Pervious Concrete: EPA Accepted BMP for Stormwater Runoff

- Meets NPDES regulations
- Provides for groundwater recharge
- Has the same structural integrity as conventional concrete

Pervious Concrete Defined: *Pervious concrete provides first-flush pollution mitigation and stormwater management for parking areas as well as streets and intersections. Because of this no tie-ins to municipal storm water systems may be required, and no grassy swales or other land-wasting pollution mitigation measures may be required. Rainwater flows through the pervious concrete rather than running off. Many pollutants such as oil drips and heavy metal powders from cars and other sources are carried into and through the pavement, where they are stored and treated by existing soil microbes.*

The nation's first designed "cool" parking lot, and California's first pervious concrete parking lot, has been completed in the Sacramento, California suburban village of Fair Oaks. Pervious concrete was placed late December and early January, and striping was complete in late January. Tree planting and other finishing touches have also been completed.

The project provides a demonstration of the effectiveness of pervious concrete in parking lots for both stormwater management and urban heat island effect mitigation. The Sacramento Cool Communities Program was a partner in this project, which can serve as a model for future parking lots across the United States.

It was raining when this picture was taken. Stormwater percolates through the concrete.

The Cool Communities Program grew out of a Department of Energy program aimed at reducing energy usage in hot climate-zone cities by encouraging the use of light colored paving and roofing materials as well as extensive planting of shading vegetation. Cities, such as Atlanta or Sacramento, experience from 3-10 degrees hotter temperatures at their urban core on summer days due to the energy absorption of black asphalt paving and roofs. By reducing the amount of dark roofs and paving and planting shade vegetation, summer peak energy-cooling loads can be reduced over 20% in urban areas. This is especially critical in California's current energy crisis.

Pervious concrete is a high cement-content mix made with no fine aggregate and a low water-cement ratio. On this its first job of this type, Gold Valley Construction felt that placement labor of the Bannister Park parking lot was only slightly greater for pervious than conventional concrete. Overall, costs of pervious concrete parking lots should be within about 10% of the cost of a conventional concrete parking lot.

When compared to a conventional asphalt parking lot requiring stormwater system tie-in and first flush pollution measures such as drain invert filters, **pervious concrete parking lots are by far the lower initial cost solution**. In addition they are the lower life cycle cost solution concrete has always been for paving of nearly any kind.

Pervious concrete is delivered in conventional ready-mix trucks and placed between conventional forms. The forms usually have a ½"–⅝" strip tacked to the top of the form. Following the use of a vibratory screed to strike off the concrete, the strips are removed, and a roller is manually rolled across the material to densify it another ½"–⅝". The material is then misted and covered with plastic sheeting to cure. There is no finishing in the conventional sense.

Pervious concrete provides landowners with a cost-effective way of providing roads, streets and parking areas without the need for stormwater system connections or first-flush pollution prevention measures. EPA and local regulations are beginning to require more rigorous stormwater management practice and the concrete industry expects pervious concrete to be one of the leading solutions in California and Nevada.

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PORTLAND CEMENT
PERVIOUS PAVEMENT MANUAL

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PORTLAND CEMENT PERVIOUS PAVEMENT MANUAL

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INTRODUCTION

ABSTRACT

As an answer to the stormwater run-off problem associated with urban development in growth areas such as the state of Florida, portland cement pervious pavements provide a desirable combination of stormwater retention properties and essential features of conventional paving concrete. Given suitable site conditions, portland cement pervious pavements obviate or reduce the need for stormwater drainage systems and retention ponds required for impermeable pavements by Florida statues. Advantages of pervious pavements thus include generally lower installation costs and increased utilization of commercial properties, apart from its environmental function of direct replenishment of the local aquifer.

The Portland Cement Pervious Pavement Manual attempts to make the benefits of pervious pavement available for wider use through explaining what it is, how best to put it together and how to obtain a satisfactory end product. In addition to presenting product information, the manual provides guidance on use of portland cement pervious pavements. Details of subgrade preparation are discussed as well as recommended design procedures. Suggestions on determination of infiltration rates of stormwater are given, as are recommendations on making effective use of portland cement pervious pavement if unfavorable site conditions are encountered. To ease the task of the Specifier, recommended long-form and short-form specifications are included in the manual.

Design and control of a pervious material must be based on test methods that provide reproducible results. Since current standard methods are unsuitable in certain respects, modified methods have been developed in the field and described in pertinent sections of the manual.

Portland cement pervious pavements have been used over the last ten years in a fairly large number of installations, primarily in parking areas and street pavements. This manual represents the first comprehensive attempt to draw on the experience gained in these applications and present recommendations on proportioning, placing, curing and testing. Also provided is a frame of reference for the design engineer. Some of the material in the manual is necessarily tentative in nature and requires further substantiation by test data and performance reviews.

DESCRIPTION:

Portland cement pervious pavement, as the term implies, is a discontinuous mixture of coarse aggregate, hydraulic cement and other cementitious materials, admixtures and water which allow for the passage of water and air. This type of concrete has a variety of names including porous, gap-graded, no-fines, permeable, drain-crete, low density, and perk-krete.

The omission of most or all of the fine aggregate which is a standard ingredient of conventional portland cement concrete provides the porosity of pervious pavements. In order to provide a relatively smooth riding surface, and to enhance handling and placing properties, a coarse aggregate of 3/8 in. maximum size is normally used. Typically, portland cement pervious pavements using this aggregate has a void content in the 15 to 25 percent range which imparts satisfactory percolation characteristics to the product.

In portland cement pervious pavement applications for traffic loadings, the cement content is generally higher than that of normal paving concrete. The additional cementitious material provides a high strength mortar matrix capable of bonding the coarse aggregate particles and bridging the voids in the pavement structure.

The water content is held low to produce a mixture with a relative slump between zero and one-inch range. Crushed aggregate will have a low slump appearance while gravel aggregate will seem to have a higher slump range. The amount of mix water must be sufficient to promote hydration and strength gain. If less than the required water is available in the mix, hydration will not proceed adequately and the mixture remains an agglomeration of loose particles. Too much water will cause the resultant fluid cement-water slurry to drain into the lower layers of the pavement where it impairs or blocks stormwater percolation after hardening.

Although slump is sometimes referenced as a visual concept, the slump test is not suitable for determining the consistency of portland cement pervious pavements. As explained under this Manual's Mixing and Transportation section, consistency of the product is controlled by visual inspection.

When properly proportioned and placed, the hardened pervious pavement provides a smooth riding surface while retaining an open surface texture. Its friction value appears to be higher than that of conventional pavements.

BACKGROUND:

Portland cement pervious pavement is generally regarded as a new construction material. Although its use in a pavement application is relatively recent, pervious concrete has been used in structural applications in Europe and Great Britain for over fifty years. (1, Mallhotra, 1976, p.628). The earliest application was in 1852 in the United Kingdom. Two houses were built in East Cowes, Isle of Wright, with 12-14 inch thick walls consisting of pervious concrete. At the same time, a seagroyne of 200 ft.long and 7 ft. high was built at a right angle to the shore to form a breakwater protection barrier. Holland reintroduced pervious concrete to the United Kingdom in 1923 resulting in the building of over 50 two-story houses. By the 1940's over nine hundred housesmade of this material had been constructed.

After World War II, pervious concrete for building construction became wide spread in Germany, Holland, France, Belgium, Russia, and the United Kingdom. During this time, one British firm constructed 250,000 dwellings. Pervious concrete was not only used as infill panels for high rise buildings but also for load bearing walls up to ten stories high. In Stuttgart, Germany, one project consists of six lower stories of conventional concrete and the thirteen upper load bearing stories of no-fines concrete.

The only known pavement application of a portland cement pervious pavement was constructed in England. The following is the report of this project; however, due to the limited application, the conclusions may be considered preliminary in relating to methods of placement.

In the mid-1960's an experimental road was constructed in England (7. Maynard, 1970, p.245). The pavement structure included an eight (8") inch conventional dense wire reinforced concrete pavement and a two (2") inch monolithic pervious concrete surface. The surface was placed using a twelve (12") inch diameter steel pipe weighing thirty (30) pounds per foot. The portland cement pervious mixture used a 3/8" inch coarse aggregate and required six (6) passes to obtain density and an acceptable riding surface. The pipe was kept moist to reduce adhesion of the aggregate and paste to the surface of the roller. (The use of form release compound will also provide reduced adhesion to roller surfaces.) The report did not recommend a vibrating beam as it tended to drag and displace some surface aggregate across the surface. Curing was provided by covering the surface with a polyethylene sheeting. Other details included the use of battens on the forms that were one-half (1/2") inch higher than the desired surface elevations to obtain initial leveling. Upon obtaining initial profile rolling, the battens were removed and the desired elevation was then produced by additional rolling. This whole operation took place within thirty (30) minutes after introducion of the mix water to the concrete mixture.

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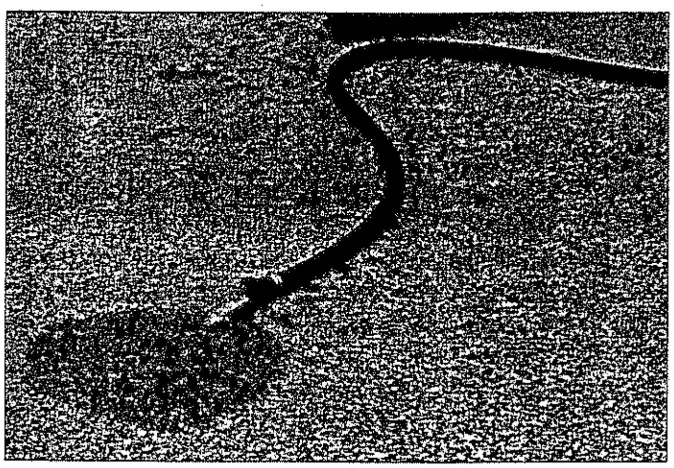
Florida Concrete and Products Association

CONSTRUCTION OF PORTLAND CEMENT PERVIOUS PAVEMENT

Stormwater management...
A challenge for design professionals, engineers, developers and contractors throughout Florida.

Sites must be planned to provide adequate run-off systems. Government regulations require that these systems also improve the quality of run-off discharge into surface waters and maintain the recharge level of the aquifer. Meeting these regulations, and still using maximum available land for development, requires creative use of proven technologies and materials.

Portland cement pervious pavement provides an environmentally sound alternative that meets the challenges of government regulations, as well as the needs of design professionals and owners.



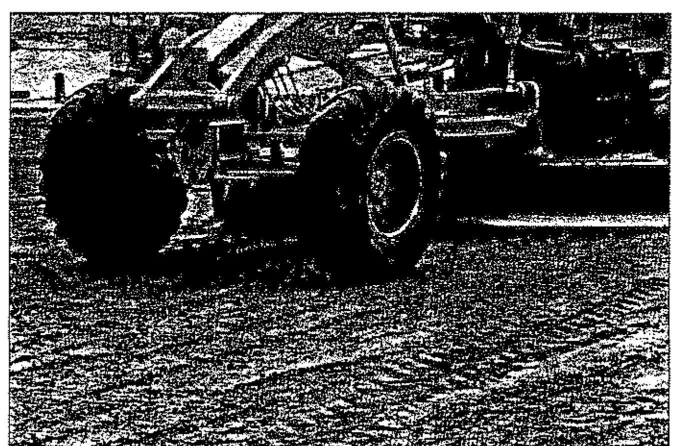
Pervious pavement retains stormwater, and improves water quality for aquifer recharge through filtration.

Pervious pavement is a discontinuous mixture of coarse aggregate, hydraulic cement and other cementitious materials, admixtures and water, which allows water and air to pass *through* the pavement. Unlike traditional concrete or asphalt pavements, pervious pavement provides a void content of 15-25 percent, which offers improved filtration for better groundwater quality. It also retains stormwater and allows for percolation of water back into the aquifer.

Field performance tests of pervious pavement installations across Florida have demonstrated the product's ability to help meet stormwater control requirements while providing a structural pavement for traffic. Investigations show that pervious pavements continue to function without signs of structural distress or clogging.

The drying shrinkage of a pervious cementitious mixture is substantially less than that of conventional concrete. This extremely low shrinkage rate is attributed to the interlock of the aggregate particles which restrains the cement paste shrinkage.

The success of pervious pavement is directly linked to subgrade quality, correct mixing and proportions, and proper placement, curing and finishing by the contractor.



Subgrades must be permeable, uniform and properly prepared and compacted.

This publication is intended as a general guide, based on the latest technology. However, mixture refinements and placing techniques are updated regularly, and contractors are encouraged to consult manuals and material specifications for the latest technical details before placing pervious pavement.

The natural soil in any project should be sampled and tested for permeability as well as load carrying capacity. Uniformity of subgrade support, rather than strength, is the major criteria of a suitable subgrade. Testing should be conducted to assure the quality of the subgrade.

Clay soils and other impervious layers impact the performance of pervious pavements, and must be modified to allow proper retention and percolation of stormwater. In these conditions, additional pervious material can be placed at least six inches above unsuitable soils. Depth of this additional subgrade material must provide the additional retention volume required for each individual project site. Filter reservoirs of an open graded stone, gravel, open graded portland cement subbase, or sand layer provide proper subgrades to retain and store surface water run-off, reduce the effect of rapid storm run-offs, and reduce compressibility.

When the existing soils are predominantly sandy and permeable, an open graded granular subbase is not generally required, unless it facilitates placing equipment. A sand and limestone subgrade offers the best conditions for pervious pavement.

In addition to the uniformity of the subgrade, the compaction and density of the soils is important. Depending on the soil type, the subgrade should be compacted to a minimum density range of 92 to 96 percent of maximum density, per AASHTO T-180 standards. The subgrade reaction determines how thick the layer of pervious pavement should be. Similar to the requirements of regular concrete placement, any truck ruts and other irregularities in the subgrade must be smoothed and compacted prior to placing the pervious pavement.

The subgrade is compacted to 92 to 96% of AASHTO T-180, must be moist and free of truck ruts and other irregularities.

The portland cement pervious pavement has minimal free moisture. If the subgrade or subbase soils are dry during placement, it may accelerate the set time and impact the performance of the pavement. At the time of placement, the subgrade is kept moist, without any freestanding water, as in conventional concrete pavement methods.

Permeable subgrade materials, proper density through compacting, and uniformity contribute to the best subgrade for placement of pervious pavements.

Discharge must be completed within 60 minutes after initial batching or 90 minutes with special admixtures.

A portland cement pervious pavement consists of unique properties that require special attention during mixing and transporting. The pervious pavement mixture should be completely discharged within one hour after the mix-water has been added. With the use of new and innovative admixtures, this time can be extended to one and a half hours. High ambient temperatures and windy conditions will directly affect the initial set time and should be taken into consideration.

The total water content of portland cement pervious pavement is confined to a narrow range. Close control of the mix water demand is critical to obtain permeability and adequate strength of cement-aggregate bond. Contractors must work closely with producers to ensure a proper mix, prior to delivery at the job site. A slight adjustment of water content may be required at the site to achieve proper consistency.

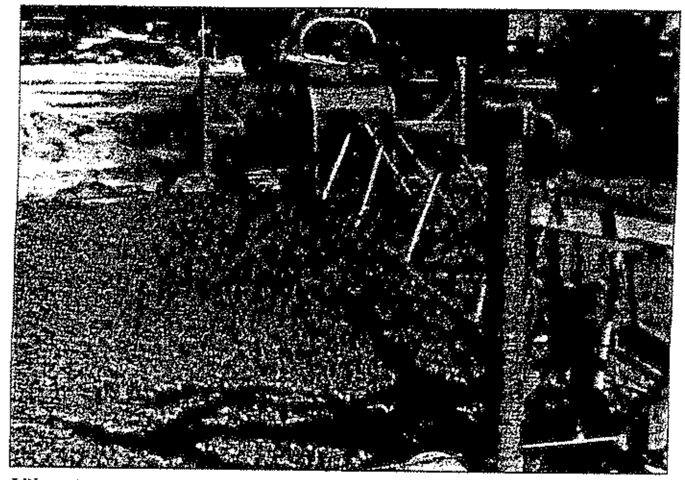
A stiff mix is required with close control of mix water to obtain both permeability and adequate cement-aggregate bond.

A correct water content gives the mixture a wet-metallic appearance, or sheen. *This is only a rough guideline to test consistency,* and nothing can replace the accuracy of objective testing. Insist on a unit weight test to ensure a good mix.

Placing and consolidating is the next phase that requires the contractor's keen eye for detail. If a contractor has not worked with pervious pavement before, it's advisable to place sample strips *before beginning a larger area to become familiar with the properties of the material.*

Spreading, strike off and compacting must be completed as quickly as possible due to the rapid setting characteristics of the mix.

Before placing pervious pavement, all forms and grade should be re-checked for alignment and plan profile. Any rutting of the subgrade by equipment or trucks should be releveled and recompacted, so that the overall subgrade is uniform. Before placing the mix from the truck, inspect each load to make sure it has the right consistency and adequate aggregate surface coating.

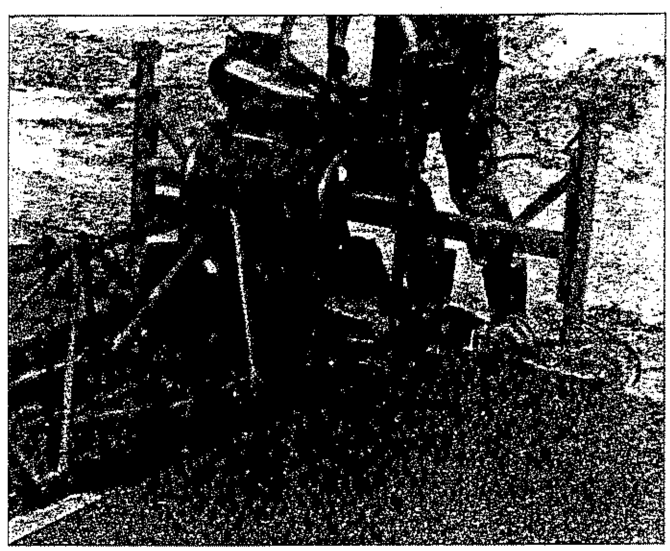


Vibrating mechanical screeds offer the best results.

Mixture discharge should be as rapid and continuous as possible. Placement width should not exceed 15 feet unless a contractor has experience and sufficient mechanical consolidating equipment.

Spreading, strike off and compacting must also be completed as quickly as possible. Both vibrating and manual screeds will accomplish *the job, but vibrating mechanical screeds offer the best results.*

Strike off should leave some material above the form to allow for proper compacting. Compaction will vary with job site conditions, but experience shows that striking off a minimum of a half-inch above the form, and then compacting down to the form, will avoid surface raveling.

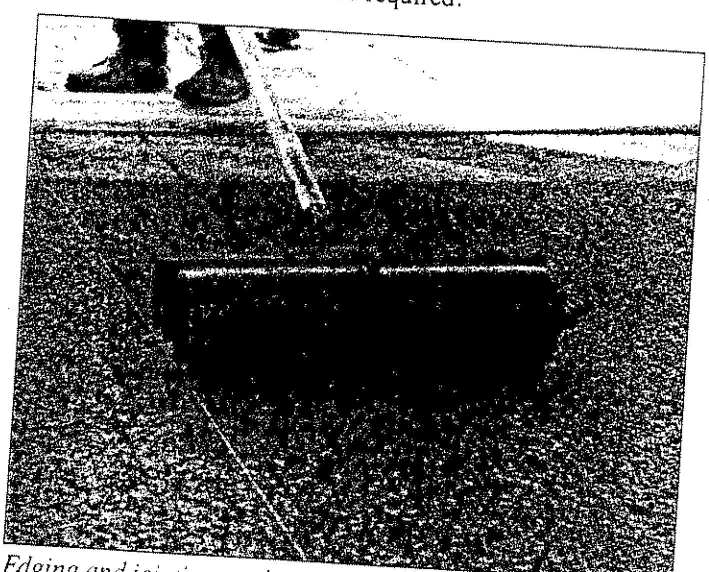


Experience has shown that striking off a minimum of ½-inch above the form and then compacting down to the form will avoid surface raveling.

Compaction must be completed immediately after strike off. Delays will harm the finished pavement surface because of the mixture's rapid moisture loss and set time. A heavy roller spanning the full distance between forms has been found to be effective in compacting material to form height in a timely manner that is true to line and grade.

Compaction must be completed immediately after strike off to prevent raveling.

Edging and joints need special attention and tools. Conventional tools and finishing methods are not appropriate for pervious pavement. After placement, compacting and edging, no additional finishing operations should be required.



Edging and jointing need special attention and tools.

Because of its susceptibility to rapid evaporation of mix-water and hydration, proper curing is essential to a successfully finished project using pervious pavement. After compaction is complete and no longer than 20 minutes after placement, the entire surface and edges of the newly placed pavement must be immediately covered with polyethylene sheeting. Cure time for pervious pavement is generally seven days.

Cover completed pavement with polyethylene within 20 minutes after placement.

Sheeting must be secured during the cure time, and no traffic can be allowed on the surface. Sand or dirt should not be used to hold down sheeting.

As with any engineered project, proper testing of pervious pavement is critical. Testing of the subgrade will assure adequate density, support value and permeability. Testing the pervious mixture in both the plastic and hardened state will assure quality of unit weight, durability and thickness.

Sheeting must be secured. Cure for seven days.

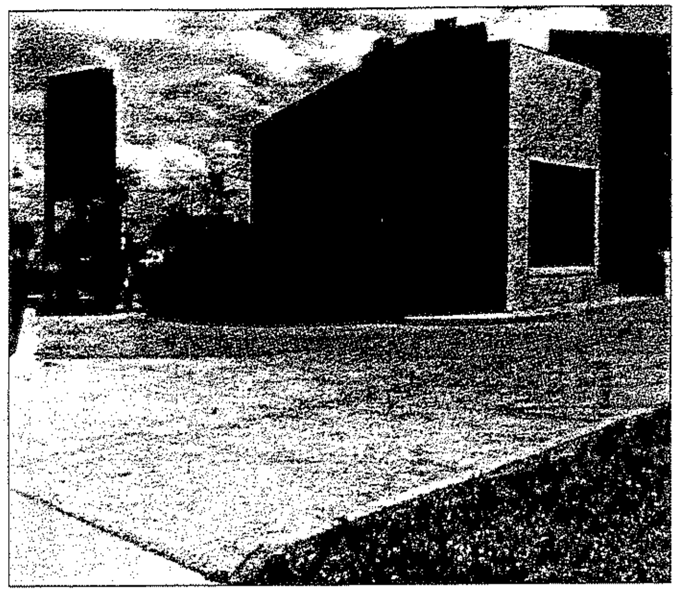
There are two different aspects of acceptance criteria for pervious pavement. The first criteria is based on the delivered mixture. At least one test for each day's placement should be conducted to verify the unit weight of the material, and should be within plus or minus five pounds per cubic foot of the design unit weight utilizing a .25 cubic foot sample.

The second criteria should be based on the hardened pavement. Three samples should be core drilled to measure thickness and unit weight. In-place unit weight should be within plus or minus five pounds per cubic foot of design unit weight, for the average of the three samples.

Summary

Portland cement pervious pavement is a unique product with characteristics unlike any other pavement material. Successful placement and finishing can be achieved quickly and efficiently when the contractor understands the best ways to prepare for, place, install and cure pervious pavement:

- Proper subgrades and subbases are critical to product performance. Subgrades must be permeable, uniform and properly prepared and compacted.
- The consistency must be carefully checked before placement. Proper consistency is very important.
- Pervious pavement mixes should be placed 60 minutes after initial batching, or 90 minutes with the use of proper admixtures.
- Spreading and strike off must be completed as quickly as possible. Compacting should be finished immediately after strike off due to rapid hydration of the product.
- Edging and joints need special attention and tools.
- Completed pavement must be covered quickly with polyethylene sheeting within 20 minutes, and cured for seven days.
- Quality of the portland cement pervious pavement can only be assured by regular testing of the mix and performed by qualified, certified personnel.



Successful placement and finishing can be achieved quickly and efficiently with long lasting results when the contractor understands the best ways to prepare for, place, install and cure pervious pavement.

Portland cement pervious pavement is a proven technique that innovatively uses traditional materials for stormwater management meeting the challenges of today's developers, design engineers and contracting professionals. A manual relating to mixing, hauling, placing, testing and suggested design procedures, and a construction training videotape are available through the Florida Concrete and Products Association at a nominal fee. These comprehensive tools will assist material suppliers, contractors, specifying agencies and design professionals in the proper procedures used to place portland cement pervious pavements.

GENERAL INFORMATION AND RECOMMENDATIONS FOR PAVEMENT APPLICATIONS:

The following information is presented for the purpose of guidance to the design professional, material supplier, and contractor. Due to the variation of materials, project soil conditions, profiles and methods of placement, this information may not be suitable in all cases and applications. Further information and test data will be presented as it is developed.

The two primary purposes of a portland cement pervious pavement are to provide a durable all-weather surface capable of withstanding anticipated traffic loadings and provide an effective storm water management system that will enhance the hydrological environment. This special material is capable of providing a pavement with the durability and longevity of concrete and the capability of an on-site retention area.

SUBGRADE PREPARATION:

The natural soil encountered in any project should be sampled and tested for permeability as well as the load carrying capacity. When the condition of the existing soils is predominantly sandy, poorly graded, and permeable, an open graded granular subbase is not generally required unless it would facilitate placing equipment.

Uniformity of subgrade support, rather than strength, is the major criteria of a suitable subgrade. Portland cement pervious pavements have a slab action which distributes the loads over a large area similar to conventional concrete pavements. This load distribution diminishes the pressure on the subgrade and eliminates the need of thick subbase courses.

Since uniformity of subgrade support is essential to pavement performance, it must be assured in both dry and moist subgrade conditions. A properly constructed pervious pavement facilitates this requirement, specifically when exposed to rainfalls. Due to the uniform distribution and infiltration of rain water over the pavement area, a uniform moisture condition is obtained in the subgrade. This may explain the absence of pumping failures in pervious pavements which could be expected to occur due to loss of subgrade support in sandy soils. However, problems related to variable subgrade support may result from the presence of silts and clays that are either highly compressible, lack cohesion, or expand when in a wet condition. These soil conditions must be analyzed individually for their support values and be modified, replaced or additional pervious material placed at least 6 inches above the unsuitable soils. Depth of additional pervious subgrade material is directly related to the volume of retention required for a project's site conditions.

The use of a narrow strip of pervious pavement between or adjacent to a standard impervious pavement is not generally recommended. Experience has demonstrated that projects designed with a four (4) to six (6) foot wide collection area adjacent to standard pavements perform poorly. Not only do the narrow pervious section show excessive clogging but the edges of the impervious pavement exhibited distress due to differential subgrade support because of the additional moisture conditions. Accumulation of moisture in the subgrade at the juncture of the two pavement types have caused excessive deflection and edge cracking in the conventional impervious pavements. Impervious pavements should be increased in thickness and reinforced as required along the edge interface of each pavement type.

Where clay soils or impervious layers are encountered, there are options available for the designer that will allow the use of a portland cement pervious pavement. Filter reservoirs of an open graded stone, gravel, open graded (no. 57) portland cement subbase, or sand layer can provide retention to store surface water run-off, reduce the effect of rapid storm run-offs and also reduce compressibility. The use of a sand subbase and a pavement fabric underlayment is also an option that should be reviewed on the basis of economics. Since pervious pavement retains water within itself, an increase in thickness of the pavement placed on a geotechnical fabric would be another viable solution. The use of a two layer bonded pervious pavement, with a lower layer of larger graded top size aggregate (1 1/2"), should also be considered. The lower layer may be designed at a lower cementitious content than the surface layer. Cement contents of 375 to 500 pounds per cubic yard may be considered as a subbase retention. This two layer system, over a silty clay soil, will increase the composite slab action of the pavement, provide increased load carrying capacity and serve as an increased retention reservoir.

Depending on the soil type, the subgrade should be compacted to a minimum density range of 90% to 95% of maximum density as determined by AASHTO T-99 or AASHTO T-180. The modulus of subgrade reaction (k) lb per cubic in. should be determined of the existing soil conditions to establish the design requirements. Appendix (A) shows the relationship of the California Bearing Ratio, Limerock Bearing Ratio, and K-Values.

Before pavement is placed, the subgrade or subbase should be consolidated in accordance to specifications and in a moist condition. The portland cement pervious pavement has minimal free moisture and if the subgrade or subbase is in a dry condition at the time of placement, accelerated set time and a reduction in performance of the pavement may result. At the time of placement, it is important to keep the subgrade moist without the presence of free standing water as in conventional concrete pavement methods.

MATERIALS AND PROPORTIONS:

A portland cement pervious pavement consists of the same materials as regular concrete except for the omission of most or all of the fine aggregate normally used in concrete. The materials should comply with applicable ASTM standards or the Florida Department of Transportation requirements. As a rule, a pervious pavement is specifically proportioned for use in applications subjected to vehicular traffic. Different proportions may be required for other applications, such as walls, pool decks, tennis courts, or drainage areas.

The same cementitious materials are used in a portland cement pervious pavement as in normal portland cement concrete, including portland Type I or II cement (ASTM C150) or blended cement Type IP or IS (ASTM C595). The cementitious content generally used to date for a typical pervious pavement mixture range from 520 to 630 lbs per cubic yard with a 600 lbs. content prevailing in pavement applications. Ground granulated blastfurnace slag (ASTM C989) may be substituted for portland cement in an amount of fifty (50%) percent of the total cementitious material. When fly ash (ASTM C618) is to be used, the quantity should not exceed a range of 15 to 20 percent of the total cementitious material.

The use of Florida limerock aggregate for pervious pavement has performed well in projects subjected to vehicular traffic throughout Florida. It is not necessary to substitute other aggregate sources that are not normally used in a standard .concrete mixture. Aggregates incorporated in the mix design are generally of a No.89 size (3/8 inch to No.50) complying with ASTM D448 (Appendix B). Another frequently used size is No. 8 coarse aggregate (3/8 inch to No.16) complying with ASTM C33. In proportioning a portland cement pervious mixture, the basic relationships are expressed in terms of the aggregate/cement ratio (A/C) and the water/cement ratio (W/C). In pavement applications, an A/C range of 4:1 to 4.5:1 and a W/C ratio range of 0.34 to 0.40 were found to produce pervious pavements of satisfactory properties in regard to permeability, load carrying capacity, and durability characteristics. The unit weight (density) of a pervious pavement will generally range from 105 lbs/cu.ft. to 125 lbs/cu.ft. and will have a void structure of 15% to 25%. A higher permeability rate would result for a pavement core with a unit weight less than the theoretical unit weight of the mixture design. The specific gravity of pervious concrete produced with crushed limestone is approximately 1.68 to 1.90, depending on the aggregate source. For given proportions utilizing hydraulic cements, the performance of pervious pavements is inversely related to its void space. A greater degree of compaction will increase bonding of aggregates with a resulting decrease in the void content. Unless a similar degree of compaction is obtained in both the in-place pavement and in a corresponding strength test specimens, no valid inference can be made from the strength indications of test specimens on the strength of a pervious pavement at this time. Some relationships have been established empirically between specific methods of placement and various levels of compaction of test specimens. These are explained later in the chapter on Methods of Test. The validity of the relationships can be verified by unit weight determinations on the pervious mixture under consideration. The unit weight of a pervious mixture is approximately 70 percent of normal concrete. A minimum frequency of one (1) test for each day of placement should be conducted to verify the rodded weight of material as delivered. The test shall be conducted in accordance with ASTM C172 and C-29.

Mix shall be within ($\pm$5) five pcf of design unit weight. If outside this range, mix proportions should be modified to comply. At seven (7) days from placement, a minimum of three (3) cores for each placement will be taken in accordance with ASTM C-42. The cores may be used for verification of pavement thickness. Subsequent to thickness verification, core ends may be trimmed to facilitate volume determination. Core unit weight should be calculated based on weight results when tested in accordance with ASTM C-140 paragraph 14.1 (disregard suspended weight).

Pavement acceptances shall be based on the average unit weight of cores being within $\pm$ 5 pcf of design weight. The thickness of the pavement for light traffic loadings should be five (5") inches. Additional thickness would be required for pavement subjected to frequent heavy axle loadings.

The total water content of portland cement pervious pavement must be held in a narrow range. A correct water content is characterized by its imparting to the mixture a wet-metallic appearance or "sheen". At this consistency level, the pervious mixture approximates the placing and handling characteristics of asphaltic paving or patching mixtures. If the mixture contains an excess of mix water, its cementitious paste will flow into the lower layers of the pavement resulting in a weak surface stratum and closure of voids in the bottom layers. A mixture with less than the required water content, on the other hand, will hydrate very rapidly and will result in a lack of adequate aggregate bond strengths. In extreme instances this will lead to the pervious pavement remaining with an agglomeration of loose particles of little or no bonding strength that must be removed from the work. At its correct consistency, squeezing of a handful of the mixture and then releasing pressure should result in a mix that neither crumbles nor turns into a highly plastic mass without air voids. Inclusion of a chemical admixture in a pervious pavement mix will improve its handling and in-place performance characteristics. Admixtures of the water reducing Type A (ASTM C494) and the water-reducing and retarding Type D conforming to ASTM C494 have shown good performance, particularly in hot weather applications. High range water reducing admixtures have not, to date, proved effective in improving the placing of pervious concrete. Future research is needed to make more definitive recommendations regarding their use. Admixture manufacturer's recommendations as to dosage rate and batching sequence should be followed.

Inclusion of air entrainment admixture (ASTM 260) was found to create void structures in the cement paste which improved the pavement's resistance to damage from freeze/thaw cycles. The large void structure in the pavement and the elasticity of the air entrained cement paste produced by the absence of the fine aggregate also provides for expansion of ice lenses within the pavement structure. Mix proportions for job use are established to produce a cubic yard of a pervious mixture in conformance with ASTM C94 "Specifications for Ready-Mixed Concrete." The void content of the proposed mixture should closely approximate that anticipated with the method of placement in the work. In a limited study, the addition of double the normal amount of air entrainment admixture increased the cohesive characteristics of the cement past and aggregate.

PROPERTIES OF PERVIOUS CONCRETE:

Jointing:

Portland cement pervious pavement is a unique construction material and develops some behavior characteristics unlike standard portland cement concrete. The drying shrinkage of a pervious cementious mixture is substantially less than that of conventional concrete. Conventional concrete shrinkage is approximately .005 inches per inch of length, whereas, the pervious concrete range is 0.00015 to .00020 inches per inch of length (1, Malhotra, 1976, p.638). This explains why a project incorporating portland cement pervious pavements measuring 180 lineal feet and six to eight inches in depth using no control joints showed no visible shrinkage cracking after two to three years of service. The low shrinkage rate is attributed to the interlock of the aggregate particles which restrains the cement paste shrinkage. A conservative design should include transverse contraction (control) joints at a spacing of sixty (60') feet installed to a depth of one-fourth (1/4) the thickness of the pavement. This is particularly true when a high density of the pavement is achieved. Again, it should be noted that many projects have not included contraction (control) joints and there are no signs of cracking following two (2) to three (3) years of service. Shrinkage cracking is evident in pavements placed with higher than required slumps and that have been extensively vibrated. These pavements have shown significant cracking and very low permeability characteristics. More observations and testing are needed to determine: 1) permeability characteristics; 2) contraction joint performance; 3) joint spacing in pervious pavements.

Close control of the water demand of the mix is very important to avoid shrinkage cracking, provide adequate strength and required permeability. Although the amount of drying shrinkage is less than that of conventional concrete, it develops at a more rapid rate due to the large surface area exposed to air and the low amount of water included in the mixture. Between fifty (50%) to eighty (80%) percent of total drying shrinkage can be expected to occur within ten (10) days of placement.

Curing:

Due to the rapid rate of hydration, curing is very important to the quality of the in-place product. The method of curing normally used is to cover the exposed surfaces with a polyethylene sheet material (6 mil minimum) as soon as practical, but not later than 20 minutes after completion of placement. When ambient temperatures are high and conditions are windy at the time of placement, a light fog mist should be applied just prior to covering the surface to assure the normal strength gain of the pavement surface. Care should be exercised in covering the exposed pavement's surface and edges. The polyethylene sheeting should be carefully lapped and held securely in place for the entire curing period. The period of curing should generally be from three (3) to seven (7) days, depending on the cementitious material used and strength gain rate. Without proper curing, a pervious pavement may reach only forty (40%) percent of its potential strength gain and will be susceptible to increased surface deterioration.

A portland cement pervious pavement placed without accelerators and using Type I cement should be continuously covered for a period of five (5) to seven (7) days. When rapid hardening portland cement Type III or accelerating admixtures are used for early opening to traffic, curing should be continuous for three (3) days. A period of seven (7) to ten (10) days maybe necessary when using portland blast furnace cement, fly ash or portland cement Type II cements. To date, membrane curing compounds have been applied to a limited number of studied projects. Further investigation is needed for evaluating the effectiveness of a membrane curing compound and of other materials and methods of curing that will improve the quality and economics of the pavement.

Strength Development:

As stated previously, the strength development of pervious concrete relates to the A/C and the W/C ratio of the mix. Both ready mix and private accredited laboratories have conducted numerous tests on the various mix designs. The results of some of these tests are included in Appendix C. The flexural and compressive strength gains in seven (7) days appears to be eighty (80%) to ninety (90%) percent of its potential strength at twenty-eight (28) days using a Type I portland cement. The relationship between splitting tensile strength to flexural strength is between sixty (60%) to seventy (70%) percent. Data supports a sixty-five (65%) percent value to be used in pavement design calculations. Previous test reports show that compressive strength gain occurs at a slower rate than that of the modulus of rupture (flexural strength). Compressive strengths continue to improve for sixty (60) months with no substantial strength increase after this period. Flexural strength gains more rapidly than compressive strengths; however, virtually no additional increase is experienced after thirty (30) months. (Appendix D) (1. Malhotra, 1976, p.636).

The unit weight or density of pervious concrete is in a range of seventy (70%) to eighty (80%) percent of that of conventional concrete. The degree of compaction of the materials in test cylinders or unit weight measurements largely determines unit weight and percentage of voids. The unit weight (density) also has a direct relationship with the compressive, flexural and tensile splitting strengths of the product. The results of strength tests by different sampling and testing methods are interrelated; however, before strength specifications can be used repeatable test methods will have to be developed. Available data indicates a direct relationship of the splitting tensile strength of test cylinders of a given unit-weight to the flexural strength of the in-place pavement of the same in-situ unit weight. A major consideration in a rigid pavement design analysis is the modulus of rupture (flexural strength) of the concrete. If the splitting tensile strength of a cylinder and its weight is determined, the flexural strength of the in-situ pavement may be estimated from the unit weight of the pavement section. The suggested formula for this determination is provided in equation (4) of the Interim Guide for Design of Portland Cement Pervious Concrete Pavements.

Permeability:

Various tests for permeability have been conducted. The results of some of these tests are included in Appendix E. A pavement with fifteen (15%) percent voids or higher will provide adequate flow rates to meet the minimum acceptable storm water criteria. A wide range of test procedures have been used to determine the porosity of the pavement (Appendix E). Some tests show that six (6") inches of a pervious concrete with 4:1 A/C ratio placed on a sand base thirty six (36") inches deep had a 54.7 inches per hour flow at a depth of four (4') feet below top of pavement. Other permeability tests show the porosity of a 3/4" to No. 4 crushed aggregate having a vertical permeability of 6.8 gals. per min. through twelve (12") inches of a 6:1 A/C ratio product. Additional data shows a portland cement pervious mixture sample infiltrated with sand with an FM=2.43. The flow rate of the infiltrated sample of six (6") inches was calculated to be 3.92 gpm per sq. ft. A standardized permeability test is needed to obtain usable data for calculating percolation rates and retention volumes. This test should provide flow rate data in gpm per sq. ft. and vertical velocity in inches per minute. In lieu of specific data, a rating scale of 1 to 10 could be adopted to indicate the pavement performance for permeability.

Reinforcement:

In a pavement application, no reinforcing steel is required. This is due to minimum, if any, cracking of the pavement. Reinforcement, however, is required in building construction using a pervious mixture. Due to the low bond strength, reinforcement should be coated with a cement paste prior to concrete placement. This will improve bond strength and provide corrosion resistance.

Capillarity:

The capillary action of a pervious pavement, as expected, is extremely low. For mixes using a 3/8 inch coarse size aggregate, water capillary action would be less than one (1") inch. A significant aspect of this property is that a portland cement pervious pavement is not prone to the pumping action normally related to a conventional concrete pavement designed without adequate drainage provisions. Due to a relative low hydraulic head pressure, dynamic loading will not cause water and fine grain soils to be pumped up through the pavement unless the water level is above pavement surface elevation and in a flooded condition.

MIXING AND TRANSPORTING:

The unique properties of a pervious mixture requires special attention in the mixing and transportation. To produce a mix of the proper consistency and assure an even coating of aggregate particles with portland cement paste, proportions must be correctly adjusted for aggregate moisture. Initial charging of the materials into the mixer must be in a sequence which minimizes undesirable balling of materials. Ready mix trucks with wide discharge openings aid in discharging a pervious mixture with a relative zero slump. On rear discharging units, the front of the mixer-truck should be elevated, if possible, to aid discharging. It is recommended that the trucks be inspected for mixer blade wear prior to use and that each ready mix truck should not haul more than two (2) loads before being cycled to another type concrete. A pervious mixture exhibits a strong bonding effect and will cause rapid build-up on the mixer blades if not cleaned properly and closely inspected. The use of a water reducing retarder will assist placing operations by increasing the initial set time of mixture when long duration haul times are anticipated.

It is recommended that after batching, a visual inspection be made to assure proper water-cement (W/C) consistency. During transportation, the mixer drum should be rotated at the lowest agitating speed. Discharge of a pervious mixture from the haul unit should be complete within one hour after the mix-water has been introduced. High ambient temperatures will directly effect the initial set time and should be monitored carefully.

As a general note, there is no data to date, available on the pumping characteristics of a pervious concrete; however, due to the nature and characteristics of the mix, pumping does not seem feasible or practical.

PLACING AND CONSOLIDATING:

Proper placing procedures represent one of the most critical aspects of good performance in a portland cement pervious pavement.

It is recommended that only contractors experienced in the placement of pervious pavements be used. Others should retain the services of an experienced consultant. If this is not feasible, it is recommended that material suppliers and contractors without previous experience place sample test strips. This will provide a working knowledge of all aspects of the mixing, hauling, placing and curing procedures for those concerned with the project acceptance.

Before concrete placement, the subgrade or subbase should be consolidated in accordance to specifications and in a moist condition. A pervious mixture has a minimal free moisture content. If the subgrade or subbase is in a dry condition, rapid moisture loss to subgrade will accelerate the set time and cause a reduction in strength of the pavement.

Prior to placement of the pervious mixture, the forms and grade should be checked for alignment and plan profile as in conventional concrete placement. Rutting of the subgrade by material delivery or construction equipment should be releveled and recompacted to provide a uniform pavement thickness and uniform subgrade support. Before the discharging operation begins, a visual inspection of the mix should be made for proper water/cement paste uniformity and adequate aggregate surface coating. Refer to the "Mixing and Transporting Section" regarding "metallic-sheen" appearance. Any material balling should be reported to the batch plant and these balls should incorporated in the pavement. Material batch seque[illegible] moisture control and mix-blades should be carefully [illegible]lyzed if balling continues.

The material discharge should be as rapid and continuous as possible. If material flow is interrupted, the mixture remaining on the discharge chute should be removed and deposited on the grade. All material on the grade should be consolidated and finished as rapidly as possible. It is recommended that the mixture be distributed on the prepared subgrade or subbase as evenly as possible. The use of mechanical spreading equipment will increase production and reduce contamination with subgrade material. If mechanical spreading equipment is not available, manual distribution may be accomplished through the use of square-ended shovels, come-a-longs or asphalt rakes. Care should be exercised, by the workmen, not to track foreign material into the mixture.

The next performance operation is to strike-off and consolidate the material. To date, placement procedures have included a vibrating mechanical screed or utilized hand strike-off methods, followed by a garden-type or full-width roller. Present standard form riding vibrating mechanical screeds do not have the ability to compact the mix. This type of equipment exerts minimal vertical down pressure and is restricted in compacting an extremely low slump mixture below the established form elevation. High frequency vibrators used on most mechanical concrete placement equipment may cause the mix to become densified and greatly reduce or eliminate the void structure if left to continuously vibrate in one location. Vibration may also cause the cement paste to flow from the aggregate surface and to fill the lower pavement void structure. This will reduce the concrete strength of the surface and impair the permeability of the lower portion of the pavement. If a roller or other method is used to embed protruding aggregate particles following the screeding operation, it should be accomplished immediately. Any delays in final placement operations and compaction may be seriously detrimental to the structural capacity and durability of the pavement surface. There are some inherent problems with the methods just described that may effect pavement performance. Since a screed, mechanical or hand strike-off method imparts little compactive effort, the pavement in-place unit weight relationship to the theoretical unit weight may produce less than desired results. The reduction in unit weight, due to placing operations or mix design, may be allowed for in the thickness design analysis. An allowance for compactive effort and mix design criteria results are presented in the Interim Guide for Design of P.C. Pervious Pavement.

Another problem that may occur by using the method previously described is the dislodging of surface aggregate (raveling) evident on the in-place projects. This raveling appears three (3) to six (6) months after placement and on surfaces subjected to vehicular traffic. In most cases, the raveling is generally confined to the top 3/8 to 1/2 inch of the surface particles and little sign of continued deterioration of the surface is evident beyond these limits. In order to avoid deterioration of the pavement surface, pavement rolling procedures should be executed within 20 minutes after the strike-off procedures. Any delays in rolling, at this time, are harmful since the pavement surface has already taken initial set due to the rapid moisture loss. Delayed rolling procedures also attribute to the fracturing of the mortar matrix bonding the surface particles and increase the potential for future raveling.

After reviewing a wide variety of placing methods and the performance of existing projects, the following recommendations are presented. The width of placement should not normally exceed fifteen (15') feet. It is recommended that previous experience in placing pervious concrete can be demonstrated and adequate mechanical equipment is available for placing sections greater than fifteen (15) feet.

To the degree possible, spreading, strike-off and compaction should be performed as quickly as possible and the mixture should be placed on a moist subgrade. The compactive effort should apply a minimum of ten (10) to twenty (20) psi vertical pressure (compactive effort) to the surface of the pavement. After mechanical placement, no additional finishing operations should be required. Any additional finishing such as floating, edging, etc. will be harmful to the integrity of the surface and surface qualities of a pervious concrete pavement. Application of a light fog mist to the surface on hot, windy days prior to covering with polyethylene sheeting will improve the bonding of surface particles. Care should be observed in the fogging procedure since over fogging will cause the paste to be removed from the surface aggregate and reduce durability. A method that has recently been used, with good results, includes the use a vibrating screed (low vibration) to strike-off the pervious mixture 3/4" higher than the form elevation. This is then followed by compacting the pavement surface to the form height using a small plate vibrating or roller compactor on top of 3/4" plywood sheets. The surface is tightly bonded together while still providing permeability.

The cure time for a pervious concrete pavement is generally considered to be seven (7) days. During this cure time the polyethylene sheeting should be held down securely and no traffic should be allowed on the pavement.

TESTING AND EVALUATION:

As with any engineered material, it is important to properly test a pervious pavement project. Tests performed of the subgrade condition are to assure adequate density, support value and permeability. Testing the mixture in the plastic and hardened state for quality assurance of unit weight, durability, and thickness should be conducted. Many of the present ASTM and AASHTO testing methods are applicable to a pervious concrete pavement installation; however, due to the physical characteristics of the material, modified apparatus and procedures are recommended. Appendix J

Determining the permeability of the subgrade and soil analysis are particularly important in the design and construction of a project. Present methods of determining permeability by perk testing in accordance to septic drain field evaluation at forty eight (48") inches below surface elevation is not totally applicable for singularly determining subgrade permeability. After the subgrade has been compacted to the specified density, a surface permeability test is recommended. Double ring infiltrometer, or other suitable tests, should be performed to adequately test the permeability of the subgrade.

Another method of testing the permeability of the subgrade requires the use of a 12" (twelve inch) diameter tube containing a column of water with a head elevation equal to the pavement thickness. This column of water, kept at constant head, is allowed to penetrate the in-situ subgrade material and the amount of flow in gallons per minute (gal/min) is then determined. Care should be taken to avoid leakage at the connection of the apparatus and the surface of the subgrade. Soils that are moist exhibit a higher permeability rate than dry soils. The soil should be prewetted before performing the permeability test. A controlled amount of water should be used to impart an approximate moisture content of 4 to 5 percent. This test will indicate the rate and capacity of the subgrade material to accept storm water run off and the volume of retainage.

Normal testing procedures for density (compaction) of the subgrade could be performed without modification. These tests should be conducted prior to subgrade permeability testing.

Due to the physical characteristics of the concrete mixture, standard testing methods for unit weight (density), void ratio, yield, percolation, and other properties of portland cement pervious pavement will require modified procedures. Considerable evaluations are being performed on methods of testing strengths and permeability of the strengths and permeability of the mixture and the pervious pavement. Until such time that the various methods of making and testing of the portland cement mixture (ASTM C31-84) and compressive strengths of cylindrical concrete specimens (ASTM C42-84a) have been defined and these results are reproducable at a reasonable standard deviation, it is recommended that the specification be based on a proportional mix design. This method of design specifies minimum cementitious contents, volume of aggregate and gradation, admixtures and water.

A discussion of the strength evaluations are presented in the Pavement Design Section of this manual. Portland cement pervious pavement acceptance and design criteria will have to be modified due to the unique properties of the material.

Acceptance criteria should be considered as two distinct aspects. The first acceptance criteria is based on the portland cement mixture as delivered and is recommended to be based on the unit weight. At least (1) one test for each day's placement should be conducted to verify the rodded weight of the material. This test of the mixture should be conducted in accordance with ASTM C-172 and C-29. Acceptance should be on a value of ($\pm$5) pcf. of the design unit weight.(.25 cu.ft. sample)

The second acceptance should be based on the pavement. There are many various methods of placement that will result in considerable differences in degrees of compaction of the same delivered mixture. Coring of three (3) samples of pavement will result in acceptance samples for thickness and unit weight. The unit weight determination, after trimming, may be calculated based on weight results when tested in accordance with ASTM C-140 paragraph 14.1 (disregard suspended weight). Again, pavement acceptance should be based on average unit weight of cores to be within $\pm$ 5 pcf. of design weight.

There is presently equipment that can provide a high degree of consolidation during the placing procedures. The mix design may have to be modified to facilitate this type placing equipment. When 600 lbs. is the specified cementitious content, this content should be reduced when equipment capable of providing 95% compaction is utilized. This reduction will not be detrimental to the pavement's ability to perform under traffic conditions.

Other standard tests utilized in controlling conventional portland cement concrete for aggregate gradation, cement analysis, etc., are generally appropriate for a pervious portland cement concrete mixture. Where suitable, these tests should be performed on this product.

<u>ECONOMICS</u>:

An important aspect in the development of any construction project is the economic relationship to the intended use. If a particular solution to a given problem requires costs in excess of what is economically feasible, then another solution must be sought. Portland cement pervious pavements may be the most economical solution to optimum land utilization and a reduced development cost.

The cost of usable land has dramatically increased during the recent number of years. Water-front, commercial, industrial and residential developments in metro areas are costing anywhere from $2.00 to $5.00 per square foot. For example, a one (1) acre project with a cost of two hundred thousand ($200,000) dollars utilizing only sixty (60%) percent of the land for impervious building and paving areas due to retention restrictions would realize a savings in their land costs of $4.60 per square foot. If a reduction of retention area is achieved by utilizing portland cement pervious pavement, this would increase land use by approximately twenty (20%) percent and the cost savings to the owner would be over $40,000.00. Add to this the reduction or elimination of storm pipe, at $13.00 to $18.00 per lineal foot, inlets at $800 to $1200 each, unnecessary curbs at $4.75 to $6.50 per lineal foot, sod for retention areas, special overflow structures and flumes and continued maintenance of retention areas and an additional savings of $15,000 to $25,000 can be realized. Due to the reflective quality of concrete, a 40% reduction in the number of lighting standards, at $1500.00 each, will generate even more savings. Consideration should also be given to the requirements, in some areas, for the testing of retained storm water and the expensive clean-up procedures which are required.

In an economic analysis, the total project retention area land loss, earthwork, drainage and paving costs should be evaluated. When the project costs of storm pipe, inlets, unnecessary curbs, unusable retention areas, etc. are applied to a 4000 square yard parking area, the cost for a normal impervious installation would be approximately $23.50/square yard. It is reasonable that a net savings to the owner could exceed $30,000.00 when portland cement pervious pavement parking areas are required. Present water run-off restrictions for first-flush and retention volumes would also allow for very little future expansion potential of the facility. A portland cement pervious pavement allows for more manageable use of construction sites and allows for phased growth with a minimal effect on the environment.

Unless there is an abnormal rain, parking areas would not have standing water for patrons to avoid. The establishment of grade profiles would be simplified when using a portland cement pervious pavement and future corrective drainage and structural overlays or repairs would be minimized. A portland cement pervious pavement performs best on relatively flat grades.

A new multi-family apartment complex, using pervious pavement, was recently constructed in Jacksonville, Florida. Use of this material enabled an increase in the number of rental buildings by two (2), which amounted to a total of thirty-four (34) more income properties. This was a significant increase in investment income compared to the original plans which incorporated conventional pavement, retention areas and storm drainage systems.

If all these savings are recognized by owners and developers, there is little doubt that a portland cement pervious pavement will be selected.

FIELD PERFORMANCE INVESTIGATION

PORTLAND CEMENT PERVIOUS PAVEMENT

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FIELD PERFORMANCE INVESTIGATION
PORTLAND CEMENT PERVIOUS PAVEMENT

INTRODUCTION:

The stormwater management concept of utilizing a portland cement pervious pavement is gaining considerable interest by design professionals and owners that are seeking alternate land planning techniques. Recognizing the potential for reduction in retention requirements, many developers are investigating and implementing plans with p.c. pervious pavement as the storage area to meet the required volume. The acceptance of p.c. pervious pavement as a viable alternative to the present stormwater devices such as retention or detention areas or exfiltration systems depends on the performance of the pavement under actual field conditions.

To date, limited information has been available regarding the continued permeability features of the pavement and subgrade after years of service. The first report of p.c. pervious pavement installation was located in England and placed in the mid-1960's (7. Maynard, 1970, p.245). During the early 1970's, p.c. pervious pavements were placed in the United States. To the best of our knowledge the first placements were located in Clearwater, Ft. Myers, Naples and Sarasota, Florida. The sandy soil conditions under the pervious pavement made these locations ideally suited for its application.

PURPOSE:

Laboratory studies of the material characteristics and behavior under controlled and measurable conditions are important in determining the feasibility of the use of any product. Many laboratory studies have been conducted on p.c. pervious concrete; however, actual field studies on pavement applications are limited. Since permeability and durability are the prime factors in the evaluation of this type of pavement, field investigations were conducted of pavements installed with many years of service. The investigations and studies included in this report encompassed the following areas:

1.) Development of field test procedures.

2.) Pavement's long-term durability, significant signs of distress, and effect of materials or placing methods on performance.

3.) Subgrade conditions relative to permeability and density after years of water intrusion.

4.) Degree of infiltration (clogging) of the pavement.

5.) Field permeability relationships of pavement, subgrade or subbase, and grass sod.

6.) Unit weight determinations of pavement samples.

7.) Cylinder molding and testing relationships.

PROCEDURES:

Standard test methods suitable to conduct this particular investigation were limited or not available that would result in the data necessary to evaluate the servicability of the p.c. pervious pavement. The adoption of uniform procedures were developed and implemented to conduct the field measurements that would provide permeability and unit weight measurements. It was also determined that it was impracticable to conduct a composite pavement and subgrade analysis within the scope of this study. Each layer of the pavement's structural section was sampled and tested separately.

Determination of acceptable and reliable procedures adopted for the field study were developed from a test pavement placed at the Wingerter Laboratories' facility in North Miami Beach. The mix design and the ''no-fines'' concrete were furnished by the Rinker Materials Corporation, West Palm Beach, Florida and the p.c. pervious pavement was placed by Paving Systems, Inc. of Longwood, Florida.

The scope of the analysis of the test procedures to be used in the field was expanded to also include the effect of varying the construction placement method. Unit weight and permeability tests were conducted by sampling each placement method. The long term durability will be monitored by Wingerter Laboratories and reported at a later date.

The placement procedures used in this test study were as follows:

1.) Prior to placement, the subgrade (sandy soil density) was tested by Wingerter Laboratories in various locations for future reference. At a later date, the subgrade permeability and density will again be tested to determine if any significant changes occur after being exposed to water infiltration.

2.) Pavement Section #1 was placed in forms and struck-off by the use of a mechanical vibrating screed at a low vibration setting. No other finishing or compactive effort was performed on this pavement section. The pervious pavement was then cured for seven (7) days by applying a six (6) mil visqueen covering to the surface. (Reference Sample #1 and #2, Appendix P-1).

3.) Pavement Section #2 was placed as in section #1 except the pavement was struck-off three-fourths (3/4") inch higher than the planned pavement elevation. Directly following the mechanical screed, a layer of 3/4 inch plywood was applied to the surface and then compacted to profile elevation with a vibrating roller applied over the surface plywood. Curing procedures were followed as in previous sections. (Reference Sample #3 and #4, Appendix P-1).

4.) Upon completion of the curing period, eighteen (18") inch diameter cores were removed and tested for unit weight and permeability. The subgrade below the pavement was again tested for density and permeability after the pavement cores were removed. The results of this testing showed very little difference in density from the tests conducted prior to pavement placement. The density tests conducted of the subgrade soil and pavement unit weight are shown in Appendix P-1.

5.) A pavement core sample of a known permeability was then purposely infiltrated with one (1") inch of a fine beach sand and one (1") inch of a coarse silica sand applied to the pavement sample surface (Ref. Sample #5, App. P-1). This was an attempt to ''clog'' the pavement and measure the degree of permeability loss. The original permeability of Sample #5 was measured to be 26.4 gals./min. After pressure washing the two (2") inches of the combined graded sand applied to the pavement surface, testing of the ''clogged'' sample with one (1") inch sand remaining on the surface resulted in the permeability being reduced to 4.03 gals/min. Although there is a reduction in permeability of the pavement, it should be noted that this value is higher than grass sod's permeability.

After removal of only the excess one inch surface sand without decreasing the original infiltrated sand within the pavement sample itself, the permeability test was again conducted resulting in a restoration of over forty (40%) percent of its original permeability. Continued pressure washing of the pavement sample resulted in improvement in the permeability, indicating pressure washing and surface sweeping may be beneficial in restoring p.c. pervious pavement's storage permeability characteristics.

The field testing procedures that were adopted for use in the actual field investigation are outlined in Appendix P-2. These procedures were not modified to any degree from the procedures used in the preliminary testing and evaluations conducted at the Wingerter Laboratories. Care in pavement core drilling and removal is advisable to reduce contamination of the subgrade and pavement sample. Sealing the sample in the impervious cylinder to avoid water to bypass flowing through the pavement core is important.

Concurrently with the pervious pavement placement at the Wingerter Laboratory's facility, a study of the effect of compaction on the cylinder molding specimen method was conducted. Over sixty (60) cylinders were molded using specified number of blows of a ASTM T-99 drop hammer. The results of this study are presented in the Pervious Pavement Manual, Appendix C8, C9, and C10.

FIELD TESTING RESULTS:

Wingerter Laboratory, N. Miami

The test results of the pavement sections placed with and without a compactive effort indicate higher permeability, as expected, when only the mechanical screed was used for strike-off. Conversely, the load carrying capacity is increased when a compactive effort is applied. The graph of the permeability vs. unit weight shows that as the unit weight increases, the permeability decreases. As of this writing, the pavement continues to function well and there is little sign of distress. Minor surface ravelling did occur in the section placed with no compactive effort subjected to traffic conditions.

Fort Myers and Cape Coral

The oldest p.c. pervious pavements in service are generally located in these areas and for logistical reasons were selected as the initial field study. The specific sites were randomly selected for pavements that had been in service for at least four (4) years or longer. There were no preliminary tests conducted prior to pavement coring that would influence the test results.

The results of field tests are included in Appendix P-3, Field Investigation #1 and #2.

The permeability of the samples removed from these pavements showed that the surface had been sealed-off at the time of placement. The cement paste coated the aggregate and almost completely filled-in the voids between the aggregate particles. It was observed that this impermeable cement paste was to a depth of 1/8 to 1/4 inch from the pavement surface. The samples were taped on the edges and a permeability test was conducted. As noted in the test results, low permeability was observed. The pavement samples were then inverted and a volume of water equal to 20% of the volume of the sample was poured in the sample in the inverted position. Little permeability was observed however, the sample demonstrated the ability to absorb or store water within the sample.

The laboratory analysis verified the field results. The percentage of infiltration (clogging) was shown to be less than 0.3% for these samples. This shows that minimal pumping of the subgrade materials into the pavement occurs with portland cement pervious pavement. Although as high moisture content of the subgrade was measured, the density remained in the 94%-95%, of T-180. The higher moisture content seems to show that some surface water was penetrating the pavement in other locations but due to the sealed surface, little evaporation was occurring of the moisture in the subgrade. The higher moisture content of the subgrade might indicate a loss of subgrade support; however, no pavement failures were observed related to loss of subgrade support.

Wire reinforcement (6x6:10x10) was included in the Cape Coral pavement section. The wire was located on the bottom of the pavement sample and had deteriorated drastically due to the increased amount of water the steel was subjected to. The use of reinforcement in portland cement pervious pavement would offer little value to the pavement's performance.

Naples

The thickness of the portland cement pervious pavement sampled in this area was approximately five inches thick and the pavement was functioning well. Little ravelling was observed and generally isolated to longitudinal construction joints of filled-in pavements placed between adjacent pavements. The density and moisture content of the subgrade indicated little loss of any density over the years and a moisture content of almost 10% lower than measured for the previous projects sampled. The modified split ring infiltrometer test showed a subgrade permeability of 0.25 gals/min/sft. To give a perspective permeability of the subgrade, the time required for a six inch head of water to penetrate the subgrade was approximately 30 minutes. The pavement permeability test showed the six inch head of water passed completely through the pavement in 30 seconds. There were no signs of subgrade failure in the pavement surface.

The pavement sample permeability testing showed a permeability rate of 7.27 gals/min/sft. after subjected to traffic and potential clogging material infiltration for 6.5 years. Only 3.4% of the sample was infiltrated by impermeable material (sand) during the life of the pavement. This strongly indicated that potential clogging of the pavement is not a great consideration in the long term performance of the pavement's permeability.

A surface permeability was conducted with the sample cylinder apparatus used in testing the pavement sample. The cylinder was placed on the pavement's surface and sealed. The results of this method showed a reduction in the composite pavement permeability of 40%. The thought was to use the surface test method to provide only an indication of the pavement's permeability performance. The water intrusion used in this method shows that as soon as a sufficient volume to fill the pavement void structure was reached and restricted to continuous vertical flow by the subgrade's lower permeability, the water flow then diffused laterally through the pavement's thickness.

The results of field tests are included in Appendix P-3, Field Investigation #1 & #2.

North Ft. Myers

Projects investigated in this area were parking areas that had a service life of four to eight years. The eight year old project was sampled and found to be five inches in thickness. The particular pavement sampled showed some raveling in areas subjected to traffic. There was no evidence of any pavement distress due to loss of subgrade support.
The subgrade permeability was measured to be only .01 gals/min/sft. The subgrade material was sandy with a high percentage of shell intermixed. The pavement permeability was tested to be 7.76 gals/min/sft. indicating a very high storage capacity and flow rate after eight years of service. Laboratory analysis showed that the pavement was only .16% infiltrated (clogging) with foreign material.

In order to compare the pavement's performance in relationship to the permeability of present stormwater practice, the permeability of bahia sod was tested. The bahia sod was located in an area adjacent to the pavement and the sod was tested to be 2.15 gals/min/sft. The portland cement pervious pavement had a permeability of 73% higher than the bahia sod.

Another project was then investigated for permeability. No pavement samples were removed from this project due to owner restrictions. A surface permeability test was conducted using the cylinder sealed to the surface. The results of these measurements were 9.38 gals/min/sft. This indicates that little clogging would be expected within the pavement. Surface raveling did occur in various areas of the parking facility while other areas show little sign of ravelling. No sign of subgrade failure was observed in the pavement surface.

One area was placed where the pavement was not pervious due to over-vibration of a wet mixture. The pavement did perform as a high strength pavement with normal crack patterns. Due to the lateral flow of water from adjacent pervious pavement, a section of the impervious pavement did show evidence of loss of subgrade support. The pervious pavement placed directly in front of the dumpster showed very little evidence of raveling. Also, one section 20 feet wide and 180 feet long showed no signs of any cracking after four years of service.

The results of field tests are included in Appendix P-3, Field Investigation #4 & #5.

Summary:

The performance of portland cement pervious pavement in actual field service conditions demonstrates its ability to function as a stormwater system while also providing a structural pavement for traffic loadings. Projects investigated in this study are shown to be functioning without significant signs of structural distress or infiltration of foreign material to reduce its permeability.

The investigation showed that where areas of impermeability or surface ravelling occurred, the placement method and uniformity of the mix in relationship to the mix design unit weight produced a mixture that provided a strong matrix between coarse aggregate particles and permeability of 7 to 10 gals/min/sft. An over-vibrated surface will seal the top 1/8 to 3/8 inch of the surface from water penetration. Mixtures placed without adequate water content and uncompacted will tend to cause the surface aggregate to dislodge. The field investigated showed that after initial raveling of top aggregate particles, further dislodgement did not continue.

The subgrade conditions after many years of service, do not appear to change significantly. The density of the subgrade was measured to be in the 94% to 96% of T-180 range after many wet/dry cycles. Permeability of the subgrade is an important factor in the stormwater management system and there appears that no significant reduction in the subgrade's permeability can be observed after years of service.

To date, there has not been a reported pavement failure due to the lack of subgrade support on these projects or many other pavements placed throughout the State. When a pavement is placed without a cross slope, there seems to be a vertical and lateral even distribution of fine grain particles in the presence of water entering from the pavement's surface.

The portland cement pervious pavement sampled from the various projects showed that when the pavement's unit weight was relatively in conformance to the design unit weight, the permeability and storage capacity remained high. Care should be exercised in acceptance of a portland cement pervious pavement on a unit weight criteria alone. Two projects investigated showed reasonable conformity (plus/minus 5 pcf) to the design unit weight; however, since the surface was sealed in the placement operation the pavement had little to no permeability. Acceptance can be based on unit weight as well as permeability testing.

Potential for clogging seems to be one of the largest concerns in the use of pervious pavement. The projects investigated in this study showed very small amounts of clogging after many years of service. It was also of interest that very little subgrade material was pumped into the pavement at their interface. The attempt to clog the pavement with sand in the testing procedure showed that the removal of surface material with brooming restored over 50% of the permeability immediately. Continuous flushing of the pavement during normal rain fall will also increase the permeability of the pavement. High pressure washing will also assist in restoring the permeability of the pavement.

It is of interest to note that even when the portland cement pervious pavement was clogged by pressure washing foreign material into the pavement, the permeability of the pavement was still higher than sod. The ability of the pavement to provide storage as well as a media for the transference of storm water was found to be very good. Both suspended samples and surface testing showed the pavement's ability to provide rapid absorption of significant water in a minimal time.

The field testing procedures incorporated in this field performance study showed relatively consistent results. Since this was an initial study, modifications of existing and development of new test procedures were required. Further improvements of these procedures will be made including the use of the nuclear density unit to show relative density of the pavement.

The performance investigations of the various projects demonstrated the ability of a portland cement pervious pavement's ability to perform under field conditions. Additional studies will be performed on pavements placed over types of subgrades or subbases and reported at a later date. Based on the results of these studies and other field observations, portland cement pervious pavement will provide an effective stormwater management system and long service life.

*** Special Note: This information is to be used by the design professional that is competent toevaluate its significance and limitation and who will accept the responsibility for its proper application. The Florida Concrete and Products Association, authors and contributors disclaim any and all responsibility for any other use and all responsibility for any other use of the information supplies herein.

APPENDIX

PORTLAND CEMENT PERVIOUS PAVEMENT

Test Pavement
Date: September, 1987

Location: Wingerter Laboratories Test Pavement

Pavement Age: September, 1987

Subgrade Condition:

Density: 94 dry
Permeability: .48 gals/min/sft.

Pavement:

Thickness: Avg. 5 inches
Material Design Unit Wt: 116 lbs/cuft.

Placement:

Sample #1: vibrating screed only
Sample #2,#3: vibrating screed and plate compactor
Sample #4: vibrating screed only
Sample #5: vibrating screed and plate compactor

Sample #1:
Pavement Permeability: 4 tests @ avg. 44.89 gals/min/sft.
Unit Wt. (field): 109.7 lbs/cuft.

Sample #2:
Pavement Permeability: 14.94 gals/min/sft.
Unit Wt. (field): 112.4 lbs/cuft.

Sample #3:
Pavement Permeability: 8.31 gals/min/sft.
Unit Wt. (field): 115.2 lbs/cuft.

Sample #4:
Pavement Permeability: 7.01 gals/min/sft.
Unit Wt. (field): 123.1 lbs/cuft.

Sample #5:
Sand infiltrated sample:
1 inch beach sand
1 inch silica sand
Original pavement permeability: 14.94 gals/min/sft. (Ref. Sample #2)

After 1.5 hours of pressure washing sand into sample:

1. Sample with 1" of surface sand permeability:
   5 tests: avg. 2.28 gals/min/sft.

2. Sample 1" of surface sand removed
   4 tests: avg. 6.37 gals/min/sft.

Bahia Sod: avg. 2.63 gals/min/sft.

FIELD INVESTIGATION PROCEDURES
PERVIOUS PAVEMENTS

1. Core 18" diameter sample using minimum water.

2. Remove sample. Insert red head and bolt in center of sample to facilitate removal.

3. Set sample on edge and bottom toward sun on breeze.

4. Test subgrade with nuclear gauge for density and record.

5 Brush bottom of sample of pavement to remove any subgrade material adhered to bottom surface and weigh.

6. Wrap sample edge with impervious material (duct tape, etc.).

7. Insert sample in metal cylinder that extends at least twelve inches above sample surface and tighten. Seal interface of sample with metal cylinder (model clay, silicone, etc.) to prevent water passage along sample edge.

8. Attach vertical scale in inches to inside of cylinder.

9. Suspend sample above impervious surface and fill cylinder to height of at lease 8 to 9 inches above sample surface. Allow water to drain to height of 6 inches above sample and begin timing. Stop timing when water reaches sample surface and record time.

10. Repeat procedure 9 at least 3 times or until time is constant.

11.

$A = .785398 d^2$

$A = .785398\,(18)^2 = 254.657\ in^2$

$V = 254.657\ in^2 \times 6" = 1{,}527.95$ cubic inches

1 gal =231 cubic inches

1527.95 cu.in./231 cu.in.gal=6.61 gals./time required

12. Allow core to surface dry and weigh.

13. Subgrade permeability is measured by modifying ASTM D3385 double ring infiltrometer test procedure. The outer ring diameter is reduced to 17 7/8" to allow the test to be conducted in the 18" diameter core hole.

14. A second core is removed and placed in a moisture proof container and delivered to laboratory as soon as possible. Also a sample of subgrade materials is also delivered to laboratory.

15. The second core sample is prepared and tested as follows:

a. Brush off subgrade material from bottom.
b. Oven dried and weighed.
c. Sample thoroughly flushed and oven dried. Initial dry weight and final dry weight are recorded. The net difference is considered the percentage of infiltration (clogging).
d. The subgrade material is chemically analyzed for hydrocarbon content.
e. A six (6) inch core is removed from sample and a split tensile test is performed and recorded.

16. Core holes are filled to original surface elevation.

PORTLAND CEMENT PERVIOUS PAVEMENT

Field Performance Investigation #1
Date: March 1-2, 1988

Location: 1492 Colonial, Fort Myers, Florida

Pavement age: 10 years

Subgrade Condition:

Density: 95.8 dry, 117.4 wet, 22.5% moisture
Permeability: .123 gals/min/sample = .157 gals/min/sft.

Pavement:

Field Sample:

Thickness: avg. - 3.45"
Wt. (surface dry): 63.98 lbs.
Permeability: .01 gals/min/sft.
Note: Sample surface sealed with cement paste. Inverted sample accepted water with no sign of clogging.

Laboratory Cylinder (from field sample):

Absorption = 9.5 pcf.
Absorption (%) = 7.7%
Density = 124.2 pcf.
% Infiltrated = .3%

PORTLAND CEMENT PERVIOUS PAVEMENT

Field Performance Investigation #2
Date: March 1-2, 1988

Location: Royal Building, Cape Coral, Florida

Pavement age: 12 years

Subgrade Condition:

Density: 94.0 dry, 118.5 wet, 26% moisture
Permeability: .09 gals/min/sample = .12 gals/min/sft.

Pavement:

Field Sample:

Thickness: Avg. 4.6 inches
Wt. (surface dry): 82.4 lbs
Permeability: Sample surface sealed with cement paste. Inverted sample accepted water with no sign of clogging. Other areas not sampled show permeability, note subgrade moisture content. Wire reinforcement on bottom of pavement.

Laboratory Cylinder (from field sample):

Absorption = 12.4 pcf
Absorption (%) = 10.7%
Density = 116.3 pcf.
% Infiltrated = 0.1%

PORTLAND CEMENT PERVIOUS PAVEMENT

Field Performance Investigation #3
Date: March 1-2, 1988

Location: Witch's Brew Restaurant, Naples, Florida

Pavement age: 6.5 years

<u>Subgrade Condition:</u>

Density: 97.8 dry, 117.9 wet, 14.4% moisture
Permeability: .20 gals/min/sample = .25 gals/min/sft.

<u>Pavement:</u>
Field Sample:

Thickness: Avg. 4.9 inches
Wt. (air dry): 77.85 lbs.
Theo. Unit Wt.: 114.4 lbs/cuft.
Permeability: 5 tests; 12.8 gals/min=7.24 gals/min/sft.
Surface permeability test: 4.41 gals/min.

<u>Laboratory Cylinder (from field sample):</u>

Absorption = 9.5 pcf.
Absorption (%) = 7.4%
Density = 127.6 pcf.
% Infiltrated: 3.4%

PORTLAND CEMENT PERVIOUS PAVEMENT

Field Performance Investigation #4
Date: April 6, 1988

Location: Palm Fron, North Fort Myers, Florida

Pavement Age: 8 years

<u>Subgrade:</u>

Permeability = .01 gals/min = .013 gals/min/sft.

<u>Pavement:</u>

Field Sample:

Thickness: Avg .5 inches
Permeability = 13.67 gals/min/sample = 7.74 gals/min/sft.

<u>Laboratory cylinder (from field sample):</u>

Absorption = 11.04 pcf.
Absorption (%) = 9.3 %
Density = 118.5 pcf.
% Infiltrated = .16%

<u>Bahia Sod:</u>

Permeability = 3.79 gals/min/sample = 2.14 gals/min/sft.

PORTLAND CEMENT PERVIOUS PAVEMENT

Field Performance Investigation #5
Date: April 6, 1988

Location: Hampton Inn, North Fort Myers, Florida

Pavement Age: 4+ years

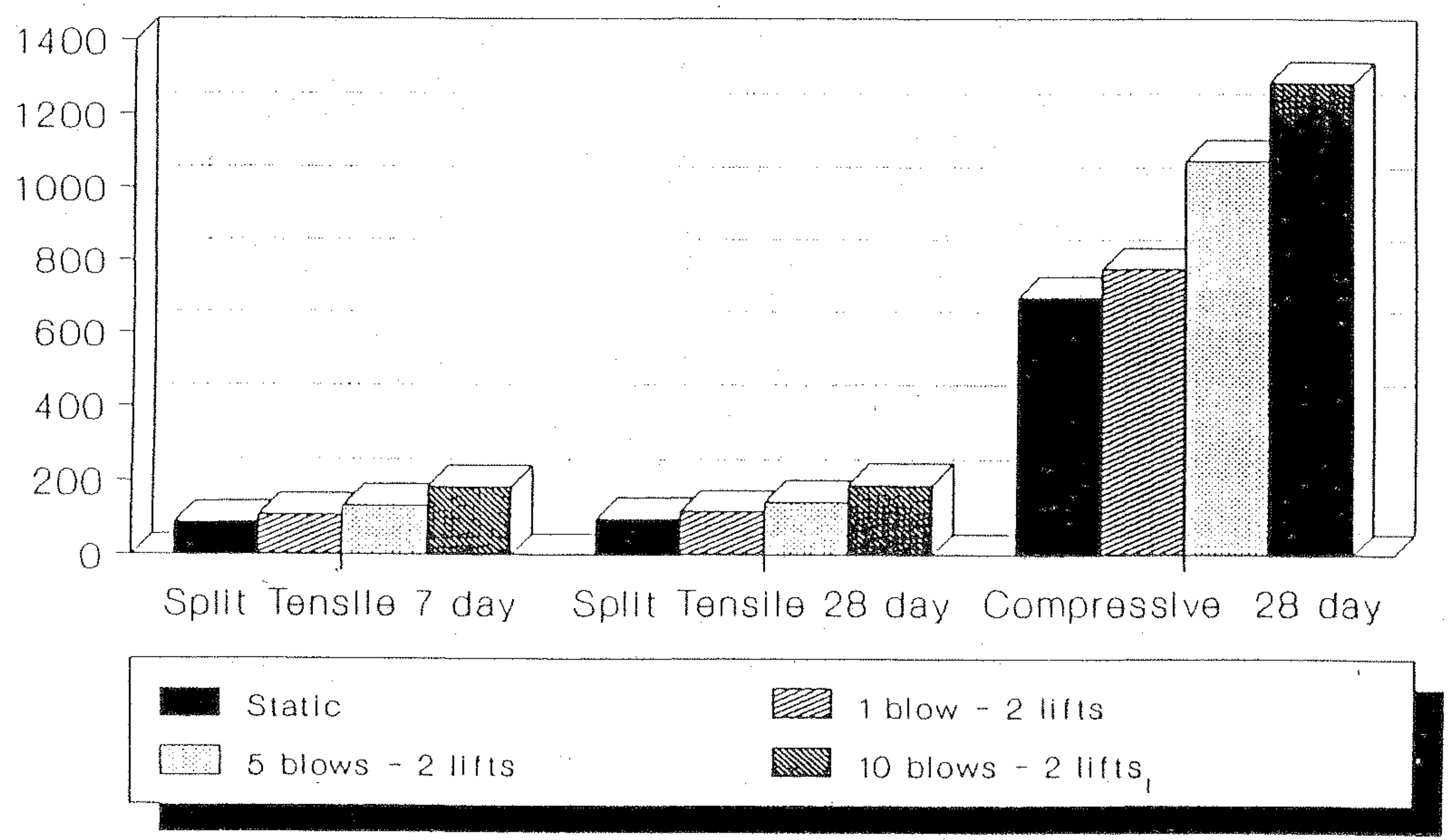
Pavement surface permeability = 16.52 gals/min = 9.35 gals/min/sft.

Note: no sign of clogging

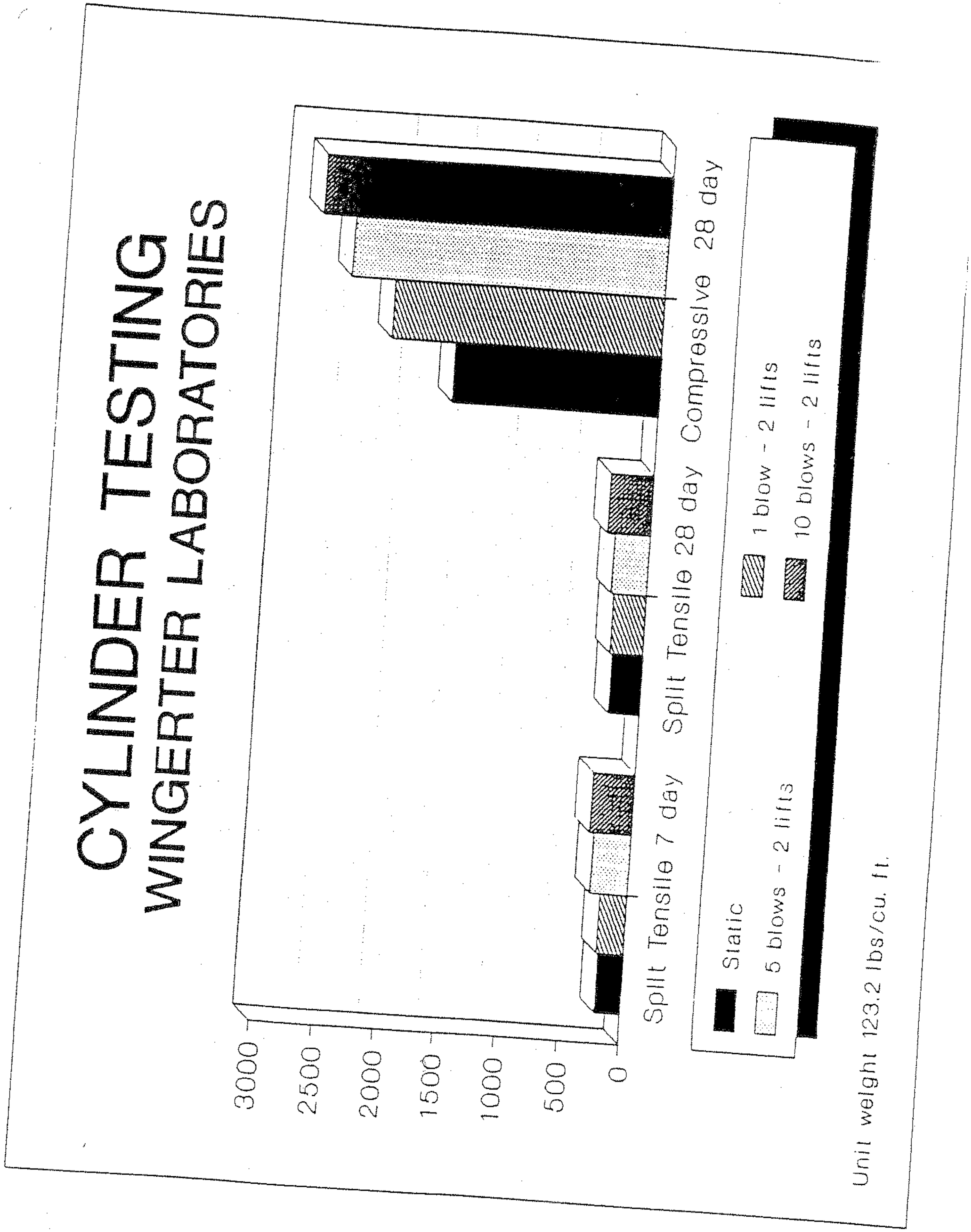
Bahia sod:

Permeability = 2.45 gals/min = 3.12 gals/min/sft.

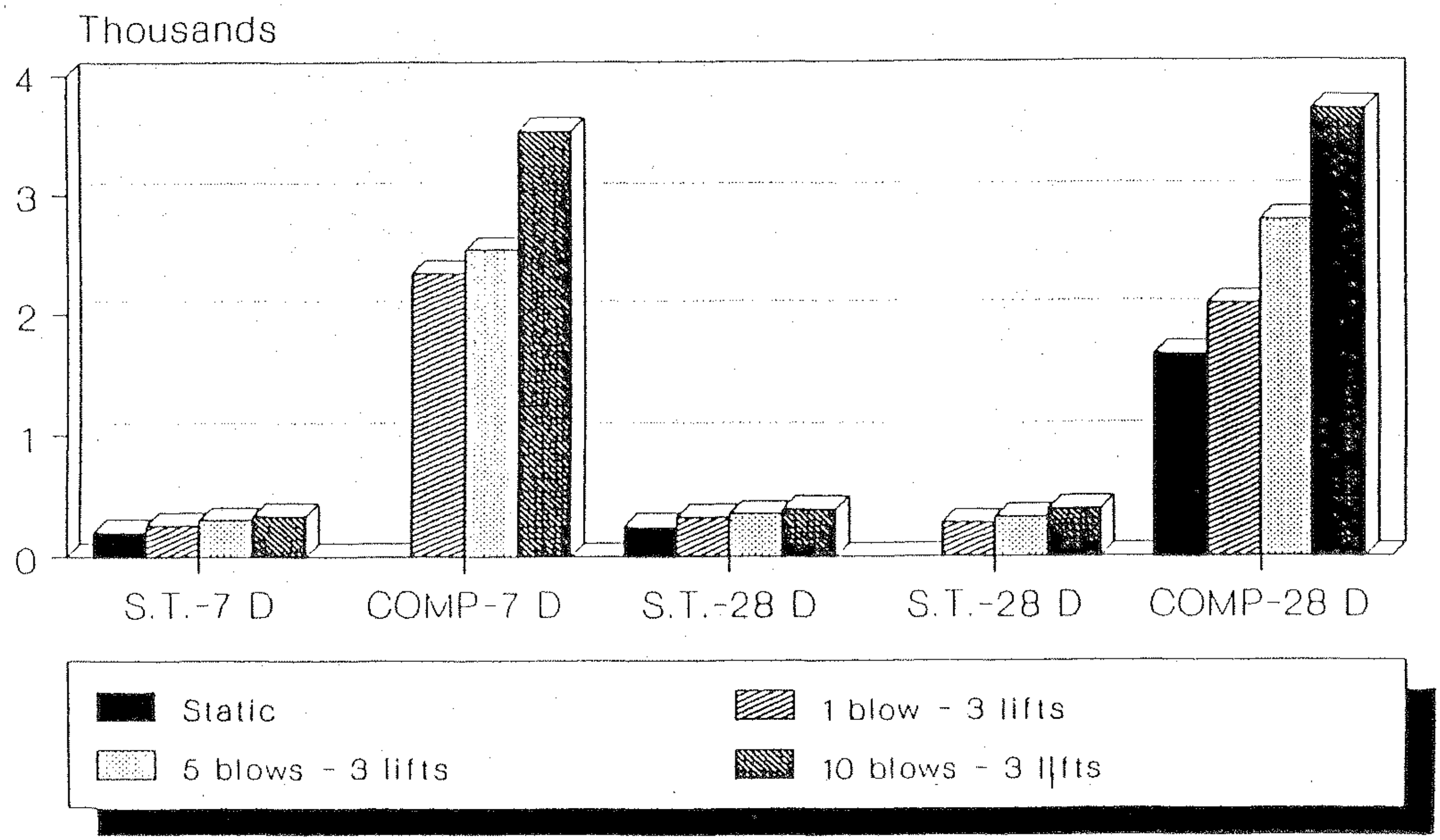
CYLINDER TESTING
WINGERTER LABORATORIES



Unit weight 112.4 lbs/cu. ft.


CYLINDER TESTING
WINGERTER LABORATORIES
3000
2500
2000
1500
1000
500
0
Split Tensile 7 day
Split Tensile 28 day
Compressive 28 day
Static
5 blows - 2 lifts
1 blow - 2 lifts
10 blows - 2 lifts
Unit weight 123.2 lbs/cu. ft.

CYLINDER TESTING
WINGERTER LABORATORIES



Unit weight 123.2 lbs/cu. ft.

RECOMMENDED SPECIFICATIONS

Florida Concrete and Products Association Inc.

Recommended Specifications For Portland Cement Pervious Pavement

Foreword

Portland Cement Pervious Pavements have become increasingly popular as a method to meet water quality and quantity standards throughout Florida. The largest demand is found in parking area paving. This abbreviated specification is presented as a recommended guide for light traffic pavement loading.

Traditional portland cement pavement testing procedures based on strength, air content and slump control are not applicable to this type of pavement material. As continued testing of this product yields test methods that are reproducible in the field, these recommended specifications will be modified.

100. GENERAL PROVISIONS

101. Scope of Work : The Work to be completed under this contract includes the furnishing of all labor, materials, and equipment necessary for construction of the proposed improvements in conformance with the plans and specifications.

102. References:

A. American Society of Testing and Materials
1. ASTM C 29 "Test for Unit Weight and Voids in Aggregate."
2. ASTM C 33 "Specification for Concrete Aggregates."
3. ASTM C 42 "Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete."
4. ASTM C 117 "Test Method for Material Finer than 75 µm (No. 200) Sieve in Mineral Aggregates by Washing."
5. ASTM C 138 "Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete."
6. ASTM C 140 "Methods of Sampling and Testing Concrete Masonry Units."

7. ASTM C 150 "Specifications for Portland Cement" (Types I or II only).
8. ASTM C 172 "Practice for Sampling Fresh Concrete."
9. ASTM C 260 "Specification for Air-Entraining Admixtures for Concrete."
10. ASTM C 494 "Specification for Chemical Admixtures for Concrete."
11. ASTM C 595 "Specifications for Blended Hydraulic Cements" (Types IP or IS only).
12. ASTM C 618 "Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete."
13. ASTM C 989 "Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars."
14. ASTM C 1077 "Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation."
15. ASTM D 448 "Specification for Standard Sizes of Coarse Aggregate for Highway Construction."
16. ASTM D 1557 "Tests for Moisture-Density Relations of Soils and Soil Aggregate Mixtures Using 10 Pound Rammer and 18-inch Drop."
17. ASTM E 329 "Standard Recommended Practice for Inspection and Testing Agencies for Concrete, Steel and Bituminous Materials as Used in Construction."

B. American Association of State Highway and Transportation Officials (AASHTO)
   1. AASHTO T-180 "Moisture-Density Relations of Soils Using a 101 pound (454kg) Rammer and an 18 in. (457mm) Drop."

C. Florida Department of Transportation (FDOT), Standard Specifications for Road and Bridge Construction.
   1. Section 345-10 - Plant and Equipment
   2. Section 350-18 - Thickness Determinations
   3. Section 923-1 - Chemical and Physical Requirements of Water for Concrete

103. Contractor Qualifications : The use of an ACI Concrete Flatwork Certified Finisher is strongly recommended. Prior to award of the contract, the placing contractor shall furnish Owner/Engineer/Architect a statement attesting to qualifications and experience and the following :

1. A minimum of 2 completed projects with addresses.
2. Unit weight acceptance data.

3. In-situ pavement test results including void content and unit weight.
4. Sample of product (i.e. core or test panel)

If the placing contractor and concrete producer have insufficient experience with portland cement pervious concrete pavement, the placing contractor shall retain an experienced consultant (as qualified above) to monitor production, handling, and placement operations at the contractor's expense.

Test Panels:

Regardless of qualification, Contractor is to place, joint and cure two test panels, each to be a minimum of 225 sq. ft. at the required project thickness to demonstrate to the Architect's satisfaction that in-place unit weights can be achieved and a satisfactory pavement can be installed at the site location.

1. Test panels may be placed at any of the specified portland cement pervious locations. Test panels shall be tested for thickness in accordance with ASTM C 42; void structure in accordance with ASTM C 138; and for core unit weight in accordance with ASTM C 140, paragraph 6.3.

2. Satisfactory performance of the test panels will be determined by:
   - Compacted thickness no less than 1/4" of specified thickness.
   - Void Structure : 15 % minimum, 21 % maximum.
   - Unit weight plus or minus 5 pcf of the design unit weight.

3. If measured void structure falls below 15 % or if measured thickness is greater than 1/4" less than the specified thickness or if measured weight falls less than 5 pcf below design unit weight, the test panel shall be removed at the contractor's expense and disposed of in an approved landfill.

4. If the test panel meets the above mentioned requirements, it can be left in-place and included in the completed work.

104. Concrete Mix Design: Contractor shall furnish a proposed mix design with proportions of materials to Owner or Agent prior to commencement of work. The data shall include unit weights determined in accordance with ASTM C 29 paragraph 11, jigging procedure.

200. Materials:

201. General : Locally available material having a record of satisfactory performance shall be used.

202. Cement: Portland Cement Type I or II conforming to ASTM C 150 or Portland Cement Type IP or IS conforming to ASTM C 595.

202.1 Flyash and Ground Iron Blast-Furnace Slag : Flyash conforming to ASTM C 618 may be used in amounts not to exceed 20 percent of total cementitious material. Ground Iron Blast-Furnace Slag conforming to ASTM C 989 may be used in amounts not to exceed 50 percent by weight of total cementitious material.

Note: When Class 'F' Flyash is used as part of the minimum cementitious content specified in Section 301, bond strength development may be delayed and additional curing time is required. See Section 505.

203. Aggregate : Use Florida Department of Transportation (FDOT) No 8 coarse aggregate (3/8 to No. 16) per ASTM C 33 or No. 89 coarse aggregate (3/8 to No. 50) per ASTM D 448. If other gradation of aggregate is to be used, submit data on proposed material to owner for approval.

204. Air Entraining Agent: Shall comply with ASTM C 260.

205 Admixtures:
Type A Water Reducing Admixtures - ASTM C 494.
Type B Retarding - ASTM C 494.
Type D Water Reducing/Retarding - ASTM C 494.

Also, a hydration stabilizer can be utilized and is recommended in the design and production of pervious concrete. This stabilizer suspends cement hydration by forming a protective barrier around the cementitious particles, which delays the particles from achieving initial set. The admixture's primary function should be as a hydration stabilizer, however it must also meet the requirements of ASTM C 494 Type B Retarding or Type D Water Reducing/Retarding admixtures.

206. Water : Potable or shall comply with FDOT Standard Specifications, Section 923.

300. Proportions :

301. Cement Content : For pavements subjected to vehicular traffic loading, the total cementitious material shall not be less than 600 lbs. per cu. yd.

302. Aggregate Content : The volume of aggregate per cu. yd. shall be equal to 27 cu.ft. when calculated as a function of the unit weight determined in accordance with ASTM C 29 jigging procedure. Fine aggregate, if used, should not exceed 3 cu. ft. and shall be included in the total aggregate volume.

303. Admixtures : Shall be used in accordance with the manufacturer's instructions and recommendations.

304. Mix Water : Mix water shall be such that the cement paste displays a wet metallic sheen without causing the paste to flow from the aggregate. (Mix water yielding a cement paste with a dull-dry appearance has insufficient water for hydration).

- Insufficient water results in inconsistency in the mix and poor bond strength.

- High water content results in the paste sealing the void system primarily at the bottom and poor surface bond.

400. Subgrade Preparation and Form-Work:

401. Subgrade Material : The top 6 inches shall be composed of granular or gravely soil that is predominantly sandy with no more than a moderate amount of silt or clay.

402. Subgrade Permeability : Prior to placement of Portland Cement Pervious Pavement, the subgrade shall be tested for rate of permeability by double ring infiltrometer, or other suitable test of subgrade soil permeability. The tested permeability must reasonably compare to the design permeability.

403. Subgrade Support : The subgrade shall be compacted by a mechanical vibratory compactor to a minimum density of 92 % of a maximum dry density as established by ASTM D 1557 or AASHTO T 180. Subgrade stabilization shall not be permitted.

If fill material (embankment) is required to bring the subgrade to final elevation, it shall be clean and free of deleterious materials. It shall be placed in 8 inch maximum layers, and compacted by a mechanical vibratory compactor to a minimum density of 92 % of a maximum dry density as established by ASTM D 1557 or AASHTO T 180.

404. Subgrade Moisture : The subgrade shall be in a moist condition (within +/- 3% of the optimum moisture content as determined by the modified compaction test ASTM D 1557 or AASHTO T 180).

405. Forms : Forms may be of wood or steel and shall be the depth of the pavement. Forms shall be of sufficient strength and stability to support mechanical equipment without deformation of plan profiles following spreading, strike-off and compaction operations.

500. MIXING, HAULING AND PLACING :

501. Mix Time : Truck mixers shall be operated at the speed designated as mixing speed by the manufacturer for 75 to 100 revolutions of the drum.

502. Transportation : The portland cement aggregate mixture may be transported or mixed on site and should be used within one (1) hour of the introduction of mix water, unless otherwise approved by an engineer. This time can be increased to 90 minutes when utilizing the hydration stabilizer specified in Section 205.

503. Discharge : Each mixer truck will be inspected for appearance of concrete uniformity according to Section 304. Water may be added to obtain the required mix consistency. A minimum of 20 revolutions at the manufacturer's designated mixing speed shall be required following any addition of water to the mix. Discharge shall be a continuous operation and shall be completed as quickly as possible. Concrete shall be deposited as close to its final position as practicable and such that fresh concrete enters the mass of previously placed concrete. The practice of discharging onto subgrade and pulling or shoveling to final placement is not allowed.

504. Placing and Finishing Equipment : Unless otherwise approved by the Owner or Engineer in writing, the Contractor shall provide mechanical equipment of either slipform or form riding with a following compactive unit that will provide a minimum of 10 psi vertical force. The pervious concrete pavement will be placed to the required cross section and shall not deviate more than +/- 3/8 inch in 10 feet from profile grade. If placing equipment does not provide the minimum specified vertical force, a full width roller or other full width compaction device that provides sufficient compactive effort shall be used immediately following the strike-off operation. After mechanical or other approved strike-off and compaction operation, no other finishing operation will be allowed. If vibration, internal or surface applied, is used, it shall be shut off immediately when forward progress is halted for any reason. The Contractor will be restricted to pavement placement widths of a maximum of fifteen (15') feet unless the Contractor can demonstrate competence to provide pavement placement widths greater than the maximum specified to the satisfaction of the Engineer.

505. Curing : Curing procedures shall begin within 20 minutes after the final placement operations. The pavement surface shall be covered with a minimum six (6) mil thick polyethylene sheet or other approved covering material. Prior to covering, a fog or light mist shall be sprayed above the surface when required due to ambient conditions (temperature, wind, and humidity). The cover shall overlap all exposed edges and shall be secured (without using dirt or stone) to prevent dislocation due to winds or adjacent traffic conditions.

Cure Time :

1. Portland Cement Type I , II, or IS - 7 days minimum.
2. Portland Cement Type I or II with Class F Flyash (as part of the 600 lbs/cy minimum cementitious) or Type IP- 10 days minimum.
3. No truck traffic shall be allowed for 10 days (no passenger car/light trucks for 7 days).

506. Jointing : Control (contraction) joints shall be installed at 40 foot intervals. They shall be installed at a depth of 1/4 the thickness of the pavement. These joints can be installed in the plastic concrete or saw cut. If saw cut, the procedure should begin as soon as the pavement has hardened sufficiently to prevent raveling and uncontrolled cracking (normally after curing). Transverse construction joints shall be installed whenever placing is suspended a sufficient length of time that concrete may begin to harden. In order to assure aggregate bond at construction joints, a bonding agent suitable for bonding fresh concrete to existing concrete shall be brushed, rolled, or sprayed on the existing pavement surface edge. Isolation (expansion) joints will not be used except when pavement is abutting slabs or other adjoining structures.

600. Testing, Inspection and Acceptance :

601. Laboratory Testing : The owner will retain an independent testing laboratory. The testing laboratory shall conform to the applicable requirements of ASTM E 329 "Standard Recommended Practice for Inspection and Testing Agencies for Concrete, Steel, and Bituminous Materials as Used in Construction" and ASTM C 1077 " Standard Practice for Testing Concrete and Concrete Aggregates for use in Construction, and Criteria for Laboratory Evaluation" and shall be inspected and accredited by the Construction Materials Engineering Council, Inc. or by an equivalent recognized national authority.

The Agent of the testing laboratory performing field sampling and testing of concrete shall be certified by the American Concrete Institute as a Concrete Field Testing Technician Grade I, or by a recognized state or national authority for an equivalent level of competence.

602. Testing and Acceptance: A minimum of 1 gradation test of the subgrade is required every 5000 square feet to determine percent passing the No. 200 sieve per ASTM C 117.

A minimum of one test for each day's placement of pervious concrete in accordance with ASTM C 172 and ASTM C 29 to verify unit weight shall be conducted. Delivered unit weights are to be determined in accordance with ASTM C 29 using a 0.25 cubic foot cylindrical metal measure. The measure is to be filled and compacted in accordance with ASTM C 29 paragraph 11, jigging procedure. The unit weight of the delivered concrete shall be +/- 5 pcf of the design unit weight.

Test panels shall have two cores taken from each panel in accordance with ASTM C 42 at a minimum of seven (7) days after placement of the pervious concrete. The cores shall be measured for thickness, void structure, and unit weight. Untrimmed, hardened core samples shall be used to determine placement thickness. The average of all production cores shall not be less than the specified thickness with no individual core being more than 1/2 inch less than the specified thickness. After thickness determination, the cores shall be trimmed and measured for unit weight in the saturated condition as described in paragraph 6.3.1 'Saturation' of ASTM C 140 "Standard Methods of Sampling and Testing Concrete

Masonry Units". The trimmed cores shall be immersed in water for 24 hours, allowed to drain for one (1) minute, surface water removed with a damp cloth, then weighed immediately. Range of satisfactory unit weight values are +/- 5 pcf of the design unit weight.

After a minimum of 7 days following each placement, three cores shall be taken in accordance with ASTM C 42. The cores shall be measured for thickness and unit weight determined as described above for test panels. Core holes shall be filled with concrete meeting the pervious mix design.

***SPECIAL NOTE: This information is intended to be used by the design professional competent to evaluate its significance and limitation and who will accept the responsibility for its proper application. The Florida Concrete and Products Association disclaims any and all responsibility for any other use of the information supplied herein.

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DESIGN PROCEDURES

INTERIM GUIDE FOR DESIGN OF

PORTLAND CEMENT PERVIOUS PAVEMENT

FOREWORD

The object ofthis interim guide is to provide a basis for analysis of known data and offer procedures in the determination of thickness requirements and geometric design considerations for portland cement pervious pavements.

A pervious concrete mixture is a unique material and has behavior characteristics unlike conventional portland cement concrete or asphaltic concrete pavements. Although these characteristics differ, they are predictable and measurable. To date, most research and testing data relates to building construction applications and limited research is specifically pavement related.

Although there is limited research relative to subgrade reactions, basic material properties and analysis of construction procedures, observations have been conducted on a number of projects in Florida that have shown good performance. These projects have a range of good service from six (6) months to as long as ten (10) years.

As more research and field observations are obtained, future revisions will be made to the proposed methods presented.

PAVEMENT STRUCTURAL DESIGN

In the structural determination of a pervious pavement, two distinct analyses should be conducted. Recognized procedures for designing both rigid and flexible pavements will provide acceptable thickness requirements for specific applications with predictable results. The resulting pavement thickness and subgrade criteria should then be analyzed for reservoir capacity and subgrade permeability. Since the void structure of the pavement is to be used, in many cases, as a storage reservoir for storm water run-off, the thickness must also allow for anticipated volumes. The greater thickness requirement of the two analyses, structural or storage retention, should be used.

Pervious mixtures exhibit physical properties that allow for pavement structural determinations to be conducted by either a flexible or rigid pavement procedure. In either procedure, guidelines for pavement performance, traffic, roadbed soil, material properties, environment, drainage, reliability and life cycle costs should be considered.

The design of a pervious pavement should normally provide for the top six (6") to twelve (12) inches to be predominantly sandy with moderate amounts of silts and clays and poorly graded (AASHTO A-3). This type of subgrade material offers good support values as defined in terms of the Westergaard modulus of subgrade reaction (k) in pci. Support values will generally range from k=150 to 220. It is suggested that the k not exceed 200 and 150 to 175 may be suitable for design purposes (Appendix F). The composite modulus of subgrade reaction is defined using a theoretical relationship between k-values from the plate bearing test and the elastic modulus of subgrade soil as: k-MR/19.4 where MR is roadbed soil resilient modulus (psi). Field test results and their evaluation will provide site data that would increase the reliability of the design and are recommended (See Testing & Evaluation section of Manual for LBR, CBR; permeability, density, etc.).

Special precautions should be considered in the design of a pervious concrete pavement in areas with roadbed soils containing significant amounts of clay and silts of high compressibility, muck and expansive soils (AASHTO A4 to A7). It is recommended that highly organic materials be excavated and replaced with soils containing high amounts of sand conforming to A-3. Also, the design may include filter reservoirs of sand, open graded stone and gravels to provide adequate containment and increase the support values. Another design alternative is a sandy subbase material placed over a pavement drainage fabric to contain fine particles. In lieu of the sandy soil, a pervious pavement of larger open graded coarse aggregate (1-1/2") may provide a subbase for a surface coarse of a pervious mixture containing (3/8") aggregate.

The depth of the subgrade consideration is directly related to the permeability of the soil and void percentage of the pavement structure. The calculated permeability of the subgrade combined with the void percentage of the pavement thickness will determine the retention capacity values of the system. If the total value of the system meets twenty-four (24) hour requirements but would not be adequate for the twenty-five (25) year retainment regulations, a container curb of sufficient height for containment purposes may be included for the perimeter of a parking facility.

Anticipated traffic loading projections (E18kipSAL) and appropriate terminal serviceabilties (Pt) can be determined as in any recognized design procedures (Appendix G). Careful attention to this anticipated loading will provide the data required to project the life expectancy of pavement performance. This design guide will not cover an in-depth analysis of anticipated loadings since these procedures are adequately discussed in other recognized design procedures. The concrete properties are a very important function of a rigid pavement design analysis. Rigid pavement design is based on the beam strength of the pavement which distributes loads uniformly to the subgrade. Since the beam strength determines the performance level of the pavement and its service life, the properties of the pervious concrete should be carefully evaluated.

A mix design for a pervious pavement application will yield a wide range of strengths and permeability values, depending on the degree of compaction. A pavement subjected to loadings will cause continuous bending of the slab. The resistance to these deflections is related to the subgrade support, the strength of the beam and relatively long joint spacing. In a rigid design procedure, a modulus of rupture (flexural strength) value is predetermined for the purpose of using specific formulas, charts or graphs. This value will directly influence the thickness requirement of the proposed pavement. The modulus of rupture should be selected on a reasonably obtainable value that would relate to the serviceability and economics of pavement.

Testing of the proposed pervious mixture will result in data that should be used in the design procedure. The testing methods and recommended modifications to standard procedures are discussed in the Testing & Evaluation section of this manual. Splitting tensile strength results of the proposed mixture can reasonably be assumed to be sixty-five (65%) percent of the actual flexural strength. Test cylinders from trial batches will indicate the level of permeability and unit weight of the concrete. As stipulated previously in this manual, a minimum void structure of fifteen (15%) percent should be achieved. Test data indicates a range of flexural strengths from 300 to over 600 psi. Pervious pavement strength is greatly influenced by the degree of compaction as well as standard strength criteria such as aggregate, cement content, w/c, etc. The designer should be cautioned that the splitting tensile strength indications of the test cylinders, prepared for mixer discharge, may differ from in-situ pavement strengths due to the difference in the consolidation methods. The degree of consolidation of pervious pavement is directly affected by its unit weight. It is recommended that until such time as acceptable standard placing procedures with predictable strength and permeability results are available, a designer should establish acceptable design criteria values for unit weight relationship to modulus of rupture, subgrade support, permeability values and anticipated equivalent 18-Kp Single Axle Loads (E18K SAL). These values will establish the thickness and retention requirements of the pavement based on a recognized rigid pavement design procedures. An adjustment in thickness based on in-situ test data for unit weight permeability is only feasible when the projects duration is such that these values become available prior to projects completion. If applicable, test results will determine thickness adjustments relative to the original design criteria.

To develop thickness adjustment factors, a set of thickness determinations were made for 25 psi increments of the modulus of rupture for values of 300 psi to 650 psi as shown in Appendix H. The E-values corresponding to each of the modulus of rupture values were used while all other values were kept constant.

The analysis showed an inverse relation of 0.12 inches in thickness for each 25 psi change in the modulus of rupture, or

$$\triangle D = \frac{0.12''}{25 \text{ psi}} (\triangle MR) \qquad (1)$$

where

$\triangle$ = change

D = Thickness

MR = modulus of rupture

Note: When MR is positive, $\triangle$ D will decrease.

The adjusted thickness becomes,

$$D_{adj.} = D_d + \triangle D \qquad (2)$$

where the superscripts are:

adj = adjusted thickness

d = design thickness

and $\triangle$ D is determined from Eq. (1)

The modulus of rupture from constructed pavement test data may be established from split tensile tests as follows:

$$MR_c = (1.54)\, ST_c \frac{w_d}{w_c} \qquad (3)$$

where superscripts are: c=construction, d=design, and notations are: ST=Split Tensile strength, w=unit weight.

The value of MR determined in Eq. (3) may be substituted into Eq. (1) to establish the necessary correction. This value is substituted into Eq. (2) to give the adjusted thickness.

The flexural strength may also be based on split tensile strength values determined from core samples using the following equation:

$$MR = [(1.54)/0.85]\ ST_p \qquad (4)$$

or,

$$MR = (1.82)\ ST_p$$

where the superscript is:

p = pavement split tensile strength.

The factor of 0.85 in Eq. (4) is based on the assumption that the core strength is 85 percent of the cylinder strength. The logarithmic relation between the calculated thickness and the modulus of rupture suggests:

$$\log D = \mathrm{Log}\ a - b\ \mathrm{Log}\ MR \qquad (5)$$

or,

$$D = a(MR)^{-b} \qquad (5a)$$

where:

$a = 11.8$

$b = -0.58$

See appendix I.

The data presented in Appendix I suggest the equation:

$$D = 11.8\ \frac{(MR)}{(100)}^{-0.58} \qquad (6)$$

The equation (5) yields approximately the values listed in Appendix H, as follows:

MR	APPENDIX H	Equation (5)
300	6.19	6.24
500	4.61	4.64
650	4.00	3.98

Calculation made easy in the following form:

$$D = \frac{(100)}{(MR)}^{0.58} * 11.8 \qquad (6a)$$

As in all design procedures, a minimum structural thickness should be established. Recommended minimum structural thicknesses are as follows:

Parking areas, cars & light trucks	= 5"
Commercial drive lanes	= 5" to 6"
Industrial drive lanes	= 6" (+)

The minimum structural thickness may have to be increased to compensate for strength or retention deficiencies. A two (2%) percent reduction below minimum void content of 15% should require an additional one (1") inch thickness.

FLEXIBLE PAVEMENT ANALYSIS:

A flexible pavement design procedure requires the establishment of layer coefficients to each layer material in the pavement structure. The layer coefficient is an empirical relationship between the Structural Number (SN) and the thickness. This structural_ layer coefficient expresses the relative ability of the material to perform as a structural component of the pavement system.

The Flexible Pavement Design Manual, Florida Department of Transportation (FDOT), (19, Florida Department of Transportation, 1980, p.27) establishes the following layer coefficients based on the compressive strength of the econocrete (lean mix) material in psi as:

Econocrete 800 psi = .22 Layer Coefficient
Econocrete 1100 psi = .25 Layer Coefficient

The 1986 AASHTO Design Guide also references a cement-treated base with 800 psi to correspond to a .22 structural layer coefficient (5, American Association of State Highway and Transportation Officials, 1986, pp.II-20). This is the same layer coefficient as stipulated in the FDOT Manual with the exception that AASHTO design is related to seven (7) day unconfined compressive strengths (psi). Therefore, the .22 structural layer coefficient may be considered a reasonable value.

In order to determine structural layer coefficients for pavement strengths in excess of 800 psi and in a strength range of normal 3000 psi compressive strengths or higher, a relationship to layer coefficient (a_c) and compressive strength

(f'_c) is as follows:

$$a_c = 0.22 + .0001\ (f'_c - 800)$$

This equation relates to structural coefficients of .44 for a 3000 psi concrete pavement. It should be noted that the .44 value is the same coefficient as FDOT Ty S-1 asphalt surface pavement. A conventional concrete pavement placed by Florida DOT specifications will generally have compressive strength in excess of 3600 psi. Applying this value to the above equation, a layer coefficient of .50 is obtained. A value of .50 for the layer coefficient also follows the 1972 AASHTO Design Guide for concrete base course.

The Structural Number (SN) is an abstract number computed by expressing the required total structural strength of the pavement. In addition to the structural layer coefficient, The SN is a function of soil support values (SSV), total equivalent 18 kip single axle loads (E 18's SAL) and terminal serviceability (Pt). In addition, the 1986 AASHTO Design of Pavement Structures identifies other performance criteria that should be included in a flexible pavement system. This criteria includes reliability and design serviceability loss, environmental effects, economics, etc. The SN Conversion to actual thicknesses of surfacing, base and subbase, is calculated as follows for a pervious concrete pavement:

$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3$$

where

a_1, a_1, a_3 = layer coefficients representative of surface, base, and subbase courses, respectively,

D_1, D_2, D_3 = actual thickness (in inches) of surface, base, and subbase courses, respectively,

m_2, m_3 = drainage coefficients for base and subbase layers, respectively.

For recommended values of modifying structural layer coefficients and design charts, refer to AASHTO Design Guide and Florida DOT Flexible Design Manual.

GEOMETRIC DESIGN CONSIDERATIONS:

The establishment of profile grades for a portland cement pervious pavement is relatively simple in comparison to an impervious pavement. The void structure of a pervious concrete mixture not only allows for the vertical transmission of water, but will also allow horizontal flow. This unique ability should be considered in establishing the drainage profiles.

The vertical rate of flow is directly related to the permeability of the subgrade and the thickness and void ratio of the pavement. To the extent possible, parking area profiles should be graded level. This will allow increased time for the subgrade to absorb and transmit water to the lower strata and reduce the horizontal flow rate. Where conditions do not allow for level profile grades, the designer may consider providing impervious barriers transverse to the direction of horizontal flow. These barriers can easily be installed by increased consolidation of the pavement strip along the edge of transverse construction joints. The increased consolidation will close the void structure in this location. Installing of transverse strips of normal impervious concrete could also offer reduction in lateral flow in the down grade direction. Container curbs around the perimeter of a given area will also assist in reducing lateral flow rates and assist in meeting 25 and 100 year containment requirements.

The designer should be cautioned that observation of projects with grades inclined in excess of 5% were found to significantly undermine pavement edges. This undermining had also occurred when a perimeter barrier curb was provided on a project with a vertical grade of -5% cross slope.

On projects that were converted to a pervious pavements after a storm drainage system was already installed, it was observed that significant amounts of water had collected on the outside of the inlets. If inlets and storm drain pipe designs are used for collection of excessive stormwater, provisions for allowing water to enter the inlet at a elevation of less than 1 to 1 1/2 inches above the bottom of the pavement should be made. This will allow for storm water in the pavement to enter the inlet and reduce consolidation of material backfilled around the inlet due to excessive moisture.

Geometric design is important to the performance of pervious pavements. Local and state regulations should be observed in relation to run-off restrictions. Pervious concrete pavements have the ability to meet requirements for storm water containment and provide structural integrity.

Additionally, subgrade materials of free draining sands may be necessary to a depth of 6 to 12 inches in areas with soils of low permeability. After compaction, soils have much less vertical water transmission than lateral transmission by a ratio of as much as 1:10. In these cases, holes or trenches 12 to 24 inches deep and filled with open graded aggregate or a pervious mixture may be provided to increase the rate of absorption of water into the subgrade. This method may be useful where the water storage capacity of the pavement is marginal or where soils have low permeability. A word of caution is appropriate: this method may cause differential support values of the pavement.

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REFERENCES

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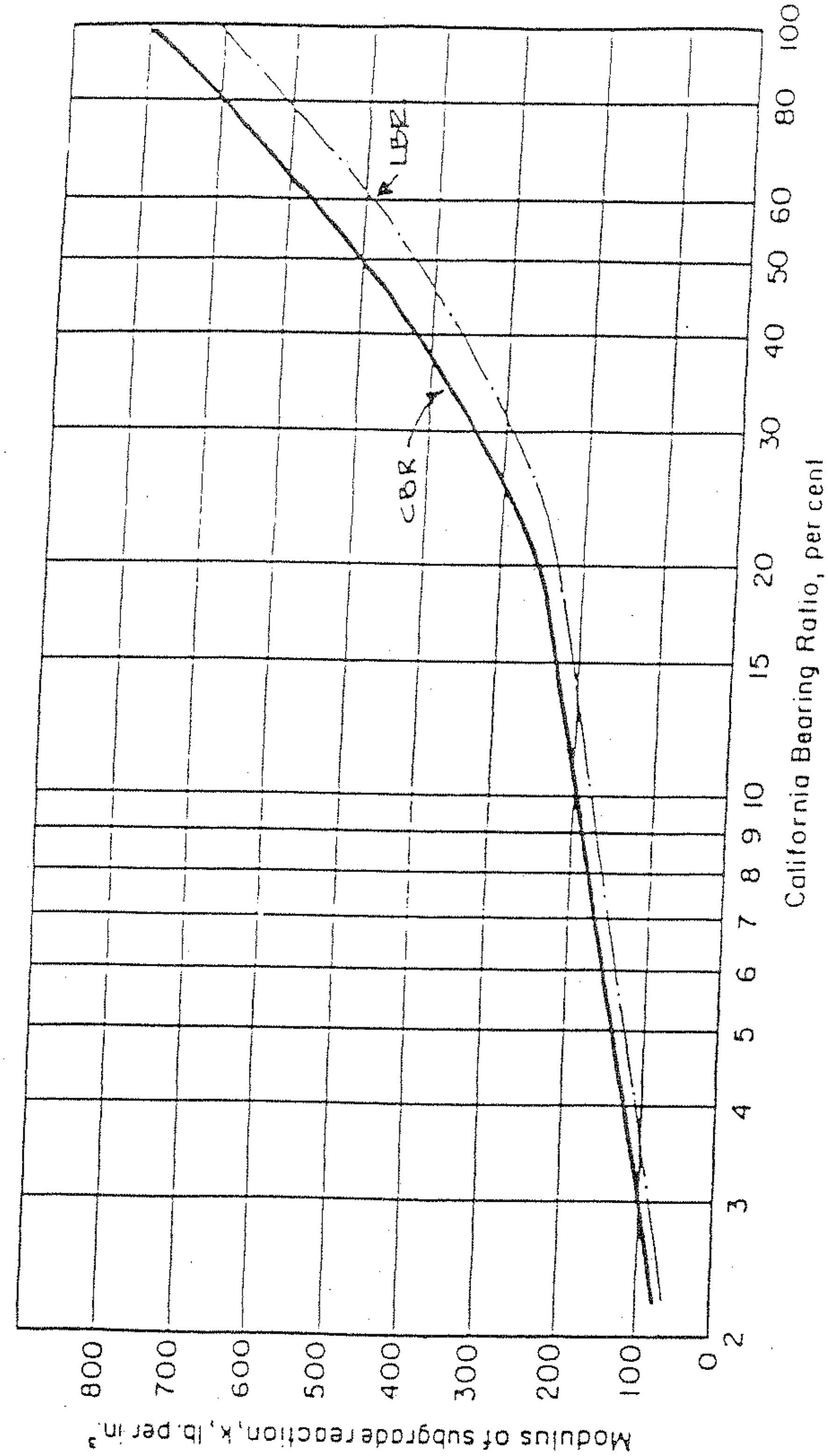
APPENDIX



Relationship between California Bearing Ratio and modulus of subgrade reaction.

APPENDIX A.

TABLE 1. STANDARD SIZES OF COARSE AGGREGATE

SIZE NUMBER	NOMINAL SIZE SQUARE OPENINGS	Amounts Finer than Each Laboratory Sieve (Square Openings), weight percent					
		1/2-in. (12.5-mm)	3/8-in. (9.5-mm)	No. 4 (4.75-mm)	No. 8 (2.36-mm)	No. 16 (1.18-mm)	No. 50 (0.300-mm)
8	3/8-in. to No. 8 (9.5 to 2.36-mm)	100	85 to 100	10 to 30	0 to 10	0 to 5	
89	3/8-in. to No. 16 (9.5-1.18-mm)	100	90 to 100	20 to 55	5 to 30	0 to 10	0 to 5
9	No. 4 to No. 16 (4.75 to 1.18-mm)	-------	100	85 to 100	10 to 40	0 to 10	0 to 5

NOTE: The above gradations represent the extreme limits for the various sizes indicated, which will be used in determining the suitability for use of coarse aggregate from all sources of supply. For any grade from any one source, the gradation shall be held reasonably uniform and not subject to the extreme percentage of gradation specified above.

Reference: Florida Department of Transportation Standard Specifications for Road and Bridge Construction

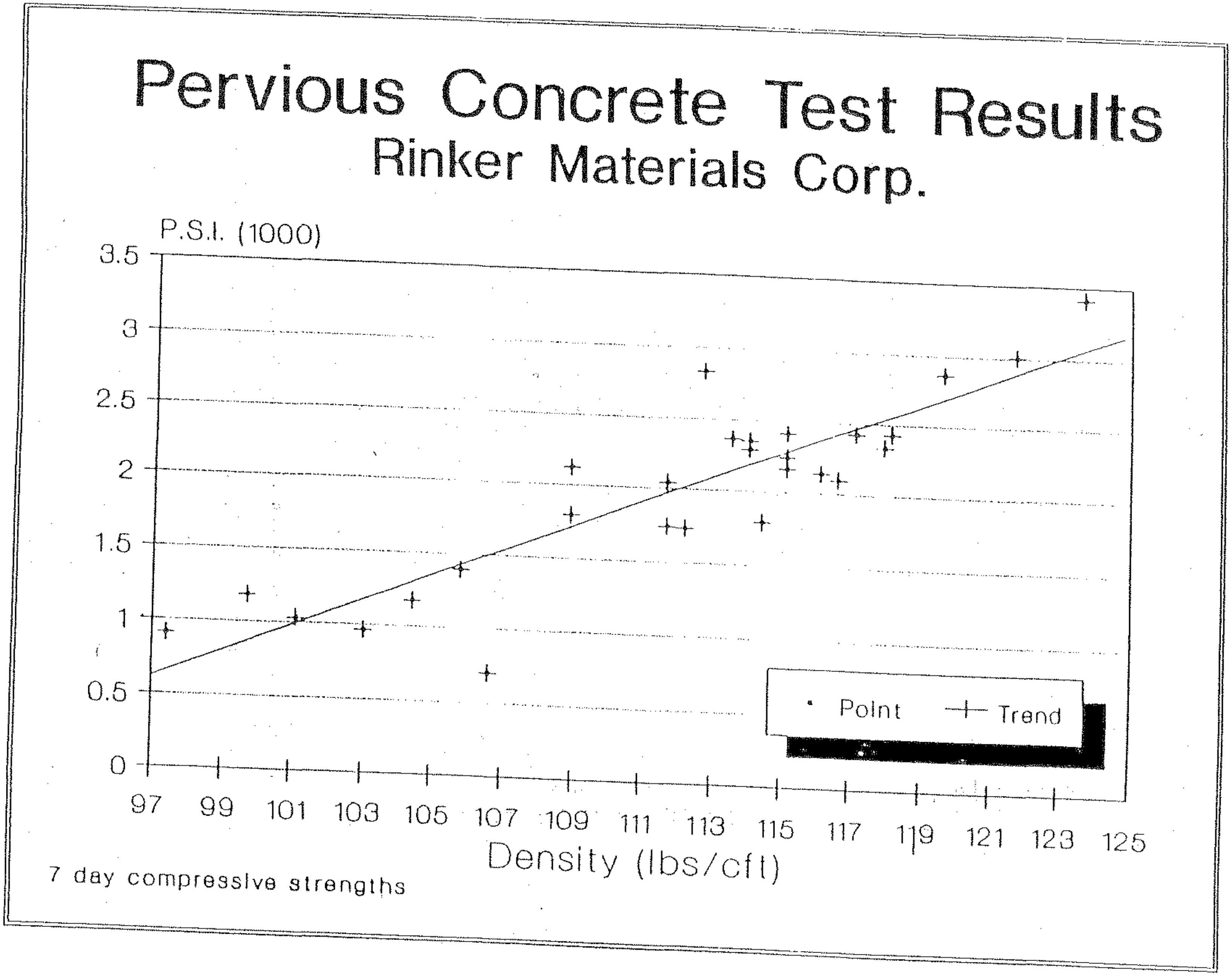
APPENDIX B

PERVIOUS CONCRETE TEST RESULTS
RINKER MATERIALS CORP.

A/G RATIO	W/C RATIO	TEST AGE (Days)	VOID RATIO (%)	COMPRESSIVE STRENGTH (PSI)	FLEXURAL STRENGTH (psi)	DENSITY (lbs/cft)
4.01:1	0.25	7	21.0	700	N/A	106.6
"	0.25	N/A	25.5	--	N/A	101.0
"	0.25	N/A	22.4	--	N/A	102.0
"	0.24	7	28.8	910	N/A	97.4
"	0.24	N/A	31.0	--	N/A	94.0
"	0.25	7	27.6	1176	N/A	99.7
	0.25	N/A	28.0	--	N/A	98.5
"	0.24	7	--	--	225	--
"	0.24	7	--	--	190	--
4.07:1	0.25	7	16.2	2040	N/A	111.7
"	0.25	7	19.8	1794	N/A	108.9
"	0.25	7	19.8	2119	N/A	108.9
"	0.25	7	24.2	1389	N/A	105.8
"	0.25	7	--	--	305	107.1
"	0.25	7	--	--	285	105.1
3.69:1	0.22	7	--	1170	N/A	104.4
"	0.22	7	--	960	N/A	103.0
"	0.22	7	--	1030	N/A	101.1
"	0.30	7	--	1790	N/A	114.4
"	0.30	28	--	2830	N/A	112.7
"	0.30	7	--	--	140	--
3.69:1	0.30	7	17.1	2360	--	113.5
"	0.30	7	17.1	2350	--	114.0
"	0.30	7	16.8	2290	--	114.0
"	0.30	14	16.3	2290	--	115.0
"	0.30	14	17.1	2210	--	112.8
"	0.30	14	15.9	2060	--	114.3
"	0.30	28	17.1	2310	--	113.0
"	0.30	28	17.1	2470	--	112.8
"	0.30	28	14.7	2640	--	114.5
"	0.30	7	--	--	295	--
"	0.30	28	--	--	355	--

PERVIOUS CONCRETE TEST RESULTS
RINKER MATERIALS CORPORATION

A/C RATIO	W/C RATIO	TEST AGE (DAYS)	VOID RATIO (%)	COMPRESSIVE STRENGTH (PSI)	FLEXURAL STRENGTH (PSI)	DENSITY (WET) lbs/cft
4.07:1	0.30	7	15.3	2427	N/A	118.1
4.07:1	0.30	7	10.8	3416	N/A	123.7
4.07:1	0.30	7	12.6	3009	N/A	121.7
4.07:1	0.30	7	15.3	2866	N/A	119.6
4.07:1	0.30	7	----	----	555	124.0
4.07:1	0.30	7	----	----	565	125.0
4.07:1	0.30	14	----	----	550	-----
4.07:1	0.30	14	----	----	565	-----
4.07:1	0.30	28	----	----	540	-----
4.07:1	0.30	28	----	----	545	-----
4.10:1	0.29	7	16.6	2409	---	115.1
4.10:1	0.29	7	16.0	2337	---	117.9
4.10:1	0.29	7	16.2	2423	---	117.1
4.10:1	0.29	7	17.1	2092	---	116.6
4.10:1	0.29	7	17.3	2135	---	116.1
4.10:1	0.29	7	17.9	2242	---	115.1
4.10:1	0.29	7	17.9	2157	---	115.1
4.10:1	0.29	7	20.7	1741	---	111.7
4.10:1	0.29	7	21.2	1733	---	112.2
4.10:1	0.29	7	----	----	370	108.8
4.10:1	0.29	28	----	----	380	109.6
4.10:1	0.29	28	----	----	440	121.5


Pervious Concrete Test Results
Rinker Materials Corp.
P.S.I. (1000)
3.5
3
2.5
2
1.5
1
0.5
0
97
99
101
103
105
107
109
111
113
115
117
119
121
123
125
Density (lbs/cft)
Point
Trend
7 day compressive strengths

RINKER MATERIALS CORPORATION

% VOIDS-GRAVIMETRIC	% VOIDS-USABLE
22.2	16.6
20.3	16.0
20.8	16.2
21.1	17.1
21.5	17.3
22.2	17.9
22.2	17.9
24.5	20.7
24.1	21.2
20.0	15.3
16.2	10.8
17.7	12.6
18.9	15.3
25.1	16.2
26.9	19.8
26.9	19.8
29.0	24.2
28.3	21.0
32.1	25.5
31.4	22.4
34.5	28.8
36.8	31.0
33.0	27.6
33.8	28.0
22.8	17.1
22.5	17.1
22.8	16.8
21.8	16.3
23.3	17.1
22.3	15.9
23.2	17.1
23.3	17.1
22.2	14.7
$\bar{X}$ = 24.7	$\bar{X}$ = 19.04
S= 5.08	S = 4.75

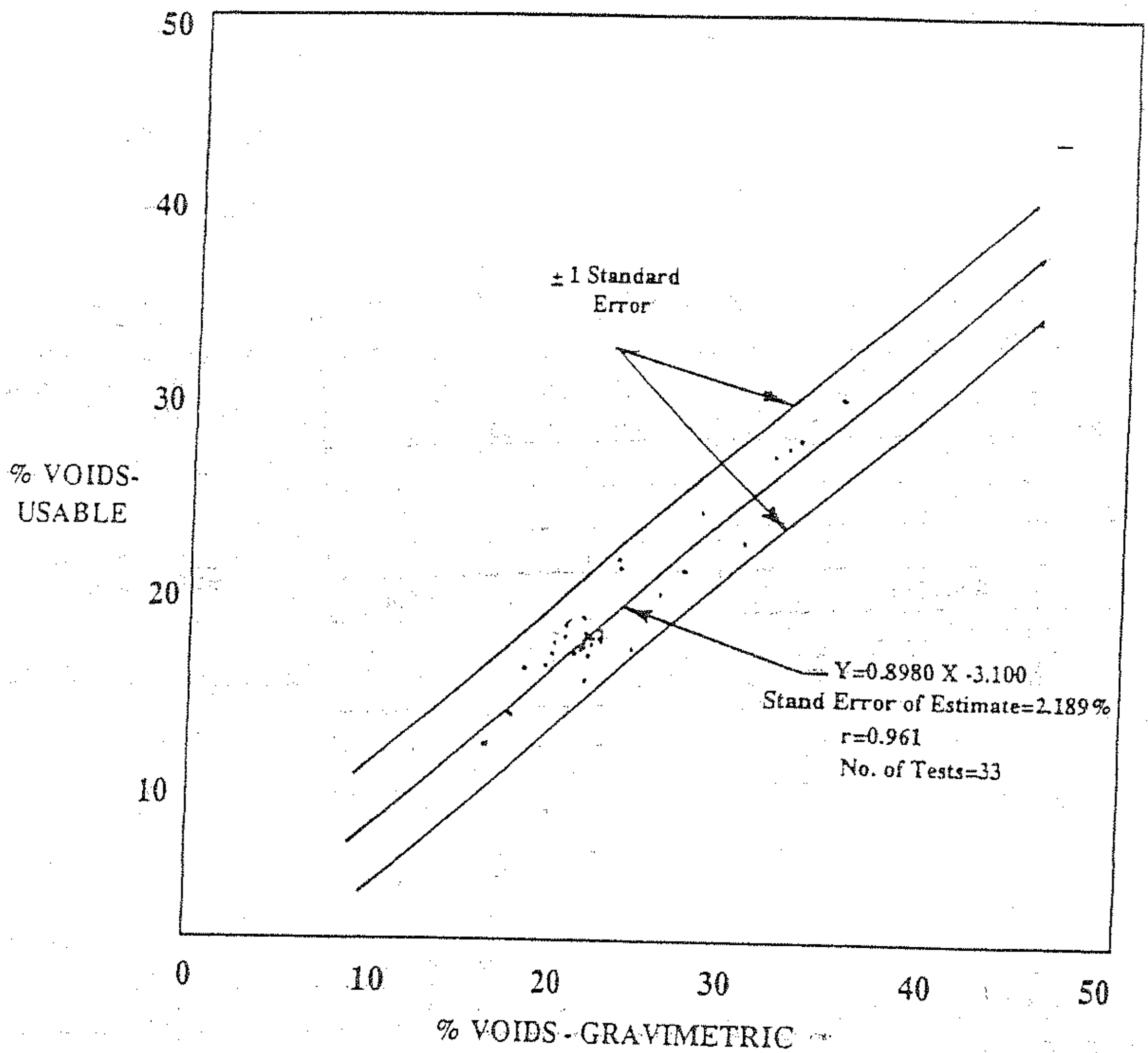
The % voids-usuable was determined in the following manner:

1) the volume of a 6x12" test cylinder is (0.196 cu.ft.) or(5552 cu. cm.)

2) after 20 hrs. ± 4, the pervious concrete test specimen was filled with water and the volume noted.

3) this volume was divided by the total volume capacity and the % retention noted.

The % voids-gravimetric was determined in accordance with ASTM C-138-81 using the wet-unit weight of the individual test cylinders.



Cement = Type I Portland
Coarse Agg = Crushed Limestone 3/8" Pea Rock
Addmixtures = A.E.A. and Water Reducer

APPENDIX C5

RINKER MATERIALS CORP.
QUALITY CONTROL LABORATORY
BLOCKS — CONCRETE — STEEL — BUILDING SUPPLIES
FIR[illegible] WITH THE BEST
P. O. DRAWER K WEST PALM BEACH, FLORIDA 33402 TELEPHONE 833-5

CONCRETE MIX DESIGN

Plant	Customer	Date: May 22, 1987
Mix No.: N1960	Job	Approved By –
Concrete Type: NO FINES		Control No.

Material	Type	% Solid	% Agg.	Cubic Ft.	Mix Wgt.
Cement	ASTM C150 I	16.02		2.87	564
Coarse Agg.	PEA ROCK	83.98	100.00	15.05	2310
Fine Agg.					
Water	25 GALLONS				
Air	VOIDS 21.3%			3.33	208
Admix	ASTM C4?4 TYPE A&D WRDA 79			5.75	
Admix					
Totals		100.00	100.00	27.00	3082

REMARKS

THIS MIX IS DESIGNED FOR A NORMAL RATE OF COMPACTION IN THE FORM.

CONCRETE TEST CYLINDERS

SIZE: 6 X 12"
CONSOLIDATION: TAMPED WIT.. PROTOR HAMMER

FLEXURAL DATA: SPLITTING TENSILE X 1.35

MIX DATA

Design Slump	-0-
W/C Ratio. Lb./Lb.	0.37
W/C Ratio-Gal./Sx.	4.17
FM Combined Mix	4.22
FM Aggregate	5.56
Total Solids (Cu.Ft)	17.92
Total Aggregate	15.05
Weight / Cu. Ft.	114.15
Wgt. / Cu. Ft. / Dry	
Cement Brand	RINKER
ADMIX BRAND	WR GRACE
A.E.A. BRAND	WR GRACE

*All Aggregate Wgts are S.S.D.

TEST DATA

TYPICAL	7 DAY	28 DAY
FLEXURAL		
	370	380
	380	440
TYPICAL 28 DAY COMPRESSIVE	2500	3000

AGGREGATE DATA

Material	S-1-B					
	sieve	% pass	sieve	% pass	sieve	% pass
	1/2	100				
	3/8	100				
	4	43				
	8	4				
	16	2				
Source	RSMI					
Specific Gravity	2.46					
FM	5.50					
Dry Rodded Weight	800					

UNIVERSAL
ENGINEERING TESTING COMPANY
P.O. Box 857 • Merritt Island, Florida 32952 • (305) 452-1008

Order No: 86-1069
Report No: 4274-C
Date 1st Issue: 8-14-86
2nd Issue: 8-20-86
3rd Issue: ---
Final Issue: 9-03-86

FLEXURAL STRENGTH OF CONCRETE BEAMS

Client: Rinker Materials
P.O. Box 6385
Titusville, FL 32780

REVISED: 8-21-86 (Order No.)

Project: No Fines Concrete, Titusville, FL

DESIGN DATA

Specified Strength: ----

FIELD & LAB DATA

Date Sampled:	8-06-86		Time Sampled:	11:20a.m.	
Sampled By:	K. Hill (Rinker, Q.C)		Slump:	--	in.
Truck Number:	--		Air Content (by volume):	--	%
Ticket Number:	--		Concrete Temperature:	92	F
Time Batched:	11:05a.m.		No. of Beams Cast:	1 Set of 6	
Quantity of Load:	--	cu. yds.	Ambient Temperature:	90	F
Water Added at Site:	--	gallons	Weather Conditions:	Sunny	
Contractor:	Client		Admixture:	--	
Supplier:	--				
Location of Placement:	--				

RESULTS OF TESTING

Date Tested	Age (days)	Beam Dimensions Width x Depth (in.)	Max. Applied Load (lbs.)	Modulus of Rupture (psi.)	Average (psi.)
8-13-86	7	6 x 6 x 18	6,650	555	560
8-13-86	7	6 x 6 x 18	6,750	565	
8-20-86	14	6 x 6 x 18	6,600	550	560
8-20-86	14	6 x 6 x 18	6,750	565	
9-03-86	28	6 x 6 x 18	6,500	540	545
9-03-86	28	6 x 6 x 18	6,550	545	

REMARKS

Test Performed per ASTM C-78   Test Span = 18.0 inches

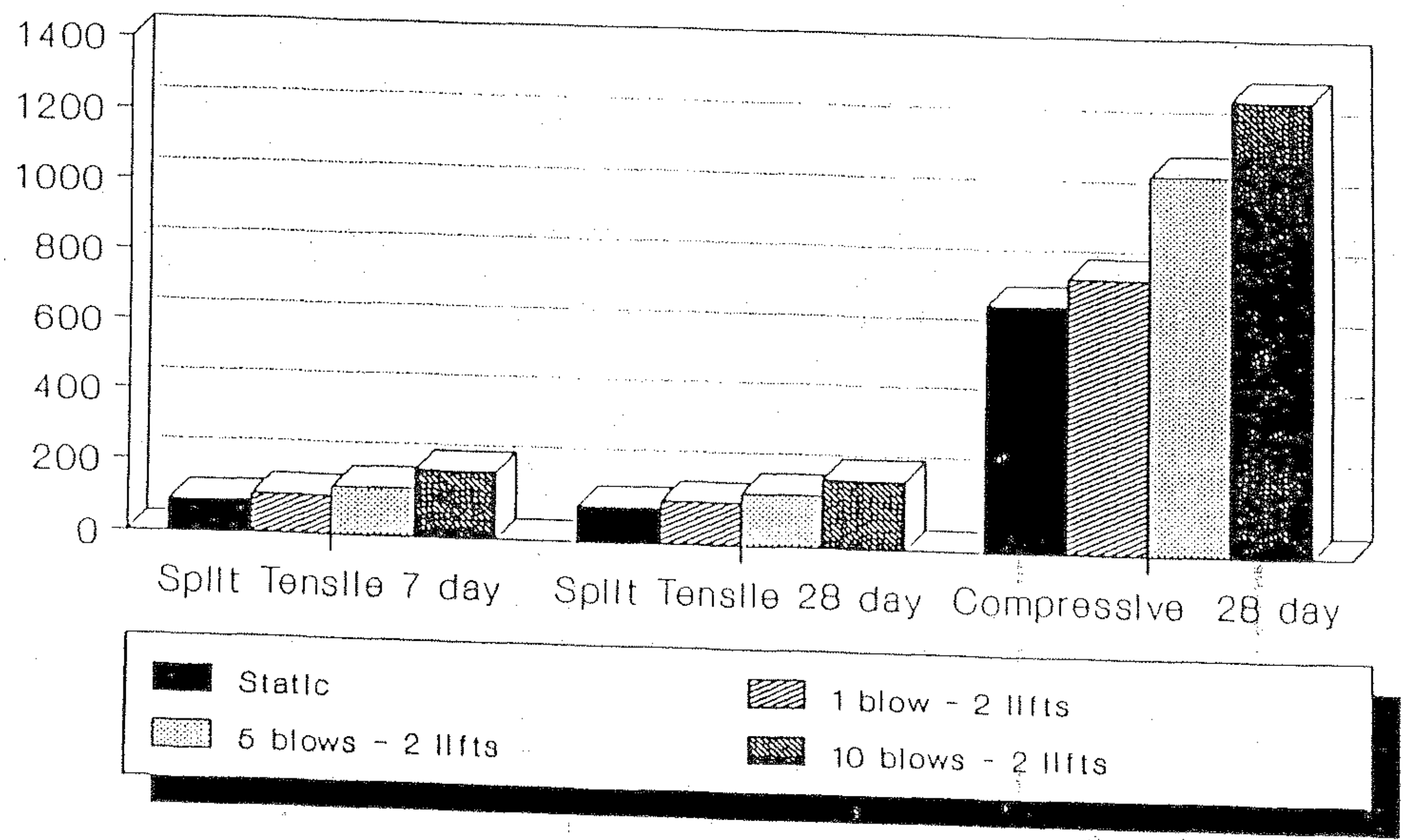
Charles Samuelson, P.E.

APPENDIX C 7

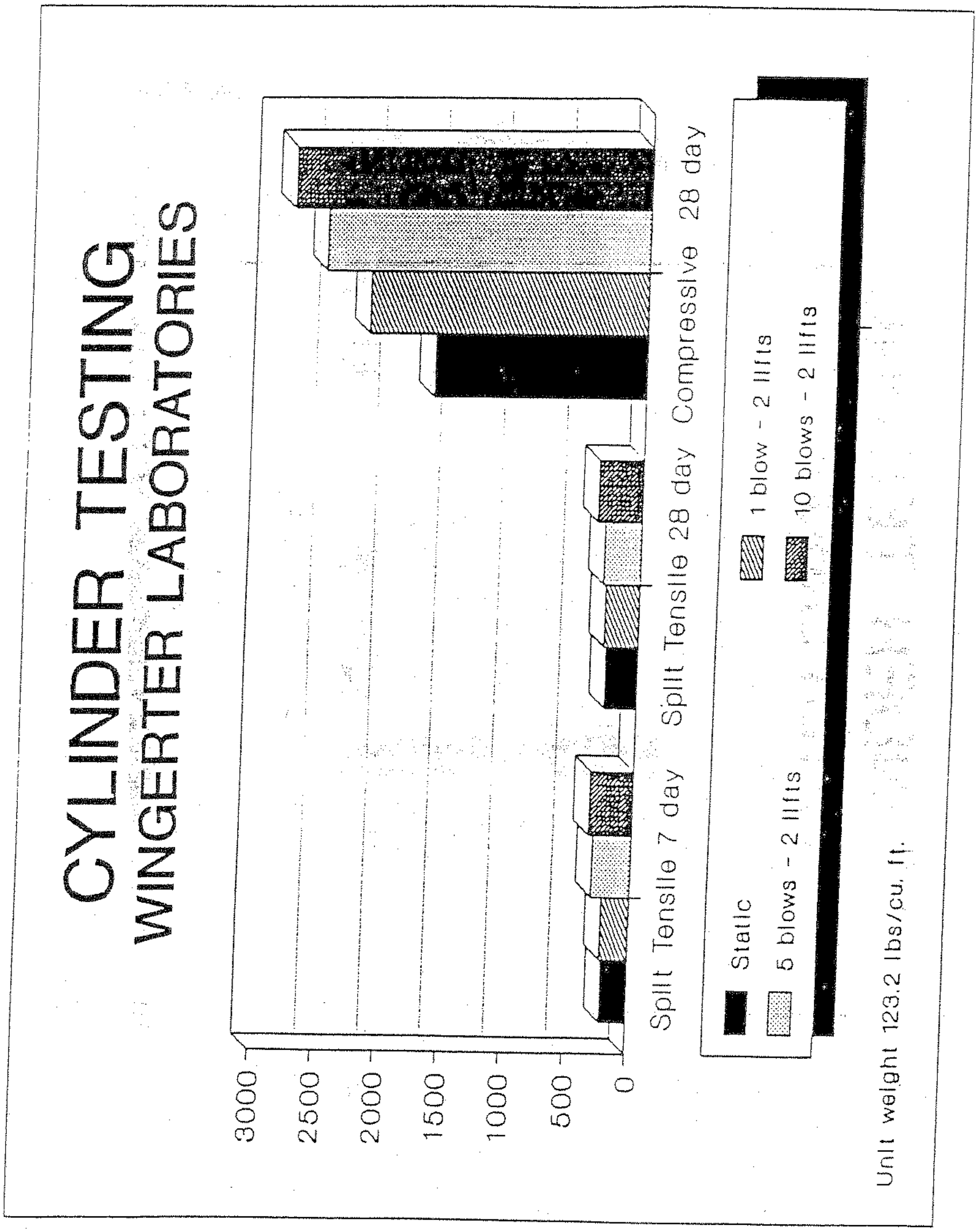
UNIVERSAL ENGINEERING TESTING COMPANY

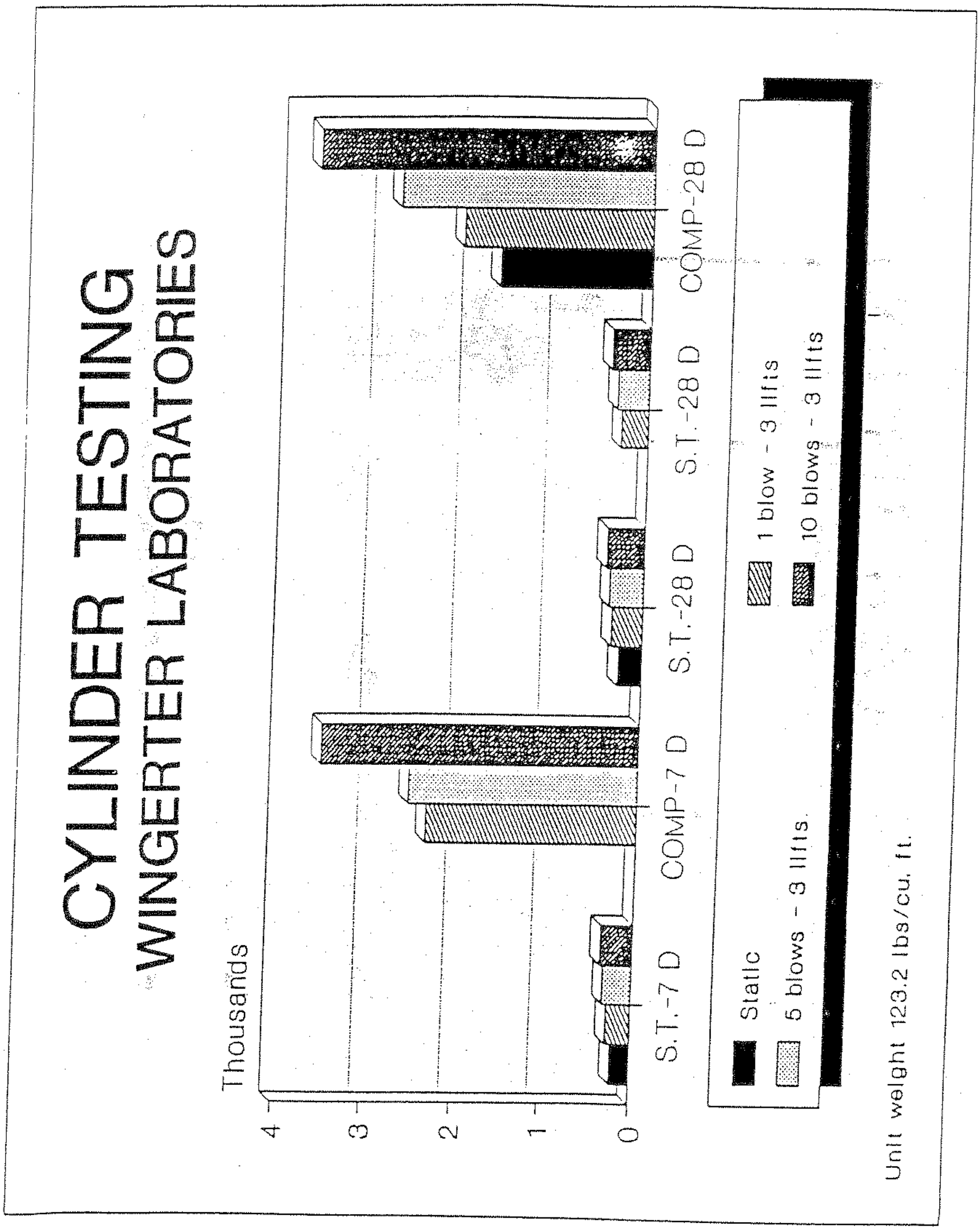
The Original of this Report was Signed and Embossed Sealed by the Above Registered Engineer in Accordance with Rule 21H-18.11, Chapter 471, Florida Statute

CYLINDER TESTING
WINGERTER LABORATORIES



Unit weight 112.4 lbs/cu. ft.


CYLINDER TESTING
WINGERTER LABORATORIES
3000
2500
2000
1500
1000
500
0
Split Tensile 7 day
Split Tensile 28 day
Compressive 28 day
Static
1 blow - 2 lifts
5 blows - 2 lifts
10 blows - 2 lifts
Unit weight 123.2 lbs/cu. ft.


CYLINDER TESTING
WINGERTER LABORATORIES
Thousands
4
3
2
1
0
S.T.-7 D
COMP-7 D
S.T.-28 D
S.T.-28 D
COMP-28 D
Static
1 blow - 3 lifts
5 blows - 3 lifts.
10 blows - 3 lifts
Unit weight 123.2 lbs/cu. ft.

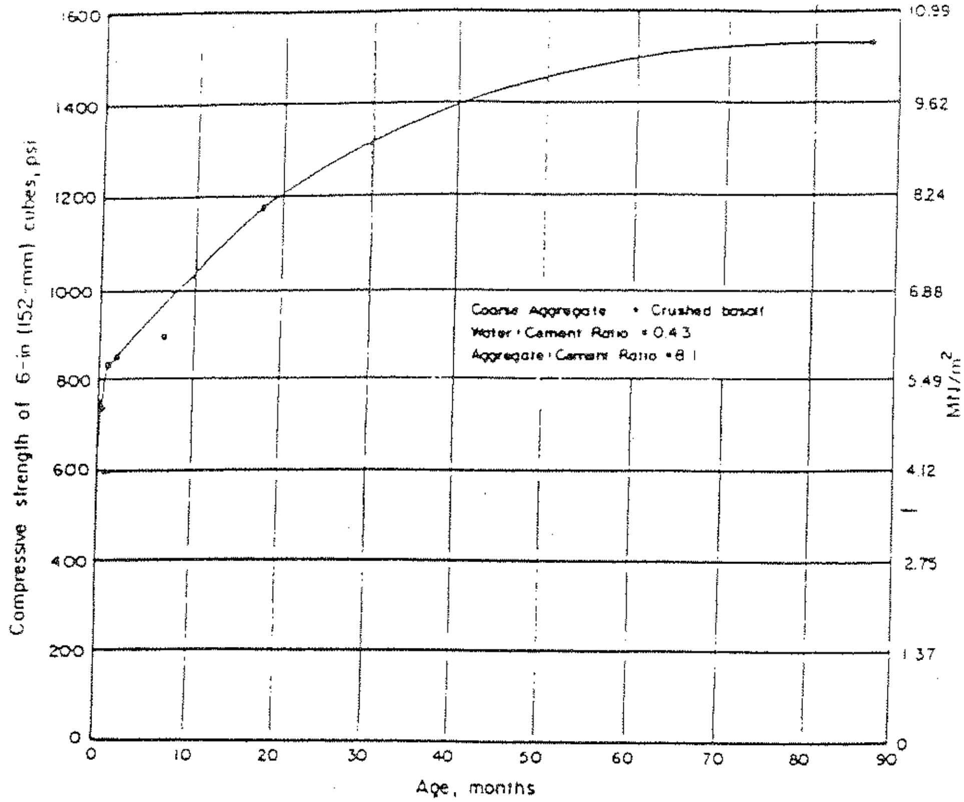


Fig. 9—Relationship between age and compressive strength of no-fines concrete. (From Reference

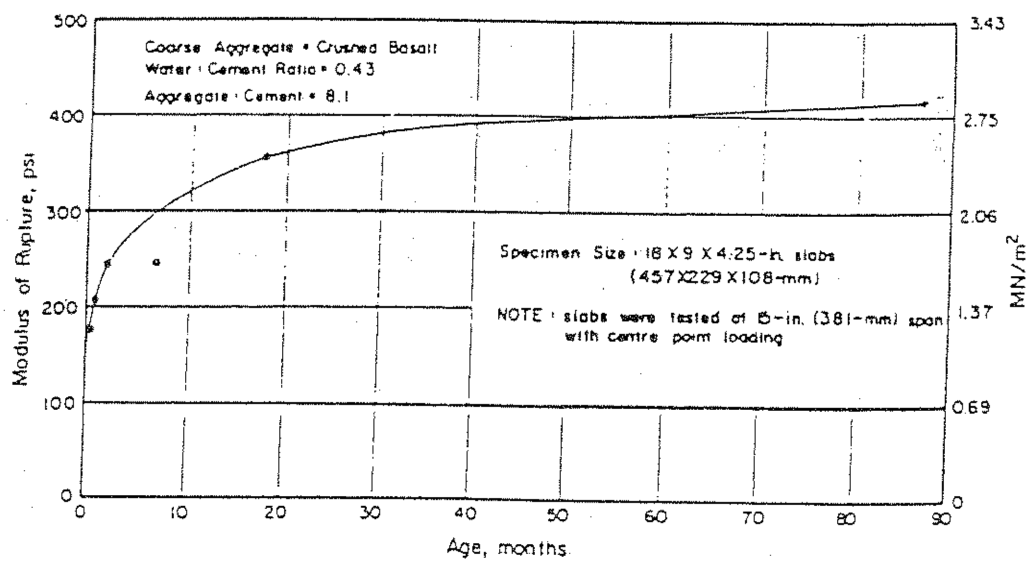


Fig. 10—Relationship between age and modulus of rupture of no-fines concrete. (From Reference

MATERIALS ENGINEERING, TESTING AND INSPECTION
TESTLAB

March 18, 1986

Florida Rock Industries
5920 West Linebaugh Avenue
Tampa, Florida 33624

Subject: Flow Rate
Porous Concrete Specimens
Project No. TL-2863

Gentlemen:

On March 8, Terry Posner of Florida Rock Industries delivered two samples of porous concrete to our laboratory for the purpose of determining the flow rate of water through these samples. The object of the test program was to provide comparative test data between the field molded test specimen and the actual in place concrete. Sample No. 1 was a 6" x 12" cylindrical specimen, which we were informed had been molded in the field in accordance with FDOT test procedure FM 5-529. Sample No. 2 was a 3' x 1.75' field sample 5½" thick, which we were informed had been obtained from the pavement. Both samples were cut to obtain test specimens of approximately the same size. The top 5½" of Specimen No. 1 and a 6" core from Specimen No. 2 were tested.

The samples were confined in plastic molds to prevent lateral flow. Then, water was placed over the samples and permitted to flow freely through the samples. The water level was maintained at a constant height of 0.25" above the top of the samples. The amount of water flowing through the samples in a one minute period was determined by collecting and weighing the water. This procedure was repeated 5 times for each sample and the average flow rate calculated therefrom. Next, 100 grams of mortar sand (FDOT 902-22) was spread uniformly over each sample and the same testing

4619 WEST CURTIS STREET • P. O. BOX 15732 • TAMPA, FLORIDA 33614 • PHONE (813) 872-7821

procedure followed. The results of the tests are attached. It should be noted that the test results only pertain to free-flow through the samples under the conditions stated. Actual flow rates under different conditions would vary and could be significantly affected by changes in mix design, method of concrete placement, subgrade characteristics and many other factors.

Thanks for utilizing our services in this matter. If there are any questions concerning these tests, please do not hesitate to ca '.

Sincerely yours,

James F. Orofino, PE
President

MATERIALS ENGINEERING, TESTING AND INSPECTION

TEST LAB INC

1610 W. CURTIS STREET • P.O. BOX 15732 • TAMPA, FLORIDA 33614

PROJECT: Flow Rate of Porous Concrete

PROJECT NO: TL-2863

LAB NO:

CLIENT: Florida Rock Industries, Inc.

DATE: March 17, 1986

SAMPLE NO. 1 – Compacted Cylinder

Test Number	Flow Rate* (gals./sq. ft./min.)
1	3.55
2	3.52
3	3.61
4	3.59
5	3.57
Average	3.57

Test Number	Flow Rate* with 100 grams Masonry Sand (gals./sq. ft./min.)
1	1.43
2	1.33
3	1.22
4	1.24
5	1.09
Average	1.26

SAMPLE NO. 2 – Field Specimen

Test Number	Flow Rate* (gals./sq. ft./min.)
1	5.10
2	5.15
3	5.15
4	5.16
5	5.10
Average	5.13

Test Number	Flow Rate* with 100 grams Masonry Sand (gals./sq. ft./min.)
1	1.61
2	1.59
3	1.52
4	1.52
5	1.47
Average	1.54

*Flow rate when water level maintained 0.25" above top of sample.

REPORTS TO: Florida Rock Industries, Inc. (3)

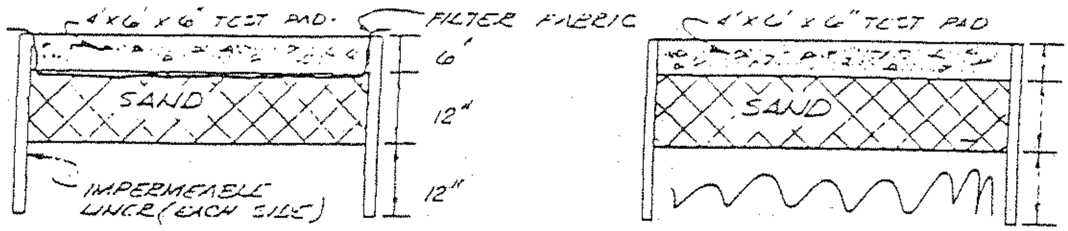
TEST LAB, INC.

WILSON, MILLER, BARTON, SOLL & PEEK, INC.
PROFESSIONAL ENGINEERS, PLANNERS AND LAND SURVEYORS

PER-KRETE TEST PADS

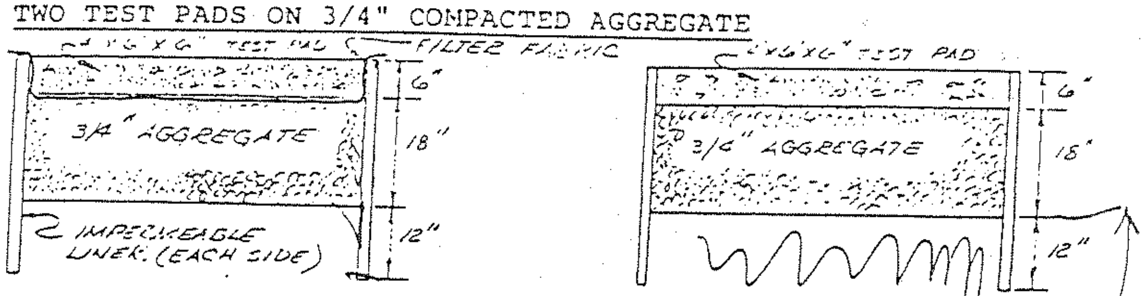
LOCATION: KREHLING INDUSTRIES, NORTH NAPLES PLANT

TWO TEST PADS ON COMPACTED SAND



1. Impermeable liner will be 3/4" waterproof plywood, with all joints and corners watertight.
2. Sand will be compacted to 95% of the maximum density as determined by AASHTO T-180.
3. Filter fabric will be placed only at one test paid and will be Mirafi 140 or equal.
4. Per-Krete will be 6" thick and placed in accordance with attached preliminary specifications.

TWO TEST PADS ON 3/4" COMPACTED AGGREGATE



1. Impermeable liner will be 3/4" waterproof plywood, with all joints and corners watertight.
2. 3/4" aggregate subgrade will be 18" thick and compacted to form a firm, uniform base.
3. Filter fabric will be placed only at one test pad and will be Mirafi 140 or equal.
4. Per-Krete will be 6" thick and placed in accordance with attached preliminary specifications.

W. R. WILSON, P.E., P.L.S. • R. W. MILLER, P.E. • W. L. BARTON, P.E. • C. H. SOLL, P.L.S. • T. R. PEEK, P.E., P.L.S.
W. M. CHRISTIANSEN, JR., P.L.S. • F. T. BARBER, III, P.E. • J. S. AGNOLI, P.L.S. • C. H. SCHNEIDER, P.E. • W. F. ASSAAD, A.I

WILSON, MILLER, BARTON, SOLL & PEEK, INC.

PER-KRETE

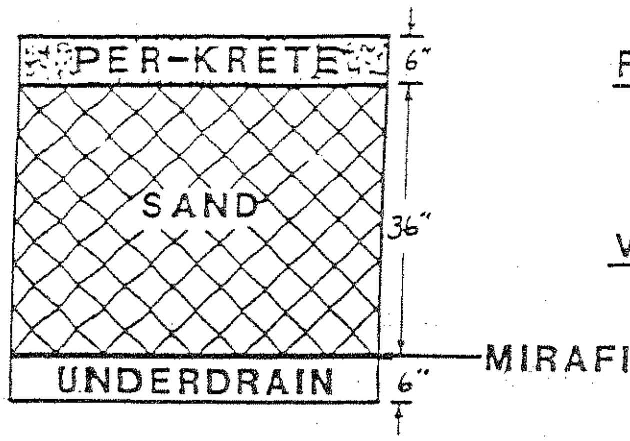
PHYSICAL CHARACTERISTICS

Specific Gravity	
Bulk	2.14
Bulk (S.S.D.)	2.33
Apparent	2.64

Percent Voids by Volume 15.1% to 17.4%

Storage (12" x 12" x 6" Section) 0.906" to 1.04"

Vertical Conductivity
269.930 GPH/S.F.
4.499 GPM/S.F.
433.013 Inches/Hr.
7.217 Inches/Min.



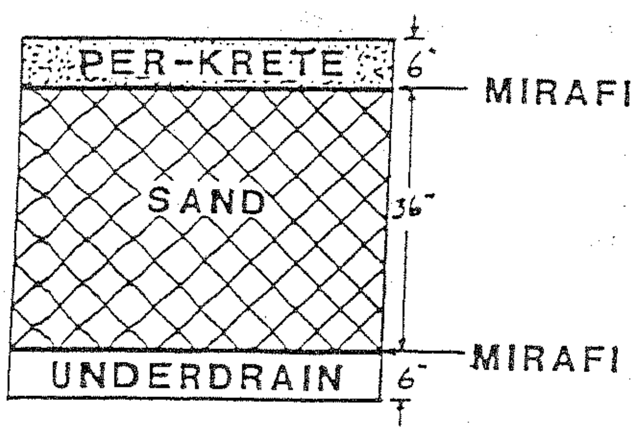
FLOW RATE

0.785 GPM
47.10 GPH
1130 GPD

VELOCITY

0.079 INCH/MIN.
4.722 INCH/HR.
1.13.3 INCH/DAY

TEST BOX #1



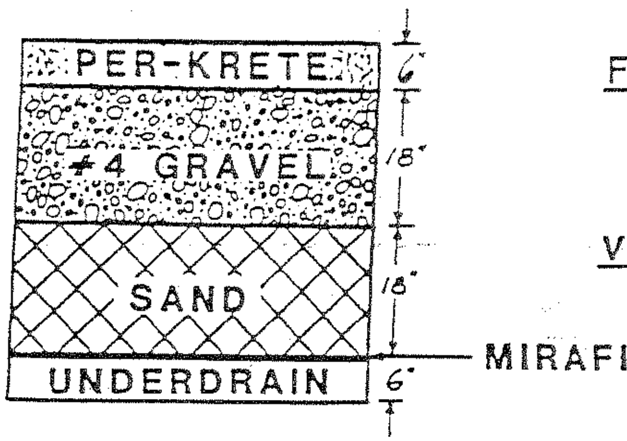
FLOW RATE

0.838 GPM
50.30 GPH
1207 GPD

VELOCITY

0.084 INCH/MIN.
5.040 INCH/HR.
121.0 INCH/DAY

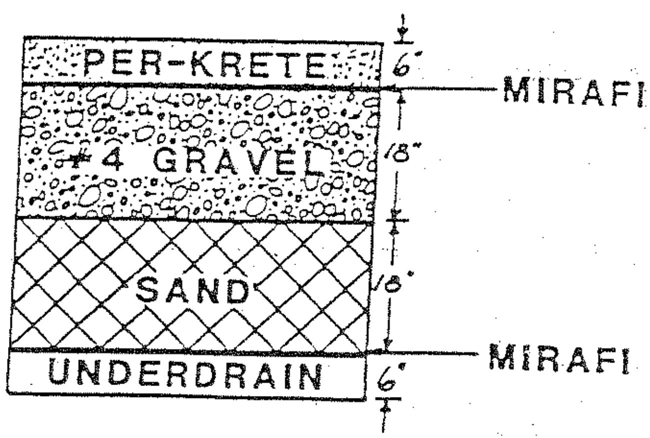
TEST BOX #2



FLOW RATE
0.798 GPM
47.90 GPH
1150 GPD

VELOCITY
0.080 INCH/MIN.
4.800 INCH/HR.
115.2 INCH/DAY

TEST BOX #3



FLOW RATE
0.781 GPM
46.88 GPH
1125 GPD

VELOCITY
0.070 INCH/MIN.
4.210 INCH/HR.
101.1 INCH/DAY

TEST BOX #4

STATE OF CALIFORNIA, PERMEABLE CONCRETE LAB MEMO, 1979

COMPRESSIVE STRENGTH

Permeable Concrete Using 3/4" X No. 4 Crushed Aggregate									
Aggregate Cement Ratio	6:1	6:1	6:1	8:1	8:1	8:1	10:1	10:1	10:1
Water-Cement Ratio	0.35	0.38	0.41	0.35	0.38	0.41	0.35	0.38	0.41
7 Day Compressive Strength (psi)*	2030	2100	1990	1330	1590	1740	860	1030	1210
28 Day Compressive Strength (psi)**	2430	2130	2270	1330	1655	1935	985	1170	1440

*Average of four cylinders (two from Round I and two from Round II)

**Round I only

Permeable Concrete Using 1" X No. 4 Rounded Aggregate			
Aggregate-Cement ratio	8:1	8:1	8:1
Water-Cement ratio	0.35	0.38	0.41
7 Day Compressive Strength (psi)*	1550	1570	1680
28 Day Compressive Strength (psi)*	1725	1805	2210

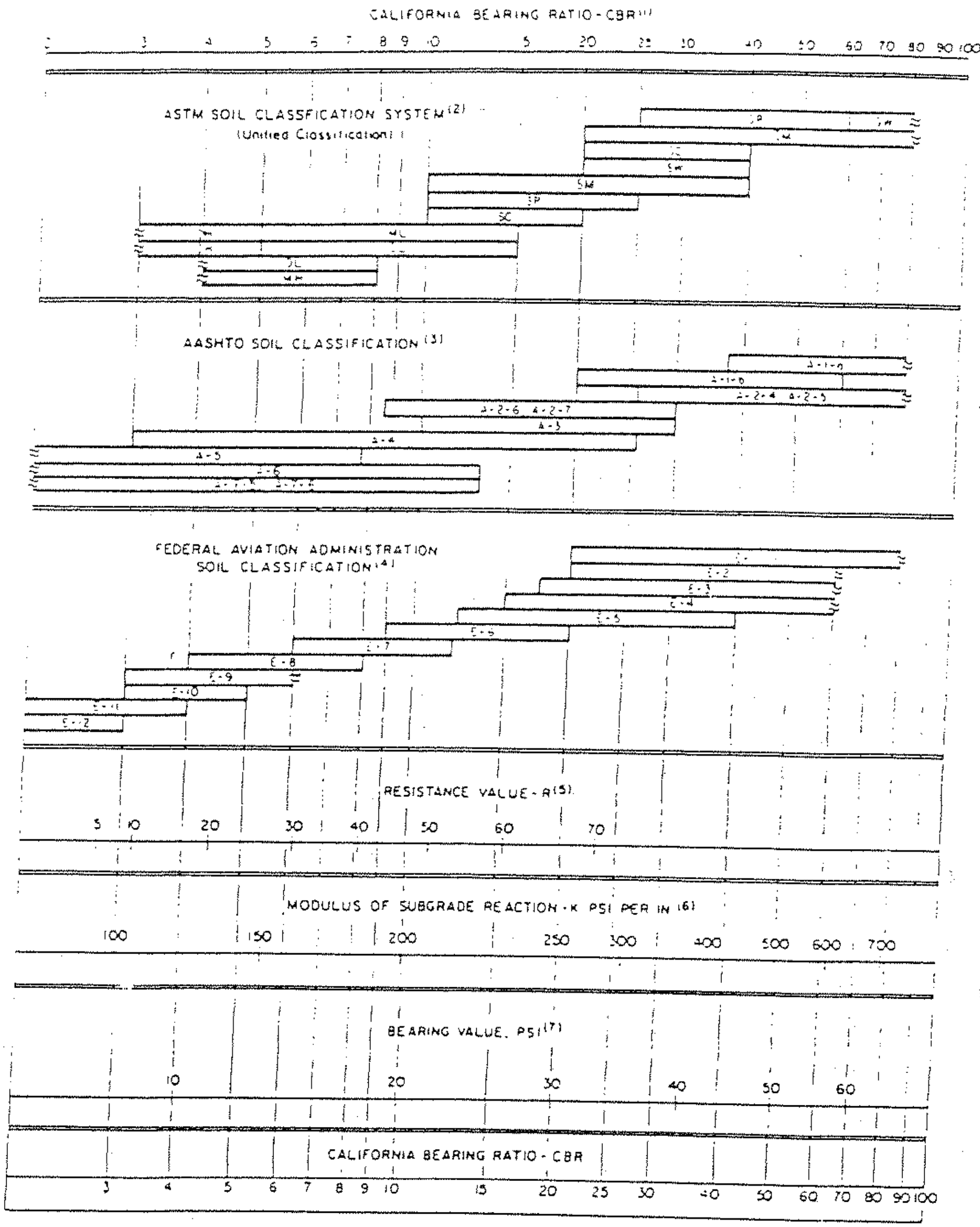
*Average of four cylinders (two from Round I and two from Round II)
**Round I only

PERMEABILITY TEST RESULTS

3/4" x No. 4 Crushed Aggregate									
Aggregate-Cement ratio	6:1	6:1	6:1	8:1	8:1	8:1	10:1	10:1	10:1
Water-Cement ratio	0.35	0.38	0.41	0.35	0.38	0.41	0.35	0.38	0.41
Vertical Permeability of 12 inch cylinder (gallons per minute)	6.8	5.2	4.4	15.2	10.4	10.0	15.8	13.1	13.7

1" x 4 Rounded Aggregate			
Aggregate-Cement ratio	8:1	8:1	8:1
Water-Cement ratio	0.35	0.38	0.41
Vertical Permeability of 12 inch cylinder (gallons per minute)	10.3	10.7	8.2

APPENDIX F



(1) For the basic idea, see O. J. Porter, "Foundations for Flexible Pavements," Highway Research Board *Proceedings of the Twenty-second Annual Meeting*, 1942, Vol. 22, pages 100-136.

(2) ASTM Designation D2487.

(3) "Classification of Highway Subgrade Materials," Highway Research Board *Proceedings of the Twenty-fifth Annual Meeting*, 1945, Vol. 25, pages 376-392.

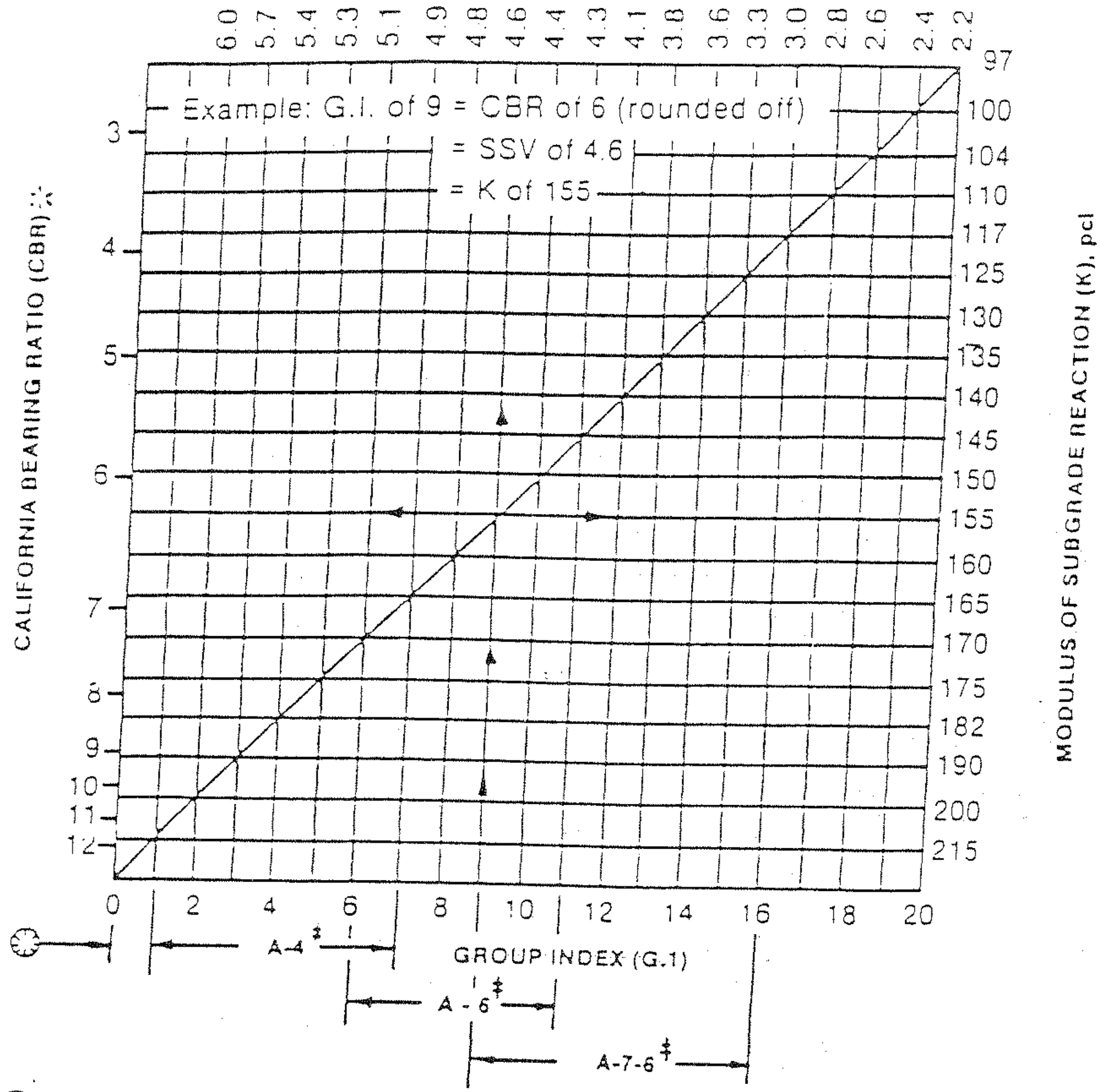
(4) *Airport Paving*, U.S. Department of Commerce, Federal Aviation Agency, May 1948, pages 11-16. Estimated using values given in FAA *Design Manual for Airport Pavements*. (Formerly used FAA Classification; Unified Classification now used.)

(5) C. E. Warnes, "Correlation Between *R* Value and *k* Value," unpublished report, Portland Cement Association, Rocky Mountain-Northwest Region, October 1971 (best-fit correlation with correction for saturation).

(6) See T. A. Middlebrooks and G. E. Bertram, "Soil Tests for Design of Runway Pavements," Highway Research Board *Proceedings of the Twenty-second Annual Meeting*, 1942, Vol. 22, page 152.

(7) See item (6), page 184.

Approximate interrelationships of soil classifications and bearing values.



AASHTO Classes A-1, A-2 & A-3 lie below 0. SSV = 6-10; K = 200 +.

‡ Usual range of AASHTO Classes.

⁑ 5-1/2 Lb. hammer, 12" drop, 4 layers, 45 blows per layer, compacted at optimum moisture as determin[e] by AASHTO T-99.

CORRELATION CHART FOR SUBGRADE STRENGTHS

TABLE 3. 18 KIP EQUIVALENTS							
Classification	VPD or ADT (2-Way)	No. of Lots	HCVPD No. per Day	Total $E_{18}SAL$ (in thousands)			
				20-Year	30-Year	40-Year	50-Year
Residential/Collector 0.20 $E_{18}SAL/HCVPD$	200-1,500	20-300	3 - 23	2-17 *	3-25	4-34	5-42
Collector 0.20 $E_{18}SAL/HCVPD$	2,000-6,000	-	80 - 240	58-175	88-268	117-350	146-438
Minor Arterial 0.25 $E_{18}SAL/HCVPD$	3,000-7,000	-	300 - 700	274-639	411-958	548-1,278	684-1,597
Arterial 0.33 $E_{18}SAL/HCVPD$	6,000-13,000	-	360 - 780	434-940	650 1,409	867-1,879	1,084-2,349
Major Arterial 0.40 $E_{18}SAL/HCVPD$	14,000-28,000	-	700 - 1,400	1,022-2,044	1,533-3,066	2,044-4,088	2,555-5,110
Business 0.35 $E_{18}SAL/HCVPD$	11,000-17,000	-	400 - 680	563-369	843-1,303	1,124-1,737	1,304-2,172
Industrial 0.38 $E_{18}SAL/HCVPD$	2,000-4,000	-	350 - 700	485-971	728-1,456	971-1,942	1,214-2,427

*23 (HCVPD) x .5 (one-way traffic) x 0.20 (coefficient, $E_{18}SAL/HCVPD$) x 365 (days/year) x 20 (years) = 16,790 (total $E_{18}SAL$)

American Concrete Pavement Association

Traffic - 18,000-pound (18-kip) Equivalent Single Axle Loads

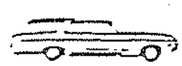
Traffic at the AASHTO Road Test consisted of multiple applic. tions of identical vehicle loads. In actual practice, pavements are subjected to a mixture of vehicles with a different number of axles and axle loads. Therefore, to design pavement it is necessary to convert this mixture of axle loads to a common factor. At the completion of the road test, traffic was converte to equivalent 18,000-pound single axle loads. The procedures in this manual follow the same conversion process used by AASHTO.

Traffic used in pavement design is based on traffic informat. determined by surveys and modified for expected changes and growth. Loadometer data is the most popular traffic data used in designing pavements. Loadometer data consists of the number of axles observed for each load group at 2,000-pound intervals. Factors have been determined for each load group and axle configuration (Appendix). These factors are multiplied by the number of axle applications in each group to arrive at the equivalent 18,000-pound single axle loads (See example 2). The total of all groups is the equivalent 18,000-pound single axle load used for pavement design.

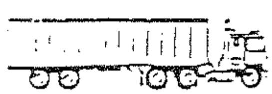
EXAMPLE 1. THE NUMBER AND WEIGHTS OF AXLE LOADS EXPECTED OVER THE DESIGN LIFE FOR A 7" RIGID PAVEMENT @ Pt = 2.0.

TRAFFIC

The number and weights of heavy axle loads expected over the design lif Expressed in 18 kips (18,000 lbs.) equivalent axle loads. (E-18's)



	SINGLE AXLE		SINGLE AXLE		Totals
Axle Weights	2000 Pounds	+	2000 Pounds	=	4000 Pounds
Equivalent Number of Automobiles	0.5 Autos	+	0.5 Autos	=	1 Auto
E-18k	0.00021	+	0.00021	=	0.00042-18k Equivalent



	TANDEM AXLE		TANDEM AXLE		SINGLE AXLE		
Axle Weights Empty	12,900 lbs.	+	9,100 lbs.	+	8,800 lbs.	=	30,800 lbs.
E-18 K's	0.04	+	0.01	+	0.05	=	0.10 E-18's
Equivalent Number of Automobiles	95	+	24	+	119	=	238 Automobil.
Axle Weights Average Load	27,200 lbs.	+	25,200 lbs.	+	9,800 lbs.	=	62,500 lbs.
E-18 K's	0.76	+	0.55	+	0.08	=	1.39 E-18's
Equivalent Number of Automobiles	1,810	+	1,310	+	190	=	3,310 Automobil
Axle Weights Full Legal Load	34,000 lbs.	+	34,000 lbs.	+	12,000 lbs.	=	80,000 lbs.
E-18 K's	1.90	+	1.90	+	0.19	=	3.99 E-18's
Equivalent Number of Automobiles	4,524	+	4,524	+	475	=	9,523 Automobile

A similar process would be followed for the entire mix of traffic.

The interpretation of the AASHTO Road Test results imply that there are differences in the way E-18's should be counted between flexible and rigid pavements. Under the same traffic loadings a rigid pavement will normally experience a larger number of E-18's than a flexible pavement. Actual traffic counts should be used when available for comparing the two types of pavements. However, if such figures are not available the following factors can be applied with reasonable accuracy:

% Trucks	Type of Project	Factor
> 20% Trucks	Interstate	1.30
10-20% Trucks	Primary/Secondary/Interstate/Urban	1.25
5-10% Trucks	Urban/Municipal	1.15
< 5% Trucks	Municipal/Parking Lots	1.05

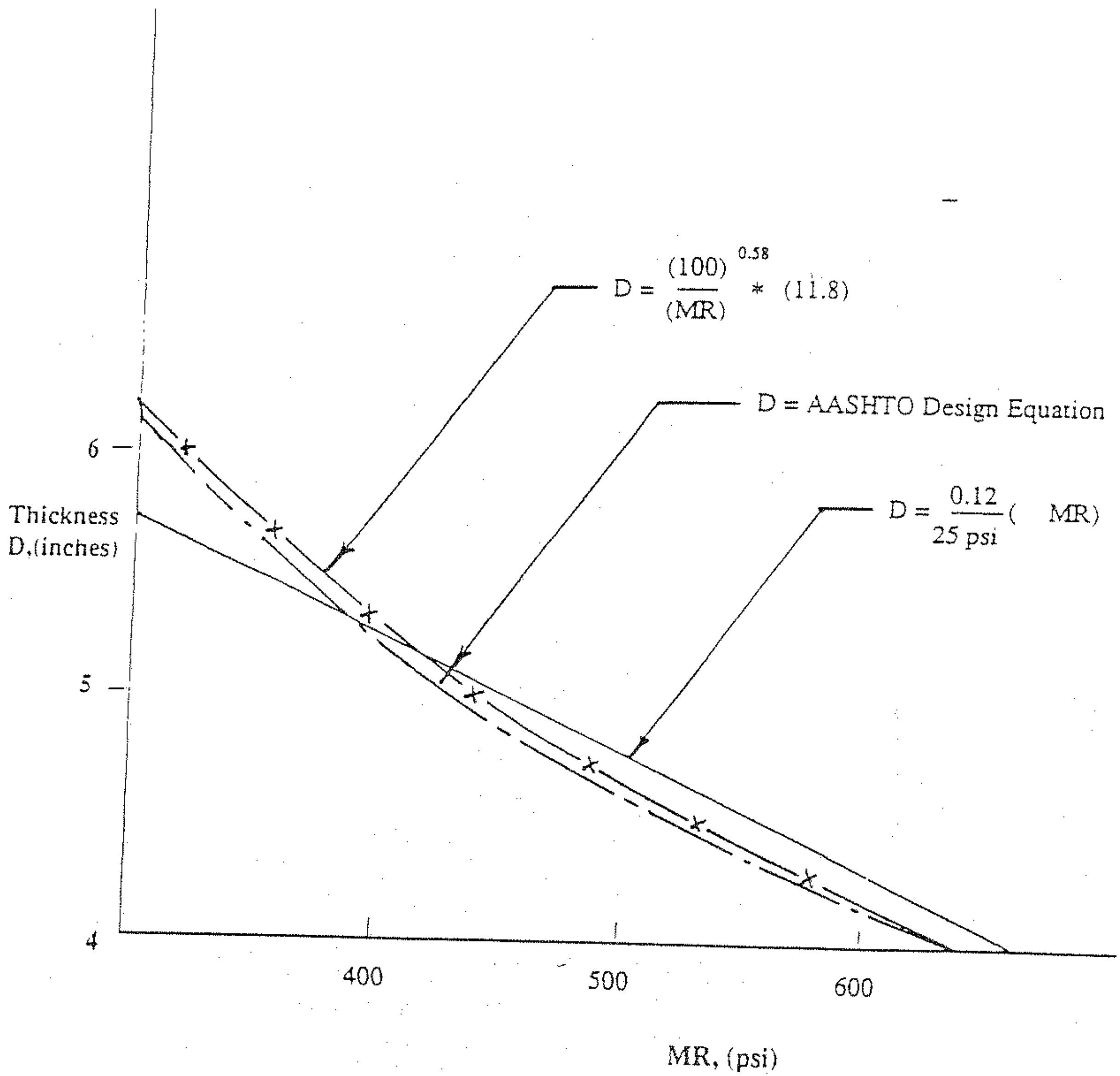
Example: $\text{E-18 Flexible} = \dfrac{\text{E-18 Rigid}}{\text{Factor}}$

The accepted historical period of time used for design traffic predictions is 20 years. Normally, any time interval may be used by the designer. The traffic is expressed as the total equivalent 18,000-pound single axle loads the pavement is expected to carry between the time of construction and the time it reaches an indicated terminal serviceability index (Pt). Terminal serviceability index is usually 2.5 for high speed, high volume pavements, and 2.0 for low volume, low speed pavements. The terminal serviceability index indicates that the pavement has reached the end of its acceptable service life.

Recently considerable thought has been given to increasing the 20-year design traffic predictions for our road and street system and, primarily, the Interstate System. This is due to a large increase in the percentage of truck traffic and increasing the maximum truck weights from 72,000 pounds to 80,000 pounds gross loads.

Since the equivalent axle loads usually represent traffic from all lanes in both directions, it is necessary to distribute this traffic by lanes and by direction before using the pavement design procedure. Generally 50 percent of the traffic is assigned for each direction and 100 percent of the traffic is assigned to each lane for design purposes. However, factors may be applied based on experience to assign portions of traffic per each lane.

A computer program has also been developed for compiling 18-kip equivalent single and tandem axle loads.



Design Thickness Relationships

Appendix I

Quality Control & Test Methods
P. C. Pervious Pavement

James L. Mross
Assistant Quality Control Manager
RINKER MATERIALS CORP.

There are several problems and much confusion surrounding the measurement of quality or conformity with specified properties of no-fines concrete and pervious concrete pavement.

The problems and confusion exist because of the materials properties and their sensitivity to variations in consolidation and curing. This sensitivity to variations in placing, consolidation, and curing appears to be greater than that for normal structural concretes, and the common field measurements of slump, for example, are not applicable. For this reason, it is suggested that acceptance of the material and pavement be separated. Further; a simple, repeatable, and reproducible field test method should be used to monitor and accept the fresh no-fines concrete. If resulting measurements from an existing consensus method of test can be correlated to the desirable properties of both material and pavement, then it would seem reasonable to use that method of test for acceptance. The caution given here applies particularly to strength tests, whether in compression, flexure, or split tensile. It sould be remembered than any test method conducted in the field tends to be less precise and reliable than when conducted in a laboratory. Also, the supplier and contractor as well as the owner have a right to assurance that the product will serve its intended function.

The test method suggested here is ASTM C29 "Standard Test Method for Unit Weight and Voids in Aggregate". The reasons are:

1. It appears to be appropriate
2. It is both repreatable and reproducible
3. It "fits" in confirming actual fresh unit weights with mix design weights
4. Most commercial testing laboratories have available and approx. 1/4 cu ft. measure as part of their Type B Pressure Air Meter
5. It is an inexpensive and quick method.

It should be noted that the 1/4 cu. ft. measure is used here (with No. 8 or 89 aggregate) because results with it have been more repeatable and reproducible than with either 1/10 cu. ft. or 1/2 cu. ft. measure. Also, because other common methods of measuring or judging apparent quality, i.e. slump and air, are being excluded; much greater attention to quality assurance plans and programs, and increased frequency of testing should be expected. Correlations between unit weight and compressive, flexural, or split tensile strengths in laboratory trials can be expected to be good, and once the relationship between measurements have been defined for any particular or specific mix, unit weights may be used to confirm that the fresh no-fines concrete delivered was batched and mixed in accordance with the design. If it is desired, compressive strength specimens may then be made at a decreased frequency to confirm that their individual unit weight (specimen unit weight)/compressive strength relationship complies with the prequalification relationship and that component materials, such as cement, meet their requirements.

It is imperative that for strength test uniformity for within batch samples, test specimens be consolidated using a Proctor Hammer (with a given and uniform force) in conjunction with a circular steel plate of approximate 1/4" thickness and 5 3/4" diameter. Other proposed methods of consolidation, such as rodding or tamping with a 2"x2"x24" wooden stake do not appear to produce adequately uniform consolidation or densities closely approximating those of cores taken from existing pavements.

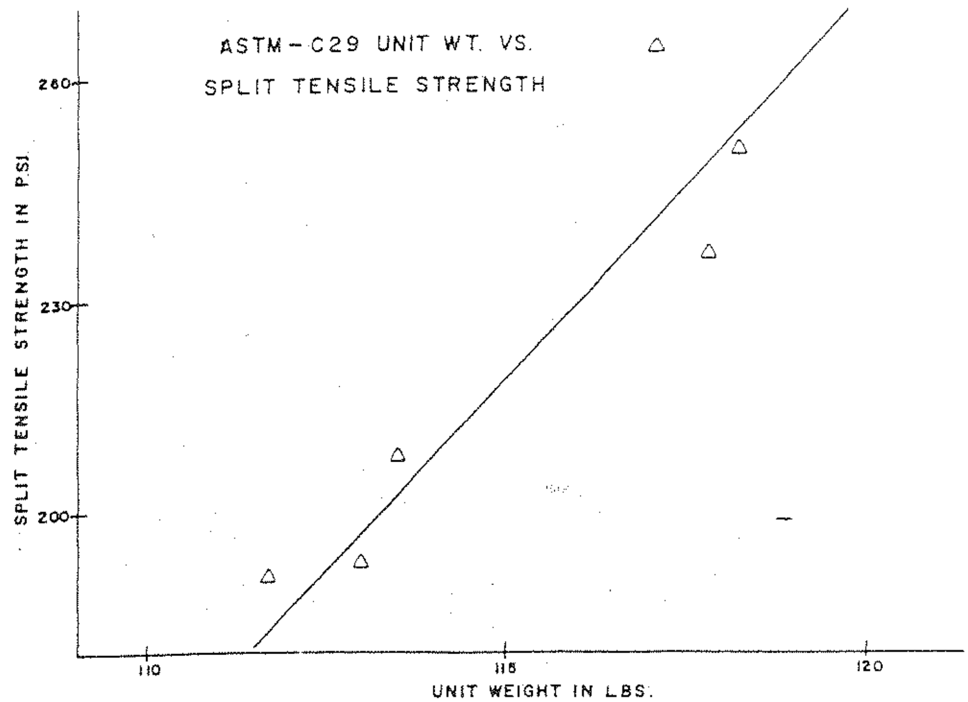
The ASTM C29 unit weights should not be expected to correlate well with strength measurements. Strength test results should be correlated to their individual specimen unit weight. As an example from a recent placement of approximately 1000 units of no-fines concrete: The regression analysis of C29 unit weight vs. C496 split tensile strength tests had a correlation coefficient of only 0.267 although all split tensile strengths and unit weights were acceptable.

The unit weight of hardened specimens, either cores or molded strength specimens must be taken in stable moisture condition. This may be "oven-dry" or saturated. To obviate several testing problems, it is suggested that the saturated condition be used as described in paragraph 14.1 Saturation of ASTM C140 "Standard Methods of Sampling and Testing Concrete Masonry Units". Thus the wet (SSD) unit weight of cores or molded specimens would be determined by 24 hr. immersion in water, allowed to drain for 1 minute while removing visible surface water with a damp cloth and weighing immediately.

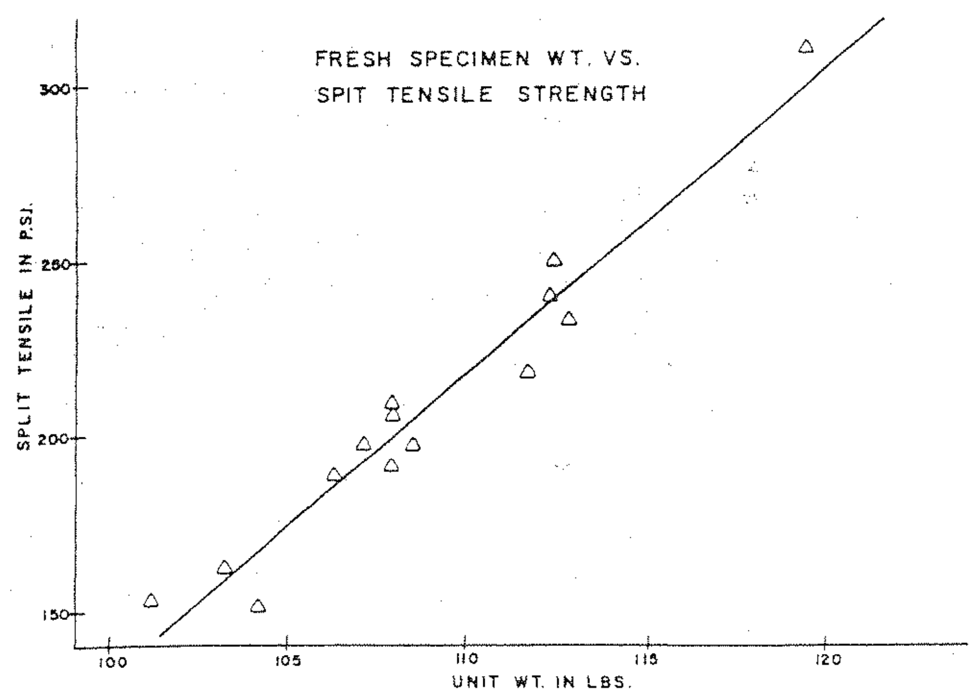
Pavement acceptance could then be based on pavement thickness and unit weight as determined from the cores. The owner is cautioned against testing cores in compression or split tensile for acceptance purpose, and any strength tests should only be to confirm the original prequalification relationship.

Finally, the owner and designer are cautioned against specifying strengths or void contents that are not in sympathy with one another or may be too difficult to test or achieve in practice.

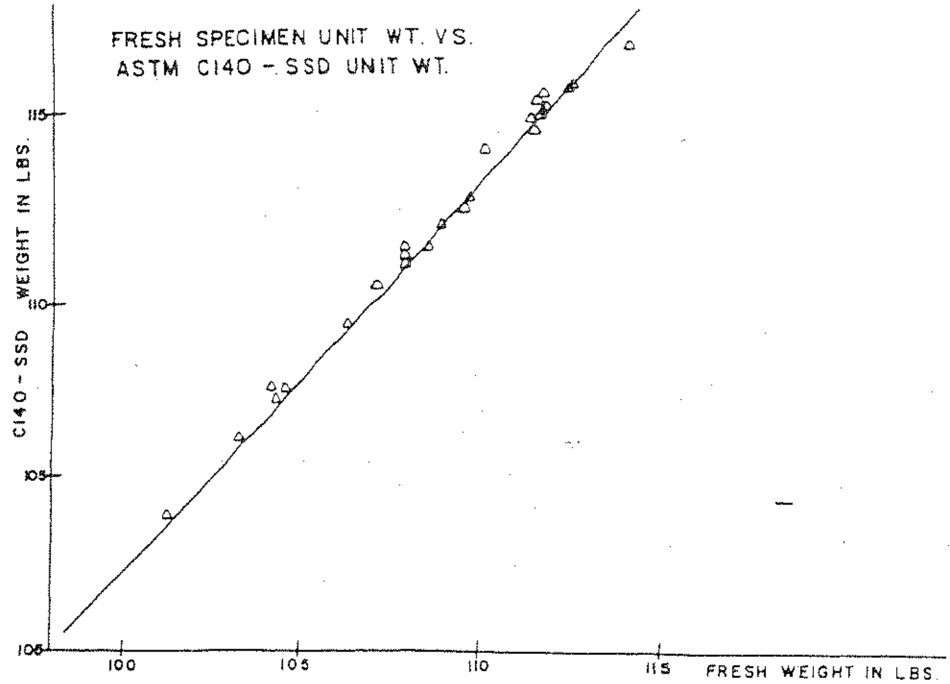
The correlations presented next, only represent those for a specific mix design using specific materials. It is the strong recommendation of this report that relationships between unit weights and other properties be developed by the producer for his proposed mix, prior to production.



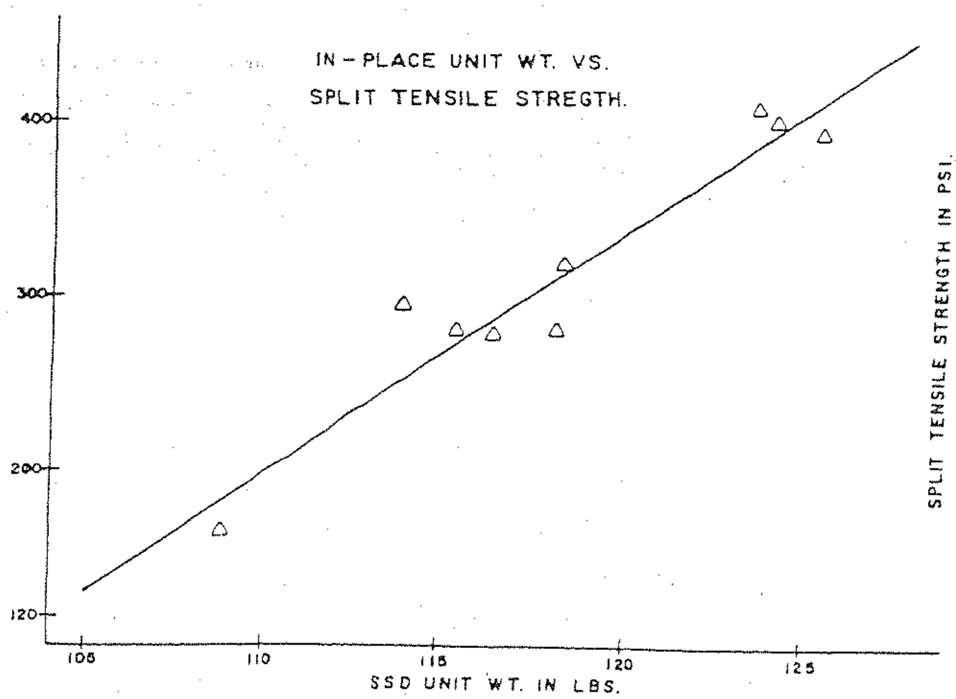
y = 10.13x - 943.5
Correlation Coefficient 0.92
Standard Error 14



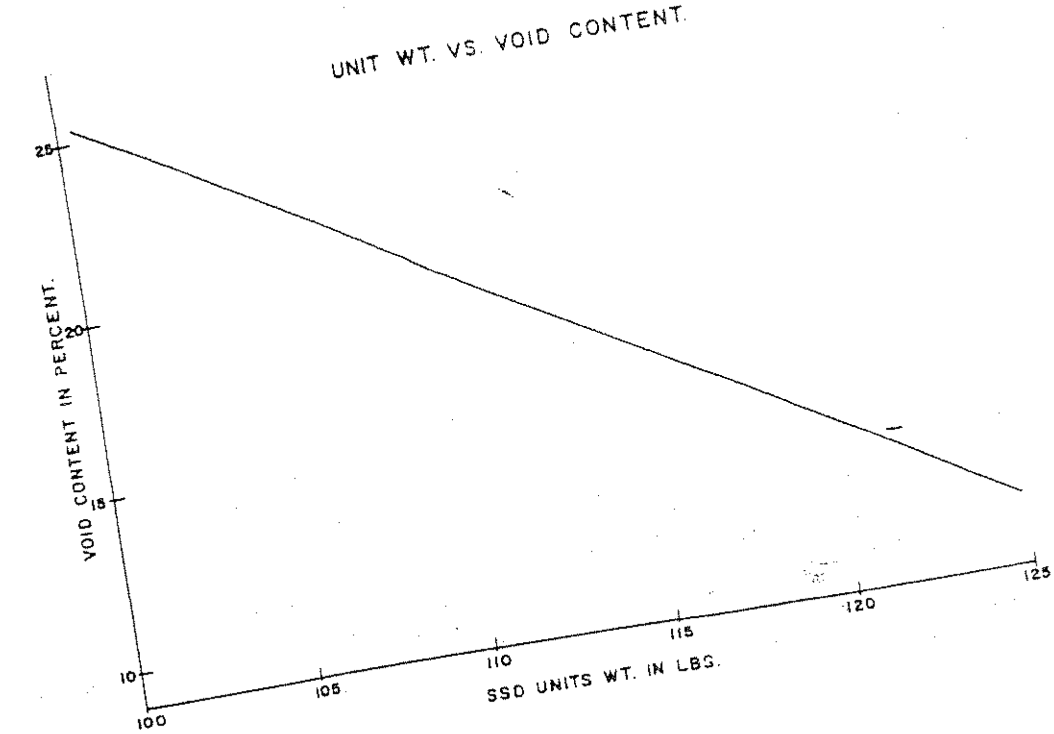
y = 8.82x - 752
Correlation Coefficient 0.97
Standard Error 10



y = 1.046x - 1.812
Correlation Coefficient 0.997
Standard Error 0.298



y = 13.73x - 1311
Correlation Coefficient 0.96
Standard Error 23.51



y = 83.9 + (-.5836x)
Correlation Coefficient 0.92
Standard Error 1.31

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