – 60 35 - No. 30 35 – No. 30 35 – No. 4 4.75 – 5 60 35 – 60 35 – 35 – No. 4 4.75 mm 25 – 60 10 2.00 mm — No. 40 425 µm 15 – 45 — No. 200 75 µm 3 – 12 3 – 10 Steps , crushing and the size of the operation can produce dust and fine substances clinging to larger aggregate particles. In the free-draining subbase, water that looks through recycled concrete particles can wash dust from large aggregate over time. Water and fine materials sometimes flow through the coating and, if a edge drainage system exists along the route, fines can be expelled from it. Some agencies reported observing leachate in drain shops due to this action (TRB 1993). Fine material can also settle in a filter cloth or drain pipe before reaching the store. Over time, leachate can clogg the side drain pipes and blind filter fabrics, if they circle the pipe trenches. To prevent this from happening, it is important to use the daylight drainage design or to ensure that the filter cloth for the edge drain pipe does not completely surround the trenches (see the section entitled Daylightingthe Subbase, earlier in this public cassasi). In any case, there are no potential obstacles to free water flow and fine materials, which allow it to flow through subbase to store pipes or side drains. Although the leachate of the recycled concrete aggregate subbase is initially very alkali (pH high due to the high concentration of hydroxyl ions in solution), it is harmless to the environment. If the effluent from the pavement system is a pH high enough to be a concern, it is usually heavily diluted by the time it reaches drainage stores, restricting environmental concerns to small areas surrounding the shops (MNDOT 1995). Furthermore, several states (including Minnesota, Virginia, California and Texas) have proactive stance by reducing the regulatory burden on recycled concrete aggregates to promote its use effectively. These states are aware that environmental benefits do not have an expired concrete pavement placed on landfill and subsequent virgin aggregate conservation (FHWA 2004). Materials Waste Requirements recycled waste into pavement construction has never been greater than at the moment. Many united States and international road agencies have studied the use of different wastes in the subbase layer. Through such studies, it is known that asphalt pavements (RAP), factory tails, and other stones can be used as subbases that cannot be billed in the application of concrete pavement construction. RAP - Claimed asfabat pavement (RAP) will perform satisfactorily as the aggregate subbase (TFHRC 2007). The ingredients must be properly processed, and in most cases, it must be cuffed with conventional aggregate and soil to develop effective grading of subbases. Mill Tailings - The tail of the factory can be used as a partial addition to the unstable subbase layer (TFHRC 2006). However, only coarser-sized particles are accepted to be able to as long as no harmful or reactive chemical components are detected from the host rock. Other stones - Other stones, sometimes called waste stones, include ignorant or metamorphic stones, as well as properly consolidated limestone, sandstone, and dolomitic stones, which are generally acceptable for granular subbases although not classified for use in concrete (TFHRC 2006). Perissive Subbase: Reasons for Avoiding Its Use of Permade Subbases, also known as subbases can be drained or open-graded subbases, becoming a very popular design element to the pavement of concrete highways in the 1990s (FHWA 1992). This subbase is generally deemed to be a crushed aggregate (often stabilized with cement or asphalt) with reduced fines to increase subbase perseverance up to levels from 500 to 20,000 feet/day (152 to 6,100 m/day) in laboratory tests. Despite the intuitive advantages of subbase capabilities that are exemplary to remove the surplus water from the pavement quickly, the exemplary subbase has a problematic history due to: Stability as a construction platform during construction. Inherent stability and destruction associated with concrete slabs under repeated loads. Cracked the early middle of the panel on the right sized slab. The initial pavement of erratic cracks due to the high friction between the subbase and the pavement. The initial mistake of unsolifortable support caused by the unification of an instable layer. Intrude concrete into voids in a transparent subbase, transforming the necessary parts of the structure and joint pattern. Infire fine from the base layer into a persistent subbase void, clogging the system, and trapping water in a subbase. Settling, crushing, and installing retrofitted edge drain pipes during and after installation. Delayed or no planned maintenance to the drain pipe system, causing water to be trapped in the structure of the pavement. Initial costs up to 25 per cent more than subbases others. Exemplary subbase - greater reliability than about 350 feet/day (107 m/day) in laboratory tests - is no longer considered a cost-effective design for concrete paths. This conclusion is achieved through experience with less prescient pavements built on a permeable layer of subbase. It was supported by several performance assessment studies concluding that the system had no significant positive influence on the performance of concrete pavements for many design conditions (Elfino and Hossain 2007; Hall and Crovetti 2007; NCHRP 2002). Without significantly contributing to the performance of concrete pavements, there is no way to justify the high cost of this rapid draining system. Research showed that the cost of concrete pavements increased by 25% with subbase systems that could be drained rapidly on a comparable to the design with unstable conventional subbases (Cole and Hall 1996). The following sections discuss the mechanisms behind some of the problems mentioned above with exemplary subbases, as well as the results of the most comprehensive review of the performance of the concrete pavement structure that includes transparent subbages. Loss of Support Due to Aggregate Breakdown Beginning in 1996, cracks began to appear on the field on a pavement placed on an unbilled subbase that had a persistent coating of around 1,000 feet/day (305 m/day) or higher. The cause of this fracture is the rupture of the material in the joints, which creates an uniform support condition between the tip of the slab (joints) and the center of the slab. The mechanism for deterioration crushes the aggregate in the subbase under the pavement joint due to high adhesives* and pressure of point-to-point contact between unstable subbases particles (Fig. 44). When this happens, crushed aggregate particles fall into the open void structure of the subbase pervasive and, after enough repetition, the subbase in mutual consolidation, leaves the tip of the unsported slab. Although this phenomenon has mainly occurred on an inbilable basis, it has also occurred on asphalt-treated subbases that have been deprived of. Theoretically, it can also occur on a stable subbases of cement if the action of cement inges between the particles is broken, although this has yet to be recorded in the field. * Auctions in slab joints are usually between 2 and 5 times higher than auctions in the slab center. Figure 44. Subbase schemes are unbilable and potentially for high bearing pressure. Because of their increased fine content, freedraining subbase material will reduce this mechanism of loss of support by increasing the point of contact between aggregate particles and reducing the pressure of bearing point to point between particles. Loss of Support Due to Subgrade Integration into Subbase Support Loss due to subgrade inupplution into the subbase occurs because the subbase under the entire slab consolidates, causing the entire slab to complete (Fig. 45). The most common reason for this is poor layer or no filter separation does not prevent the migration of fines (minus No. 200 (75 µm) material) into subbases allowed from the subgrade. When this infiilation occurs, the pavement part settles to a level that corresponds to the infirtation. Although this can occur with both unstable and stable subbases, stable subbases can worsen the effects by grading cheese themselves into subgrade material as the pavement system develops and contracts due to temperature changes throughout the year. Figure 45. Subbase is persistent with and without a separatist layer. Note the inficidence of subgrades and solutions resulting from pavements in cases without separatist layers. Early Age Cracks Due to Mortar Penetration from Concrete Pavement into the initial cracks of the subbase due to mortar penetration from concrete pavement into the subbase is a problem that can occur in exemplary subbases. Because of the openness of exemplary subbase structures, mortars work into voids as concrete vibrates and unified. This penetrating into the subbase restricts the movement of the slab, which increases the risk of both early age and long-term cracks on the trail. Stability as a Subbase Material Stability Construction Platform is another important consideration. Granular materials and materials are compact or drain-free stable with cement or asphalt creating firm support for construction equipment. An instable layer, how ever, has caused some settlement problems. A profile pan (the pavement part of the slipform that controls the surface of the pavement) usually refers to its position from the sensor following a tight line placed along the grade, usually on both sides of the paver. The string line is not necessarily parallel to the grade, but rather set to form a surface regardless of the height of the grade. A good string line can help overcome some small surface irregularities in subbases or track lines, but it's not a substitute for seamless and stable track lines built for tolerance. The hydraulic system that controls the slipform paving machine profile pan cannot quickly adjust to significant variations in the vertical position of the machine caused by subbase solutions or unstable track lines. The unstable track line caused the profile pan to continue trying to adjust its position compared to the machine frame. If it is too sharp or frequent, this type of mechanical adjustment is known to cause bruising or dipping on the surface of the pavement. Layers with high persistent cocaines have no stability in the places needed to enable contractors to consistently build smooth surfaces. Also, agencies must consider if determining an indiminable subbase will limit the option to estimate concrete to the site opening because of the high potential bursts of surfaces. Field Performance The most comprehensive study of performance subbase and concrete pavement drainage system come to the following conclusions (NCHRP 2002): To be properly designed, doweled, alongside ments pave, co-general offences are relatively low and permeablesubbase has a relatively small effect on reducing joint offences When compact grade syubbase exists, edgedrainswere is not found to have a significant impact on reducing joint offences when compact grade syubbase exists, edgedrainswere is not found to have a significant impact on reducing joint offences when compact grade syubbase exists, edgedrainswere is not found to have a significant impact on reducing joint offences when compact grade syubbase exists, edgedrainswere is not found to have a significant impact on reducing joint offences when compact grade syubbase exists, edgedrainswere is not found to have a significant impact on reducing joint offences when compact grade syubbase exists, edgedrainswere is not found to have a significant impact on reducing joint offences when compact grade syubbase exists, edgedrainswere is not found Dowelbars greatly minimize differential deflections across joints, thereby reducing the potential for elinosion pumps. For non-doweled, mutual concrete pavements, joint offense generals are higher and basehas permeablesub a significant impact on reducing mutual offenses. However, the exemplary subbase must be well designed or it can be contaminated by fines, allowing faultingto to grow. Edgedrains must also be properly maintained or they will clogg up and any potential benefits in the performance of the pavement will be lost. Significant D-cracking reductions have been identified at experimental sites in Michigan containing asphalt-treatedpermeablesubbase (0-, 6-, and 12 percent orated joints on three parts), compared with sites with compact grades, asphalt-treated and shoulder AC depth full (79- to 100 per cent joints deteriorating When observed over the entire database, tion sec concrete with permeablesubbases averaged less than half of the joints that deteriorated concrete parts with a quotes of compact grade. The possible reason is that concrete slabs with permeablesubbase may be less saturated than with compact grade subbases, causing lower amounts of frozen-melted during saturation to cause D-cracks. Thisfinding is based on very limited data, but, if legitimate in general, it will have significant implications for the pavement of concrete building the areainfreezethaw with aggregate exposed to D-cracking*. Cost Effective Final consideration is the exemplary subbase cost compared to the additional increase in mance pavement perfor. Figure 46 shows a relative cost comparison for various types of subbase used under concrete pavement (Cole and Hall 1996). On average, an instable subbase adds about 15% to the cost of concrete pavements compared to traditional unstable subbases; Stabilizable subbases add about 25% to the cost of concrete pavements because of their additional requirements for layers, materials and side drain systems. Other studies estimate cost differential at over 30% (Hoerner, Smith, Bruinsma 2004). Interest cost analysis shows that exemplary subbases need to extend the pavement life of between 8 and 15 years in cost-effective analysis of life cycles to be considered cost effective. Experience over the past two decades shows that persistent subbases do not give that level of impact, and the positive effects of drainage can be provided more effectively free-view subbase layer. That's it. subbase design is capable of carrying with a great risk that the system will not function properly throughout life of tidaling and will not prolong the life of enough pavement to be ruled out cost-effective, denying the beneficial concept of this drainage feature (NCHRP 2002). Figure 46. The type of impact has total construction costs, with a compact crushed aggregate base given a relative cost of 100 per cent. * The importance of selecting materials, in particular the selection of aggregates, for durable concrete should not be overset. The selection of design features, such as exemplary subbases, does not replace the appropriate controls and selection of materials. SPECIAL CONSIDERATION OF SUBBASE DURING RECONSTRUCTION DUE TO REPLACEMENT OF INTERSECTIONS, UTILITY CUTS OR INLAYS Once a subgrade has been prepared with special considerations for subgrades discussed earlier in this publication, new subbases or replacements must be placed. All placement techniques, heating requirements, heating tolerance, etc. are the same as for new construction, but some considerations must be taken for the size of the working area. At large intersections, contractors can use automatic prefighting equipment to form subbases and deposit any excessive material outside the area. For a fixed form paving, automatic prefestive ma chine rides on the form after they are fastened to its place. To open the slipform, the prehying machine references the string line for the slipform paving machine. On small projects and in constrained work zones, it may not be practical to use automatic tearing equipment and contractors will likely cut grades with motor graders or small fittings. Because final warming interferes with the surface of the subbase a little, additional heating rolling is usually necessary after the installation. ACAA Reference, Land Stabilization and Recycling of Pavement with Ash Coal Cement Self, American Society of Coal Abu Coal, 2006. ACPA, Econocrete: Report No. 1, American Concrete Pavement Society, 1975. ACPA, Making Grades - Grade Setup is Important in Achieving Pavement Performance, R&d; T Update 6.02, American Concrete Pavement Society, 2005. ACPA, Recycling Concrete Pavement,TB014P, American Concrete Pavement Society, 1993. ACPA, Subgrades and Subbases for Concrete Pavements,TB011P, American Concrete Pavement Society, 1995. AI, Asphalt Industries Glossary of Terms, Asphalt Institute, PDFs/Asphalt_Industry_Glossary_of_Terms.pdf, June 2007. Army Design, Pavement Design for Seasonal Frost Conditions, Technical Manual No. 5-818-2 (Army), Air Force Manual No. 88-6, Chapter 4, Army and Air Force Department, January 1985. Army, Land Stabilization for Pavement, Technical Manual No. 5-822-14 (Army), Air Force Manual No. 32-1019, Army and Air Force Department, October 1994. ASCE, its Control Frost Actionand, Society American Civil Servants, 1984. Beskow, G., Land and Frost Heaving with Special Attention to Roads and Railways, Swedish Geological Society,Book n3, Series n 375. Translated by J. O. Osterberg, Northwestern University, Published by Institute of Technology, Northwestern University, 1947. Bhatty, J.; Bhattacharja, S.; and Todres, H., Use of Cement Kiln Dustin Stabilizes Clay, RP343,

Portland Cement Association, 1996. Burak, R., Operates Wet Land, Interlocking Magazine Concrete Pavement, Vol. 14, No. 2, May 2007. CALTRANS, Test Method for Evaluating the Vast Potential of Portland Base Land Concrete Pavements, California Test 354, State of California, Department of Transportation, Sacramento, 1978. Casagrande, A., Heaving Frost Discussion, Highway Research Authority, Proceedings, Vol. 11, p. 163-172, 1931. Chamberlain, E. J., Frozen-Thaw Test for Determining the Land Chips Framework, Special Report 87-1, Corps of Engineers, Cold Territory Research and Engineering Laboratory, 1987. Chamberlain, E. J., Frost Susceptibility of Soils, Review of Index Tests, DOT/FAA/RD-81/91, U.S. Department of Transportation, 1981. Children, L. D.; Colley, B. E.; and Kapernick, J. W., Testing to Evaluate The Concrete Pavement Subbase, D11 Bulletin, Research and Development Laboratory, Portland Cement Association, Republished from Paper 1297, Proceedings, American Society of Civil Engineers, Vol. 83, HW3, July 1957. Children, L. D., and Kapernick, J. W., Concrete Pavement Test on Crushed Stone Subbase, Proceedings, American Civil Engineers Association, Proc. Paper 3497, Vol. 89, HWI, page 57-80, April 1963. Children, L. D., and Kapernick, J. W., Concrete Pavement Test on Pebbles Subbase, Paper 1800, Proceedings, American Society of Civil Engineers, Vol. 84, HW3, October 1958. Children, L. D., and Nussbaum, P. J., Pressure on The Ground Interface Fundamentals Under loaded Concrete and Land-Cement Highways, Proceedings, American Test and Materials Association, Vol. 62, page 1243-1263, 1962. Cho, Y. H., and Yeo, S. H., Aggregate Recycling Waste Application to Lean Concrete Subbase on Highway Routes, Canadian Journal of Civil Engineering, Volume 31, Number 6, 1, pp. 1101-1108(8), December 2004. Cole, L. W., and Hall, M. J., Relative Cost Of Various Concrete Pavement Features, Transportation Research Record 1574, Transportation Research Board, pp 99-102, 1996. Colley, B. E., and Humphrey, H. A., Aggregate Interlock at Joints in Concrete Pavements, Highway Research Record No. 189, Highway Research Board, National Research Council, 1967. Colley, B. E., and Nowlen, W. J., Concrete Path performance Under Recurring Loading, D23 Bulletin, Research and Development Laboratory, Portland Cement Association, 1958. Crovetti, J., and Schabelski, J., Comprehensive Subgrade Sticker Acceptance Criteria – Final Report Phase III, WI/SPR 02-01, January 2001. Dubose, L. A., Evaluates Taylor Marl Clay for Better Use in Subgrades, Research 35, Texas Engineering Experimental Station, March 1952. Earth Manual, U.S. Interior Department, Reclamation Bureau, U.S. Government Printing Office, 1985. Elfino, M.K., and Hossain, M.S., Case Study: Subsurface Drainage and Premature Distress at a Concrete Pavement in Virginia, the 86th Annual Meeting of the CD, TransportAtion Research Board, 2007. FAA, Stable Basic Course for Advanced Pavement Design - Report 1: Field Literature and Performance Data Review, U.S. Department of Transportation, Federal Aviation Administration, September 1999. Felt, E.J., Influence of Land Volume Change and Application of Highway Engineering, Bulletin D1, Research and Development Laboratory, Portland Cement Association, 1953. FHWA, Portable Pavement System, FHWA-SA-92-008, Federal Highway Administration, 1992. FHWA, Fly Ash Facts for Highway Engineers, FHWA-IF-03-019, Federal Highway Administration, fafacts.pdf, 2003. FHWA, Pavement, Subbase, and Shoulder Design Using Econocrete and NEEP Startup, Project No. 20 – Construction of Experimental Pavement Using Econocrete, Notice of FHWA N5080.34, U.S. Transportation Department, Federal Highway Administration, April 1975. FHWA, Technical Guidelines for Subsurface Pavement, Technical Paper 90-01, Federal Highway Administration, Engineering Office, Pavement Division, October 1990. FHWA, Application for Aggregate Recycling Concrete Transportation, Federal Highway Administration, September 2004. Fredrickson, F. C., Highway Related Frrost Action, Proceedings, Fourth Annual Conference on Land Mechanics and Foundation Engineering, The University of Minnesota Center for Continuous Review. Gordon, R. G., and Waters, T. J., Pavement Performance Case Study on Extensive Land Subgrade, Fifth International Conference on Expan-siveSoils,Institute of Engineers, Barton, Australia, 1984. Hall, K.T., and Crovetti, J.A., Performance of Drainage and Unmanaged Hardcore Pavements in LTPP SPS-2 Experiment, 86th Annual Meeting of CD, Transportation Research Board, 2007. Halm, H. J.; Yrjanson, W. A.; and Lokken, E. C., Investigation of Pavement Cracking Utah I-70, Phase I of the Final Report. ID-70-1 (31) 7. American Concrete Pavement Society, 1985. Henrichs, K. W., et. al., Hardcore Pavement Analysis and Design, FHWA-RD-88-068, Federal Highway Administration, June 1989. Holtz, W. G., Broad Land - Properties and Problems, Colorado Mine School Quarterback, Vol. 54, No. 4, October 1959. Holtz, W. G., and Gibbs, H. J., Expansive Clay Engineering Properties, Transactions, ASCE, Paper No. 2814, Vol. 121, 1956. Hoerner, T. E.; Smith, K. D.; and Bruinsma, J. E., Additional Costs and Benefits of Performance Of Various Concrete Pavement Features, FHWA-HRT-04-044, Federal Highway Administration, February 2004. HRB, AASHO Road Test, Report 5, Pavement Research, Highway Research Board Special Report 61E, 1962. Ioannides, A.M., and G.T., Interlock Aggregate: A Pure-Shear Load Transfer Mechanism, Paper No. 89-0189, is presented to the Transportation Research Board Annual Meeting 1990, March 1990. IPRF, Best Practice for Airport Portlane Cement Concrete Pavement Construction (Rigid Airport Pavement), Report IPRF-01-G-002-1 or ACPA JP007P, Innovative Pavement Research Foundation, April 2003. Johnson, L. D., Thermocouple Psychrometer Technique Assessment for Suction Measurement in Clay, Technical Report No. S-71-1, U.S. Army Engineer Waterways Experiment Station, January 1974. Luttrell, B., and Reeves, I. N. R., Experience and Development with Road Construction on Wide Clay Land in Northwest Queensland, Fifth International Conference on Broad Land, Institute of Engineers, Barton, Australia, 1984. McDonald, E. B., Construction Method for Controlling Expansive Soil in South Dakota, Geotechnical Engineering, Transport Research Record 1089, Transportation Research Board, 1986. McDowell, C., Laboratory testing relationship for Design for Pavement and Structure in Broad Ground, Colorado Mining School Quarterback, Vol. 54, No. 4, October 1959. McKeen, R. G., and Nielsen, J. P., Wide Land Characterisation for Airport Pavement Design, FAA-RD-78-59, Federal Aviation Administration, August 1978. MNDOT, Special Practice of Subgrades Design and Construction in Poor, Wet, and/or Saturated Soil, MN/RC – 2003-36, Minnesota Transportation Department, 2003. MNDOT, Use of Crushed Concrete Products at the Minnesota Pavement Foundation, MN/RC – 96/12, Minnesota Transportation Department, 1995. Mou, C. H., and Chu, T. Y., Land Suction Approach to Suction Of Land for Potential Swelling, Shales and Swelling Land Assessment, TransportAtion Research Record 790, Transportation Research Board, 1981. NCHRP, Empirical Design Guide Mechanical Structure New and Restored – Final Report – Part 3. Design Analysis - Chapter 1. Drainage, National Cooperative Highway Research Program, Subdrainage.pdf, March 2004. NCHRP, Pavement Subsurface Drainage Performance, Project 1-34, National Cooperative Highway Research Programme 2002. NLA, Guidelines for Technical Memorandum of Soil Stabilization Containing Sulfate, Austin White Lime, Chemical Lime, Texas Lime, National Lime Association, August 2000. NMDOT, Land Mixed Classification and Aggregate Lands for The Purpose of Construction of AASHTO M-145-91 Expressway (2004), New Mexico Technician Training and Certification Program, . state.nm.us/upload/images/State_Material_Bureau/S oil/M-145.pdf, October 2006. Now, W. J., Field Test Report in Wisconsin, State Highway 30, Unpublished Report, Portland Cement Association, 1959. Parcher, J. B., and Lie, P. C., Some Features of Compact Clay Swelling, Journal of Land Mechanics and Foundation Division, Proceedings Association of Civil Engineers, Vol. 91, No. SM3, Part 1, May 1965. PCA, PCA Soil Primary, EB007S, Portland Cement Association, 1992. PCA, Real Estate and Land Use Modified Cement, IS411.02, Portland Cement Association, 2003. PCA, Land Cement Construction Handbook, EB003, Portland Cement Association, 1995. PCA, Land-Cement Laboratory Handbook, EB052, Portland Cement Association, 1992. PCA, Subgrades and Subbases for Concrete Routes, IS029, Portland Cement Association, 1975. PCA, Recycling Road: Full Reclamation of Cement, CD032, Portland Cement Association, 2006. Petry, T. M., and Armstrong, J. C., Vast Clay Stabilization, Geotechnical Engineering, TransportAtion Research Record 1219,Transportation Research Board-tion, 1989. Picornell, M., and Lytton, R. L., Crack depth Field Measurement in Broad Land, Geotechnical Engineering, Transport Research Records 1219, Transportation Research Board, 1989. Picornell, M., and Lytton, R. L., Vertical Moisture Behavior and Design, Ground Mechanical Considerations in Arid and Semi-Arid Areas, TransportAtion Research Records 1137,TransportAtion Research Board, 1987. Ramaswamy, S. D., and Aziz, M. A., Membran Encapsulation to Control Swelling of Subgrades for Pavements, Sixth International Conference Proceedings on Land of Expansive,New Delhi, India, 1987. Ray, M., and Christory, J. P., Fighting Pam Papak Turapan Concrete, State of Art and Proposal, Proceedings, Fourth International Conference on The Design and Rehabilitation of Concrete Paurapan, Purdue University, 1989. Reed, R. F., Road Performance on Extensive Clay, Land Mechanical Considerations in Arid and Semi-Arid Areas, Transport Research Record 1137, Transportation Research Board, 1987. SHRP, Distress Introduction Manual for Long-Term Pavement Performance Project, SHRP-P-338, Strategic Highway Research Program, 1993. Snethen, D. R., Expeditionary Method Assessment for Identification and Broad Land Classification, 5th International Conference Proceedings on Expansive Land, Institute of Engineers, Barton, Australia, 1984. Snethen, D. R., Technical Guidelines for Subgrades Of Broadland Highway, FHWA-RD-79-51, Federal Highway Administration, June 1979. Springenschmid, R., Water Content Influence on Unified and Stable Soil Frost Behavior, (In German) Rock Mechanics and Engineering Geology, Vol. 3, No. 3/4, 1965, page 113-121. (Abstract in Highway Research Abstract, Vol. 36, No. 9, September 1965, page 5). Steinberg, M. L., Deep-Vertical-Fabric Moisture barrier in Swoled Land, Shales and Swoled Soil, Transport Research Record 790,Transportation Research Board, 1981. TFHRC, Application Description – Detailed Base, Turner-Fairbank Highway Research Centre, Accessed December 2006. TFHRC, Reclaimed Asphalt Concrete – Consumer Guidelines – Granular Highway Research Centre, recycle/waste/rap134.htm, Accessed June 2007. TRB, Frost Actionin Roads and Airfields, AReview of Literature 1765-1951 – Special Report TRB No. 1, Transportation Research Board, 1953. TRB, Landworks Construction Guide, Latest Report 8, Transportation Research Board, 1990. TRB, Problem Statement 175: Effects of Portland Recycled Cement Concrete as Subbase Material on Subsurface Drainage System, A2KO6 Committee, Transportation Research Authority, Unpublished, 1993. TRB, Road Design in Seasonal Frost Area, National Cooperative Highway Research Programme 26, Transportation Research Board, 1974. US ACoE, Engineering and Design, Rapid Drainage Basic Course for Pavement, Technical Letter of Engineering, Army Department, U.S. Military Engineer Corps, 1991. US ACoE, Investigation of Filter Requirements for Underdrains, Technical Memorandum No. 183-1, U.S. Waterways Experimental Station, U.S. Military Engineer Corps, 1941. Voigt, G. F., Cracking on Highway 115 Petersborough, Ontario, American Concrete Pavement Society, 1992. Voigt, G. F., Investigation of Pavement Cracking at General Aviation Airport, Fremont Nebraska, American Concrete Pavement Society, 1994. Watt, W. G., and Steinberg, M. L., Clay Measurement Swelling in Pool Cuts, Texas Highway Department Research Report No. 118-b, Cooperative Highway Research Program, Highway Research Center, University of Texas, Austin, 1972. Weston, D. J., Extensive Road Treatment for South Africa. Proceedings, Fourth International Conference on Broadland, Denver, American Society of Civil Engineers, Vol. Me, June 1980. White, D., Optimum Pavement Base Characteristics, Technical Transfer Summary, Concrete Pavement Technology Center, Summary May 2004. Wiseman, C.; Commornics, A.; and Greenstein, J., Experience with Roads and Buildings on Expansive Clay, Vast Land Assessment and Control, Transport Research Records 1032, Transportation Research Board, 1985. Yrjanson, W., Recycling Portland Cement Concrete Pavements, Synthesis of Highway Practice 154, National Cooperative Highway Research Program, Transportation Research Board, December 1989. Glossary Attachments Because the terms used in connection with subgradates and subbases are unique and often unfamiliar to pavement design engineers, this vast Glossary has been included as a way to define many of the terms used in this publication quickly. This glossary, however, is not intended to accommodate all the terms used in subgrades and subbase vernaculars but some other vast sources of terms, such as the ACI Committee 116 and ASTM standards. A: AASHTO Land Classification System - Land classification system developed to categorize soil by capacity load and service life generated when used as part of a pavement Moisture is observed - Moisture held in substances and has physical properties not much different from normal water at the same temperature and pressure. Absorption – The amount of water absorbed under certain conditions, usually expressed as a dry weight percentage of the material; process in which water is instiled. Water Instilled - Water held on the surface of the material by physical and chemical power, and has physical properties much different from the water that is instilled or the water combination of chemicals at the same temperature and pressure. Basically, it is water maintained by the soil after the moisture of gravity and capilary is removed; it can be described as water associated with dry moisture content of the air. Adsorption - Development on the solid surface of higher concentration material than those that exist in most mediums; especially in concrete and cement technology, the formation of water layers on solid surfaces, such as cement, or aggregate, or airborne empowerment agents at water borders; process in which the material is observed. Aggregate - Granular materials, such as sand, gravel, crushed stone, crushed hydraulic cement concrete, or slabs of iron explosive furnace, are used alone in unstable subbases or with hydraulic or asphanic cement binders in a stable subbase. Aggregate Dying – An intermixing process of two or more aggregates to produce a different set of properties, generally, but not exclusively, to increase grading. Aggregate Grading - Distribution of granular material particles between various sizes, usually expressed in terms of a larger or smaller cumulative percentage of each series of sizes (opening filtration) or percentage between specific ranges of size (opening filtering). Subbase Treated Asfaphalt (ATB) – A stable subbase tied to an asphalt binding. ASTM Land Classification System (United) – Land classification systems developed to categorize the soil according to their texture and plastic quality in relation to their performance as engineering construction materials. B: Basic – Layer in the asphalt pavement structure; usually granular or stable material, whether previously placed and hardened or newly placed, where the surface of the pavement was placed in the operation later. Basic Courses (also known as Binder Courses) – An immediate layer of asfath hot mix under the surface course, generally consists of less asphalt and aggregate larger than surface courses. Binding Courses - See Basic Courses. C: California Bearing Ratio (CBR) – The force ratio of each unit needed to penetrate the soil mass by 3 in.2 (19 cm2) of circular pistons. The value of the index (CBR) is a percentage of the robust reference value for 0.1 in. (2.5 mm) and 0.2 in. (5.0 mm) of penetration. The reference value of 100 was originally thought to represent well-crushed crushed stone resistance. Typical the value may range from 2 to 8 for clay and 70 to 90 for crushed stone. Kapilariti – (also known as Capillary Actionor Capillary Absorption) - Actions in which the liquid (water) rises or wicks on the channels on the free water supply (water table) by way of a team of surface tension and without respectable external pressure. The number and size of channels in the soil determines the distribution of pore size and therefore its capabilities. These land properties are measured as distances (from zero to 30 feet (9.1 m) or more) of moisture rises on the water table with this action. Capillary Action - See Kapilarity. Capillary Absorption - See Kapilarity. Capriary Water - Water held in land pores or capilies by capilary action. Cement-Treated Subbase (CTB) – A stable subbase tied to portland cement with a general dose of about 4 or 5 percent cement by weight. CTB is best controlled using the requirements of computerisation and/or density, but the strength of the typical target for the CTB layer is between 300 and 800 psi (2.1 and 5.5 MPa) compression on 7 days. Cement-level subbase - A stable subbase class that includes cement-treated subbases (CTB) and lean concrete. Centrifuge Equivalent Moisture (CME) - Soil moisture content after a saturated sample is turned for an hour under force equivalent to 1,000 times the force of gravity. Low values, such as 12 or less, show low capillary soils such as transparent sand and stops; high value, like 25, shows high-capsity soils such as inevitable clay. Chemical Modification - Treatment of subgrade subgrade materials sub-ideal with chalk, portland cement, kiln cement dust, Class C flying ash, or Class Frued ashes in conjunction with chalk to provide shrinking resistance and uniform stability required for the ideal working platform. Clay - Categories of classification of soil texture methods. Fine ground that breaks into clods or lumps very hard when dry and plastic and unusually sticky when wet. When a wetland ball is pressed between the thumb and the finger, it will form a long ribbon. Classification System - View Land Classification System. Cone Penetrometers - Devices used to measure ground strength; examples include Wes Cone Penetrometer and Dynamic Conetrometer (DCP). Penetrometers are driven into the ground either at a constant rate (WES) or by dropping a certain hammer weight at a certain distance (DCP). The measured value is associated with CBR, shear strength, or soil modulus value. Cross-transport - Sub-ideal soil replacement with ideal soil at critical point in the pavement structure with either by choosing to transfer sub-ideal materials to lower altitude and beyond more ideal material towards the surface or removes the subgrade part and replaces it with a more ideal substance. Crushed gravel - Products resulting from crushing artificial gravel with a minimum percentage of prescribed debris have one or more faces resulting from fractures. Crushed Stone - A product resulting from crushing stones, gallstones, or large cobbles, significantly all faces that have well-defined edges and have resulted from crushing operations. Crusher-run Aggregate - Aggregate that has been broken in mechanical cruise ships and is not subject to any subsequent screening process. Cut Filling Shift - Locations where uniformly isolated areas are eliminated by combining or estimating sub-ideal subgrade material with more ideal material to produce a more gradual and uniform transition area. D: Daylight Subbase - (also known as Daylight)– The side drainage system where subbase is extended through the edge of the pavement system to the point where it is able to bring water to the side drains, therefore becoming daylight. Daylight - See Daytime Subbase. Degree of Saturn – The ratio of water seals in the substance (i.e., in aggregate) to the number of voids, is usually expressed as a percentage. Density – Weight of total units of land. It can be stated either as wet density (including both soil and water) or as dry density (soil only). Drainage – Interception and removal of water from, inside, or under areas or roads; process of producing surfing of soil or surface water artificially; general terms for the flow of liquid gravity in conduit. Subbase can be drained- See Exemplary Subbase. E: Econocrete - See Lean Concrete. Side Drainage System – A system designed to carry water that has infiltration surfaces of the pavement into the side drains. The two most common types of drainage systems are collector pipes with excess stores and daytime subbases. Increase – Methods eliminate excess moisture in wet soil by providing drainage through drains or toe drains at the lowest point; compress subgrade using heavy equipment, which forces excess moisture from sub-grade due to high applied pressure; or adjust the moisture content through chemical modifications (soil stabilization). Broad Soil - Land that changes the volume with changes in moisture content; Vast land that may swell enough to cause pavement problems generally clay falls into the AASHTO A-6 or A-7 group, or is classified as CH, MH or OH by the Integrated Classification System, and with the Plastic Index larger than about 25 by ASTM D4318. F: Blame – Vertical dissociation of slabs or other members adjacent to joints or cracks; often caused by pumping. Clay - Category classification of soil texture methods. Highly plastic plastic clay; highly show off the features shown for clay. Terrain humidity – Minimal humidity content where smooth soil surfaces will absorb no more water within 30 seconds when water is added in individual drops; The FME reports the moisture content needed to fill all the pores in the sand, when the vast capillity of solid soil is completely satisfied and when the solid soil approaches saturn. Fine Aggregate – Aggregate surpasses 3/8 in. (9.5 mm) filters and almost completely pass no. 4 (4.75 mm) of sieveand mostly maintained on no. 200 (75 µm) filter. Fineness modulus – Subtle or rough measurements of aggregate samples, usually fine aggregate (sand). It is determined by adding a cumulative percentage maintained on each specified filtering series, and dividing the total by 100. Fly Ash - Fine waste is divided as a result of burning ground coal or powder and transported from fire boxes through boilers by cold gas; used as a mineral mixture in cement-treated subbases. Fills can be flown – A controlled low-strength filling material that does not require computing and flowing easily to fill the trenches. The mixture contains portland cement, sand, flying ash and water and usually develops a compressive strength of 28 days about 50 to 100 psi (0.35 to 0.70 MPa). Fillmaterials can flowers provide enough strength to prevent solutions, but it is easy to remove using buckets on the back hoe or front-end loaders if future excavations are required. Free draining subbase - Subbase with target reliability of between 50 and 150 feet/day (15 and 46 m/day) in laboratory tests; The maximum reliability for the free draining subbase is about 350 feet/day (107 m/day) in laboratory tests and any material that provides a higher reliability rate should be considered an exemplary subbase. Free Humidity - (also known as Free Water) - Moisture that basically has pure water properties in bulk; moisture is not observed by the aggregate. Free Water - View Free Moisture. Frozen Action - A phenomenon in which freezing and diluting of soil in winter and early spring may cause uneewhere support beneath the surface of the pavement. The freezing phase of frost action may result in significant road surface weight (see Frost Heave) and the phase of frost action dilution may result in significant road survival (see Sub-grade Softening) Frost Heave - (also known as Frost Heaving) - Heaving from the road surface due to frost pavement, especially when in the remote area, Frost Weight - See Frost Weight. Frost-Susceptible Soil - Low plastic, fine soil with a high percentage of plastic sized particles of 0.02 to 2 miles (0.0005 to 0.05 mm). Other considered frost-exposed soils include loam, sandy loam, clay loam, fine sand, clay gravel and flour The simple soils exposed frost-susceptible include dirty sand and gravel and glaciers to this day. The only land that can be considered non-frost-suscep-tible is a very clean mix of sand Gravel. G: Geosynthesis - Thin sheets of varying textile materials. Various geosyntheses include geotechnical, geogrid, geonet, geocells and geomembrane. The use and effectiveness of geosynthesis directly depends on the type of geosynthesis, the intended function (filtration, separation and/or reinforcement), soil conditions and installation techniques in-situ. Crediting - View Crediting. Grading - Distribution of granular material particles between various sizes, usually expressed in terms of a cumulative percentage that is larger or smaller than each series of sizes (opening filtration) or percentage between specific ranges of size (opening filtering). Subbase Granular - See Unstable Subbase. Gravel - Granular material is mostly maintained on filtration No. 4 (4.75 mm) and resulting from natural splits and abrasions of stones or poorly tied conglomerate processing. Gravity Water – Free water moves under the influence of gravity. This is water that will flow from the ground. For the land in-situ it is water inside and under the groundwater table and is often termed groundwater. H: Heavy Clay - See Fat Clay. Hygroscopic Water – See Water That Is Scraped. I: Illinois Bearing Ratio (IBR) – A measure of support provided by receptive soil or by uncroalthed granular materials. The IBR test is a slight modification of the California Bearing Ratio (CBR) procedure and is a soaked laboratory test. IBR is considered the same as CBR in most cases. Ion Exchange Stabilization – A chemical mechanism of subgrade soil chemical modifications in which flocculation and agglomeration of clay particles result in granular particles with lower PI and lower sensitivity to humidity fluctuations. Q: k-value – See Subgrade Reaction Modulus. L: Lean Clay - Categories of classification of soil texture methods. Moderate plastic clay; indicates the characteristics indicated for clay, but to a lower level. Lean Concrete Subbase - Subbase is tied to portland cement and with higher cement and water content than cement-treated subbases, but they are less cement than conventional concrete and average compression strength of 7 days between 750 and 1,200 psi (5.2 and 8.3 MPa). The aggregate used in lean concrete subbases does not necessarily meet conventional quality standards for aggregates used in pavements. Lighter clay - See Lean Clay. Liquid Limits (LL) – This limit separates the plastic conditions from liquid conditions. It is represented by moisture content where the soil, when separated by a standard groove [0.04 in. (1 mm)] in a standard cup, will flow back together [0.4 in. (1 cm) long] under 25 standard pipes or blows [0.4 in. (1 cm) fall impact]. Liquid limits are considered to be directly related to the compression of the soil; the higher the LL, the greater the competency. M: Aggregate size - view the maximum nominal size. Mill Tailings - Mineral processing waste that can be used as partial subbase layer that is not stabilized. However, only coarser-sized particles are acceptable as long as there are no hazardous or reactive chemical components concentrated from the host rock. Subgrade Response Modulus – Bearing tests, conducted in the field, which provides an index for assessing support provided by the soil or subbase layer directly under the concrete slab; Subgrade response per unit of deformation area is usually given in psi/in. (MPa/m). Damp – slightly damp but not dry enough to touch; Wet terms imply visible free, humid water implies less wet than wet, and damp implies not dry enough. Moisture Content - The ratio of water mass in granular aggregate samples given to dry weight of mass. N: Natural Sand - Sand resulting from natural steering and rock abrasions. Nominal Maximum Size - In specifications for and aggregate description, the smallest filter opening in which the entire aggregate volume is allowed to pass; sometimes referred to as maximum size (aggregate). Nonfarm soil – Land consisting of almost entirely the size of sand, pebbles or rough sleeves that will not indicate a significant variation of consistency with variations in humidity. O: Open-gridded subbase - See Exemplary Subbase. P: Pavement Structure – A combination of asphalt/concrete surface courses and basic/subbase courses placed on subgrades provided to support traffic load. Peanut Pebbles – Screened pebbles particle size that ranges from 3/16 and 3/8 in. (4.75 and 9.5 mm) diameter. Penalty Percentage – The amount, expressed as a percentage, is aggregate material more subtle than the given filter, usually siege No. 200 (75 µm). Subbase Telap - (also known as Open Grade Drainable Subbaseor) – An unfundable layer consisting of crushed aggregates with reduced fine amounts to promote drainage and increase subbase perishability above 350 feet/day (107 m/day) in laboratory tests, although typical levels range from 500 to 20,000 feet/day (152 to 6,100 m/day) in laboratory tests. Despite their intuitive advantages quickly being able to remove cess water containers, exemplary subbases are no longer considered a cost-effective design element to concrete pavements because of their highly problematic history. Perseverance – The ability of the soil to transmit water through its voums. The accuracy of any material depends heavily on the connectivity of the pore network; The more connected and larger the pore network, the greater the reliability. Plastic Limits (PL) – This limit separates the state of semisolids from plastic conditions. It is represented by the moisture content in which the soil, when launched into a cylindrical ribbon of 1/8 in. (3.2 mm), will begin to break into the short section. Plastic Soil – Land containing fractions slock or clay, or a combination of both, which will pass from solid to semisolid to plastic and eventually to liquid conditions with water addition. Plastic Index (PI) – Numeric differences between liquid limits (LL) and plastic limits (PL), are each expressed as moisture content in percentage. Low PI soil is very sensitive to moisture changes because the addition of only a few percent moisture can change the soil from plastic to liquid conditions. Porosity – The ratio of total voids to total mass regardless of the amount of air or water contained in the voids. Porosity can also be expressed as a percentage. Pozzolanic Stabilization - A physical mechanism of physical modification of subgrade soil where the direct cementation effects of cereal soils together. Pumping - A strong shift in the soil and water mixtures occurring under the slab joints, cracks and edges of the pavement that erupt and are rapidly released by the load of high-speed heavy vehicles; occurs when a concrete pavement is placed directly on fine grains, plastic soil or subbase materials that can be eroded. This nonuniform support state often results in premature fractures in the corners of the slab and the rotation of the pavement, generally in the form of the wrong reverse joint. R: R-value - See Resistance Value. Relative Stubly Radius - Character or property of a concrete slab that measures the hardship of the slab in relation to sub-foundation/subgrade. Reclaimed Asphalt Pavement (RAP) - An existing asphalt pavement that has been processed for reuse, usually as an aggregate in a subbase layer. Recycled concrete - Previously existing, hard concrete that has been crushed and sorted for reuse, usually as an aggregate in a subbase layer. Recycled concrete can come from any number of sources, not just concrete pavements, and the sorting process can be adjusted to remove contaminants such as strengthening steel. Reinforcement – Method of eliminating excess moisture in wet soils using geosynthesis. Relative humidity - The ratio of the quantity of water vapor is actually present to the amount present in a saturated atmosphere at a certain temperature; expressed as a percentage. R-value value – The size of the hardship of subgrade/subbase material by means of resistance to plastic flow. The typical R values for heavy clay are 0 to 5, for high plastic slippers are 15 to 30 and for a graded crushed stone foundation is 80 or more. Subgrade Land Resilient Modulus (MRSG or MR or ESG) – A measure of subgrade hardship as an estimated modulus of erodity (E) of a material; Employability modulus is a pressure divided by tension for loads used slowly and resilient modulus is pressure divided by tension for fast-to-use loads. Q: Sand – Delicate granular material (usually less than 3⁄16 in. (4.75 mm) in diameter) resulting from the natural split of the rock, or from crushing fried sandstone. Also, the classification category of soil texture methods. when dry, the soil will fall in addition to when the pressure is released. Released. when damp, it will form an actor who will hold his shape when the pressure is released but will collapse when touched. Sand Equivalents (SE) – Ways to measure the presence of unwanted clay materials in soil and aggregate materials; This method tends to enlarge the amount of clay found in samples that are quite pro propelable to the harmful effects. Concrete and crushed stone sands have SE value of about 80; Very spacious clay has a value of ZERO to 5. Saturated-dry surfaces - State of aggregate particles or other angle solids when pervasive voids are filled with water but there is no water on the exposed surface. Saturation- 1) In general, the state of coexistence in the stable balance of either vapor and liquid or vapor and the solid phase of the same material at the same temperature. 2) As used for aggregate or concrete, the condition that no more liquids can be held or placed in it. Selected Grading – Grading operations where extremely vulnerable soils are proponented to the bottom of embankments and less exposed soil is lifted to the bottom of the sub-grade towards the top. Separation – Method of eliminating excess moisture in wet soils using geosynthesis. Separatists - (also known as Separating Fabrics) Geotextile Fabrics and a compact graded granular layer that prevents the migration of fines from subgrade into an independent draining subbase. Separatist Fabric - See Separatists. Filters - Metal plates or sheets, woolly barbed fabrics, or other similar devices, with frequently spaced apertures of uniform size, are installed in frames or handles suitable for use in separating granular materials by size. Filter analysis - Particle classification, especially aggregate, according to the size as determined with a series of different opening filters. Silent – The classification category of soil texture method. Consists of a large number of stool particles with no amount of sand and small clay. Lumps in dry, unsuitable conditions look a bit cloddy, but they can be greeted easily; the soil then feels soft and floured. When wet, the stool loam runs together and puddles. Whether the actor is dry or damp can be handled freely without breaking. When a wetland ball is pressed between the thumb and the finger, the moisture of its surface will disappear, and it will not press into a smooth ribbon, uncrocked but will have a broken appearance. Silk clay - Categories of soil texture methods. Consists of plastic (cubic) fines mixed with significant quantities of sickness. It's a fine ground that breaks into hard clods or lumps when dry. When a wetland ball is pressed between the thumb and the finger, it will form a thin ribbon that will break easily, barely maintaining its own weight. Wetlands plastic and will form an actor who will withstand great handling. Silty-sand – Categories of soil texture methods. Consists of most of the sand, but has a Stools and clay are present to provide some stability. Individual sand grains can be seen and felt easily. Squeezed on hand when dry, this soil will fall apart when the pressure is released. Squeezed when sluggish, it forms an actor who will not only hold his shape when the pressure is released but will also withstand cautious submission without breaking. The stability of the damp cast distinguishes this land from the sand. Shrinkage Limit (SL) – This limit separates solid conditions from the semisolid state. It is represented by a point in the drying process where no further shrinkage occurs during continuous drying. Land Classification System – A system created to group soil materials in categories according to their physical properties. Two widely used land classification systems are ASTM Integrated Land Classification System (USCS) and the American State Highway and TransportAtion Officers Association (AASHTO) system. Soil Moisture Suction - See Kapilarity. Certain gravity - The ratio of weight in the air amounts the material given at the temperature specified to the weight in the air volume of the same tide at the same temperature. Special Gravity Factor - Aggregate heavy ratio (including all humidity), as introduced into the mixer, to the effective volume transferred by the aggregate. Stable subbase - A subbase layer tied either with portland cement or asphphalt tie. Stable subbase falls into three common categories: treated cement, lean concrete and treated asphalt. The main benefit of a stable foundation is that they provide relatively strong, uniform and resistant support to eosion (pumping). Subbase – A layer of selected material or a planned thickness engineering is placed between a subgrade and a concrete pavement that serves one or more functions such as preventing pumping, distributing loads, providing drainage, minimizing frost action, or facilitating the construction of pavements. Subgrade - Natural, graded and compact soil, where the pavement structure is built. Subgrade Softens - A sharp reduction in sub-grade support that occurs when the subgrade melts both from the surface down and from the ground up. Usually a little concern for the structure of a concrete pavement designed adequately to counter the weight of the frost. Replacement - Methods of eliminating excess moisture in wet soils emit inappropriate soils, unstable or excessively wet and replacing them with selected loan materials or, alternatively, covering wet soil with suitable materials to develop the necessary incompatiency and stability. Surface moisture - See Water Infused. Surface Tension - Property that, caused by molecular forces, exists in the surface film U: Integrated Land Classification System - See ASTM Land Classification System. Subbase is not stabilized - (also known as The Granular Subbase or Subbase Treated) - The subbas layer consists of crushed rock, banks running sand pebbles, sand, ground stable gravel, lower ash, crushed or granulated cages, recycled concrete aggregates, or local materials such as crushed wine waste and sand shell mixtures and excluding any stabilizing agents (i.e. cement or asphald binders). This is the most common type of subbase for applications such as roads, roads and highways. The main criterion for creating a good unstable subbase is to limit the number of fines passing filtration No. 200 (75 µm) to 15%; if there are too many fines, an unstable subbase can hold water more easily and will be exposed to ownership, pumps and frost action. Untreated subbase - See Unstable Subbase. V: Invalid ratio – Volume ratio of voids to soil particles. The ratio of porosity and invalidity of the soil depends on the level of computing or consolidation. Therefore, for certain soils in different circumstances, the ratio of porosity and illegality will vary and can be used to assess relative stability and the load carries capacity with these factors increasing as porosity and invalidity ratio decreases. W: Water Content - View Moisture Content. Aggregate GoodBergred - Aggregate has a distribution of particle size that will produce maximum density; that is, the invalid space is minimal. Wet soil - In-situ soil conditions where the soil has excessive moisture content. Wet soils may be encountered during construction for reasons ranging from naturally high water tables to seasonal rainfall, as well as changes in drainage conditions due to construction. AASHTO Standards All reference documents of the American State Highway and TransportAtion Officers Association (AASHTO) in the text of this publication are listed as follows and can be obtained www.aashto.org; please consult the AASHTO website to ensure that you have obtained the latest version of any AASHTO standard before using it. Standard M145 Specification for Soil Classification and Land Aggregate Mixture for The Purpose of Construction of Highway M147 Standard Specification for Materials for Aggregate Subbase and Aggregate Land, Base, and Surface Course M155 Standard Specification of granular materials to Control Pumps under Concrete Route Standard Specification M252 for Corrosion Polyethylene Drainage Pipe M278 Specific Standardation for Class PS46 Poly (Vinyl Chloride) (PVC) Pipe T89 Standard Test Method for Determining Ground Liquid Limits T90 T93 Standard Specification for Determining Moisture of Soil Equivalent Field (Discontinued) T96 Standard Test Method for Resistance to Aggregate Deterioration of Small-Sized Koars by Abras effects in Los 1Angeles Machine T99 Standard Test Method for Moisture-Density of Land Relations Using 2.5 kg (5.5-lb) Rammer and 305-mm (12-in.) Drop T103 StandardIzed Test for Aggregate Destation by Freezing and Disbursement of T134 Test Standard Method for Mixed Relations Land-Cement T176 Test Standard Method for Plastic Fines in Aggregate Bergred and Soil using Sand Equivalent Test T180 Test Method for Humidity-Density of Land Relations Using Rammer 4.54 kg (10-lb) and 457-mm (18-in.) Drop T190 Standard Test Method for R-Value Resistance and Compact Land Expansion Pressure T193 Standard Test Method for California Bearing Ratio T221 Standard Test Method for Ground Recurrent Static Plate Load Testing and Flexible T Components Resolution for Use in Airport Assessment and Design and Pavements Highway T222 Standard Test Method for Non-Soil Static Plate Load Testing and Flexible Pavepan Components for Use in Airport Assessment and Design and Pavement T Routes 265 Standard Test Method for Determination of Soil Moisture Content Laboratory T273 Standard Test Method for Land Suction T283 Standard Test Method for Destruction of Compact Asphalt Mixture to Moisture- Damage Caused T 307 Test Standard Methods for Determining Soil Resilient Modulus and Aggregate Materials ASTM Standards All American Society for Testing and Materials (ASTM) reference documents in this publication text are listed as follows and can be obtained in www.astm.org; please refer to ASTM's website to ensure that you have obtained the latest version of any standard PROCEDURE ASTM before using it. Standard C131 Test Method for Resistance to Aggregate Decline of Small-Sized Coarse Aggregate by Abrasion and Impact in Standard Test Method Los Angeles D422 For Particle Size Analysis Standard D425 Test Method for Centrifuge Ke Soil Equivalent Moisture D4 Method of Moisture Testing of Soil Equivalent Field (Withdrawn 1958) Test Method D427 for Soil Shrinkage Factor by Mercury Method D558 Standard Test Method for Humidity (Units) Weight) Soil-Cement Relations Mixed D559 Standard Test Method for Compact Soil-Cement D560 Standard Test Method for Freezing and Dilution of Compact Soil-Cement Mixture D698 Standard Test Method for Corrective Characteristics Labs Using Standard Efforts (12,400 feet-lbf/ft3 (600 kN-m/m3)) D1195 Standard Test Method for Ground Recurrent Static Plate Load Testing and Flexible Ment Pave Components , for Use in Airport Assessment and Design and Path pavements D1196 Standard Test Method for Nonrepetitive Land Static Plate Load Testing and Flexible Pavement Components, for Airport Assessment and Design Use and Pavements Route D1241 Standard Specifications for Materials for Subbase Land-Aggregate, Base, and Surface Course D1633 Standard Test Method for Compressive Strength of Cement Blonde Soil Cylinders D1883 Standard Test Method for CBR (California Bearing Ratio) Compact Soil Laboratory D2216 Standard Test Method for Determination of Water Laboratory (Moisture) Soil Content and Mass TestIng Method for Land Sands Equivalent Value and Fine Aggregate D2487 Soil Classification Standard Practice for Engineering Purposes (Integrated Land Classification System) D2488 Standard Practice for Land Information and Identification (Visual-Manual Procedures) D2844 Standard Test Method for R-Value Resistance and Expansion Compact Soil Pressure D3152 Standard Test Method for Moisture Relations Of Capilary Moisture for Delicate Hardcore Soil by Press- Membrane Apprehension D3282 Practice Standard for Land Classification and Land-Aggregate Mixture for Highway Construction Purposes D4253 Standard Testing Method for Index Density Maximum and Weight of Soil Units Using Geared Schedule D4254 Standard Test Method for Minimum Index Density and Weight of Soil Units and Relative Density Calculation D4318 Standard Test Method for Liquid Limits, Plastic Limits, and Ground Plastic Index D4546 Standard Test Method for One Swolnd Dimension or Solid Land Potential Solution D4829 Standard Test Method for Land Expansion Index D1883 Standard Test Method for CBR (California Bearing Ratio) Compact Laboratory D2216 Standard Test Method for Determination of Water Laboratory (Moisture) and Standard Test Method D422 for Stone Particle Size Analysis by Soil Mass D2419 Standard Test Method for Equivalent Sands D425 Standard Test Method for Centrifuge Soil Humidity Value and Fine Aggregate Soil Equivalent D2487 Standard