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16. Abstract

The primary objective of this research project was to evaluate geotextiles placed under or within a hot mix asphalt (HMA) overlay to reduce the severity or delay the appearance of reflection cracks. Researchers evaluated six geosynthetics, representing fabrics, grids, and composites in the laboratory using the TTI Overlay Tester. The overlay tester accommodates a 3x6x20-inch HMA beam and evaluates the relative ability of different beams (with and without a geosynthetic) to resist thermal cracking. Geosynthetics consistently increased number of cycles to failure in laboratory tests. Researchers then used fracture mechanics to evaluate the laboratory results and develop a new evaluation methodology termed the "reinforcing factor. "

Comparative field test pavements were established in three regions of Texas (Amarillo, Waco, and Pharr Districts) with widely different climates. Due to unavoidable delays, only the Pharr test pavements were constructed before this report was written. These planned field tests will be constructed and all three will be evaluated for several years particularly regarding reflective cracking.

Syntheses of the findings from the literature and personal interviews were prepared. Supplementary benefits of additional tack coat and a leveling course in overlay systems were demonstrated. Significant changes in pertinent construction specifications were recommended. When placing a self-adhesive grid product, particularly on a high-traffic facility, a tack coat should be applied on top of the grid to minimize slippage problems. Generally, the cost effectiveness of fabrics for reducing reflection cracking appears to be marginal. Information on cost effectiveness of grids and composites is not available. An asphalt-impregnated fabric or composite is essentially impermeable to water and thus can provide significant benefits or possibly cause significant problems. The presence of an impermeable layer in an overlay system should be carefully considered during the design stage.

Finally, researchers prepared comprehensive guidelines for using geosynthetics with HMA overlays to reduce reflection cracking and recommended they be printed in a handbook.

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GEOSYNTHETICS IN FLEXIBLE AND RIGID PAVEMENT OVERLAY SYSTEMS TO REDUCE REFLECTION CRACKING

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation. It is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Joe W. Button, P.E. #40874.

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Three districts agreed to cooperate in the placement of test pavements to evaluate long-term performance of a variety geosynthetic products. The engineers in these districts that were instrumental in securing these agreements and working with the researchers included the following: Amarrillo – Joe Chapel, P.E. and Randy Hochstein, P.E.; Pharr – Rosendo Garcia, P.E. and Carlos Peralez, P.E.; and Waco – Jeff Kennedy, P.E. and Larry Stewart, P.E. Their cooperation and assistance is gratefully acknowledged.

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CHAPTER I
INTRODUCTION

I.1. BACKGROUND

Flexible pavements, synonymously referred to as asphaltic concrete or hot mix asphalt (HMA) pavements, are a major component associated with the construction of highway facilities and, at present, constitute approximately 94 percent of surfaced roadways in the United States (NAPA, 2001). Other major pavement types include rigid, or portland cement concrete (PCC) pavements, and composite pavements consisting of a PCC pavement overlaid with an HMA pavement (Huang, 1993). For both flexible and composite pavements, a common technique used by many agencies for preventive maintenance and/or rehabilitation is simply to construct a thin HMA overlay, normally between 1 and 2 inches thick. This approach is designed to protect the existing surface against water intrusion, reduce roughness, restore skid resistance, increase structural capacity, and improve the overall ride quality to the traveling public (Roberts et al., 1996). Finn and Monismith (1984) provide an excellent summary of HMA overlay design procedures commonly used in the United States.

One of the more serious problems associated with the use of thin overlays is reflective cracking. This phenomenon is commonly defined as the propagation of cracks from the movement of the underlying pavement or base course into and through the new overlay as a result of load-induced and/or temperature-induced stresses. Increasing traffic loads, inclement weather, and insufficient maintenance funding compound this problem and inhibit the serviceable life of these pavements for many cities, counties, and state Departments of Transportation (DOTs). With the U.S. Department of Energy (USDOE, 2000) projecting a 60 percent increase in world oil consumption from 1997 to 2020, the costs associated with constructing and maintaining these pavements will undoubtedly continue to increase.

The above factors decrease the useful life of HMA overlays and/or increase the need for cost-effective preventive maintenance techniques. Some of the latest techniques include incorporating geosynthetic products, defined herein as grids, fabrics, or composites, into the pavement structure. This procedure is typically accomplished by attaching the geosynthetic product to the existing pavement (flexible or rigid) with an asphalt tack coat and then overlaying with a specified thickness of HMA pavement. These materials have exhibited varying degrees of success, and their use within a particular agency has been based primarily on local experience or a willingness to try a product that appears to have merit.

I.2. DEFINITION OF GEOSYNTHETICS

Geosynthetics are defined herein as fabrics, grids, composites, or membranes. *Geo* relates to placement of the material on or in the earth or ground (e.g., in a pavement) while *synthetic* indicates a man-made material. The prefix *geo* may also be used with fabric, grid, composite, or membrane. Grids and composites are newer generation materials developed for specific purposes by certain manufacturers.

Fabrics or geotextiles may be woven or nonwoven and are typically composed of thermoplastics such as polypropylene or polyester but may also contain nylon, other polymers, natural organic materials, or fiberglass. Filaments in nonwoven fabrics are typically bonded together mechanically (needle-punched) or by adhesion (spun-bonded, using heat or chemicals). Paving fabrics typically weigh about 4 to 6 ounces/yd^2. Technically, grids and composites are not geotextiles (Holtz et al., 1998).

Grids (mesh or geonets) may be woven from glass fibers or polymeric (polypropylene or polyester) filaments, or they may be cut or pressed from plastic sheets and then post tensioned to maximize strength and modulus. Grids typically have rectangular openings from ¼ inch to 2 inches wide. A grid may have a thin membrane laminated onto it that assists in construction (i.e., attach to the asphalt tack coat) but melts and disappears when the hot HMA overlay is applied. Additionally, some grids have thin, permanent fiber strands partially filling the apertures which adhere the grid to the tack coat without forming a waterproof barrier. Grids are designed to exhibit high modulus at low strain levels such that their reinforcing benefits begin before the protected HMA pavement layer fails in tension.

Composites generally consist of a laminate of fabric onto a grid. For the composite, the fabric provides absorbency (primarily to hold asphalt) and a continuous sheet to permit adequate adhesion of the composite onto a pavement surface; whereas, the grid provides high tensile strength and stiffness. Manufacturers custom designed these third-generation products, based on laboratory and field research, to meet the needs of asphalt retention and high initial tangent modulus (i.e., high modulus at low strain levels).

A heavy-duty membrane is a composite system, usually consisting of a polypropylene or polyester mesh laminated on either one or both sides with an impermeable rubber-asphalt membrane. Membranes, weighing about 50 to 100 ounces/yd^2, are typically placed in strips on joints in concrete pavements.

I.3. OBJECTIVES

The objective of the research is to investigate and develop information that will aid in the evaluation of the relative effectiveness of commercially available geosynthetic materials in reducing the severity or delaying the appearance of reflective cracking in HMA overlays due, in part, to thermally induced stresses. Specific objectives of this research include:

- Conduct a review of published and, to the extent possible, unpublished information and synthesize the findings.
- Identify and obtain geosynthetic products that will represent, to the extent possible, the different types of materials commercially available for reducing reflection cracking in asphaltic concrete overlays.
- Fabricate laboratory samples of HMA beams reinforced with geosynthetic materials and measure their relative resistance to thermally induced stresses.
- Identify and utilize the best available model to analyze the test data and determine the material properties that have the greatest effect on overlay performance.
- Work with TxDOT to plan and construct field test pavements to evaluate relative resistance to reflective cracking of various geosynthetics.
- Determine the relative effectiveness of each category of geosynthetic product in reducing or delaying reflective cracking.

I.4. SCOPE

In summary, researchers selected six different state-of-the-art geosynthetic products, which include two fiberglass grid composites, two polyester grid composites, one fiberglass grid, and one polypropylene nonwoven fabric. These products were evaluated in the laboratory by measuring relative resistance to thermal cracking of an HMA/geosynthetic system. The Texas Transportation Institute (TTI) Overlay Tester, which accommodates 3-inch by 6-inch by 20-inch beam specimens, was used in this testing program.

Researchers identified pavements in the Pharr, Waco, and Amarillo Districts for construction of test pavements. These districts will provide mild, moderate, and cold Texas climates, respectively, for evaluating geosynthetics. Due to unavoidable construction delays, only the Pharr District test pavements were constructed during the first phase of the study. All three of the test pavements will be constructed and relative performance, particularly related to reflective cracking, will be evaluated for several years.

I.5. IMPLEMENTABLE PRODUCTS

Implementable products of this research include guidelines for using geosynthetics with HMA overlays to reduce reflective cracking, recommended specification changes for using geotextiles to reduce reflective cracking, and a design check for the FPS-19 computer program which permits consideration of geosynthetics as an alternative for reducing reflective cracking.

CHAPTER II

LITERATURE REVIEW

II.1. BACKGROUND AND PURPOSE OF LITERATURE REVIEW

Many HMA overlays prematurely exhibit a cracking pattern similar to that in the old underlying pavement. The cracking in the new overlay surface is due to the inability of the overlay to withstand shear and tensile stresses created by movements concentrated around preexisting cracks in the underlying pavement. This movement may be due to traffic loading causing differential deflections at cracks in the underlying pavement layers, expansion or contraction of subgrade soils, expansion or contraction of the pavement itself due to changes in temperature, or combinations of these phenomena. Pavement movement, induced by any of the above causes, creates shear and/or tensile stresses in the new overlay. When these stresses become greater than the shear or tensile strength of the HMA, a crack develops in the new overlay. This propagation of an existing cracking pattern from the old pavement into and through a new overlay is known as *reflective cracking*.

Reflective cracks through HMA overlays have been an international problem for decades. Although reflection cracks do not generally reduce the structural capacity of a pavement, subsequent ingress of moisture and the effects of the natural environment and traffic can lead to the premature distress and even failure of the pavement. Many different treatments have been tried over the years to *prevent* reflection cracking; *none* have been successful. However, some treatments have shown significant delays in the appearance and reductions in the amount and severity of reflective cracks. Some of the newer and more successful products are geosynthetics. Geosynthetics for reinforcing HMA overlays to reduce reflective cracking are the focus of this literature review.

In March 2000, Carver and Sprague (2000) concluded that asphalt reinforcement technology is still relatively new, and the target pavement problems are complex. Precise determinations of performance and economic benefits will not be possible until more experience is gained and actual performance is compared to that expected by currently available design and analysis techniques.

II.2. MECHANISMS OF REFLECTION CRACKING

In analyzing the treatments for delaying reflection cracking, it is essential to recognize the fundamental mechanisms associated with their behavior. Simultaneous movements of an overlay caused by wheel loads, temperature changes, temperature gradients, and subgrade moisture changes induce a complex stress state of cyclic bending, tension, and shear within the overlay. These stresses are caused by a complex sequence of cyclic crack/joint movements caused by vertical and horizontal loads, long-term (seasonal) and short-term (daily) temperature changes, and subgrade volume changes due to moisture variations.

Lytton (1989) pointed out that, every time a load passes over a crack in the old pavement, three pulses of high stress concentrations occur at the tip of the crack, as it grows upward through the overlay (Figure 1). The first stress pulse is a maximum shear stress pulse (shown at point A in Figure 1). The second stress pulse is a maximum bending stress pulse (shown at point B in Figure 1). The third stress pulse is again a maximum shear stress pulse, except that it is in the opposite direction of the first shear pulse. Also, because there is often a void beneath the old surface, the maximum shearing stress when the load is at point C is usually larger than when it is at point A. These stress pulses occur in a very short period of time, in the order of 0.05 second. At these high loading rates, the stiffness of the asphalt concrete in the overlay and in the old pavement is quite high. Each pavement movement results in a small increase in crack length in the overlay. As the number of loadings increases, the magnitude of movement increases, crack growth rate increases, and overlay reflection cracks rapidly appear at the pavement surface.

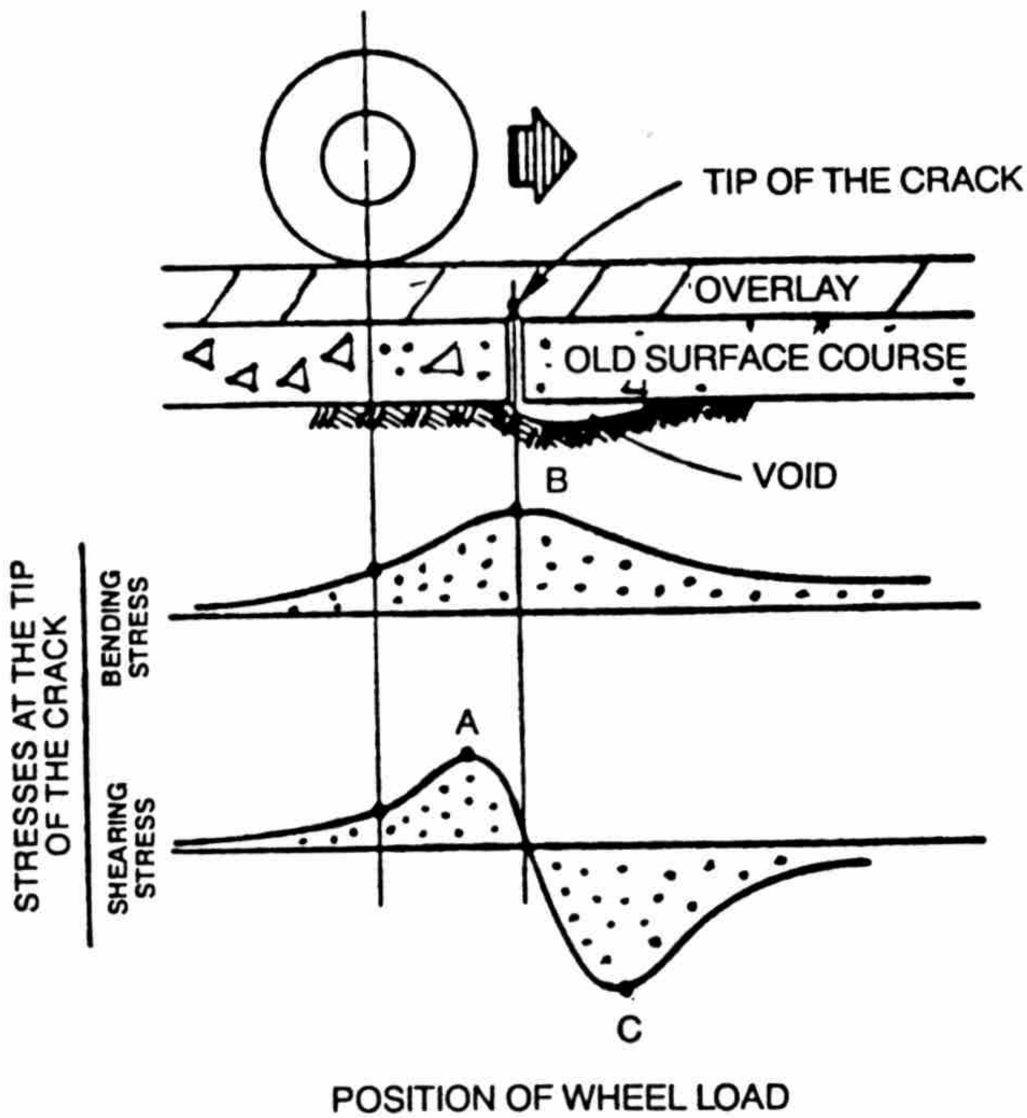


Figure 1. Shear and Bending Stress Induced at a Crack Caused by a Moving Wheel Load (after Lytton, 1989).

II.3. METHODS OF REDUCING REFLECTION CRACKING

Many studies have been performed on the subject of reducing or delaying reflective cracking in HMA overlays. An initial search of the literature revealed that more than 200 reports and papers have been published worldwide in the last 20 years (about one per month)! Distresses associated with HMA pavements have been recorded as early as 1921 when Biles (1921) summarized the latest maintenance activities of the day. During the 1925 proceedings of the Highway Research Board, concerns arose over choices of resurfacing methods for rigid pavements in the United States (Root, 1925). Early in the twentieth century, Emmons (1928) presented a synthesis, possibly the first, on the use of bituminous surface treatments as a method of preventive maintenance.

Since then, considerable effort has been expended to use "engineered" products as alternative techniques for reducing reflective cracking. Roberts et al. (1996) categorized four methods that are commonly employed in the field to reduce reflective cracking:

- increasing the HMA overlay thickness,
- performing special treatments on the existing surface,
- treatments only on the cracks and/or joints, and
- special considerations of the HMA overlay design.

II.3.1. Increasing the HMA Overlay Thickness

Increasing the thickness of HMA overlays to minimize reflective cracking has been based primarily on empirical relations developed from local experience (Finn and Monismith, 1984). The parameters affecting the thickness of the overlay depend on the type of pavement (HMA or PCC), type of distresses, climatic conditions, and traffic loadings (Sherman, 1982). Barksdale (1991) updated the findings of Synthesis NCHRP 92 (Sherman, 1982) and provides the following HMA overlay thickness information.

a) PCC pavements evaluated in Georgia (Gulden and Brown, 1984, Gulden and Brown, 1985) indicated 20 percent area cracking in six years for a 6-inch overlay compared to two years for a 4-inch overlay. Reflective cracking appeared almost immediately after construction for a 2-inch overlay.
b) Research conducted by Predoehl (1989) in California showed that 4.8 inches of overlay is required to reduce reflective cracking for 10 years. The Georgia studies (Gulden and Brown, 1984, Gulden and Brown, 1985) provided similar results with the use of a 4-inch overlay, with the prerequisite that the old pavement is structurally sound and properly repaired.

c) A minimum of 2 inches of overlay is recommended if alligator cracking is present, greater than 2 inches for base failures, and a minimum of 3 inches (3.5 desirable) for block cracking.

McLaughlin (1979) indicates that the worst cases of reflective cracking are evident in airport pavements when a thin overlay (less than 2 inches) is placed over a badly cracked HMA or PCC pavement. This investigation revealed that when a 4-inch overlay was feathered out to 2 inches, reflective cracking appeared only in the areas of the thinner HMA.

II.3.2. Performing Special Treatments on the Existing Surface

Researchers have investigated the effectiveness of performing special treatments on the existing surface as alternate techniques of minimizing reflective cracking. These treatments have included breaking and seating or rubblization of the concrete surface, pulverization or heater scarification of the asphaltic surface, and the construction of a stress-absorbing membrane interlayer (SAMI).

Generally, the process of breaking and seating or rubblization of the concrete surface involves breaking the existing PCC pavement into small fragments using an impact hammer followed by seating using a vibratory steel-wheel and/or pneumatic roller prior to overlaying. Compaction consolidates the PCC fragments and removes voids or cavities from beneath the PCC pavement and provides a firm support for the pavement structure (McLaughlin, 1979). A 10-year investigation in Louisiana by Lyon (1970) attributed the reduction of reflective cracking using this method to a reduction in Benkelman beam deflections (Sherman, 1982).

Pulverization or heater scarification of the HMA surface is a rehabilitative measure for distressed flexible pavements. Button et al. (1994) provided a recent synthesis of hot in-place recycling efforts in the United States and abroad. This report describes the equipment, mixture design, construction issues, relative performance, and comparative costs associated with this type of method. These processes generally involve heater scarification of the existing HMA surface to a specified depth (typically 1 inch) and adding a rejuvenating agent. The mixture is compacted, and a conventional wearing course is normally placed over the recycled pavement. Because this method is limited to surface rehabilitation, the pavement system must be structurally sound (Button et al., 1994) to ensure success. McLaughlin (1979) describes a 1970 Arizona DOT investigation on 18 highway sections evaluating 20 different existing pavement treatments and overlay compositions. This report concludes that, after four years of service, the use of heater scarification to a depth of 0.75 inch with an AC 2.5 (producing a rejuvenation to 200/300 penetration) was "the most effective means of retarding the appearance of reflection cracks." Jackson (1980) concludes that rejuvenators added to heater-scarified HMA materials have been moderately successful. Several DOTs (1982) consider heater scarification plus a 1-inch overlay to be cost effective for three years if only minor maintenance is required.

The construction of a SAMI normally consists of an asphalt rubber seal coat (Roberts et al., 1996). The SAMI is constructed between the existing pavement and the HMA overlay. A typical SAMI consists of 0.6 to 0.8 gal/yd^2 asphalt rubber material along with just enough aggregate (ranging in size from chips to pea gravel or coarse sand) to provide a working platform (Sherman, 1982). The thickness of the SAMI ranges from 0.35 to 0.50 inch. The principal objective of the SAMI is the reduction of stresses developed at the crack tip primarily through the properties of the asphalt rubber material. In a 10-year evaluation of geotextiles in various locations throughout Texas, Button (1989a) reported that field performance of seal coat interlayers were comparable and, in some installations, better than certain fabric materials. Similar results were obtained in investigations summarized by Barksdale (1991) where a SAMI was found to delay serious reflective cracking for three to five years. An evaluation of seven types of interlayers in New Mexico by Lorenz (1987) indicated that interlayers do *retard* the rate of reflective cracking, but do not *prevent* reflective cracking. A negative attribute was found from research conducted by Predoehl (1989) in California, which indicated that HMA overlays using asphalt rubber SAMIs exhibited bleeding and rutting more frequently than with the use of fabrics (Barksdale, 1991).

II.3.3. Treatments Only on the Cracks and/or Joints

Treatments only on the cracks and/or joints, as a method of minimizing reflective cracking in HMA overlays, have included cleaning followed by filling the crack or joint with a compressible material, and then applying a narrow strip of bond breaking material. Gurjar et al. (1997) provide guidance on the selection, testing, and performance of joint sealants used in PCC pavements. Roberts et al. (1996) explains that

> the operating theory is that the bond breaking material keeps the HMA overlay from bonding to the old surface in the vicinity of the crack, thereby increasing the gage length over which the overlay can absorb the strain produced by movement of the underlying layer.

Thin layers of agricultural lime, stone dust, and sand as well as 26-gauge sheet metal, saturated building paper, 0.001-inch thick aluminum foil, and 0.004-inch thick wax paper as bond breakers have been reported with varying success (McLaughlin, 1979). Jackson (1980) reports that use of bond breakers on PCC pavements with 1.5 to 4.75 inches of overlay have produced performance results ranging from ineffective to excellent. Bond breakers with thin overlays under heavy traffic have experienced disastrous results, likely due to excessive horizontal shear at the interface.

II.3.4. Special Considerations for HMA Overlay Design

The latest techniques investigated by researchers for reducing reflective cracking have been the use of more compliant asphalts produced by polymer or rubber modification, modification of the bituminous mixture by the addition of synthetic fibers (polypropylene or polyester), the use of ground scrap tire rubber, and installations of geosynthetic materials such as grids, fabrics, and composites. The above techniques result in either an increase in the overlay's tensile strength or an increase in its flexibility (compliance). Both of these attributes are important for minimizing reflective cracking, but a balance must be achieved in the mixture design. The use of compliant asphalts, for instance, will improve flexibility but will adversely affect mixture stability, and the pavement will be susceptible to rutting and/or flushing. Conversely, the use of harder asphalts will increase the mixture tensile strength, but flexibility will suffer and the overlay will be susceptible to cracking.

In 1966, a crumb rubber HMA overlay at the Phoenix International Airport performed excellently (McLaughlin, 1979). Other pavements constructed in Arizona utilizing rubber modification have resisted fatigue cracking and reduced reflective cracking (McLaughlin, 1979). Laboratory and field tests were performed on eight types of chopped synthetic fibers as additives to reduce reflective cracking in HMA overlays (Button and Hunter, 1984). Results from this investigation indicated that fibers added flexibility and improved resistance to crack propagation but increased field compaction requirements.

Beckham and Mills (1935) presented one of the earliest records of fabrics to reinforce roadways. This paper presented the results of eight experimental sections constructed between 1926 and 1935 in South Carolina using cotton fabric to reinforce HMA surface treatments on both roads and wooden bridge floors. This report describes the installation procedures used and the "superior durability achieved." Nine nonwoven polypropylene and/or polyester fabrics were investigated by Button (1989a) in four sets of test pavements throughout Texas. This investigation concluded that there were no significant improvements to using fabrics as compared to seal coats or no fabric at all. A recent synthesis by Barksdale (1991) provides an in-depth review of fabrics in HMA overlays and pavement maintenance operations for both flexible and rigid pavements. Based on laboratory tests on fabrics and fabric-mixture systems, Button et al. (1983) stated the following.

> Generally, laboratory investigations of fabrics incorporated into asphalt concrete specimens have shown improvements in tensile properties, increased fatigue performance, and a reduction in crack propagation rate, and there is evidence to indicate fabrics will not compound overlay slippage problems. A review of several existing field studies of methods used to reduce reflection cracking reveals fabrics to be a competitive product and further that fabrics will reduce pavement maintenance and extend service life.

Recommendations for the design and construction of HMA overlays with fabric interlayers are provided in Epps and Button (1984) along with improvements to written specifications. Lytton (1989) describes three uses of geotextiles: reinforcing, strain relief, and undersealing. His report provides a systematic approach to testing fracture properties of the HMA overlay for the prediction of crack growth. He also provides design equations to determine the required HMA overlay thickness.

The above literature has focused on fabrics to reduce reflective cracking. Part of the problem with designing overlay systems to include a geosynthetic is that, although manufacturers publish a wide range of properties describing their geosynthetics, most of them are index properties. That is, they describe product characteristics that are useful for manufacturing quality control but are not applicable to pavement design (Sprague, 1998).

The research herein will compare the fracture properties and relative effectiveness of six commercially available materials: one *polypropylene* nonwoven fabric, one *fiberglass* grid, two *fiberglass grid* composites, and two *polyester grid* composites.

II.4. LABORATORY TESTS

Researchers have developed laboratory testing techniques to study the relative performance of different candidate techniques for delaying reflection cracking under idealized conditions. Laboratory tests are useful in revealing and proving the effectiveness of overlay systems under different loading and environmental conditions. Laboratory tests, however, should be used only as an initial screening technique and not as a replacement for field test sections.

It is difficult to prepare standard cylindrical laboratory specimens of asphalt concrete containing geosynthetics that accurately simulate field pavements. Therefore, most researchers prepare and test asphalt concrete beams either in the tensile or bending mode.

Button and Lytton (1987), Smith (1984, 1983), Jayawicrama and Lytton (1987), Germann and Lytton (1979), Majidzadeh et al. (1976, 1975), Coppens et al. (1993, 1989), and others (Chang et al., 1998 and Brown et al., 2001) have studied the behavior in the laboratory of paving fabric, grids, asphalt rubber, fiber-reinforced HMA, and other materials. In selecting testing techniques and equipment, field stress conditions must be simulated as closely as possible, including applying appropriate relative movements and levels of stress and strain to model an overlay. These tests typically determine the number of load cycles required to produce a certain measured crack length (until the beam sample cracks completely through). Generally, geotextiles have shown significant improvements in the number of cycles to failure when compared to control beams with no geotextile.

II.5. ANALYTICAL TECHNIQUES

Just as alternative geosynthetic materials have been used, various analysis methods have been explored to identify the causes of reflective cracking with the objective of improving future overlay designs. Early research at the Texas Transportation Institute (Button et al., 1983; Lytton, 1989; Pickett and Lytton, 1983; Germann and Lytton, 1979; Chang et al., 1976; and Kohutek, 1983) was based on identifying fracture properties of the geosynthetic-mixture system using a fracture mechanics based approach. Majidzadeh et al. (1976) also applied fracture mechanics to predict the fatigue life of an asphalt mixture. Both Lytton and Majidzadeh used finite element methods to determine the crack propagation properties of pavement layers.

Finite element methods (FEMs) are the major analysis techniques used by researchers to identify causes of reflective cracking. FEMs have the basic assumption of modeling asphaltic concrete as an elastic continuum with a finite number of structural elements interconnected at their corners (or nodes). The displacement of these nodes is governed by simple approximation functions, as prescribed by the user. The use of FEMs to accurately compute stress fields at the crack tip is complex and requires the use of extensive computer resources. Molenaar (1993) describes research performed in the Netherlands to evaluate reflective cracking using FEMs and fracture mechanics principles. The research performed by de Bondt (1999) provides an in-depth review of the phenomenon of reflective cracking utilizing FEMs, fracture mechanics theories, as well as design procedures and effectiveness of overlay alternatives. The research completed in the Netherlands is clearly one of the most impressive and rigorous investigations to date on the subject of reflective cracking.

Chapter IV provides additional information on previous investigations using fracture mechanics and finite element methods. This investigation describes the application of fracture mechanics to determine material properties of laboratory-compacted HMA specimens reinforced with geosynthetic materials.

II.6. SUMMARY OF FIELD PERFORMANCE OF GEOSYNTHETICS

The second largest application of geotextiles in North America is in asphalt overlays of flexible and rigid pavements. An estimated 100 million square yards (26 percent of all geotextiles) was used in overlays in 1993 (Holtz et al., 1998). There are many and varied products on the market today. Relative performance of these products will, of course, depend on many factors related to design and construction.

Holtz et al. (1998) stated:

> Many engineers are thoroughly convinced of the performance and cost benefit of geotextiles incorporated into overlays. Many other engineers are thoroughly convinced that geotextiles are either not beneficial or not economical in overlay construction. And, still other engineers are confused by the claims of performance and cost benefits.

Observed performance of geotextiles in reducing reflection cracking have ranged from clear successes to apparent failures in which the overlay with a geotextile showed poorer performance than the conventional overlay with the same thickness (Barksdale, 1991). A particular factor affecting performance of geosynthetics is the bond between the old pavement and the new overlay two layers (Ni and Yao, 1989, Brown et al., 2001). Interfacial bonding is directly affected by the type and amount of tack coat (Van-Zyl and Louw, 1989). Ameri-Gaznon and Little (1988) developed a model to demonstrate that inadequate interface bond strength can lead to premature overlay rutting due to lateral movement of the HMA due to traffic loads. Inadequate bond strength may have contributed to early failure of an overlay in the Houston District where a fiberglass grid was used without tack coat. Hixon and Ooten (1993) found that when microsurfacing was placed over fabric, it did not normally maintain a sufficient bond. Microsurfacing uses a modified asphalt emulsion as binder.

Predoehl (1989) has compiled one of the most comprehensive, integrated fabric performance databases to date. It addresses 29 flexible pavement test sections under moderate to high traffic roadways and covers the wide range of climates encountered in California. In summarizing several studies, Barksdale (1991) and Ahlrich (1986) conclude that geosynthetics and other types of interlayers performed considerably better in reducing reflection cracking in warm and mild climates than in cold climates (Figure 2). Ahlrich (1986) recommends a minimum overlay thickness of 2 inches in warm climates, which he defined as Zone I and which includes all of Texas.

Some have expressed concern regarding recycling of geosynthetics. Although little has been reported, evidence indicates that cold milling is not usually a particular problem (Predoehl, 1989; Crow, 1993); however, heater scarification and hot milling can present significant problems when the operation penetrates deeper than the geosynthetic interlayer.

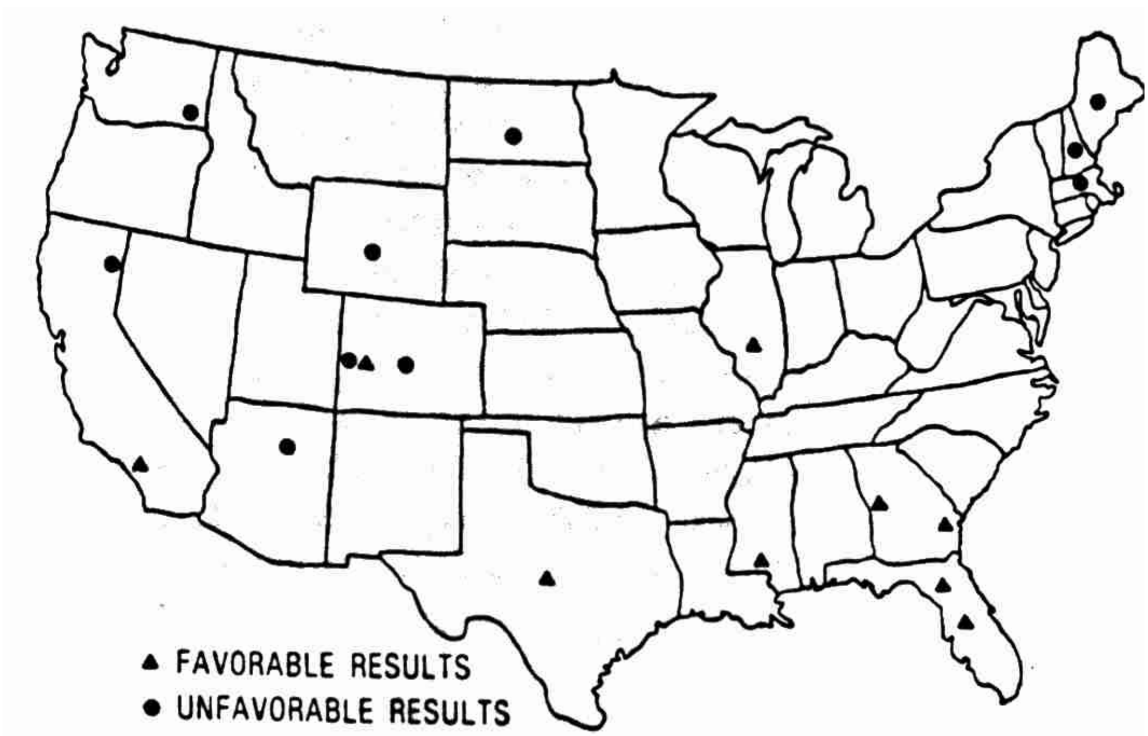


Figure 2. Location of Selected Favorable and Unfavorable Paving Fabric Installations in the United States (after Ahlrich, 1986).

II.6.1. Nonwoven Fabrics

In 1999, Carmichael and Marienfeld prepared a synthesis of findings based on a survey of more than 30 years of literature and a telephone survey of experienced users. They found that limited performance data and lack of pavement structural design methods considering the benefits of fabrics have restricted the application of paving fabrics in pavement rehabilitation systems. Many studies have concluded that asphalt concrete pavement overlays can benefit from the use of paving fabric interlayers (Barnhart, 1989, Yamaoka et al., 1990, Heins, 1989, Allison, 1989).

Carmichael and Marienfeld (1999) stated that documented field experience indicates the following positive benefits:

- waterproofing of the lower layers,
- retarding of reflection cracking in the overlay, and
- providing for more stable subgrade moisture contents.

They further found that, if fabric is applied and the HMA overlay thickness is not reduced from that determined by normal structural design methods, then an increase in performance and service life can be expected for both flexible and rigid pavements. They generally attributed performance improvement to the waterproofing capabilities and the stress absorption capabilities of the fabric-asphalt interlayer.

Using limited data, Predoehl (1990) reported an HMA thickness equivalency of 0.1 foot (1.2 inches) for a fabric. Barksdale (1991) used data from Predoehl (1990) to plot Figure 3. Looking closely at Predoehl's (1990) data (Figure 3) reveals some important findings. First, following his logic, if we enter Figure 4 with a typical overlay thickness of 1.5 inches plus a fabric, the thickness equivalency for the fabric is shown to be only about 0.04 foot (0.5 inch). Since Holtz et al. (1998) estimate the cost of a fabric interlayer to be roughly equivalent to that of about 0.60 inch of HMA, the benefit of the fabric appears marginal. Second, but much more important, the drastic drop in performance of overlays less than about 0.16 foot (2 inches) thick is readily apparent. Predoehl's (1990) data indicates that placing overlays (with or without a fabric) less than 2 inches thick is essentially guaranteeing premature cracking and thus may be very inefficient. More experimental data are needed to better define the most efficient pavement thickness for a given situation. It will surely depend on the condition of the overlaid pavement.

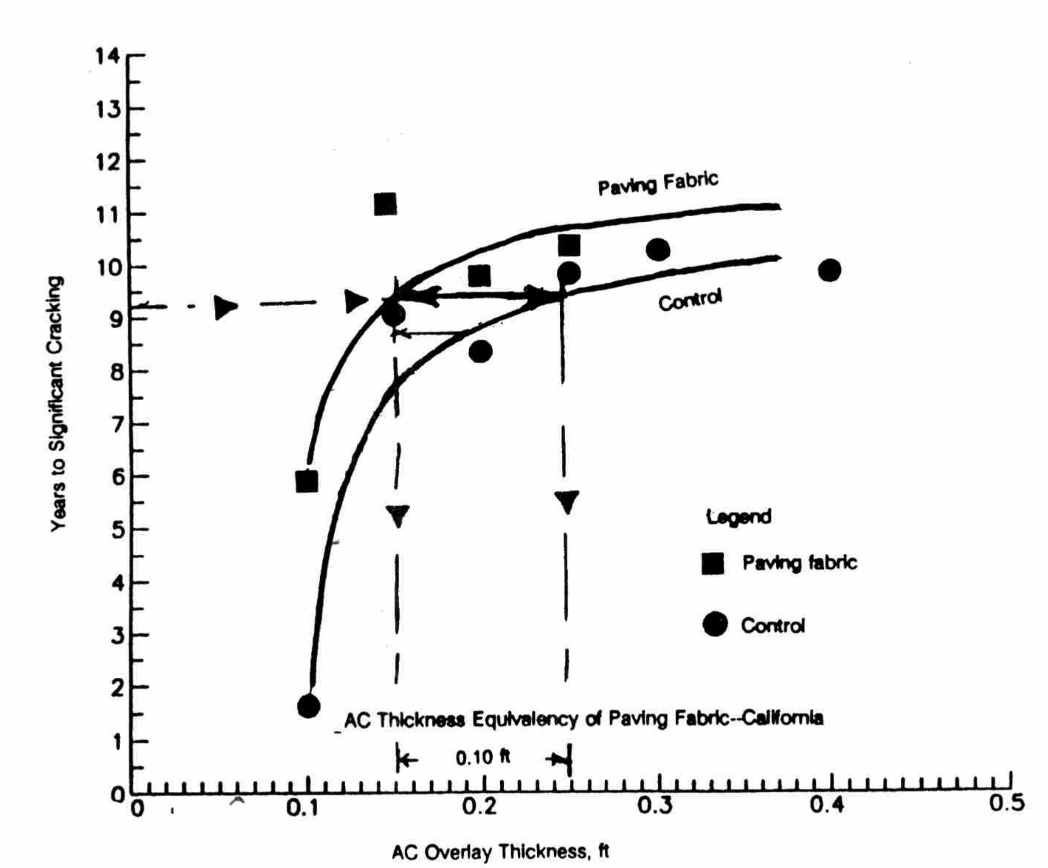


Figure 3. Estimated Paving Fabric Equivalency as a Function of AC Pavement Thickness (after Barksdale, 1991).

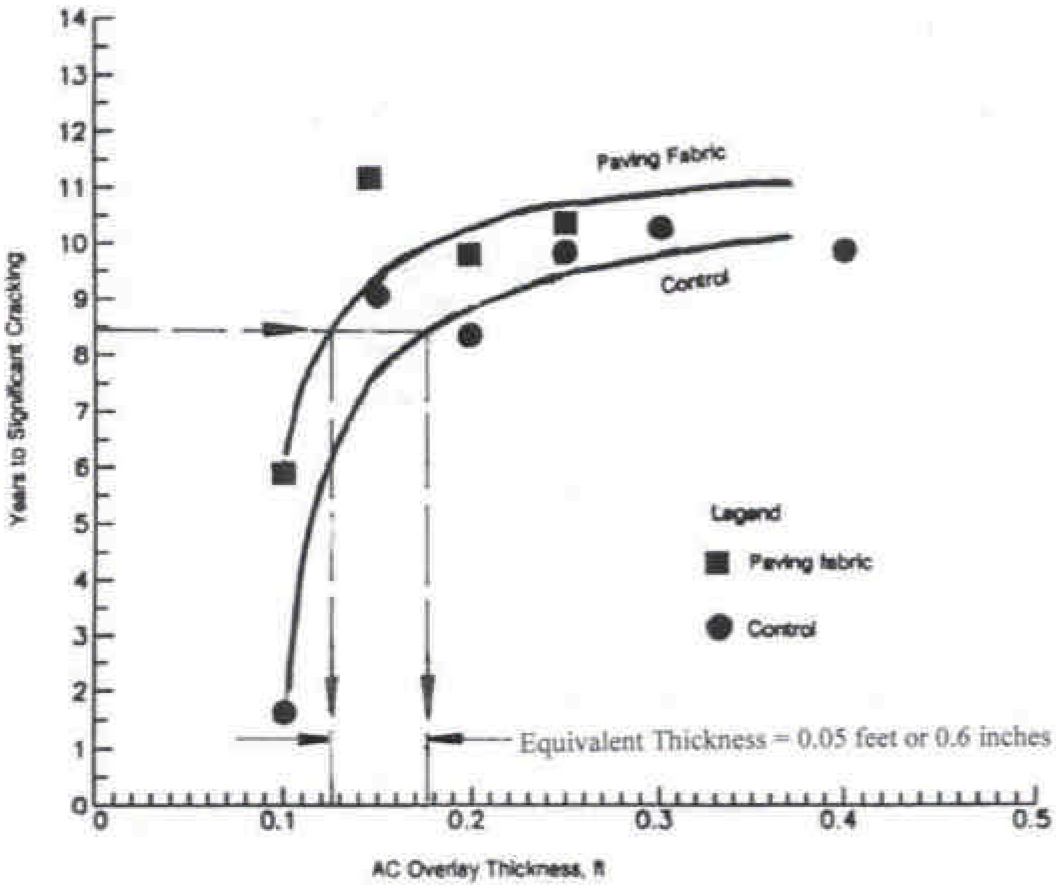


Figure 4. Estimated Paving Fabric Equivalency as a Function of AC Pavement Thickness Based on a 1.5-inch Overlay Thickness (modified after Barksdale, 1991).

In northern climates, the recurrence of thermal cracking often occurred, even in overlays with paving fabric (Carmichael and Marienfeld, 1999). (Similarly, joints in jointed concrete pavements exhibit large strains, and reflection cracks are difficult to stop.) However, even though thermal cracking returned, limited evidence suggests the asphalt-impregnated fabric offered resistance to intrusion of surface water. Several agencies have indicated benefits from reduced intrusion of water even after reflection cracks appear at the surface. This added benefit of fabrics is discussed in a subsequent subsection of this chapter.

In theory, using a thicker fabric should result in lower stresses at the tip of a crack than using a thinner one. Therefore, the thicker layer should be more effective in delaying reflection cracking. The fabric must be saturated with asphalt to its full thickness. Clearly then, asphalt retention rate is an important property. Asphalt retention should be at least 0.2 gallon/yd^2; retention is directly related to the fabric weight and thickness (AIA, 1999). Both theory and a limited evidence (Button, 1989) indicate that a thicker fabric with a greater asphalt retention may delay cracking longer than a thinner fabric.

TxDOT's current specification requires a minimum grab tensile strength of 80 lb., which could allow a fabric weight down to 3.4 ounces/yd^2. To ensure better performance, TxDOT should follow AASHTO M 288 and specify a paving fabric with a 101-pound grab tensile strength and 4.1-ounce/yd^2 minimum unit weight. This weight of fabric can more easily hold the proper amount of tack coat. Additionally, heavier fabric will reduce bleed through during construction and minimize the effect of any damage by construction traffic. The cost differential between the AASHTO M 288 recommendation and the current TxDOT specification is only 2 to 4 cents/yd^2. This difference will probably not appear in the bid price for installed paving fabric. (Barksdale, 1991, and Marienfeld, 2001)

II.6.2. Grids

Grids or geogrids are typically constructed of high-modulus filaments of glass fibers or drawn polymers (polyester or polypropylene). Grids have moduli much higher than that of HMA concrete at normal service temperatures. They are designed to decrease stresses in the new overlay so that reflective cracking will develop more slowly. The idea is to mobilize the tensile strength characteristics of the grid with only limited deformation of the pavement (Kennepohl et al., 1985). Early polymer grids were stiff and often buckled during application for overlay construction allowing portions of the grid to protrude through the surface of the overlay. This is one factor that led to the development of composites. One grid manufacturer has eliminated these construction problems by applying an adhesive to one side of his product. Correct positioning and proper installation of the grid is crucial to good performance (Kennepohl and Kamel, 1984). Newer, more flexible, self-adhesive fiberglass grids make correct positioning and proper installation easier.

Grids have been reported to reduce reflective cracking (IFAI, 1998; Cabrera et al., 1997; Cabrera et al., 1994; Herbst et al., 1993; Abdelhalim and Razaqpur 1993; Kirschner, 1990; Brown et al., 1989; Showsmith and Emery, 1985; Choi and Lytton, 1990; Zhongyin and Zhang, 1993). In fact, they are sometimes reported to benefit both low temperature (cracking) and high temperature (rutting) performance of HMA overlays (Han et al., 1998). Gilchrist (1989) concluded that polypropylene grid offers positive benefits with regard to rutting and fatigue failure. Colorado DOT (Harmelink, 1993) reported that a fabric performed better than a fiberglass grid in reducing reflection cracking; a few others support this finding (Ladner, 1990). Zhongyin and Quancai (1993) reported that application of fiberglass grid at the bottom of an HMA overlay can significantly prolong the life of the overlay against cracking progress, but it hardly delayed the initial cracking.

A self-adhesive fiberglass grid product was placed without a tack coat on IH 45 in the Houston District in accordance with manufacturer's recommendations. The project resulted in failure of the overlay within a few months. The authors surmise that the lack of tack coat allowed slippage of the overlay at the grid interface due to the heavy traffic. The fact that the fiberglass grid was ground to powder in some wheelpath locations is evidence that repeated slippage movements were occurring. Colorado DOT research (Harmelink, 1993) supports these findings. The researchers therefore recommend that a light tack coat be placed on top of the self-adhesive grid to ensure adequate bond between the old pavement and the new overlay.

Fiberglass grids consist of bundles of very small-diameter glass fibers. The small-diameter fibers provide the needed flexibility. The large surface area of the small glass fibers is apparently subject to attack by polar liquids, including water. Therefore some manufacturers encapsulate the bundles of glass fibers. (Barksdale, 1991)

II.6.3. Composites

Composites are relatively new to the market, having been introduced in 1990 (Carver and Sprague, 2000), and are generally more expensive than fabrics or grids. However, they offer the benefits of both fabrics and grids, i.e., a low-permeability asphalt-impregnated fabric laminated with a high-modulus grid. Grids are typically applied with little or no tack coat; the stiffer grid products sometimes buckled during construction to the point that they caught on the underside of the paving machine and/or protruded through the new overlay. Newer products had the non-woven fabrics laminated onto grids, forming composites, to assist in installation and to provide the additional benefits. Laboratory research found composites to be highly beneficial; however, field applications have found varying results (Carver and Sprague, 2000).

Generally, manufacturers have designed composites to meet the needs of asphalt retention and high initial tangent modulus (i.e., high modulus at low strain). Because of the combined benefits of fabrics and grid, it is no surprise that composites have been reported to demonstrate effectiveness in mitigating reflective cracking in HMA overlays (Hermann et al., 1997). However, because these products are relatively new, few findings have been reported.

Saraf et al. (1996) found, in a laboratory study of HMA fatigue test beams, that beams reinforced with composite performed significantly better than beams containing paving fabric alone, and beams reinforced with fabric performed better than unreinforced control beams.

II.6.4. Geotextiles as Moisture Barriers

Moisture is frequently the main source of pavement damage. Many believe that asphalt-impregnated fabrics will control infiltration of water into a pavement. Composites may offer similar benefits but grids alone cannot. Laboratory tests of HMA beams containing various fabrics demonstrated that nonwoven fabrics remained intact after the asphalt concrete failed in tension (Button and Epps, 1979). California (Hannon et al., 1987; Predoehl, 1990; Van Wijk and Vicelja, 1989), Colorado (Harmelink, 1986), Illinois (Hannon et al., 1987), Michigan (Barnhart, 1989), Oklahoma (Pourkhosrow, 1985; Rahman et al., 1996), and Texas (Button, 1989a) DOTs have reported reduced intrusion of water due to fabrics even after reflection cracks appear at the surface of the overlay; however, benefits related to pavement performance were not quantified.

Marienfeld and Baker (1999) summarized findings from 11 studies that reported reduced intrusion of water due to fabrics. They concluded that both laboratory specimens and field cores indicated that the presence of a properly installed paving fabric interlayer reduces the permeability of a pavement by one to three orders of magnitude. Ground penetrating radar (GPR) showed that moisture levels beneath pavement layers are decreased in pavements containing a fabric interlayer system. Their findings indicated that the fabric must be saturated with sufficient asphalt to provide a continuous moisture barrier; insufficient tack will diminish the waterproofing effect.

Marienfeld and Baker (1999) reported that results of tests on cores, where a crack was present both above and below the paving fabric, indicated that permeability was still relatively low at about 10^{-2} to 10^{-3} mm/sec. For comparison, control specimens exhibited permeabilities from 10^{-3} to 10^{-4} mm/sec, and intact fabric specimens exhibited 10^{-4} to 10^{-6} mm/sec. These results suggest that, even when underlying cracks reflect to the pavement surface, fabrics can still provide a barrier to limit intrusion of surface water. Smith (1984) reported results of permeability tests on cores from flexible and rigid pavements with HMA overlays and paving fabric with cracking through the HMA overlay. Where the original pavement was flexible, the fabric was found to be intact and probably still providing some resistance to water flow. However, for the rigid pavement, the fabric was ruptured apparently due to excessive joint movement and no longer provided resistance to water flow.

Although many papers written on the performance of fabrics cite the waterproofing benefits, there has been limited quantification of these benefits (Marienfeld and Baker, 1999). Research is needed to evaluate this apparently valuable contribution of asphalt-impregnated fabrics and composites to pavement service life.

Several nationally known pavement experts have pointed out that a moisture barrier under a new overlay can be a detriment to its performance (Roads & Bridges, 2000; Better Roads, 2000). This is particularly true if the overlay is not compacted properly or if the overlay is susceptible to water damage. Rapid premature failures have occurred when a moisture barrier (fabric, seal coat, etc.) was placed on an old pavement, then the overlay was insufficiently compacted such that it was permeable to water (Roads & Bridges, 2000; Better Roads, 2000). Surface water enters the permeable overlay and is trapped by the impermeable layer. Subsequent kneading and scouring action by traffic in the presence of the water causes rapid failure of the overlay. This problem is compounded when the overlay is also an inlay (sometimes termed the "bathtub" effect). Marienfeld and Baker (1999) stated, "The level of compaction is not as critical to achieving low permeabilities when a paving fabric moisture barrier is used." Based on personal observations, the authors strongly disagree with this statement. Compaction of dense-graded HMA is always important for achieving proper density and minimum permeability, particularly when an impermeable underseal is used.

In addition, many engineers in different parts of the world are convinced that water vapor rising from below due to solar heating and subsequent evapo-transpiration can accumulate just under a moisture barrier (seal coat, asphalt impregnated fabric, etc.), condense during the cooler nights, and cause significant damage, if the HMA mixture in the affected pavement layer is susceptible to water damage. Distress will develop first in the wheelpaths due to repetitive loading by traffic on the weakened pavement layer and will progress rapidly.

Pavement engineers considering fabric or composite in their overlay design should be aware of these potential problems and take appropriate action.

II.6.5. Recycling of Pavements/Mixtures Containing Geosynthetics

A few problems have been reported when recycling pavements containing a fabric interlayer. Although hot milling and, particularly, heater scarification can cause problems when a geosynthetic is present, cold milling does not usually present problems, nor does a typical fabric significantly affect mixture properties. However, thick fabrics or strong plastic grids may interfere with the milling process.

Dykes (1980) reported results from laboratory and field tests on recycling pavements containing a 4.3 ounce/yd^2 nonwoven polypropylene fabric and found the following: Milling HMA pavement poses no serious problems. There were no apparent differences in mixture properties. There were no visible differences in plant stack opacity. There were no operational differences. Chisel milling teeth rather than conical teeth and slower forward speed can be used to produce the smallest geotextile pieces.

II.7. COST EFFECTIVENESS OF GEOSYNTHETICS

Generally, findings from the laboratory and field indicate positive benefits from geosynthetics in reducing the severity and/or delaying the appearance of reflection cracks; however, very little information is available in the literature regarding the cost effectiveness of geosynthetics. Barksdale (1991) stated that, "This strategy, like all others, must be carefully engineered and is not a quick, easy solution suitable for all pavements in need of rehabilitation. Generally, the use of paving fabrics for delaying reflection cracking is not justified unless the benefits from reducing water infiltration are considered." Barksdale (1991) further indicated that, for pavements with light to moderate cracking, a crack filling program is likely more cost effective than other methods. He indicated that approaches such as full-width fabrics or SAMIs require additional construction steps that, in turn, may reduce quality control and thus reduce overlay performance. Alternatives for reducing reflective cracking may include: softer asphalt and/or additives such as polymers, rubber, fibers, carbon black, or sulfur in the HMA overlay; heater scarification; SAMI; etc.

Herbst et al. (1993) reported that overlays using stress-absorbing interlayers typically cost about 10 percent more than a conventional overlay. A few authors have reported that geotextiles are cost-effective treatments for prolonging overlay life (Collios, 1993; Zapata, 1985). A few more have reported that geotextiles are not cost effective for use on both flexible (Maurer and Malasheskie, 1989; Button, 1989a) and rigid (Maurer and Malasheskie, 1989; Heins, 1989; Azab et al., 1987; Allen, 1985) pavements. Holtz et al. (1998) advise that the design thickness of an HMA overlay with a geotextile should be determined as if the geotextile is not present. Thus, the economic justification of the geotextile must be derived from a combination of:

- an increase in pavement serviceability due to reduced reflective cracks,
- an increase in pavement life,
- a decrease in pavement maintenance costs, and
- an increase in structural capacity due to dryer base and subgrade.

To justify the cost of geotextiles, some engineers elect to reduce the overlay thickness based on an "equivalent performance" thickness. Research performed primarily by Caltrans (Predoehl, 1990) implies that a geotextile interlayer is equivalent to a little over 1 inch of HMA for relatively thin (i.e., < 4.5 inches) overlays on a structurally adequate pavement and that they are ineffective with overlays > 4.5 inches. On the contrary, the Queensland Transport (1994) in Australia advises that "fabrics are not effective substitutes for HMA thickness, i.e., they act only as limited reinforcement when the pavement is subjected to traffic loads. The HMA overlay thickness should be designed for future traffic considerations and this thickness should not be reduced when a fabric is used." Generally, overlay thickness should not be reduced to less than 2 inches or four times the diameter of the largest aggregate in the HMA mixture. Holtz et al. (1998) estimated that the cost of geotextile interlayer is roughly equivalent to that of about 0.60 inch of HMA.

The most significant study of cost effectiveness of fabrics that the authors found during this literature review was Buttlar et al. (1999, 2000). The study was limited to Illinois DOT projects originally constructed as rigid pavements and subsequently rehabilitated with one or more HMA overlays. This type of pavement, of course, provided a tough test for fabrics. Most of the projects they studied involved placing the fabric between a 0.75-inch level-up course and a 1.5-inch surface course; however, for 38 percent of the projects, the fabric was placed directly on a roto-milled bituminous overlay surface. The authors concluded the following:

- There is no statistical difference between the life-cycle costs of polypropylene fabric strip- or area-treated projects relative to untreated projects.
- However, based upon performance data, strip and area treatments appear to be marginally cost effective.
- Life-cycle cost savings were estimated at a breakeven level for small projects (≤ 1 mile of two-lane pavement).
- Life-cycle cost savings were estimated to be 6.2 percent for large projects (≥ 6 miles of two-lane pavement).
- The average cost of fabrics in small projects was approximately twice the cost for large projects.
- Fabrics were minimally effective in mitigating transverse cracking.

- Based on overall Illinois DOT serviceability ratings, overlay life spans were predicted to increase when fabrics were used. (They noted that significant extrapolations were required for these estimates.) The reduced rate of serviceability loss was attributed to reduced infiltration of water even after the cracks reflect through the overlay.

Determination of cost effectiveness of products in pavements requires several years. Information on cost effectiveness of the newer grids and composites is not currently available in the literature.

II.7.1. Flexible Pavements

In his 1991 NCHRP Synthesis where he references 142 papers, Barksdale (1991) concluded:

> Under favorable conditions, moderate to significant levels of reflection cracking in HMA pavement overlays can be delayed two to four years and, in a few instances, as long five years by using a full-width paving fabric interlayer. Favorable conditions for the use of full-width paving fabrics with flexible pavements include:
>
> - The presence of fatigue (load)-related failure frequently evidenced by alligator cracking.
> - Tight surface cracks, usually less than 1/8 inch wide. Improvement where cracks are greater than 3/8 inch wide is unlikely.
> - The HMA overlay must be engineered to be structurally capable of handling the anticipated loadings. A deflection-based procedure should give the overlay thickness determination for each pavement subsection.
> - Paving fabrics are usually ineffective for controlling thermal cracks, because those cracks are usually ½ to 1 inch or more wide.
>
> The requirements for an asphalt-rubber SAMI should be similar to those given above for paving fabrics. A limited amount of field evidence suggests that a SAMI may be slightly more effective than a paving fabric in delaying reflection cracking. Whether the additional cost of using a SAMI is justified is doubtful.

Others (Majidzadeh, 1975; Pourkhosrow, 1982) agree that reflection of cracks 3/8-inch wide or less can be slowed by geotextiles and, ideally, should be less than 1/8 inch. All cracks greater than ¼ inch wide (Bushy, 1976) and preferably even smaller (LaForce et al., 1980) should be filled with sealant. The 1993 AASHTO Design Guide (1993) maintains that geotextiles can be effective in controlling (reducing) reflection cracking from low- and medium-severity alligator-cracked pavements and that they may also help control reflection of thermal cracks, although they are not as effective.

II.7.2. Portland Cement Concrete Pavements

Regarding PCC pavements, Barksdale (1991) summarized several reports and papers and concluded:

> Paving fabrics and heavy-duty membranes can also be used to delay reflection cracking in PCC pavements overlays by about two to four years under the following quite restrictive conditions:
>
> - Vertical load-induced Benkelman beam joint movements must be between 0.002 inches and 0.008 inches (California has found that a full-width fabric delays cracking when these joint movements are between 0.003 and 0.008 inches. For greater joint movements, a fabric did not help; and for lesser movements, a fabric was not required.)
> - Horizontal, thermally induced joint movements must be less than 0.05 inches.
>
> Although conflicting experimental findings exist, a limited amount of evidence suggests that heavy-duty membranes placed over joints may perform better than full-width paving fabrics. Thermally induced joint movements increase with increasing PCC panel length. Joint movements can be decreased by cracking and seating or by sawing additional transverse joints. Using paving fabrics or heavy-duty membranes together with decreased pavement joint spacing does not, however, appear to offer any advantage over just cracking and seating or additional saw cut joints. Fabrics are used to reduce water infiltration because of the cracks created by the cracking and seating techniques. (Rubblizing, of course, could be used in place of cracking and seating.)
>
> The movements at longitudinal pavement shoulder and widening joints are usually less than at transverse joints of PCC pavements. Paving

> fabrics and heavy-duty membranes have been used effectively to delay reflection cracks when longitudinal pavement shoulder joint cracking is a problem for either PCC or HMA pavements. Longitudinal joint movement should be within the limits given above for transverse joints.

The 1993 AASHTO Design Guide (1993) advises that the effectiveness of geotextiles in controlling reflective cracking in HMA overlays over jointed plain concrete and jointed reinforced concrete pavements is questionable. Since movement at the cracks in a continuously reinforced concrete pavement is (CRCP) usually small, reflective cracks through an HMA overlay are not usually serious problems. If a geosynthetic is to be used on a CRCP, it is advisable to place an HMA level-up course before placing the geosynthetic and the final overlay. Theory (Pickett and Lytton, 1983) and practice (Brewer, 1997) have shown significant benefits from placing a level-up course before placing the geosynthetic.

II.7.3. Nonwoven Fabrics

In 1989, Button (1989) and Maurer et al. (1989) reported that the economic benefits to be gained by the use of nonwoven fabrics studied in overlay test pavements applications were marginal and Barnhart (1989) reported that further use of fabrics for crack reduction is not warranted. However, since that time, the relative costs of fabrics and asphalt overlays has changed in favor of the use of fabrics. Ladner (1990) and Van Wijk et al. (1989) indicated, without proof, that fabrics were cost-effective treatments for prolonging overlay life by reducing reflection cracking and providing a moisture barrier.

Barnhart (1989) stated that, with the use of an assumed maintenance plan of routing and sealing the cracks in the year that they occur as a basis for cost comparison, the use of fabrics was found to be cost effective. Carmichael and Marienfeld (1999) reported in 1999 that the in-place cost of nonwoven paving fabric is approximately equivalent to the cost of 0.5 inch of HMA but provides performance equivalent to approximately 1.3 inches of HMA.

The authors found no information specifically related to the cost effectiveness of grids and composites, probably because these products are relatively new to the market.

CHAPTER III

LABORATORY PROCEDURES

III.1. GENERAL

The purpose of the laboratory investigation was to develop information to aid in the evaluation of the relative effectiveness of commercially available geosynthetic materials in reducing the severity or delaying the appearance of reflective cracking in bituminous overlays due, in part, to thermally induced stresses. This chapter describes the procedures used to construct and test HMA test beams with the geosynthetic materials incorporated. Each beam was uniformly fabricated using a TxDOT Type D HMA acquired from a local production plant. Appendix A provides the job-mix formula (JMF) describing the mixture design. Six types of geosynthetic material were acquired from material suppliers and are listed in Table 1.

In general, the laboratory procedures were performed as follows. A 1-inch HMA "level-up" course was compacted and cured in the mold for a minimum of 24 hours at room temperature. A geosynthetic material was applied to the level-up course using AC-20 asphalt cement supplied by Gulf States Asphalt Company using the geosynthetic manufacturer's recommended tack coat rate. After the material was allowed to set overnight and obtain full adhesion with the level-up course, the final "overlay" course of HMA was compacted in two 1-inch layers. The final compacted beam dimensions measured 3 inches in height by 6 inches in width by 20 inches in length.

Six beams were reinforced with geosynthetic material, with the seventh unreinforced beam representing the "control" beam. Three replicates of each set were fabricated, producing a total of 21 beams for the final evaluation. Many other beams were fabricated during the study to learn how to produce beams within a certain range of air voids, properly tack geosynthetics, and remake beams that produced anomalous results. Each beam was tested using the TTI Overlay Tester developed at Texas A&M University. The following sections describe the materials selected, beam fabrication procedures, TTI Overlay Tester, and the testing procedures in greater detail.

Table 1. Geosynthetic Materials Selected for Testing.

Product	Manufacturer	General Description
Bitutex Composite	Synteen USA	Woven/Coated Polyester Grid/Nonwoven Composite
Pave-Dry 381	Synthetic Industries	Polypropylene Nonwoven Fabric
PetroGrid 4582	Amoco Fabrics	Woven/Coated Fiberglass Grid/Nonwoven Composite
HaTelit C40/17	Huesker	Woven/Coated Polyester Grid/Nonwoven Composite
GlasGrid 8501	Bayex, Inc.	Woven/Coated Fiberglass Grid
StarGrid G+PF	Luckenhaus N.A.	Woven/Coated Fiberglass Grid/Nonwoven Composite

III.2. MATERIAL SELECTION

III.2.1. Geosynthetic Products

For this experiment, researchers selected six geosynthetic products to investigate their effects on the rate of crack propagation through a compacted bituminous mixture. Various terminologies are used to describe or categorize geosynthetic products. In general, the industry is composed of manufacturers that produce grids, fabrics, and/or composites. The researchers select the material based on the goal of encompassing these three types of products currently purported to reduce or delay reflective cracking in HMA overlays. The geosynthetic materials selected and tested are listed in Table 1 along with a general description of the materials from which the products are made. Included in this experiment were two fiberglass grid composites, two polyester grid composites, one fiberglass grid, and one polypropylene nonwoven fabric. Table 2 provides sample identifications for each of these materials along with the tack coat rates recommended by the respective manufacturers.

Table 2. Sample Identifications and Manufacturers Recommended' Tack Coat Rates.

Product	Sample Identification	Recommended Tack Coat Rate (gal/yd^2)	Weight of Tack Coat (grams)	Tack Coat Temperature (deg F)
Bitutex Composite	B	0.25	87.6	300
Pave-Dry 381	PD3	0.20	70.1	300
HaTelit C40/17	HC	0.10	35.1	300
PetroGrid 4582	PG2	0.23	80.6	300
Control Beam	C	None	N/A	N/A
StarGrid G+PF	S	0.25	87.6	300
GlasGrid 8501	G	N/A	N/A	N/A

III.2.2. Tack Coat

AC-20 supplied by Gulf States Asphalt Company was used to tack the geosynthetic materials to the compacted 1-inch level-up bituminous layer. The weight of tack coat listed in Table 2 was calculated based on the top surface area of the compacted beam (6 inches by 20 inches) and the specific gravity of the tack material.

During the initial phases of the laboratory experiment, MS-1 emulsified asphalt cement (67 percent asphalt and 33 percent water) was evaluated due to its ease of application in a laboratory setting. Since most geosynthetic manufacturers list tack coat rates for viscosity graded asphalt cement in their literature and not for emulsions, a conversion was made that would result in the recommended quantity of residual asphalt cement. A trial experiment was performed to observe how well the geosynthetic products would adhere using the emulsified asphalt cement. Figures 5 through 7 show photos of the beams using the emulsified asphalt. After sufficient time had elapsed for the emulsion to cure, researchers observed (Figures 5 and 6) that the geosynthetic products were not sufficiently and evenly tacked to the surface of the beam. Unlike the beams in Figures 5 and 6, the beams in Figure 7 were fully constructed with the final 2-inch overlay course using MS-1 to tack the geosynthetics and then tested to failure. Figures 7(a) and 7(b) show the 2-inch overlay course with the geosynthetic, which has been sheared along the plane within the tack coat on the 1-inch level-up course. Both the fabric and the composite could be easily separated by hand from the 2-inch overlay course due to poor adhesion. Based on these findings, the MS-1 emulsified tack coat was abandoned in favor of the viscosity graded AC-20 asphalt cement for the remainder of the study.

It should be noted that, for sample C-9 (control beam from container number 9), a tack coat was applied at the rate of 0.05 gal/yd^2. The remaining control beams did not have tack coat applied. The significance of the tack coat quantity on specimen C-9 will be discussed in the conclusions and recommendations.

III.3.3. Hot-Mix Asphaltic Concrete

To expedite preparation of the test beams and to maximize test beam uniformity, approximately one ton of Type D HMA concrete was acquired from a local supplier in the Bryan District of the Texas Department of Transportation. The JMF detailing the Type D

Figure 5. Uneven Coverage Using MS-1 Emulsified Asphalt Applied to Sample Beam C-20A with the HaTelit C40/17 Composite Product.

Figure 6. Lack of Complete Adhesion Using MS-1 Emulsified Asphalt Applied To Sample Beam C-3A with the Pave-Dry 381 Fabric.

(a)

(b)

Figure 7. Top 2-Inch Overlays from Failed Beams Containing (a) Pave-Dry 381 and (b) Petrogrid 4582. Note: The Photos indicate complete separation/failure along the plane of compaction between 1-inch level-up and 2-inch overlay course using Ms-1 emulsified asphalt cement. The geosynthetic material was easily removed from the upper layer.

mixture design is provided in Appendix A. Researchers performed periodic assurance tests on HMA materials from the control beams and compared to the JMF. These tests included bulk specific gravity, rice specific gravity, asphalt extraction, bitumen content, and dry sieve analysis. Appendix A provides results of these laboratory tests.

HMA mix was obtained from a production plant and placed into 40 five-gallon metal cans and sealed with metal lids having rubber seals. These containers were labeled from 1 through 40, in the order that they were sampled, then they were stored for future use. Each can contained sufficient material to produce one beam having the dimensions of 3 inches in height by 6 inches in width by 20 inches in length. Beam identification numbers incorporate the number of the container from which the sample was compacted. For example, beam B-5 was constructed using Bitutex Composite using material from container number 5. Likewise, beam PD3-6 was constructed with Pave-Dry 381 from container number 6, and so forth. A random approach was taken in the selection of containers for beam fabrication. Table 3 lists the containers used to fabricate HMA specimens with different geosynthetic materials.

III.4. SAMPLE PREPARATION

This section of the report describes the equipment and techniques used to compact the HMA beams containing different geosynthetic products. Since the purpose of the laboratory investigation was to compare the relative effectiveness of commercially available geosynthetic products, the goals during the sample preparation were to produce compacted beams that were homogenous in nature and contained air void levels that were realistic when compared to field conditions (e.g., about 6 percent). During the initial phase of the experiment, researchers determined the quantity of bituminous mixture and compactive effort needed to construct a 1-inch level-up course followed by two 1-inch overlay courses that, when compacted, would be within the expected air void level. This process was accomplished by trial and error using various compactive efforts to produce beams with acceptable air void levels in each layer.

Table 3. Containers Used to Fabricate HMA Beams with Different Geosynthetic Materials.

Container Number	Geosynthetic Material						
1	* Control molding						
2	Control molding						
3	Control molding						
4	* Control molding						
5	Bitutex Composite						
6		PaveDry					
7			HaTelit				
8				PetroGrid			
9					Control beam		
10						StarGrid	
11							GlasGrid
12					Control beam		
13							
14		PaveDry					
15							
16			HaTelit				
17							
18				PetroGrid			
19							
20							
21							GlasGrid
22							
23							
24					Control beam		
25	Bitutex Composite						
26							
27							
28						StarGrid	
29		PaveDry					
30							
31							
32			HaTelit				
33							
34	Bitutex Composite						
35							GlasGrid
36				PetroGrid			
37							
38					Control beam		
39						StarGrid	
40							

* Beams prepared using MS-1 emulsified asphalt tack coat.

III.4.1. Compaction Equipment

The fabrication of the bituminous beams utilized a CS 1500 compactor manufactured by Cox & Sons (Figure 8). This machine was equipped with an electronically heated 2-inch by 6-inch steel tamping foot attached to a vertical loading ram. Researchers used a dwell time of 1.5 seconds to control the amount of time the ram applied compactive force to the specimen. Each layer of the bituminous mixture was compacted in a 275°F preheated steel mold having dimensions of 7½ inches in height by 6 inches in width by 20 inches in length. Four steel prongs at the base of the compactor held the mold securely in place while the base plate was allowed to slide along rails in relation to the vertical loading ram. To remove surface irregularities, a leveling load of 20,000 lbs (approximately 167 psi) was applied to the final compacted layer for approximately 2 minutes using an Instron 4505 testing machine (Figure 9).

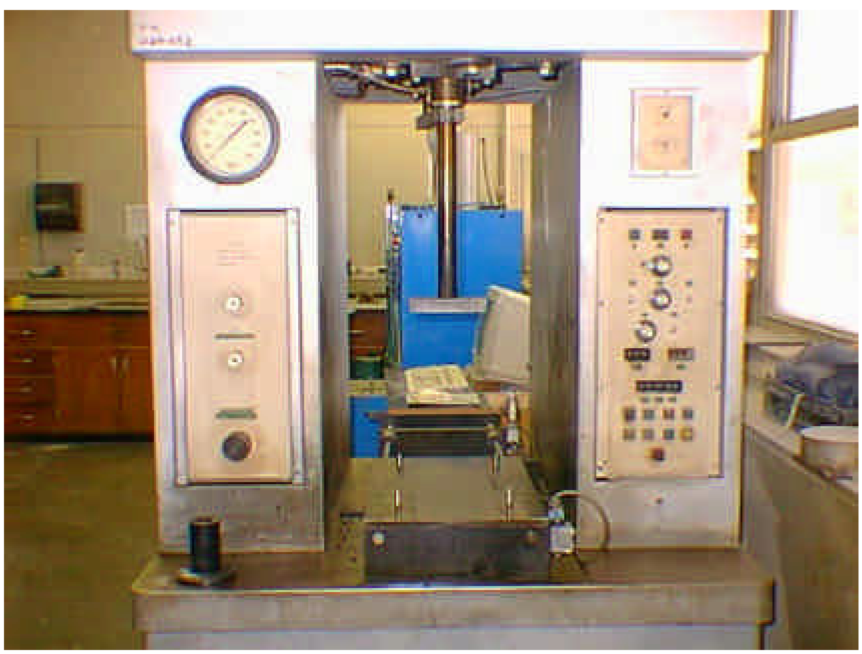


Figure 8. CS 1500 Cox and Sons Compactor with Vertical Loading Ram, Tamping Foot, and Movable Base Plate.

Figure 9. Instron 4505 Testing Machine with Instrument Panel Used to Apply 20,000-lb Leveling Load.

III.4.2. Compaction Procedures

As previously stated, Table 3 lists the numbers of the containers from which the beams were fabricated. The rubber seals were removed from inside the lid of each can and the entire container was heated in a large oven at 275°F for approximately 30 minutes. This procedure allowed the contents to be easily removed. The mixture was transferred into a large metal pan and then split into three smaller pans containing 4800 grams each. Each pan was covered with aluminum foil to minimize further oxidation and volatilization of the asphalt.

The three covered pans were heated to 275°F prior to molding, and a simple trial and error approach was used to determine the number of tamps required to achieve the desired air void level. The vertical ram pressure was gradually increased for each series of tamps. Bulk and rice specific gravities were measured (see Appendix A) to determine the resulting air void level. Table 4 lists the number of tamps at the specified ram

Table 4. Compaction Procedures Used and Air Void Levels Obtained to Achieve an Acceptable Specimen.

Sample Container	Date Molded	Sample I.D.	Sample Size	Compaction Procedure number of tamps @ vertical ram pressure					Specific Gravity		Percent Air Voids (%)
				50@200	50@400	100@600	100@800	200@800	Bulk	Rice	
1	5/23/00	C-1A	1 inch	ŏ	ŏ	ŏ		ŏ	2.283	2.461	7.2
	5/24/00	C-1B	1 inch	ŏ	ŏ	ŏ		ŏ	2.283	2.461	7.2
2	5/30/00	C-2A	2 inch	ŏ	ŏ	ŏ		ŏ	2.377	2.444	2.8
	5/31/00	C-2B	2 inch	ŏ	ŏ	ŏ			2.246	2.444	8.1
3	6/01/00	C-3A	1 inch	ŏ	ŏ	ŏ	ŏ		2.310	2.468	6.4
	6/01/00	C-3B	1 inch	ŏ	ŏ	ŏ	ŏ		2.322	2.468	5.9
	6/01/00	C-3C	2 inch	ŏ	ŏ	ŏ	ŏ		2.326	2.468	5.7
4	6/05/00	C-4A	1 inch	ŏ	ŏ	ŏ	ŏ		2.304	2.463	6.5
	6/07/00	C-4B	2 inch	ŏ	ŏ	ŏ	ŏ		2.316	2.463	6.0
20	6/13/00	C-20A	1 inch	ŏ	ŏ	ŏ	ŏ		2.315	2.465	6.1
	6/09/00	C-20B	2 inch	ŏ	ŏ	ŏ	ŏ		2.353	2.465	4.5
	6/15/00	C-20C	2 inch	ŏ	ŏ	ŏ	ŏ		2.353	2.465	4.6
12	8/16/00	C-12	3 inch	ŏ	ŏ	ŏ	ŏ		2.352	2.460	4.4
38	8/16/00	C-38	3 inch	ŏ	ŏ	ŏ	ŏ		2.358	2.459	4.1
24	8/16/00	C-38	3 inch	ŏ	ŏ	ŏ	ŏ		2.356	2.480	5.0

pressure and resulting air void level for the initial trial beams and "control" specimens. The variation in air void levels (from a low of 4.1 percent to a high of 6.5 percent) was determined to be a function of the compaction equipment and the manual process of fabricating the beams. The compactive pressures ranged from 8 psi to 67 psi (100 psi to 800 psi ram pressure). With an acceptable compaction procedure established, the beams for the testing program were fabricated.

For each specimen produced, a 1-inch "level-up" course was compacted and cured for a minimum of 24 hours at laboratory room temperature. A geosynthetic material was then applied to the level-up course using AC-20 at the manufacturer's recommended tack coat rate. After the material was allowed to set and obtain maximum adhesion, the final "overlay" course of hot mix was compacted in two 1-inch layers. The final compacted beam dimensions measured 3 inches in height by 6 inches in width by 20 inches in length. Table 5 indicates the sequence of laboratory fabrication. This table lists the sample identifications, molding dates, and testing dates for each beam produced in this experiment.

III.5. TESTING PROCEDURES

III.5.1. TTI Overlay Tester

Each HMA beam was tested to failure on a tensile fatigue testing machine called the TTI Overlay Tester. This machine was designed and constructed by personnel at the Texas Transportation Institute at Texas A&M University (Germann and Lytton, 1979). The TTI Overlay Tester consists of a hydraulic servo-controlled mechanism designed to simulate the tensile and compressive stresses induced in a bituminous pavement or base course as a result of cyclic changes in temperature (Pickett and Lytton, 1983). These stresses create horizontal displacements in the pavement structure, which form cracks commonly known as thermal cracks. To simulate these displacements, the Overlay Tester consists of one fixed plate and one movable plate driven by a hydraulically powered ram (Figures 10 and 11). The Overlay Tester is controlled by a Gilmore Model

Table 5. Sequence of Compaction and Testing for Each Laboratory Fabricated Beam.

Sample I.D.	1-inch Level-up Date Molded	AC-20 Tack Coat Rate (gal/sy)	Date Tacked	2-inch Overlay Date Molded	TTI Overlay Date Tested	Test Temperature (deg F)
PD4-1	5/24/00	0.37 *	6/22/00	6/23/00	6/28/00	77.5
PG1-4	6/05/00	0.34 *	6/22/00	6/24/00	6/29/00	77.3
B-5	6/29/00	0.25	6/30/00	7/04/00	7/18/00	77.5
PD3-6	7/05/00	0.20	7/06/00	7/07/00	7/17/00	78.0
HC-7	7/06/00	0.10	7/07/00	7/11/00	7/20/00	77.4
PG2-8	7/11/00	0.23	7/12/00	7/12/00	7/21/00	77.5
C-9	7/12/00	0.05	7/14/00	7/14/00	7/24/00	77.6
S-10	7/13/00	0.25	7/20/00	7/21/00	7/31/00	77.5
G-11	7/31/00	N/A	N/A	8/03/00	8/08/00	77.6
C-12	8/07/00	None	N/A	8/08/00	8/11/00	77.3
B-25	7/15/00	0.25	7/17/00	7/18/00	8/01/00	77.6
PD3-14	7/17/00	0.20	7/19/00	7/20/00	8/02/00	77.8
HC-32	7/21/00	0.10	7/28/00	7/28/00	8/03/00	77.9
PG2-18	7/24/00	0.23	8/01/00	8/01/00	8/04/00	77.8
C-38	8/02/00	None	N/A	8/04/00	8/09/00	77.7
S-28	8/03/00	0.25	8/07/00	8/07/00	8/11/00	77.3
G-35	8/04/00	N/A	N/A	8/15/00	8/17/00	77.8
B-34	9/24/00	0.25	9/28/00	9/28/00	10/23/00	75.0
PD3-29	9/20/00	0.20	9/25/00	9/25/00	10/24/00	77.0
HC-16	9/18/00	0.10	9/19/00	9/19/00	10/25/00	77.6
PG2-36	9/29/00	0.23	10/02/00	10/02/00	10/26/00	77.8
C-24	10/03/00	None	N/A	10/04/00	10/27/00	77.3
S-39	10/10/00	0.25	10/11/00	10/11/00	10/30/00	77.4
G-21	10/05/00	N/A	N/A	10/09/00	11/03/00	77.0

* Note: MS-1 emulsified asphalt rate (67% asphalt and 33% water). Rate shown will result in recommended residual asphalt rate.

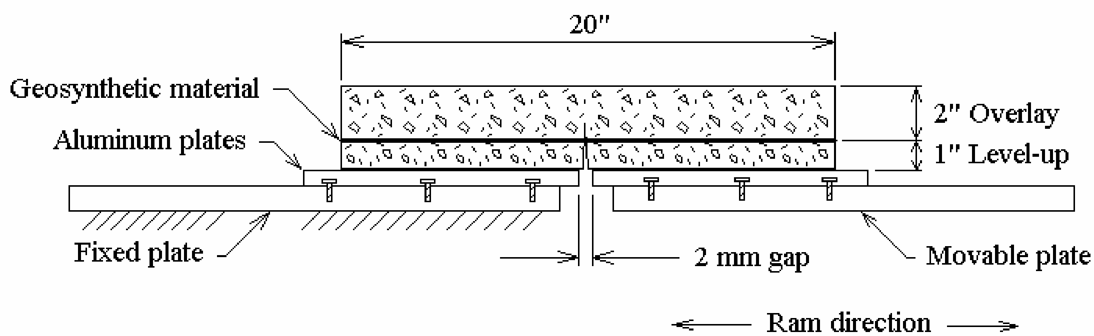


Figure 10. Schematic Diagram of Compacted Test Beam and TTI Overlay Tester.

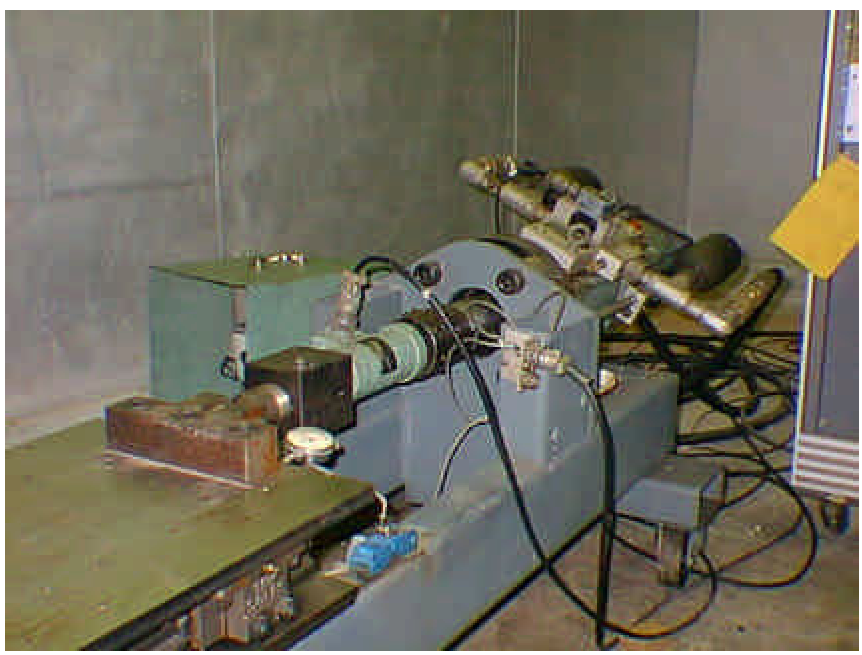


Figure 11. TTI Overlay Tester and Hydraulically Powered Ram Assembly. (Only the Movable Base Plate is Shown.)

435 control panel and an MTS 458.20 MicroConsole (Figure 12). The data acquisition system consists of an analog-to-digital converter board, a 486 PC, and data collection software developed at TTI. Automated data collection consisted of time in seconds, displacement in inches, and load in pounds.

Figure 12. TTI Overlay Tester Command Console and Data Collection System.

III.5.2. Sample Testing

Each fabricated beam was epoxied to two aluminum plates and allowed to cure for 24 hours. To represent an "existing" crack in the old pavement surface, the two aluminum plates were separated by 2 mm under the center of the beam (Figure 10). This was achieved by placing a plastic straightedge between the plates during alignment. The straightedge was removed and the gap was covered with clear adhesive tape to prevent the epoxy resin from entering. The compacted beam was then spanned across the crack and epoxied in place.

Each beam was painted white in the areas where cracking was most likely to occur. This technique enhanced the visibility and detection of cracks during the testing phase. Researchers then placed the assembly on the overlay tester and allowed it to relax for 24 hours in an environmental chamber at a constant temperature of 77°F and relative humidity of 25 percent. The aluminum plates were bolted to the overlay tester (Figure 13) using incremental torque values of 20, 40, and 50 ft-lb.

Figure 13. Beam Sample Epoxied to Aluminum Plates, Painted, and Bolted to the TTI Overlay Tester.

Prior to each beam test, researchers calibrated the overlay tester to ensure the desired ram displacements and loading rates. They then tested each beam to failure in a controlled displacement mode in two phases. The first phase incorporated a constant waveform with a ram displacement of 0.010 inches. The displacement was applied for 30 seconds then ramped down to zero displacement for a total cycle length of 40 seconds. Measurements of displacement and load as a function of time were recorded and used to create plots from which the relaxation modulus was determined (discussed in Chapter IV). The second phase proceeded without a rest period between the first and second load cycles. The second phase of the test used a loading rate of one cycle per 10 seconds with a cyclic triangular (saw-tooth) waveform having a ram displacement of 0.070 inch. This amount of movement is approximately equal to the displacement experienced by PCC pavement undergoing a 60°F change in pavement temperature with a 15-foot joint or crack spacing (Pickett and Lytton, 1983).

During the test, the location of each crack and corresponding load cycle was recorded directly on the beam using a felt-tip pen. Crack measurements were recorded simultaneously on both sides of the specimen. Specimen "failure" was defined as the condition in which a continuous crack propagated up each side of the beam and completely across the top of the sample. Figure 14 shows a beam tested to failure with the crack patterns drawn.

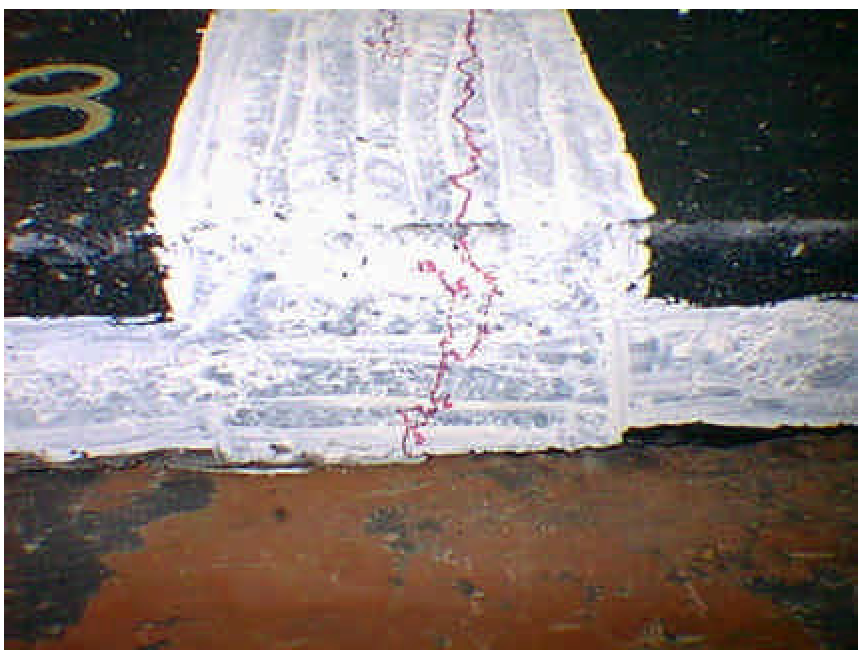


Figure 14. Sample Tested to Failure with Crack Locations and Load Cycles Indicated.

After the failure condition was achieved, the test was halted and the bolts were removed from the aluminum plates. A large sheet of tracing paper was draped over the beam and used to record the locations of the cracks and the corresponding load cycles for a permanent record (Figure 15). Appendix B provides a description of the tracing process and reduced examples of tracings. Cleveland (2001) contains tracings for all the beams tested. An engineer's scale was used to manually measure the crack height on both sides of the test specimen. To locate the left and right side of the beam, the movable base plate was defined as the "top" of the Overlay Tester (Figure 11).

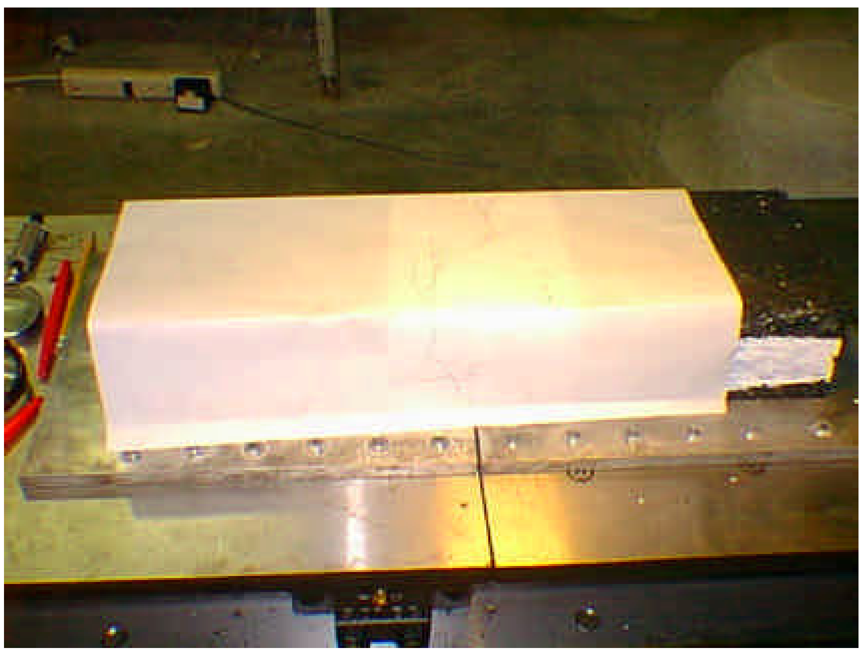


Figure 15. Tracing Paper Used to Record the Crack Patterns and Corresponding Load Cycles.

III.6. SUMMARY

The purpose of the laboratory investigation was to develop information that would aid in the evaluation of the relative effectiveness of commercially available geosynthetic materials in reducing or delaying reflective cracking in HMA overlays due, in part, to thermally induced stresses. Type D HMA was acquired from a local supplier in the Bryan District of the Texas Department of Transportation. Periodic assurance tests were performed on this mixture for quality control purposes. Six commercially available geosynthetics materials (one grid, one fabric, and four composites) were tack coated to a 1-inch level-up course using AC-20 and subsequently overlaid with 2 inches of HMA.

Each compacted beam (Table 5) was evaluated using a fatigue testing device called the TTI Overlay Tester (Figure 10) at a temperature and humidity. This device generates a cyclic horizontal ram displacement of 0.070 inch at the bottom of the compacted beam to simulate thermal expansion and contraction stresses induced as a result of cyclic changes in ambient temperature. During testing, crack lengths and corresponding load cycles were recorded and an automated data collection system was used to record load and displacement as a function of time.

The next chapter describes the fracture mechanics based approach used to analyze these data.

CHAPTER IV

ANALYSIS OF THE MECHANICS OF ASPHALT FRACTURE TESTS

IV.1. GENERAL

The objective of this chapter is to introduce the equations used in analyzing the data collected during this laboratory investigation. To determine the relative effectiveness of the geosynthetic products tested, researchers analyzed the data collected from the TTI Overlay Tester using a fracture mechanics based approach. This approach has been used previously by other researchers with the basic assumption of modeling the HMA as a linear elastic material. Therefore, the rate of crack growth was analyzed using Paris' Law, the fundamental fracture law. The field of fracture mechanics was developed to understand the phenomenon of fracture and crack growth in metal and/or alloy materials due to premature catastrophic failures (Broek, 1984). These concepts have been extended to crack growth in HMA in the original work guided by R. A. Schapery and R. L. Lytton at Texas A&M University in College Station, Texas.

The characterization of HMA should include the elastic, viscoelastic, plastic, fracture, and healing properties of the material. These material properties can be used with mechanistic models to predict distresses such as rutting, load-related fatigue cracking, and thermal cracking (Lytton et al., 1993). Lytton et al. (1993) provide detailed explanations of these properties and the pavement prediction models in which they are inputs. The equations derived in this chapter account for the nonlinear viscoelastic nature of HMA pavements.

The following paragraphs introduce elementary engineering fracture mechanics. The progression of these concepts herein will proceed from linear elastic to nonlinear viscoelastic material characterization. In this process, the authors show that the J-Integral is a more universal fracture criterion than either the stress intensity factor or the elastic energy strain rate, since it accounts for the plastic deformation at the tip of a crack in HMA materials. The elastic-viscoelastic correspondence principle will then be applied to the well-known linear elastic constitutive equation, $\sigma = E\,\varepsilon$. The time-dependent viscoelastic solution produced will be transformed to a load-displacement relation that will be the basis for the analysis of this investigation.

IV.2. ELEMENTARY ENGINEERING FRACTURE MECHANICS

IV.2.1. Paris' Law

Fatigue is the general phenomenon of material failure due to the growth of microscopic flaws as a result of repeated loadings (Shackelford, 1992). These microcracks become more visible as the stress concentrations at the tip of the crack increase and cause further crack propagation. Paris' Law (Paris and Erdogan, 1963), as provided in Equation 4-1, defines the fundamental fracture law governing the rate of crack growth (commonly referred to as 'crack extension' in fracture mechanics) in a material based on linear elastic fracture mechanics.

$$\frac{dc}{dN} = A(\Delta K)^n \tag{4-1}$$

where:

c	=	crack length
N	=	number of load applications
$\frac{dc}{dN}$	=	rate of crack growth {or "crack speed" (Lytton et al., 1993)}
ΔK	=	change of stress intensity factor during loading and unloading
A, n	=	fracture parameters for asphalt mixture

Fracture will occur in HMA when the stress intensity factor reaches a critical value. Fracture toughness is defined as the critical value of the stress intensity factor, K_{IC}, at the crack tip necessary to produce failure under simple uniaxial loading (Shackelford, 1992). If a material does not deform plastically at the crack tip, it is considered brittle and will have low fracture toughness. Conversely, high fracture toughness is usually associated with low strength and/or ductile materials. Asphaltic concrete mixtures can be characterized as having elastic, viscoelastic, plastic, fracture, and healing material properties (Lytton et al., 1993). Therefore, HMA paving materials transition the range of brittle and ductile behavior, and the use of Paris' Law, based on linear elastic fracture mechanics, should be modified to account for the complex nature of this material.

IV.2.2. Elastic Energy Strain Rate

In 1921, Griffith provided a criterion that stated that "crack propagation would occur if the energy released upon crack growth is sufficient to provide all of the energy that is required for crack growth" (Broek, 1984). In 1948, Irwin modified Griffith's Crack Theory to incorporate an energy balance analysis of crack growth (Tada et al. 2000). Tada et al. (2000) explains that, for the linear-elastic case, the elastic energy release rate, G, per crack tip:

> may be viewed as the energy made available for the crack extension processes at the crack-tip as a result of the work from displacements of loading forces and/or reductions in strain energy in a body accompanying a unit increase in crack area.

Pickett and Lytton (1983) used the elastic energy release rate concept for the evaluation of geotextile materials in the following manner. Using the above definition of "work from displacements of loading forces…accompanying a unit increase in crack area," they made a plot of load versus displacement (Figure 16) using data produced from the TTI Overlay Tester. The difference in bounded areas represented the dissipated elastic energy having the units of inch-pound. Crack growth was visually observed and regression techniques were applied to define equations relating elastic energy and crack length to load cycle. The derivative of each equation was calculated and the rate of change of elastic energy was divided by the unit increase in crack area (computed by multiplying the rate of crack growth by twice the width of the specimen) to determine the elastic energy release rate. Equation 4-2 presents the progression of computations

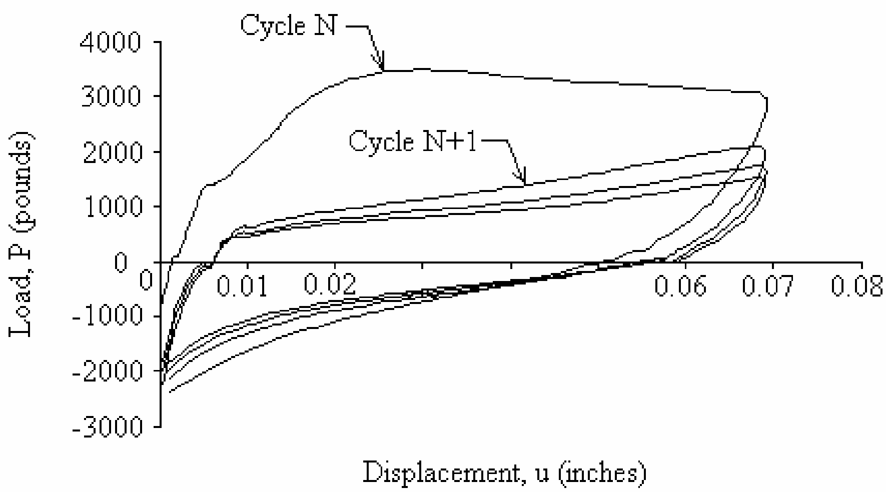


Figure 16. Typical Recordings of Load versus Displacement Used to Calculate Elastic Strain Energies as Investigated by Picket and Lytton (1983).

$$G = \frac{\frac{\partial E}{\partial N}}{\frac{\partial c}{\partial N}} = \frac{\partial E}{\partial c} = \frac{\partial E}{\partial c(2b)} = \frac{\partial E}{\partial a} \qquad (4\text{-}2)$$

where:

E	=	elastic energy (inch-pound)
c	=	observed crack length (inches)
b	=	width of compacted specimen (inches)
a	=	cracked area (square inches)
$\frac{\partial E}{\partial a}$	=	rate of change of elastic energy per unit of crack growth area

Although this research was successful in terms of determining fracture properties using fracture mechanics theories, the basic assumption used was that the HMA material behaved as a linear elastic material. The following paragraphs will show how the above concepts were expanded to account for HMA's nonlinear viscoelastic behavior.

IV.2.3. Relationship between K and G

The stress-intensity factor (K) and the elastic energy release rate (G) are related by the following equations (Tada et al., 2000):

$$G = \frac{K^2}{E} \quad \text{(for plain stress conditions)} \tag{4-3}$$

$$G = \frac{K^2\left(1-\nu^2\right)}{E} \quad \text{(for plain strain conditions)} \tag{4-4}$$

where:

E = Young's modulus, and

ν = Poisson's ratio

Broek (1984) provides a chapter in his textbook describing alternative methods by which the stress intensity factor can be determined. To summarize his findings, he explains that, in cases of simple geometry, analytical methods can be used, but the complexity of the boundary conditions often necessitates numerical solution of the equations. Furthermore, finite element methods are often necessary with complex geometry and complicated stress systems. Finite element methods have the basic assumption of modeling asphaltic concrete as an elastic continuum with a finite number of structural elements interconnected by nodes. The displacement of these nodes is governed by functions, either simple or complex, as prescribed by the user. The use of finite element methods to accurately compute stress fields at the crack tip is quite complex and requires the use of extensive computer resources.

IV.2.4. J-Integral

Lytton et al. (1993) describe HMA materials as behaving "as a linear elastic or viscoelastic material at low temperatures and as a nonlinear elasto-visco-plastic material at high temperatures." Since there is appreciable plasticity at the crack tip, the elastic energy release rate, G, cannot be "determined from the elastic stress field, since G may be affected considerably by the crack tip plastic zone" (Broek, 1984). The J-Integral provides a means to determine the energy release rate for elastic-plastic behavior (Broek, 1984). The equation for the J-Integral, as illustrated in Figure 17, was developed by Rice (1968) and is presented below.

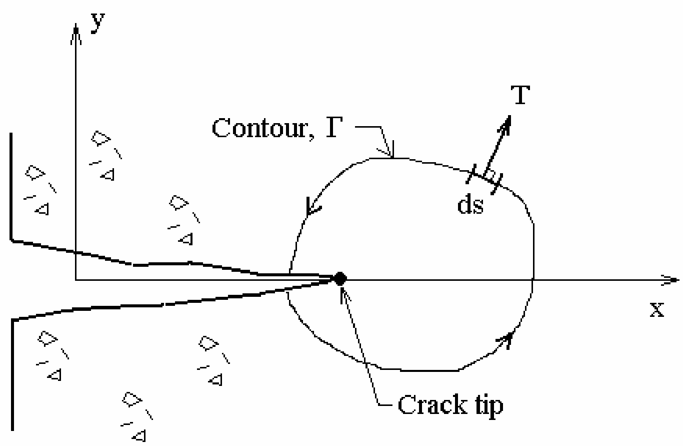


Figure 17. Illustration of the J-Integral as Mathematically Described by Equation 4-5.

$$J = \oint_{\Gamma} \left(W dy - T_i \frac{\partial u_i}{\partial x} ds \right) \qquad (4\text{-}5)$$

where:

$\oint$ = the surface integral of the strain energy within the closed contour, Γ

Γ = the closed contour surrounding the crack tip

W = the strain energy per unit volume, which is defined as:

$$W = W(x, y) = W(\varepsilon) = \int_0^{\varepsilon} \sigma_{ij} d\varepsilon_{ij}$$

T = the tension vector (traction) perpendicular to Γ in the outward direction and is defined as:

$$T_i = \sigma_{ij} n_j$$

u_i = displacement in the x-direction

ds = arc length along Γ

σ_{ij} = stress components acting on an arc of Γ

n_j = directional cosines of the stress components

ε_{ij} = strains acting in the direction of the stress components

The contour surface integration is made necessary to avoid the stress singularity at the tip of a sharp-pointed crack.

The J-Integral can be interpreted as the nonlinear counterpart of G (Tada et al., 2000). For nonlinear *elastic* materials, Paris' Law can therefore be re-written as given in Equation 4-6. (Lytton et al., 1993). The 'A' and 'n' fracture parameters in Equation 4-6 are different than those in the linear elastic fracture mechanics case as described by Equation 4-1.

$$\frac{dc}{dN} = A(J)^n \tag{4-6}$$

IV.3. ELASTIC-VISCOELASTIC CORRESPONDENCE PRINCIPLE

The inelastic response of asphalt concrete is determined not only by its current state of stress, but also on all past states of stress (Kim, 1988). The elastic-viscoelastic correspondence principle can be used to represent the response of a viscoelastic material to a time-dependent load (Lytton et al., 1993). This is accomplished by applying the Laplace transform to a viscoelastic solution to obtain a corresponding elastic solution. This procedure removes the time variable, t, which is replaced by the Laplace transformed variable, s. Conversely, inverse Laplace transforms can be applied to elastic solutions to compute desired viscoelastic solutions. This latter method allows the vast number of linear elastic solutions to be converted to linear viscoelastic solutions. The inverse Laplace transform of Equation 4-7 below produces the linear viscoelastic solution given in Equation 4-8 (Cleveland, 2001).

Linear elastic constitutive equation:

$$\sigma = E\,\varepsilon \tag{4-7}$$

Linear viscoelastic constitutive equation:

$$\sigma(t) = \int_0^t E(t-\tau)\,\frac{d\varepsilon}{d\tau}\,d\tau \tag{4-8}$$

IV.4. THEORY OF NONLINEAR VISCOELASTICITY

Equation 4-8 is applicable for calculating time-dependent stress for *linear* viscoelastic media. Schapery (1984) suggested that similar constitutive relationships exist for *nonlinear* viscoelastic materials, but the stresses and strains should be considered as "pseudo stresses" and "pseudo strains," since they are not necessarily physical quantities in the viscoelastic media (Kim, 1988). Figures 18 through 20 illustrate this concept. Figure 18 shows the relationship of stress versus strain for a nonlinear elastic material. If there is

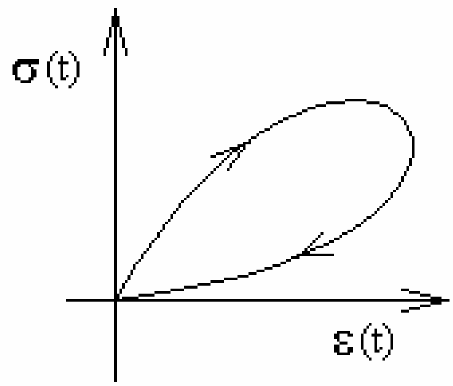


Figure 18. Undamaged Nonlinear Elastic Material.

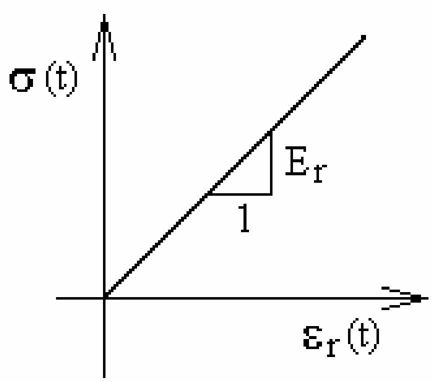
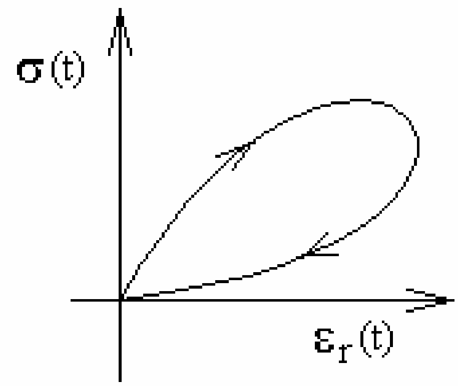
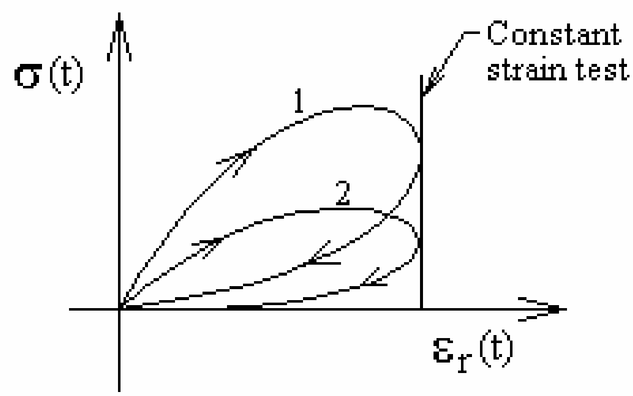


Figure 19. Undamaged Linear Viscoelastic Material Using Pseudo Strain [$\varepsilon_R(t)$].



(a)



(b)

Figure 20. Nonlinear Viscoelastic Behavior Indicated for (a) Undamaged Material, and (b) Damaged Material Using the Concept of Pseudo Strain.

no change in the bounded area during successive load cycles, then no damage is said to occur. Application of the elastic-viscoelastic correspondence principle produces the linear viscoelastic relationship (Figure 19). Notice that pseudo strain, $\varepsilon_R(t)$, is used in this figure as suggested by Schapery's concept. The departure from a linear relationship, as illustrated in Figure 20(a), indicates nonlinear viscoelastic material behavior. A change in the bounded areas during successive loads cycles, as seen in Figure 20(b), indicates that damage has occurred in the form of cracks and plastic deformation at the crack tip. The difference in bounded areas is calculated as the pseudo strain energy released during crack propagation. By dividing this energy by the unit area of crack growth, the pseudo J-Integral is thus defined.

IV.5. EQUATION DERIVATIONS FOR DATA ANALYSIS

The preceding sections have provided a theoretical background necessary to characterize the nonlinear viscoelastic response of HMA materials. Furthermore, a modification to Paris' Law, whereby the pseudo J-Integral is used in lieu of the stress intensity factor, was demonstrated to be a valid relationship for governing the rate of crack growth in nonlinear viscoelastic materials. This section provides the derivations of the final equations used to analyze the data produced from the TTI Overlay tester.

Automated data collection, used in conjunction with the TTI Overlay Tester, consisted of displacement (u) and load (P) as a function of time (t). Figure 21 provides the variables used to define the beam dimensions, crack length as a function of load cycle, and cyclic ram load. Each beam was tested to failure in a controlled displacement mode in two phases (Figure 22). The first phase incorporated a constant displacement waveform having a ram displacement of 0.010 inch. Measurements of displacement and load from 5 to 35 seconds were used to determine the relaxation modulus curve (Figure 23). Regression techniques were used to provide relationships in the form given by Equation 4-9. The second phase testing was conducted until failure occurred at a loading rate of one cycle per 10 seconds using a cyclic triangular displacement waveform (saw-tooth) having a ram displacement of 0.070 inch.

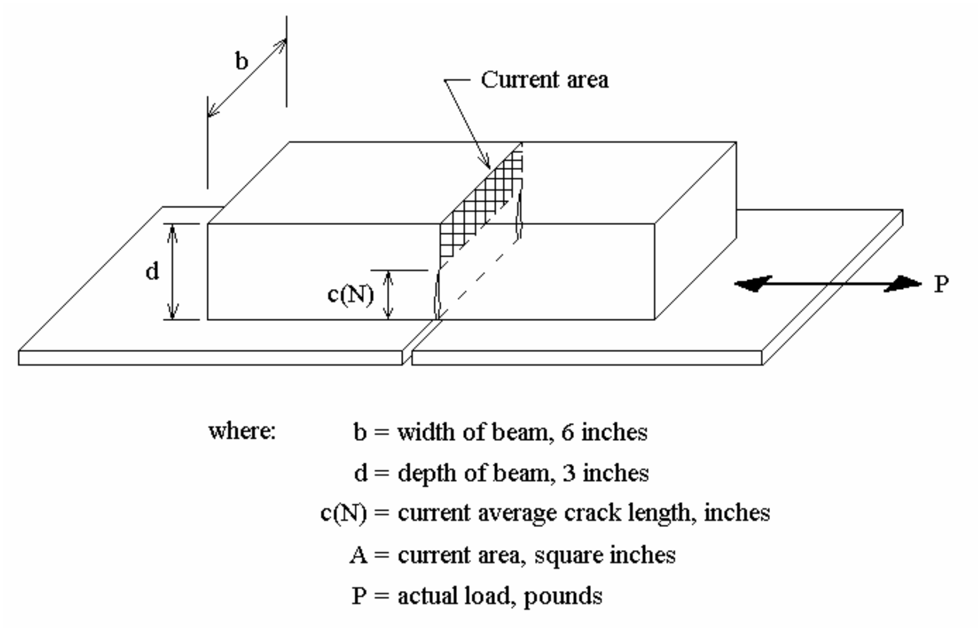


Figure 21. Variables Used to Describe the Compacted HMA Beam.

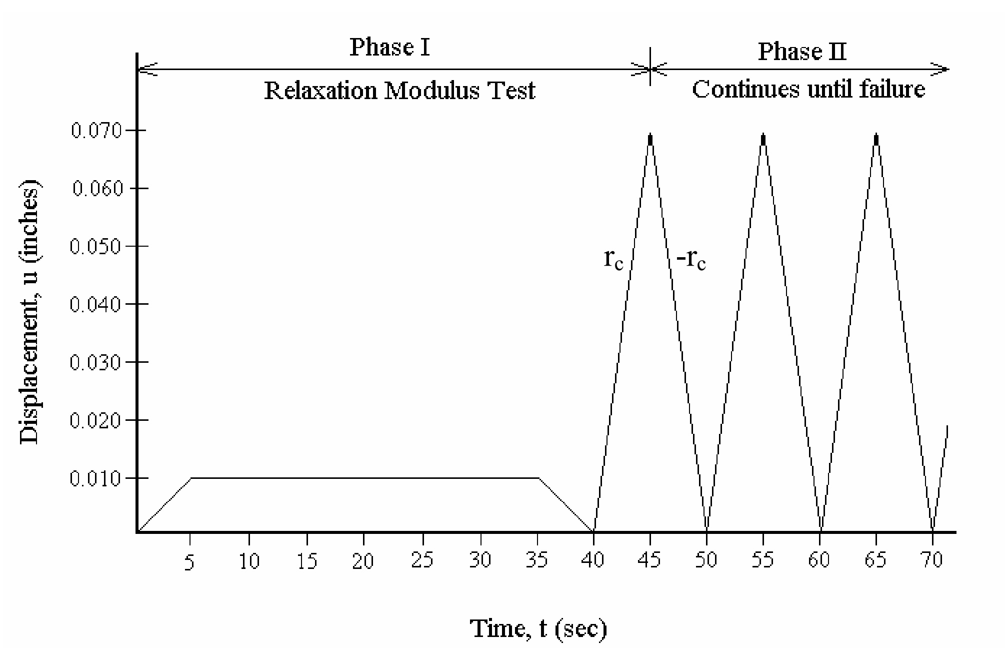


Figure 22. Loading Pattern Applied in Two Phases.

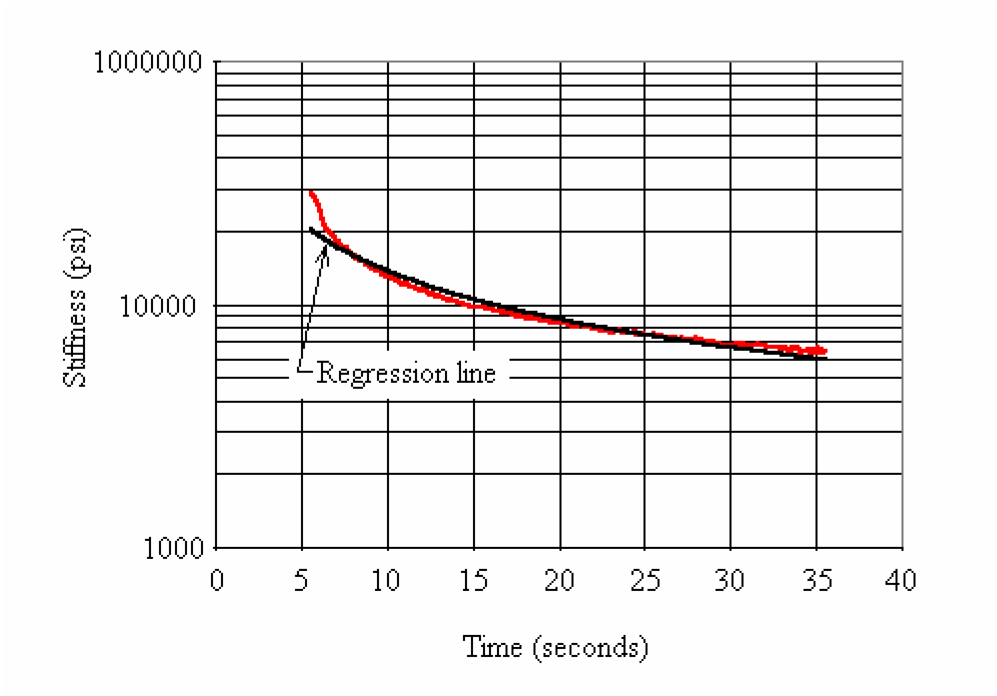


Figure 23. Typical Phase I Relaxation Modulus Curve as Developed for Each Fabricated Beam.

A power law regression trendline for the relaxation modulus test is given by

$$E(t-\tau) = E_1(t-\tau)^{-s} \tag{4-9}$$

where:

E_1 = regression constant representing the relaxation modulus of the HMA (i.e., the Y-intercept of the log stiffness versus time)

s = slope of the log stiffness versus time curve

Since the Overlay Tester produces data in terms of loads and displacements, it is necessary to transform Equation 4-8 from a stress-strain relation into a load-displacement relation. This is accomplished by the use of Equations 4-10 and 4-11. Substituting these relationships into Equation 4-8 produces the needed load-displacement transformation as shown in Equation 4-12 below. Equation 4-12 can be evaluated for each 10-second load cycle. This is accomplished by integrating from 0 to 5 seconds and from 5 to 10 seconds, recognizing that the displacement rate, r_c (Figure 21), is a constant value. Cleveland (2001) provides details of these procedures. The solutions for the appropriate time range are given in Equations 4-13 and 4-14.

$$\sigma(t) = \frac{P_{LVE}(t)}{A} \tag{4-10}$$

where:

$P_{LVE}(t)$ = predicted linear viscoelastic load as a function of time, pounds

A = current area = b {d – c (N)}, square inches (see Figure 20)

$$\frac{d\varepsilon}{d\tau} = \frac{1}{d}\left(\frac{du}{d\tau}\right) \tag{4-11}$$

where:

$\frac{du}{d\tau}$ = displacement rate, inches/second

$$r_c = +\frac{du}{d\tau} \quad \text{for} \quad 0 < t < 5 \text{ sec} \qquad \text{and}$$

$$r_c = -\frac{du}{d\tau} \quad \text{for} \quad 5 < t < 10 \text{ sec}$$

Substitution of Equations 4-9 through 4-11 into Equation 4-8 produces the following equation for the predicted linear viscoelastic load.

$$P_{LVE}(t) = \int_0^t E_1 (t - \tau)^{-s} \; b\{d - c(N)\} \frac{1}{d} \left(\frac{du}{d\tau} \right) d\tau \qquad (4\text{-}12)$$

Integration of Equation 4-12, using the limits shown, yields

For $0 < t < 5$ sec

$$P_{LVE}(t) = \frac{E_1 r_c}{1 - s} \left(\frac{b\left[d - c(N) \right]}{d} \right) (t)^{1-s} \qquad (4\text{-}13)$$

For $5 < t < 10$ sec

$$P_{LVE}(t) = \frac{E_1 r_c}{1 - s} \left(\frac{b\left[d - c(N) \right]}{d} \right) \left[(t)^{1-s} - 2\,(t - 5)^{1-s} \right] \qquad (4\text{-}14)$$

To briefly summarize, Equations 4-13 and 4-14 define time-dependent linear viscoelastic (LVE) loads based on the applicable time ranges. To determine the pseudo J-Integral, it is necessary to further transform these equations into pseudo (or reference) displacements. This is accomplished by dividing the LVE loads by a reference stiffness as shown in Equation 4-15.

$$u_r(t) = \frac{P_{LVE}(t)}{k_r} \qquad (4\text{-}15)$$

where:

u_r = pseudo (or reference) displacement, inch

k_r = reference stiffness, pound/inch

The reference stiffness is found, as illustrated in Figure 24, by dividing the maximum load, P_{max} (t), measured on the first load cycle, by the maximum measured displacement, u_{max} (t).

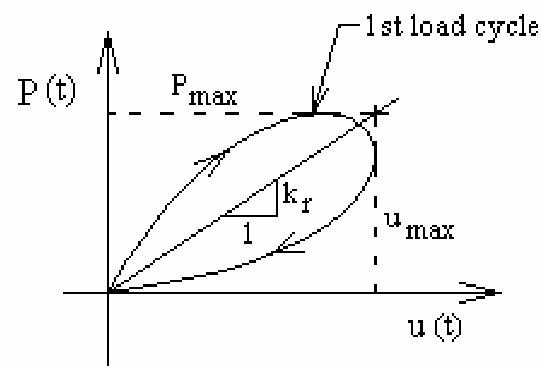


Figure 24. Definition of Reference Stiffness, k_r, as Determined During Phase I Testing.

A plot of the measured load, P, versus pseudo displacement, u_r, is shown in Figure 25. This plot is analogous to Figure 20(b) in which the change in bounded area during successive load cycles is considered the pseudo strain energy released during crack propagation. Similarly, by dividing this change of energy by the change of area of crack growth, the pseudo J-Integral is defined.

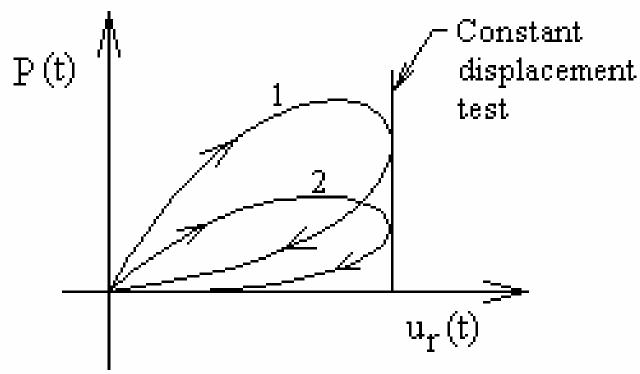


Figure 25. Damaged Nonlinear Viscoelastic Material Using Measured Loads and Pseudo Displacements.

IV.6. SUMMARY

This chapter has introduced elementary engineering fracture mechanics and the elastic-viscoelastic correspondence principle as analytical methods of characterizing the nonlinear viscoelastic response of HMA materials. A progression of these concepts leads to the development of pseudo displacement equations that, when plotted against measured loads from the TTI Overlay Tester, can be used to calculate values of the pseudo J-Integral. This chapter has also demonstrated that the pseudo J-Integral can be used in a modified version of Paris' Law to calculate the rate of crack propagation in HMA materials.

The following chapter utilizes the equations derived in this section for the reduction of asphalt fracture data collected using the TTI Overlay Tester. The crack propagation properties discussed in this chapter will be computed. As will be shown, the reduction of data leads to the development of a reinforcing factor that characterizes the reinforcing behavior provided by the geosynthetic materials.

CHAPTER V

REDUCTION OF ASPHALT FRACTURE DATA

V.1. GENERAL

The objective of this chapter is to introduce the procedures used for the reduction of asphalt fracture data collected using the TTI Overlay Tester. These procedures will include applications of the equations derived in the previous chapter. The culmination of this effort will result in the determination of crack propagation parameters, A and n, as described in Equation 4-6. A semi-logarithmic plot will be made from these values to determine the relative effectiveness of each geosynthetic product in reducing or delaying reflective cracking. The relative position of these values and the slopes produced will aid in making a comparative analysis of the geosynthetic products tested. Relations between n and the relaxation modulus properties of the asphalt concrete mix and between log A and arithmetic n will be developed for use in reflection crack prediction methods.

During the reduction of data, plots were produced that did not conform to the theoretical patterns as shown in Figure 25, namely, traversing in a clockwise loop direction. Instead, these plots showed the load-vs-opening path traversing the loop in a counterclockwise direction. It was observed that this only occurred when the beams were reinforced with geosynthetic materials. Because of this, the authors developed a new concept to account for the effect of overlay reinforcing which they termed the *Reinforcing Factor, R*. This value was calculated for each load cycle and was plotted against the rate of crack growth. Regression techniques were then applied to determine the parameters B and m to describe the effect of the reinforcing factor, R, on the crack growth rate, similar to Equation 4-6. Using the values of A, n, B, and m, a crack speed index was developed to compare the relative effectiveness of the geosynthetic materials tested.

A simple relationship between the slope, s, of the relaxation modulus curve and volumetric properties of the HMA mixture was introduced. This relationship allows the relaxation properties of any HMA mixture to be predicted from laboratory calculated volumetric properties without having to perform a relaxation modulus test. From the data analyzed, design equations were developed between the aforementioned values. These equations can be used in design calculations to support the design of an overlay to resist reflection cracking. All calculations were performed using a standard computer spreadsheet program.

V.2. DETERMINATION OF THE PSEUDO J-INTEGRAL

The pseudo J-Integral is defined as the rate of change of dissipated pseudo strain energy per unit area of crack growth. To calculate this value, the data collected from the Overlay Tester was analyzed to determine the relationships between energy dissipation and crack growth for each successive load cycle. The following subsections provide the procedures used to determine the pseudo J-Integral.

V.2.1. Relaxation Modulus Test

To briefly summarize the laboratory procedures, each fabricated HMA beam was tested to failure in two phases, using a fatigue-testing machine called the Overlay Tester. Phase 1 consisted of a relaxation modulus test performed for 30 seconds at a constant displacement of 0.01 inch. The modulus as a function of time was calculated from the loads recorded, and a power law regression analysis was performed to determine the regression coefficients E_1 and s as given by Equation 4-9. Table 6 lists these values for each beam fabricated and tested. Phase 2 was conducted at a loading rate of one cycle per 10 seconds using a saw-tooth waveform having a maximum ram displacement of 0.070 inch. Measurements of load and displacement as a function of time were recorded along with the location of each crack and corresponding load cycle. It should be noted that, during the analysis of the third series of test replicates, it was determined that an error in the hydraulic servo-controlled mechanism produced erroneous data. Therefore, the data for Series 3 is not shown in Table 6.

Table. 6 Regression Constants and R^2 Values as Determined from Various Graphs.

Sample I.D.		Relaxation Modulus Test			Crack length vs. Load cycle			Pseudo work vs. Load cycle		
		E_1	s	R^2	d	e	R^2	a	m	R^2
Series one	B-5	64560	0.7299	0.9464	0.6097	0.2533	0.6080	81.168	0.2175	0.7981
	PD3-6	41082	0.5989	0.9264	0.4487	0.5081	0.9724	9.7236	0.2568	0.8525
	HC-7	63297	0.6633	0.9596	0.6119	0.6607	0.9613	563.59	0.1118	0.7565
	PG2-8	71764	0.6024	0.9403	0.8091	0.3273	0.9704	94.442	0.2030	0.8201
	C-9	53108	0.6553	0.9572	0.7458	0.7714	0.9128	5697.1	0.0271	0.7424
	S-10	60672	0.6819	0.9283	0.3688	0.7088	0.9370	452.95	0.1584	0.7783
	G-11	60556	0.5360	0.9658	0.1621	2.0314	0.8360	1602.4	0.0702	0.9065
	C-12	55225	0.6165	0.9584	0.2630	2.3994	0.9930	3570.9	0.0295	0.9284
Series two	B-25	36887	0.5751	0.9199	0.5872	0.7953	0.9429	109.13	0.2013	0.9102
	PD3-14	46441	0.5817	0.9559	0.5896	0.5649	0.9175	30.458	0.1582	0.7817
	HC-32	55261	0.5934	0.9687	1.0142	0.5884	0.7918	554.15	0.0557	0.7857
	PG2-18	48835	0.5947	0.9647	0.4475	0.8088	0.7788	49.553	0.3274	0.9261
	C-38	54887	0.5652	0.9670	0.2471	2.9335	0.9983	1347.9	0.1710	0.9915
	S-28	43285	0.5478	0.9471	0.9276	0.0607	0.5151	2.9233	0.3671	0.9026
	G-35	60908	0.5730	0.9706	0.6900	0.4484	0.8694	167.77	0.2250	0.9598

V.2.2. Rate of Crack Growth

During each test, the location of each crack and corresponding load cycle was recorded directly on the beam using a felt-tip pen. Crack measurements were recorded simultaneously on both sides of the specimen. These measurements were transferred to tracing paper, and an engineer's scale was used to measure the crack length during each load cycle on the left and right side of the specimen. Example tracings are provided in Appendix B. The specimen cross sections in Figure 26 provide three potential cases from which the average crack length can be computed. The darker lines in Figure 26 represent crack locations within a specimen.

From Figure 26(a) When $c_1 < d$ and $c_2 < d$, then

$$c_{avg} = \frac{(c_1 + c_2)}{2} \tag{5-1a}$$

From Figure 26(b) When $c_1 > d$ and $c_2 < d$, then

$$c_{avg} = \frac{(d - c_2)(c_1 - d)}{2b} + \frac{1}{2}(d + c_2) \tag{5-1b}$$

From Figure 26(c) When $c_1 < d$ and $c_2 > d$, then

$$c_{avg} = \frac{(d - c_1)(c_2 - d)}{2b} + \frac{1}{2}(d + c_1) \tag{5-1c}$$

Average crack lengths were then plotted against the corresponding load cycle as shown in Figure 27. To determine the relationship between average crack length and load cycle, a power law regression analysis was performed, which produced Equation 5-2 below. The coefficient of determination, R^2, was computed for each analysis and is provided in Table 6 above.

$$c(N) = dN^e \tag{5-2}$$

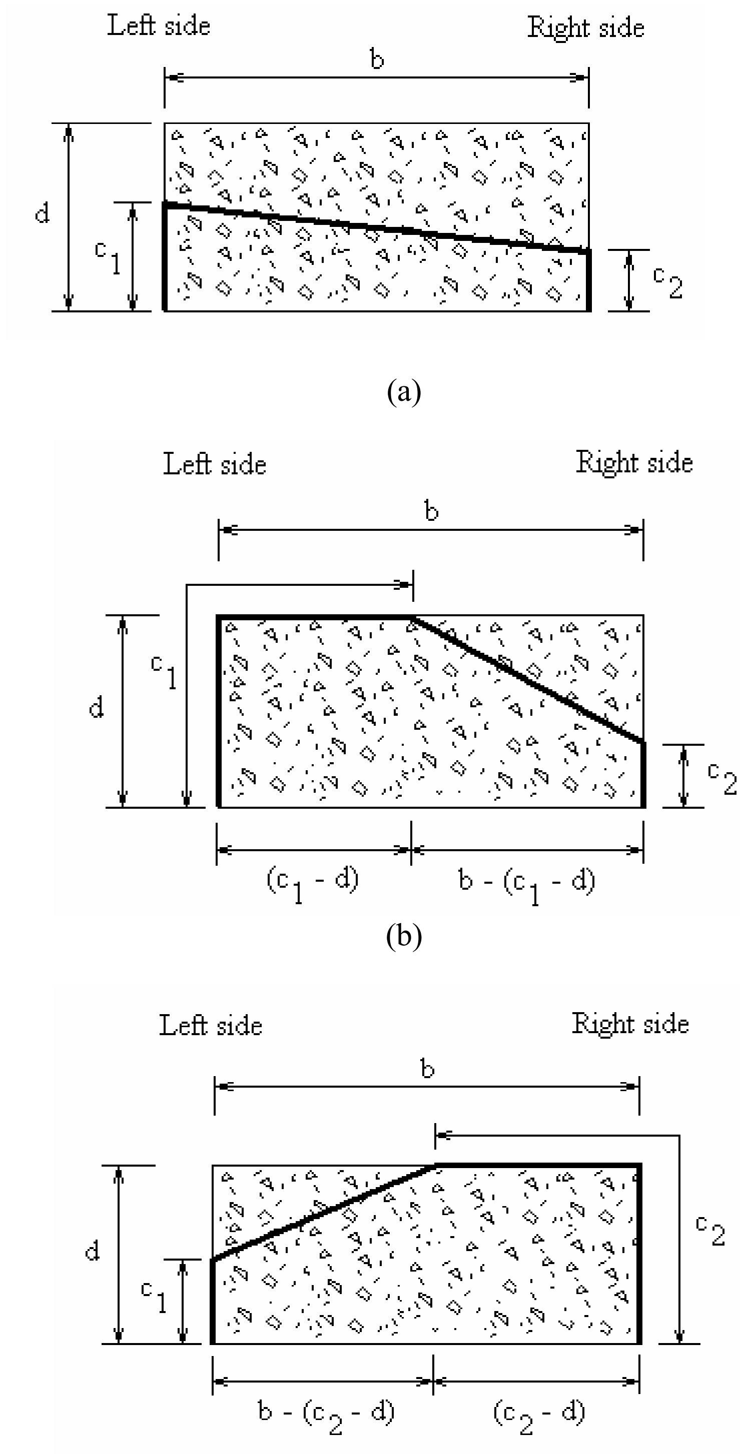
where:

d = a regression constant representing the average crack length at the first cycle opening (i.e. the Y-intercept of the log c versus log N curve)

e = the slope of the log c versus log N curve

The rate of crack growth, $\frac{dc}{dN}$, given by Equation 5-3, was determined by differentiating Equation 5-2 with respect to load cycle.

$$\frac{dc}{dN} = deN^{e-1} \tag{5-3}$$



(c)

Figure 26. Cross Sections of Specimen Used to Compute Average Crack Length Using (a) Equation 5-1a, (b) Equation 5-1b, and (c) Equation 5-1c.

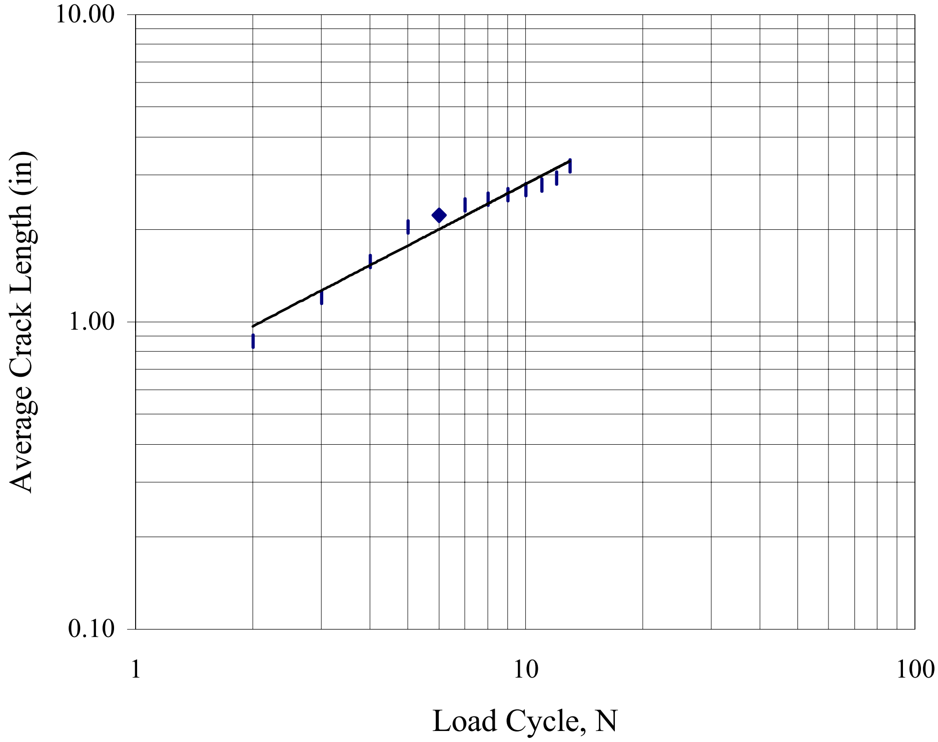


Figure 27. Typical Plot of log c versus log N Used to Determine c(N).

Table 7 provides a listing of the number of load cycles to reach failure for each specimen. Failure was defined as the condition in which a continous reflection crack propagated up each side of the beam and across the top of the sample. This failure condition occurred when the average crack length was equal to the depth of the beam. It should be noted that Table 7 includes data from the third series of test replicates since the measurements of crack lengths were not affected by the error in the hydraulic servo-controlled mechanism previously mentioned.

Table 7. Number of Load Cycles to Failure for Each Tested Specimen.

Product Identification	Sample I.D.	Number of Load Cycles to Failure	Average No. Cycles to Failure	Ranking Based on Cycles to Failure
Bitutex Composite	B-5	62	6.0	5[2]
	B-25	5		
	B-34[1]	7		
Pave-Dry 381	PD3-6	30	21	2
	PD3-14	19		
	PD3-29[1]	15		
HaTelit C40/17	HC-7	12	10	4
	HC-32	7		
	HC-16[1]	10		
PetroGrid 4582	PG2-8	27	17	3
	PG2-18	6		
	PG2-36[1]	17		
Control w/tack	C-9	6	6.0	6[2]
Control w/no tack	C-12	2.8	2.6	8
	C-24[1]	2.6		
	C-38	2.3		
StarGrid G+PF	S-10	23	43	1
	S-28	39		
	S-39[1]	68		
GlasGrid 8501	G-11	4	5.7	7
	G-35	8		
	G-21[1]	5		

[1] Denotes third series of test replicates. Number of cycles to failure for these tests is valid, but detailed analysis of these data was not performed because data acquisition software malfunctioned during this third series of tests.

[2] Average number of cycles to failure was the same. Since the control beam with no tack had only one satisfactory specimen it was ranked as number 6.

V.2.3. Dissipated Pseudo Strain Energy

The next procedure for the data reduction in this investigation involved determining the dissipated pseudo strain energy, E_R. This value was calculated for each load cycle as the area bounded by the measured (actual) load versus pseudo displacements. The calculations proceeded as follows. Using Equations 4-13 and 4-14, repeated below for convenience, the predicted linear viscoelastic loads were calculated as a function of loading time.

For $0 < t < 5$ sec

$$P_{LVE}(t) = \frac{E_1 \, r_c}{1-s} \left(\frac{b\left[d - c(N) \right]}{d} \right) (t)^{1-s} \qquad (4\text{-}13)$$

For $5 < t < 10$ sec

$$P_{LVE}(t) = \frac{E_1 \, r_c}{1-s} \left(\frac{b\left[d - c(N) \right]}{d} \right) \left[(t)^{1-s} - 2\,(t-5)^{1-s} \right] \qquad (4\text{-}14)$$

Note, the variables in the above equations are determined as follows:

- E_1 and s are constants for each beam as provided in Table 6.
- r_c is a constant equal to 0.014 in/sec as determined from Figure 22.
- b = 6 inches and d = 3 inches based on beam geometry, refer to Figure 21.
- c(N) is calculated for each load cycle using Equation 5-2 beginning with load cycle no. two (cycle one is the relaxation modulus test).

- Time, t, is determined from the Overlay Tester at every 0.1 second. A range of 10 seconds was used as shown in Figure 22.
- Calculations proceed until the failure average crack length is achieved.

Pseudo displacements, $u_r(t)$, were then determined by dividing the predicted linear viscoelastic loads by a reference stiffness using Equation 4-15, as shown below. The reference stiffness, k_r, was determined from the first load cycle as described in Figure 24.

$$u_r(t) = \frac{P_{LVE}(t)}{k_r} \tag{4-15}$$

The final step in determining the dissipated pseudo strain energy, was to produce plots of actual (measured) loads, P(t), versus pseudo displacements (Figure 28) (note that, for clarity, only one load cycle is plotted). Pseudo strain energy was calculated as the sum of the tension areas bounded by each load cycle, numbered 1 and 2, having the units of inch-pound. Although not shown in Figure 28, each successive loop diminishes in area as the crack propagates, similar to that shown in Figure 25. This trend is consistent with the fact that less energy is required to advance a crack once the crack begins.

To determine the relationship between pseudo strain energy and load cycle, a plot was generated as shown in Figure 29. A power law regression analysis was performed, which produced Equation 5-4.

$$E_R(N) = aN^{-m} \tag{5-4}$$

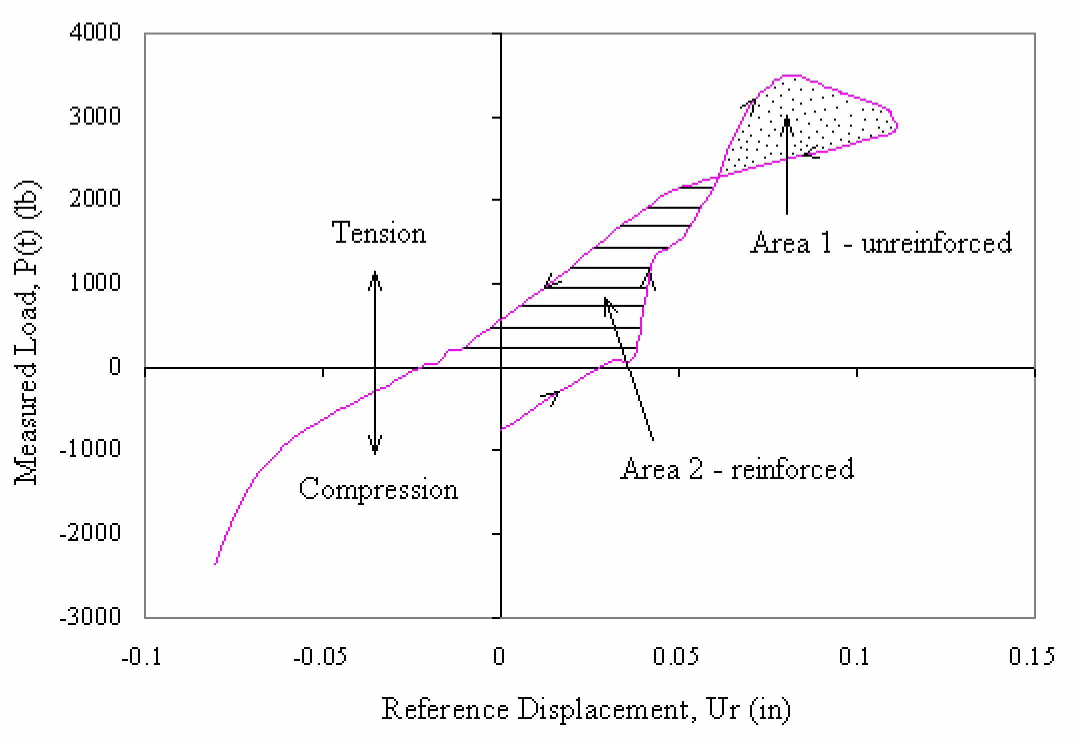


Figure 28. Measured Load versus Reference Displacement Displaying Loops Generated for Each Load Cycle. (The Pseudo Strain Energy is Calculated as the Sum of the Loop Areas.)

where:

a = a regression constant representing the energy required to produce the predetermined gap opening on the first loading cycle (i.e., the Y-intercept)

m = the slope of the log E_R versus log N curve

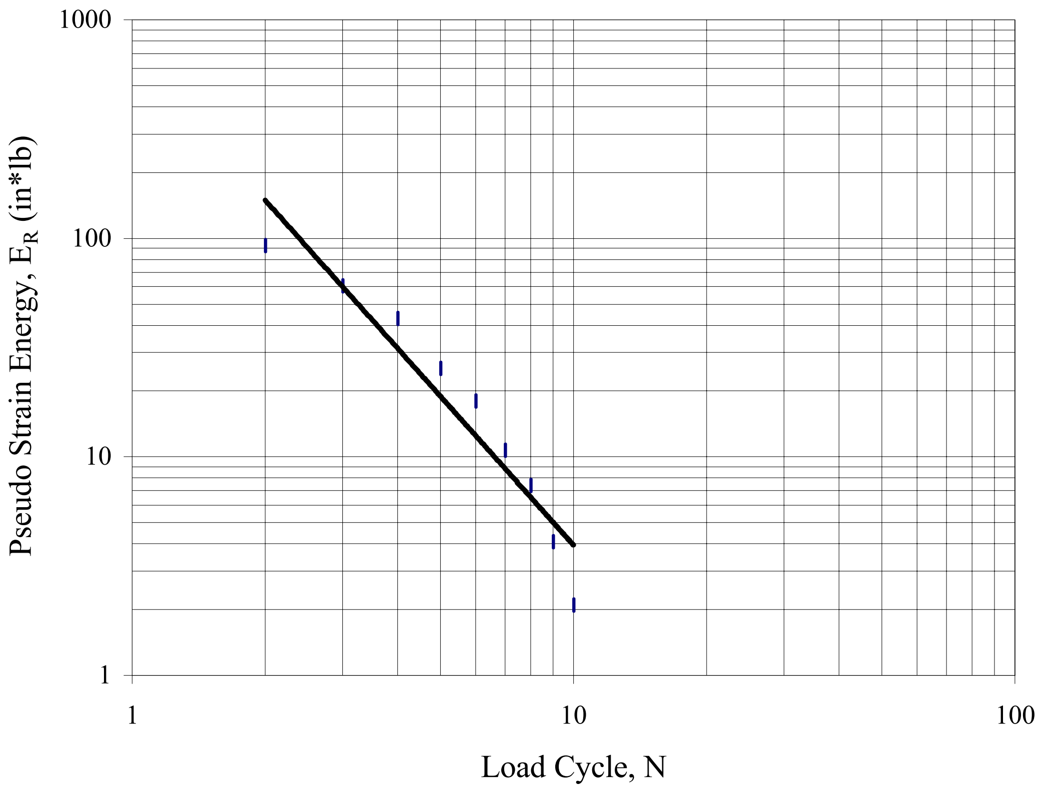


Figure 29. Typical Plot of log E_R versus log N used to Determine E_R (N).

Pseudo work, W_R, defined by Equation 5-5, was then plotted against load cycles (Figure 30). Similar regression techniques were used to find the relation given by Equation 5-6. The coefficient of determination, R^2, was computed for each specimen and is provided in Table 6 above.

$$W_R = E_o - E_R(N) \tag{5-5}$$

$$W_R(N) = aN^m \tag{5-6}$$

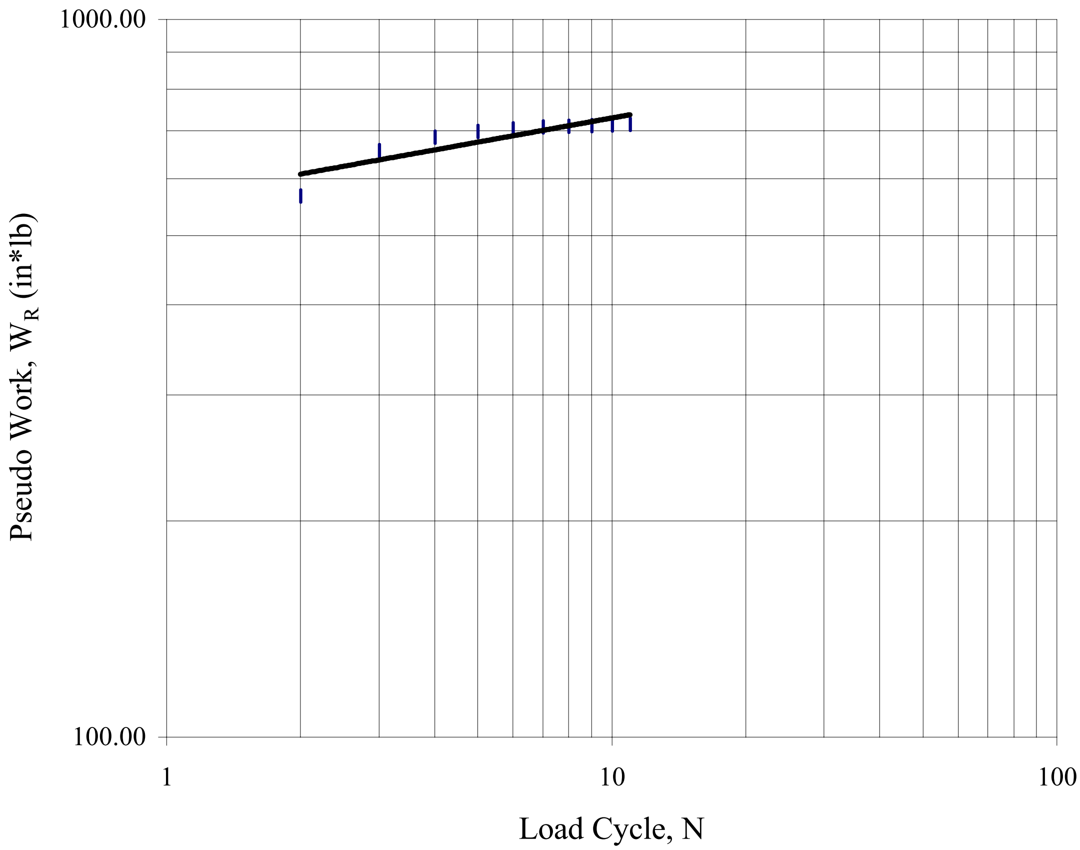


Figure 30. Typical Plot of log W_R versus log N used to Determine W_R (N).

The rate of pseudo work (or dissipated pseudo strain energy), $\frac{dW_R}{dN}$, given by Equation 5-7, was determined by differentiating Equation 5-6 with respect to load cycle.

$$\frac{dW_R}{dN} = amN^{m-1} \quad (5\text{-}7)$$

V.2.4. Pseudo J-Integral

The pseudo J-Integral is defined as the rate of change of dissipated pseudo strain energy (or pseudo work) per unit area of crack growth. This value was determined for each load cycle using Equation 5-8. Note the area of crack growth was determined by multiplying the rate of crack growth, $\frac{dc}{dN}$, by twice the width, 2b, of the specimen.

$$J_R = \frac{\frac{dW_R}{dN}}{2b\left(\frac{dc}{dN}\right)} \tag{5-8}$$

Substituting Equations 5-3 and 5-7 into the above equation produces Equation 5-9. Equation 5-9, along with the data shown in Table 6, can be used directly to calculate the pseudo J-Integral for each load cycle for every fabricated specimen.

$$J_R = \frac{amN^{m-1}}{2bdeN^{e-1}} \tag{5-9}$$

A plot of the rate of crack growth versus the pseudo J-Integral was developed as shown in Figure 31. Regression analyses, using a best-fit power trendline, were performed to determine the crack propagation parameters A and n, as described in Equation 5-10.

$$\frac{dc}{dN} = A(J_R)^n \tag{5-10}$$

Table 8 lists values of A and n for each tested specimen. A semi-logarithmic plot was produced (Figure 32) from these values. The relative position of these values and slopes aid in making comparative analyses of the geosynthetic products tested. For example, a smaller value of A for a given value of n denotes a more successful product, since a smaller A corresponds to a smaller crack growth rate.

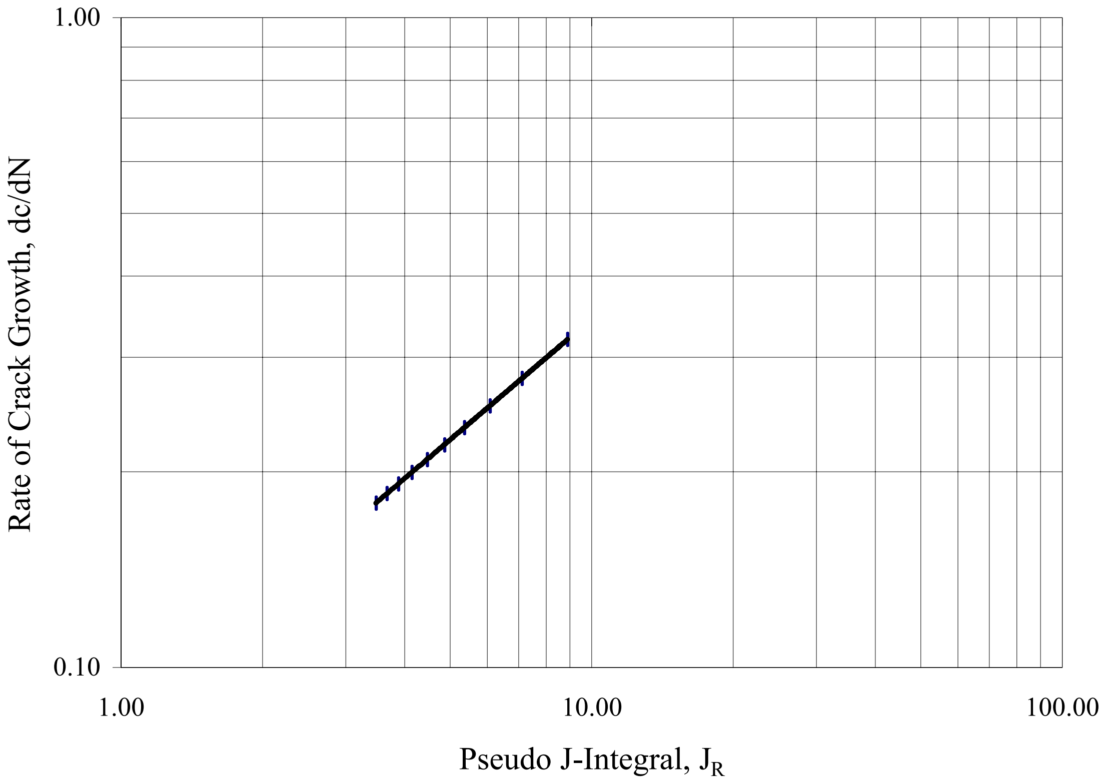


Figure 31. Typical Plot of log dc/dN versus log J_R Used to Determine the Crack Propagation Parameters, A and n, as Described in the Modified Form of Paris' Law.

Table 8. Regression Constants as Determined from Figures 30 and 33.

Sample I.D.	Regression constants			
	dc/dN versus J_R		dc/dN versus R	
	A	n	B	m
B-5	6.00E-22	20.8580	0.0099	0.3303
B-25	0.2916	0.3446	0.4067	0.0979
PD3-6	0.2726	1.9574	0.1337	0.0902
PD3-14	0.2727	1.0698	0.1538	0.0700
HC-7	0.0829	0.6181	0.1477	0.1171
HC-32	0.1930	0.7727	0.4317	-0.6704
PG2-8	0.00002	5.4119	0.0185	0.3298
PG2-18	0.2144	0.3972	0.1710	0.2184
G-11	1.9161	-0.5259	0.2381	0.6355
G-35	0.0010	2.4691	0.0180	0.2220
C-9	0.2215	0.3071	0.3321	0.0718
C-12	2.9868	-0.5905	1.4777	-0.3453
C-38	7.1842	-0.6999	0.264	-0.7553
S-10	0.0499	0.5291	0.0746	0.0834
S-28	0.2325	-3.0656	0.0203	0.2897

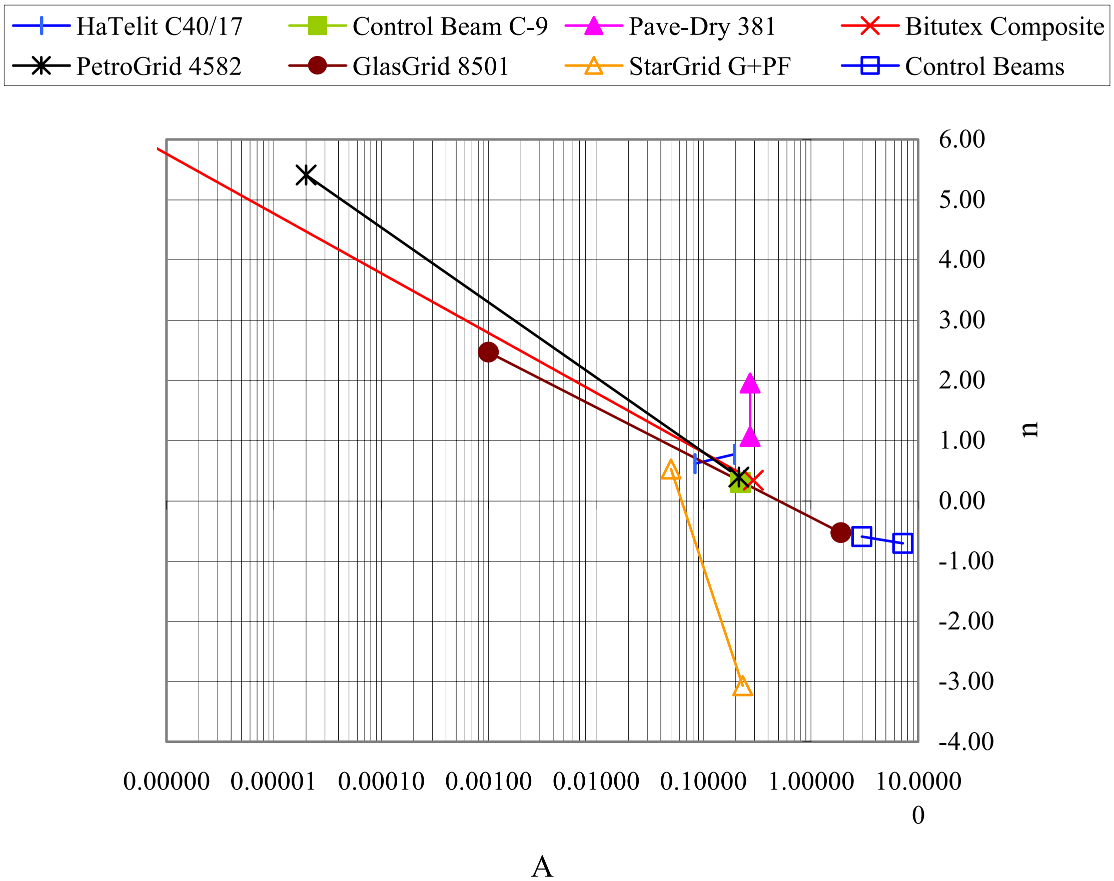


Figure 32. Results of Log A versus Arithmetic n for Each Fabricated Test Specimen.

V.3. DETERMINATION OF THE REINFORCING FACTOR

The reinforcing factor, R, was developed based on the analysis of Figure 33. The shape of the area bounded by each loop was uncharacteristic of unreinforced beams as originally described in Figure 25. After further analysis, it was determined that the loading path in Figure 33 traversed two distinct loops. The clockwise loop around Area 1 followed a path similar to that shown in Figure 25. The clockwise direction of the loops in Figure 25 was based on a non-reinforced specimen (i.e., without geosynthetic products). Therefore, the loop around Area 1 in Figure 33 is considered the non-reinforced loading path. The

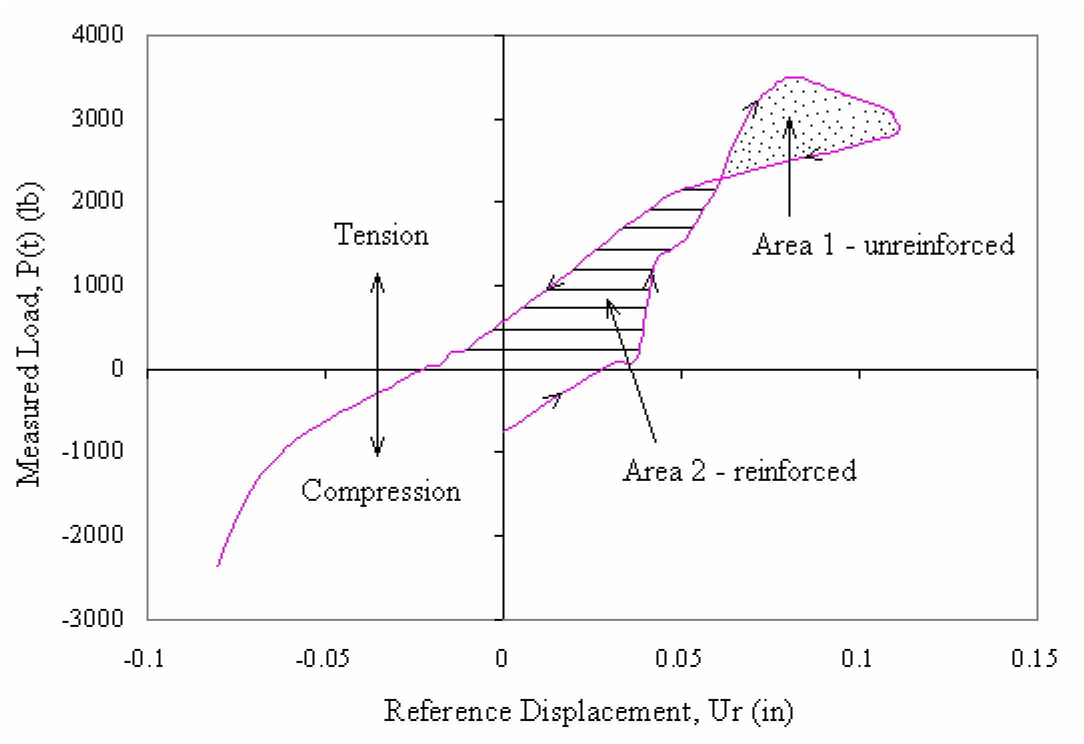


Figure 33. Measured Load versus Reference Displacement Displaying Loops Generated for Each Load Cycle Used to Define the Reinforcing Factor, R.

effect of the geosynthetic product on the loading path in Figure 33 produces the counterclockwise loop around Area 2. Therefore, the loop around Area 2 is considered the reinforced loading path.

The reinforcing factor was developed based on these observations and can be used to characterize the reinforcing behavior provided by the geosynthetic product. The reinforcing factor is therefore defined as the ratio of the reinforced to non-reinforced areas, as described in Equation 5-11. Since several of the test specimens exhibited more than one loop in each direction, a consistent approach in calculating the reinforcing factor was facilitated by Equation 5-12.

$$R = \frac{\text{Area bounded by loop 2}}{\text{Area bounded by loop 1}} = \frac{\text{Reinforced loading path}}{\text{Non - reinforced loading path}} \qquad (5\text{-}11)$$

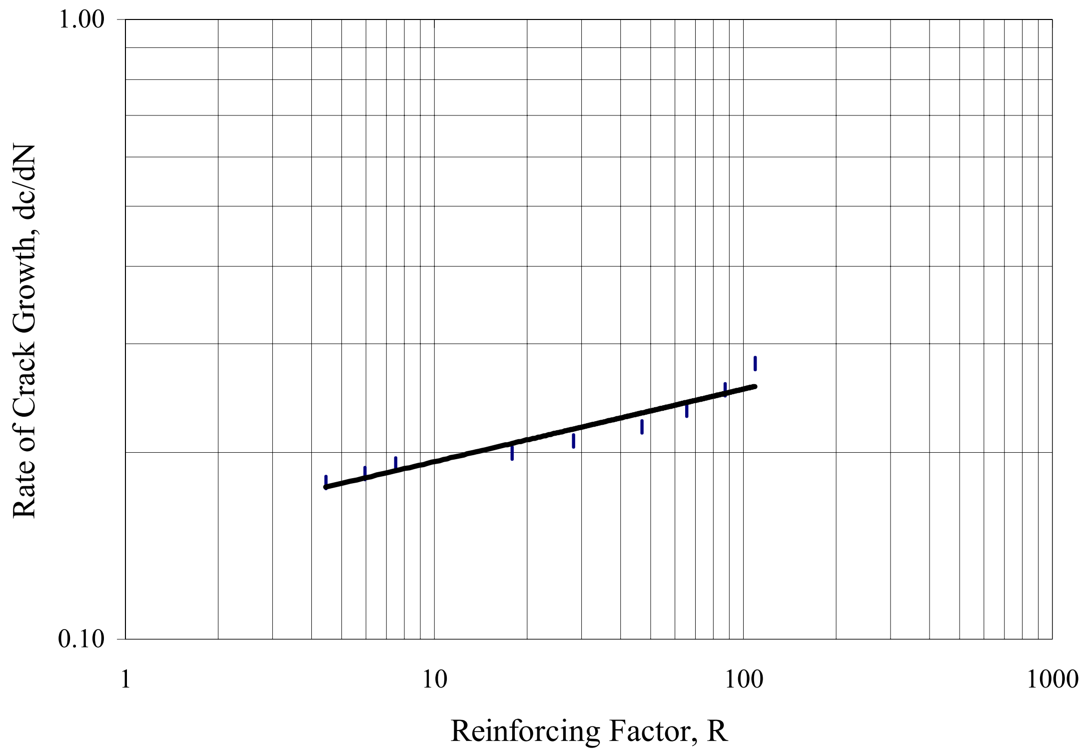


Figure 34. Typical Plot of log dc/dN versus log R Used to Determine the Regression Constants, B and m, as Described in Equation 5-13.

In general,

$$R = \frac{\sum \text{Counterclockwise loops}}{\sum \text{Clockwise loops}} \qquad (5\text{-}12)$$

A plot of the rate of crack growth versus the reinforcing factor was developed as shown in Figure 34. Regression analysis, using a best-fit power trendline, was performed to determine the regression constants B and m, as found in Equation 5-13.

$$\frac{dc}{dN} = B(R)^m \qquad (5\text{-}13)$$

Values of B and m were determined for each test specimen and are listed in Table 8 above. A semi-logarithmic plot was produced from these values (Figure 35).

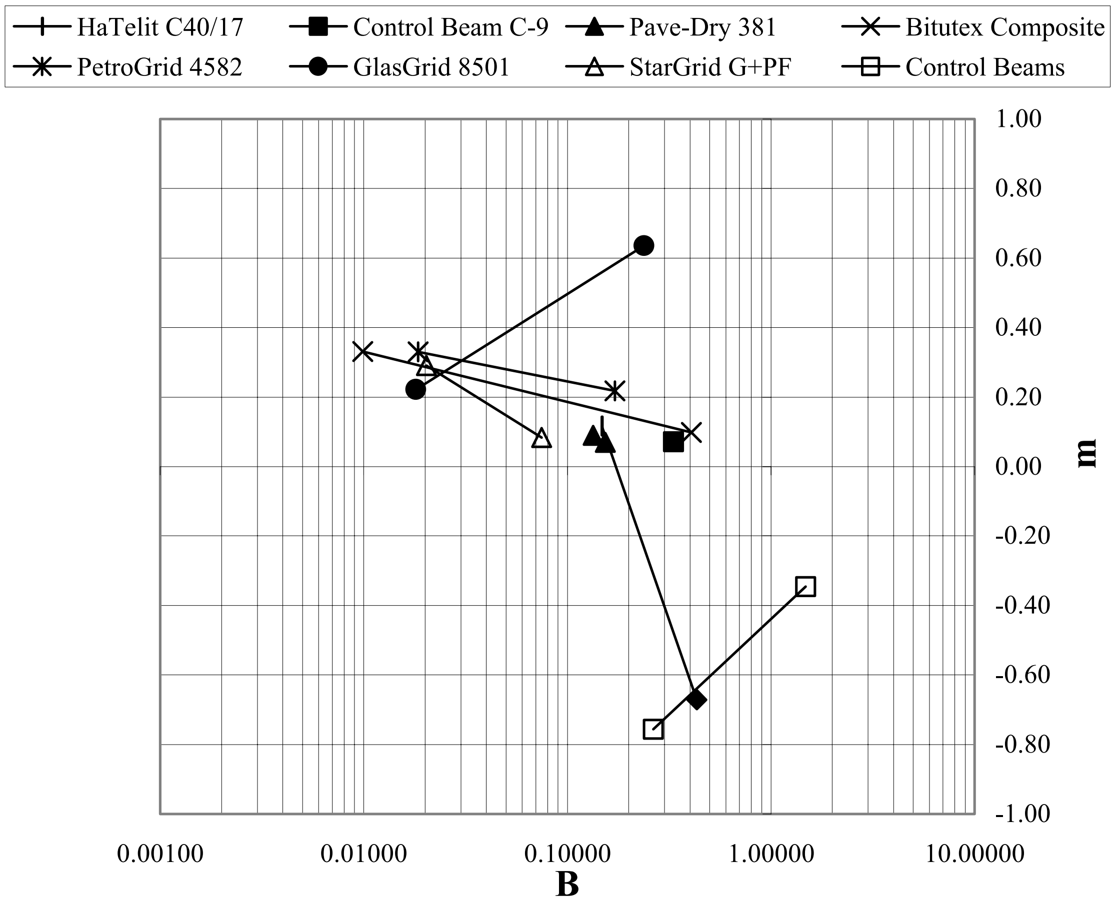


Figure 35. Results of Log B versus Arithmetic m for Each Fabricated Test Specimen.

V.4. DETERMINATION OF THE CRACK SPEED INDEX

From the above discussions, it is evident that many factors contribute to the performance of a geosynthetic material in reducing the occurrence of reflective cracking in HMA overlays. To summarize the interactions of the values of A, n, B, and m and to compare the relative effectiveness of each geosynthetic material, Equation 5-14 was developed and termed the "crack speed index."

$$\log\left(\frac{dc}{dN}\right) = \left[\log A + n \log \bar{J}_R\right] - \left[\log B + m \log\left(\bar{R} + 1\right)\right] \tag{5-14}$$

where:

$\log\left(\frac{dc}{dN}\right)$ = crack speed index

$\bar{J}_R$ = average pseudo J-Integral for each geosynthetic material

$\bar{R}$ = average reinforcing factor for each geosynthetic material

The more negative the crack speed index, the better the geosynthetic material reduces the rate of crack growth in the HMA overlay. Tables 9 and 10 provide the values used to determine the crack speed index for each specimen tested.

V.5. EQUATIONS FOR DESIGN APPLICATIONS

Using the data collected from this investigation, Figures 36 and 37 were produced and equations developed between the regression constants, n and m, and the relaxation modulus properties of the asphalt concrete mix. Table 11 provides equations developed from various graphs of overlay fracture properties presented throughout this chapter.

Table 9. Summary of Values Used to Determine the Crack Speed Index.

Sample I.D.	Average Pseudo J-Integral	Average Reinforcing Factor	Crack Propagation Parameters		Reinforcing Factor Regression Constants	
			A	n	B	m
B-5	8.5	50	6.0E-22	20.86	0.010	0.33
PD3-6	0.6	0.2	0.273	1.96	0.134	0.09
HC-7	6.2	57.2	0.083	0.62	0.148	0.12
PG2-8	4.8	102.5	2.0E-05	5.41	0.019	0.33
C-9	10.5	15.8	0.222	0.31	0.332	0.07
S-10	10.8	6035	0.050	0.53	0.075	0.08
G-11	4.6	14	1.916	-0.53	0.238	0.64
C-12	2	0.4	2.987	-0.59	1.478	-0.35
B-25	2.1	0.3	0.292	0.34	0.407	0.10
PD3-14	0.6	6	0.273	1.07	0.154	0.07
HC-32	2.4	1.5	0.193	0.77	0.432	-0.67
PG2-18	2.2	9	0.214	0.40	0.171	0.22
C-38	3.3	0.04	7.184	-0.70	0.264	-0.76
S-28	3.5	0.32	0.233	-3.07	0.020	0.29
G-35	7.2	8750	0.001	2.47	0.018	0.22

Table 10. Determination of the Crack Speed Index for Each Geosynthetic Material.

Sample I.D.	$\log \bar{J}_R$	$\log(\bar{R}+1)$	Log A	Log B	Crack Speed Index $\log\left(\frac{dc}{dN}\right)$
B-5	0.93	1.71	-21.22	-2.00	-0.40[1]
PD3-6	-0.22	0.08	-0.56	-0.87	-0.13
HC-7	0.79	1.76	-1.08	-0.83	0.03
PG2-8	0.68	2.01	-4.70	-1.73	0.06
C-9	1.02	1.23	-0.65	-0.48	0.05
S-10	1.03	3.78	-1.30	-1.13	0.06
G-11	0.66	1.18	0.28	-0.62	-0.19
C-12	0.30	0.15	0.48	0.17	0.18
B-25	0.32	0.11	-0.54	-0.39	-0.04
PD3-14	-0.22	0.85	-0.56	-0.81	-0.05
HC-32	0.38	0.40	-0.71	-0.36	0.21
PG2-18	0.34	1.00	-0.67	-0.77	0.02
C-38	0.52	0.02	0.86	-0.58	1.08
S-28	0.54	0.12	-0.63	-1.69	-0.64
G-35	0.86	3.94	-3.00	-1.74	-0.01

[1] This value was considered an outlier.

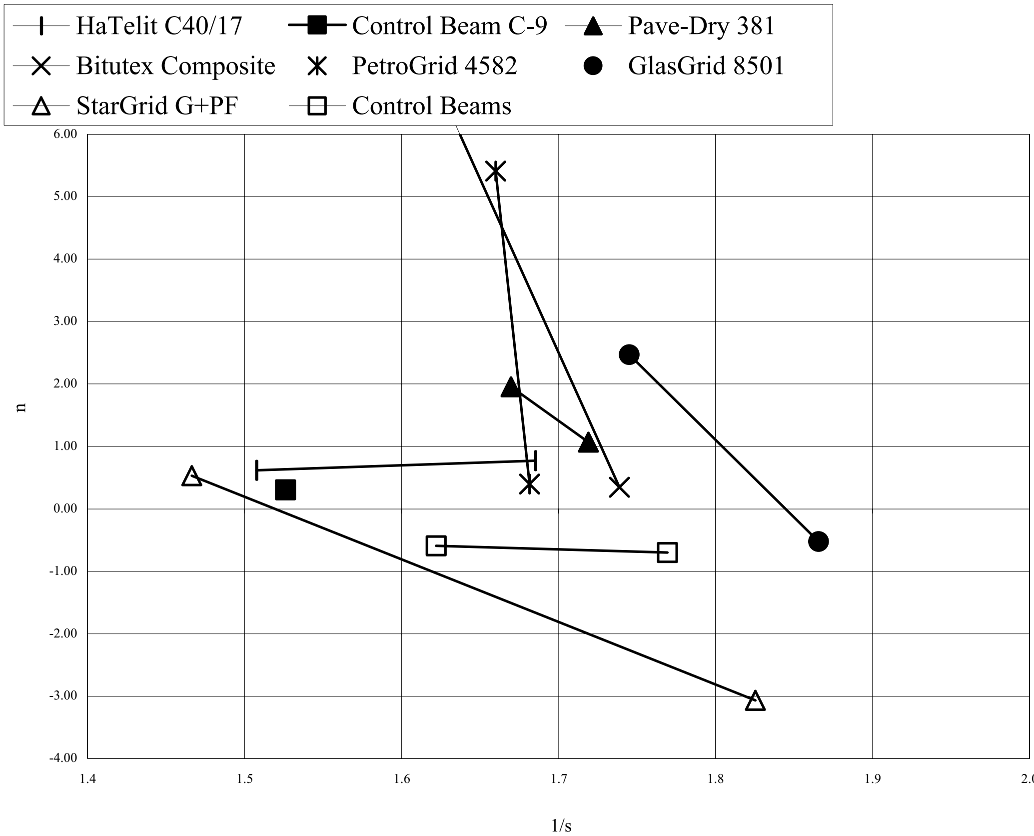


Figure 36. Crack Propagation Parameter, n, versus the Inverse of the Slope of the Relaxation Modulus Curve, 1/s, for Each Geosynthetic Product Tested.

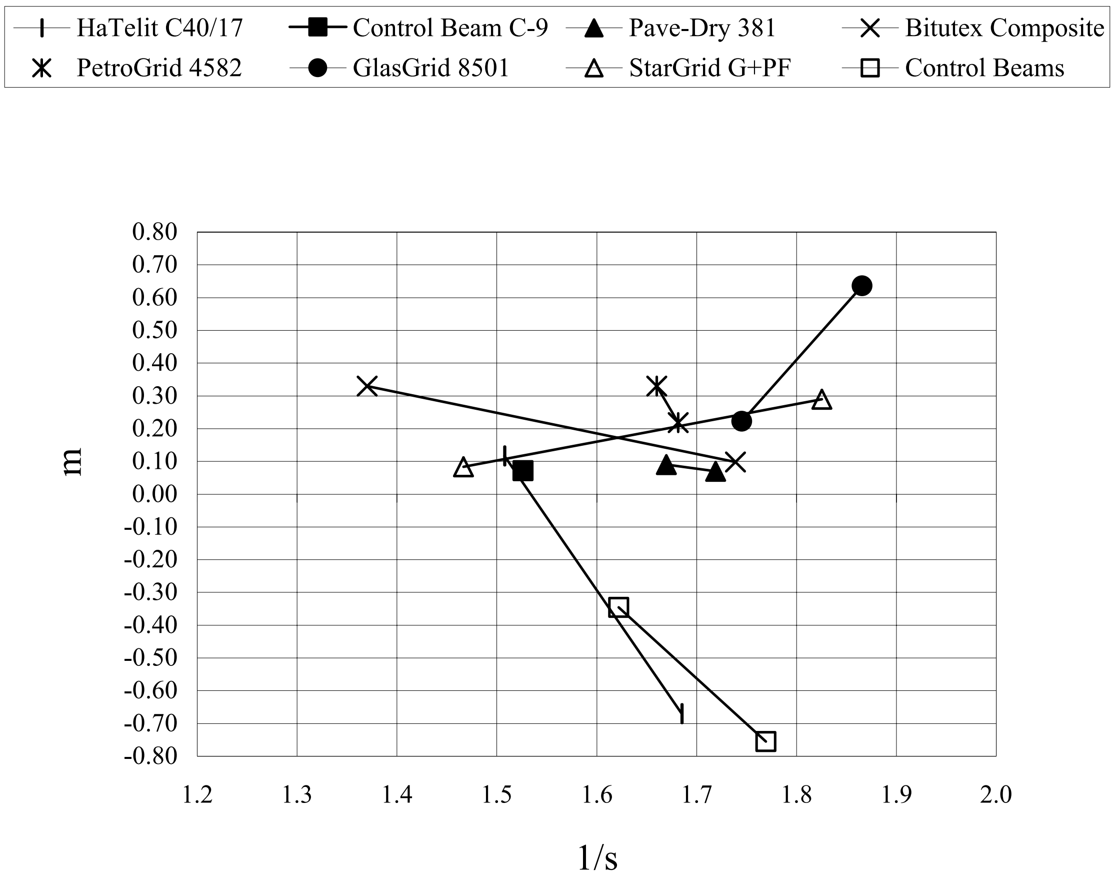


Figure 37. Regression Constant, m, versus the Inverse of the Slope of the Relaxation Modulus Curve, 1/s, for Each Geosynthetic Product Tested.

Table 11. Design Equations Relating Regression Constants from Various Graphs.

Geosynthetic Product	Log A vs. arithmetic n Log B vs. arithmetic n	n vs. 1/s m vs. 1/s
HaTelit C40/17	$\log A = -2.549 + 2.374n$ $\log B = -0.761 + 0.591m$	$n = \frac{0.870}{s} - 0.694$ $m = \frac{-4.434}{s} + 6.802$
Pave-Dry 381	$\log A = -0.564 - 1.794x10^{-4} n$ $\log B = -0.602 - 3.011m$	$n = \frac{-17.978}{s} + 31.976$ $m = \frac{-0.409}{s} + 0.773$
Bitutex Composite	$\log A = -0.188 - 1.008n$ $\log B = 0.289 - 6.947m$	$n = \frac{-55.625}{s} + 97.068$ $m = \frac{-0.630}{s} + 1.194$
PetroGrid 4582	$\log A = -0.349 - 0.804n$ $\log B = 1.126 - 8.667m$	$n = \frac{-233.310}{s} + 392.720$ $m = \frac{-5.183}{s} + 8.934$
GlasGrid 8501	$\log A = -0.294 - 1.096n$ $\log B = -2.347 + 2.712m$	$n = \frac{-24.861}{s} + 45.856$ $m = \frac{3.432}{s} - 5.768$
StarGrid G+PF	$\log A = -1.203 - 0.186n$ $\log B = -0.898 - 2.740m$	$n = \frac{-10.013}{s} + 15.213$ $m = \frac{0.575}{s} - 0.759$
Control Beams	$\log A = -1.582 - 3.485n$ $\log B = 0.799 + 1.824m$	$n = \frac{-0.743}{s} + 0.615$ $m = \frac{-2.785}{s} + 4.172$

Equation 5-15 provides a simple relationship between the slope of the relaxation modulus curve, s, and volumetric properties of the HMA mixture. This equation allows the relaxation properties of any HMA mixture to be predicted from laboratory calculated volumetric properties without having to perform a relaxation modulus test.

$$s = \chi(\Theta_{as}) + (1 - VMA)(0.02) \tag{5-15}$$

where:

s	=	slope of the relaxation modulus curve
χ	=	coefficient related volumetric properties to relaxation modulus properties of the HMA
Θ_{as}	=	volume concentration of asphalt (or volume of effective asphalt content)
(1-VMA)	=	volume concentration of solids
VMA	=	voids in the mineral aggregate

Table 12 provides the χ coefficient calculated from the volumetric properties, as presented in Appendix A, for each of the control beams.

Table 12. Determination of the χ Coefficient.

Sample I.D.	Slope of the Relaxation Curve	Volume Concentration of Asphalt	VMA	Volume Concentration of Solids	χ Coefficient
C-12	0.6165	0.11	0.15	0.85	5.55
C-38	0.5652	0.11	0.15	0.85	5.14
C-24	0.6370	0.10	0.15	0.85	6.35
			Average χ Coefficient		5.68

With the χ coefficient determined, the slope of the relaxation curve can be computed and used to predict values of A, n, B, and m for any given mix from the equations presented in Table 11. These values, in turn, can be further used in design calculations to support the design of an overlay to resist reflection cracking.

V.6. SUMMARY

This chapter introduced the procedures used to analyze HMA fracture data collected from the TTI Overlay Tester using the equations derived in the previous chapter. Measurements of load and displacement, as a function of time, were recorded along with the location of each crack and corresponding load cycle. The equations derived in the previous chapter provided a method of calculating the relaxation modulus, predicted linear viscoelastic loads, and pseudo displacements as a function of loading time. The culmination of this effort has produced various graphs of overlay fracture properties in this chapter.

From measurements on both sides of the beam, the average crack length was computed for each load cycle using Equations 5-1a through 5-1c. Table 7 provides a listing of the average crack lengths to reach failure for each specimen from which a direct comparison can be made.

Figure 32 provides a plot of the crack propagation parameters, A and n, as described in the modified form of Paris' Law, Equation 5-10, for each geosynthetic product tested. By considering the effects of the geosynthetic products on the loading and unloading paths of the HMA specimens, the reinforcing factor, R, was developed. Figure 35 depicts the relationships between the regression constants derived using the reinforcing factor and utilized in Equation 5-13. Table 8 summarizes the crack propagation parameters and regression constants obtained from Figures 32 and 35. The relative position of these values in both figures and the resulting slopes aid in making a direct comparative analysis of the geosynthetic products tested. The crack speed index, as defined by Equation 5-14, summarizes the interactions of each material property calculated in this investigation and can be used to compare the relative effectiveness of each geosynthetic material. A lower value indicates a more successful product in reducing the rate of crack growth in the HMA overlay.

Chapter VI will discuss use of the design equations determined in this chapter. Appendix C contains graphs produced in this investigation. Chapter VII discusses key relationships for these graphs and provides final conclusions for the laboratory study along with recommendations for future investigations using the analysis techniques described.

CHAPTER VI
DEVELOPMENT OF FIELD TEST PAVEMENTS

Multiple geosynthetic end-to-end test pavements were planned in three locations in Texas that would serve to evaluate, as a minimum, the same geosynthetic products that researchers evaluated in the laboratory. The products evaluated in the laboratory were selected to represent the three major categories of geosynthetics used to address reflection cracking (fabrics, grids, and composites). The three test locations selected in coordination with TxDOT were the Pharr District (McAllen), the Waco District (Marlin), and the Amarillo District (northeast of Amarillo). These regions provide mild, moderate, and cool climates, respectively, for the long-term evaluation. Pharr and Amarillo provide flexible pavements while Waco provides a rigid pavement.

VI.1. PHARR DISTRICT TEST PAVEMENTS

Test pavements were placed on FM 1926 in McAllen on April 9, 2001 as part of TxDOT construction contract CPM 1804-01-19 by Ballinger Construction. FM 1926 is a four-lane urban facility with concrete curbs and a continuous turn lane in the center (a total of five lanes). The existing roadway consisted of 12 inches of lime-stabilized subgrade, 14 inches of lime-stabilized flexible base, and 2.5 inches of HMA pavement. Plans required milling of the outer lane from near zero depth at the inside of the lane to approximately 1.5-inch depth at the curb edge, placement of reflection cracking treatments, and overlaying with 1.5 inches of Type D HMA. Milling exposed the base in a few small places near the curb.

Maps showing cracks visible at the surface of the original pavements before milling were prepared and filed. These will be used to determine on an annual basis the percent of reflection cracks that appear in the overlay.

The geosynthetics were placed in 500-foot test sections in the outer southbound lane only (Figure 38). All geosynthetics were placed from south to north. All geosynthetics were placed directly onto the milled pavement surface. After three to four geosynthetics

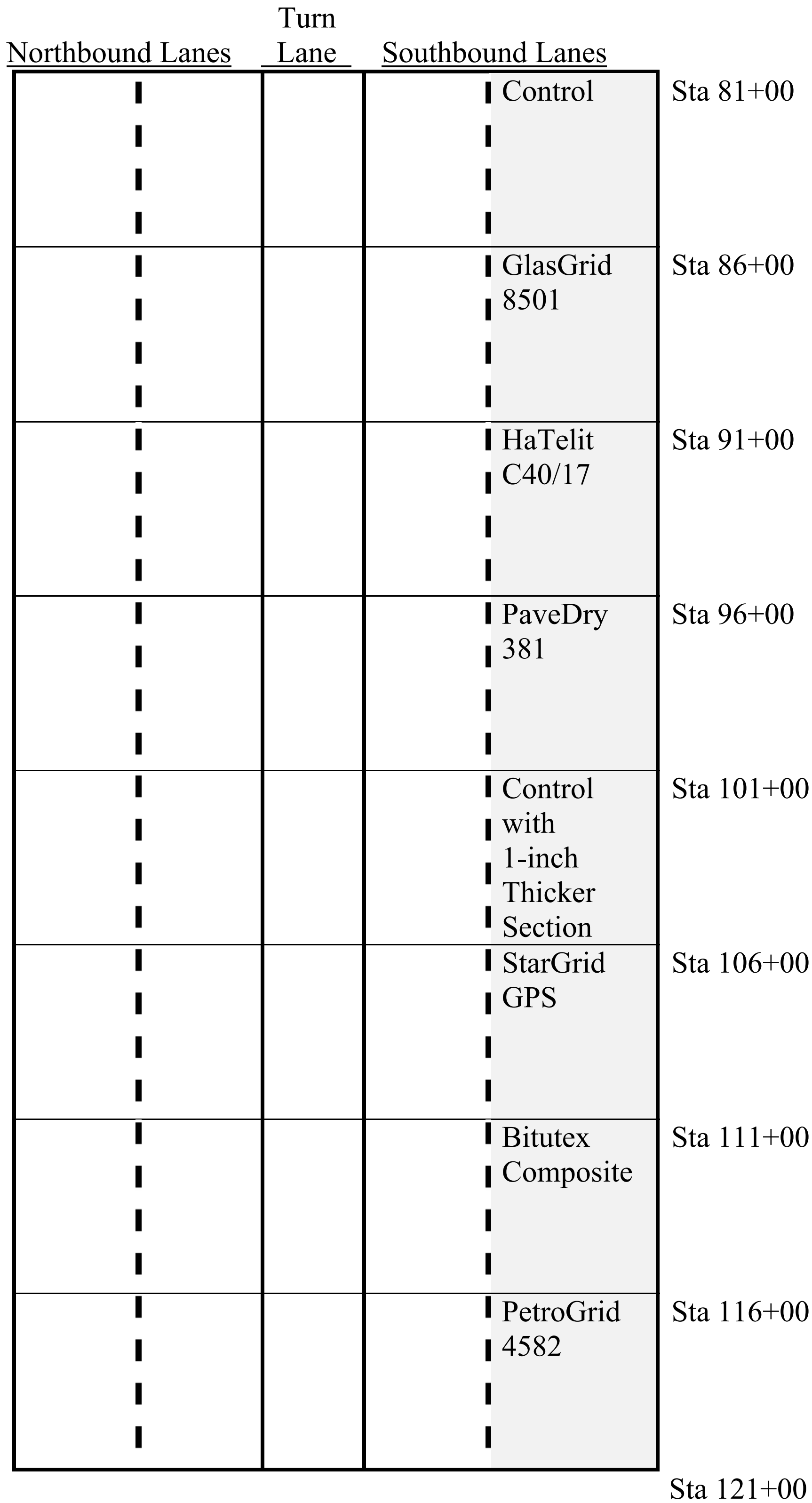


Figure 38. Plan View of Test Pavements Placed in McAllen - Pharr District.

had been placed, the contractor began placement of the overlay over the geosynthetics. In this way, the overlay operation caught up with geosynthetic installation at the end of the day leaving no geosynthetics exposed to traffic overnight.

Only Glass Grid® and Hueskar® had representatives present during construction of the test sections. Glass Grid representatives used their small tractor unit to install all six geosynthetics. Some of the geosynthetic rolls were wider than 12 feet and had to be sawn to 12 feet. This was accomplished with relative ease using a standard chain saw. Others came in widths less than 12 feet and had to be sawn to accommodate sequential placement in the 12-foot lanes.

Weather during installation was clear, 80°F to 92°F, and extremely windy with gusts upward of 40 mph (estimated).

A manhole is located adjacent to each storm drain outlet (in the curb/gutter) which could not be milled. Therefore, there is an unmilled area about 6 feet square near the outer edge of the lane at each storm drain outlet. This should be accounted for during subsequent performance evaluations.

Placement of each geosynthetic product is described below.

Sta 81+00 to Sta 86+00: This section received no treatment. It received only the 1.5-inch overlay. It will serve as the Control Section.

Sta 86+00 to Sta 91+00: GlasGrid 8501 was supplied in approximately 5-foot wide rolls. Therefore, it was placed in two ~5-foot strips plus one ~2-foot strip to cover the 12-foot lane. Strips were overlapped about 2 to 4 inches. No tack was used in accordance with the manufacturer's recommendations.

Sta 91+00 to Sta 96+00: HATElit C40/17 from Hueskar is a grid laminated to a thin sheet that assists during installation (adhesion to tack coat) but melts when overlay is applied and becomes inconsequential during service. Therefore, it should be considered a grid and not a composite. The design tack rate for HATElit was 0.10 gal/yd^2. HATElit was placed using rolls slightly wider than 12 feet and weighing about 500 pounds. HATElit rolls were 492 feet long, and about 7 feet of damaged geotextile was cut off the front end of the roll, therefore, the test section received only about 485 feet of HATElit. Pave-Dry 381 was placed in the northernmost approximately 15 feet of this section.

<u>Sta 96+00 to Sta 101+00</u>: Pave-Dry 381 fabric was placed using ~12.5-foot wide rolls that were 360 feet in length. Therefore, the contractor made a joint at 360 feet from the south end of the test section. Significant asphalt spillage occurred at this joint. Contractor personnel placed soil on the spillage, mixed with the hot asphalt, and removed the mixture from the site. (Note: if flushing slippage or other problems occur at this location (approximately Sta 99+60) later in service, this spillage may be the source of the problem.) The first 360-foot shot of tack was about 8 inches narrower than the fabric width; therefore, the inside ~8 inches of fabric did not receive tack. Although not witnessed by the researchers, it is assumed that the contractor cut away this untacked fabric before overlaying.

<u>Sta 101+00 to Sta 106+00</u>: A 1-inch (approximately) level-up was placed to provide a thicker overlay test section. This section will provide a comparison in performance with the geosynthetics. No geosynthetic was placed in this section.

<u>Sta 106+00 to Sta 111+00</u>: StarGrid-GPS composite by Luckenhaus came in 360-foot rolls and, therefore, had to be placed in two segments (360 feet then 140 feet) with separate shots of tack. It was placed using a tack rate of 0.10 gal/yd^2. The first 360 feet went down smoothly. The latter 140 feet went down with several wrinkles due to high wind gusts that pulled it partly up such that it had to be reapplied by hand.

<u>Sta 111+00 to Sta 116+00</u>: Bitutex Composite by Synteen was placed only on the first 150 feet (from the south) of the test section. The Bitutex was severely stuck to itself on the roll and was thus extremely difficult to peel off the roll. In fact, it stalled the tractor unit and the tractor tires were beginning to spin on the composite and thus cause wrinkles. After unsuccessfully attempting some adjustments to the tractor unit to accommodate this situation, the remainder of the roll was placed by hand with much difficulty in peeling the composite off the roll. This hand operation caused the Bitutex to have significant wrinkles

in the last half (approximately) of the 150 feet. The Bitutex came in 150-foot rolls and, due to extreme difficulty in getting the Bitutex off the roll, only one roll was installed. (Apparently, the Bitutex had been stored for an extended time to cause it to stick to itself.) The last 350 feet (approximately) of this section contains no geosynthetic.

Sta 116+00 to 121+00: PetroGrid 4582 by Amoco arrived in five 81-inch wide and 180-foot long rolls. Therefore, two rolls were cut down to approximately 67 inches wide such that, when the 81-inch and 67-inch rolls were placed side by side, they covered the 12-foot lane and allowed approximately 4 inches for overlap. During installation, the actual overlap was probably closer to 2 inches. The 81-inch roll was placed next to the concrete curb, therefore, the longitudinal joint between the two rolls is approximately 81 inches from the curb. Workers placed four of the five rolls starting at the south end to cover approximately 360 feet of the 500-foot section. Due to inadequate PetroGrid, the last 140 feet of this section contains no geotextile.

VI.2. WACO DISTRICT TEST PAVEMENTS

Young Contractors, Inc., will place the test pavements on BUS 6 in Marlin as part of TxDOT construction contract CPM 49-5-3. The test sections start at the junction with SH 7 and proceed north. Details of this project are contained in the project plans. BUS 6 is a two-lane urban facility. The existing structure is an old 6-inch jointed concrete pavement with several thin overlays. Construction plans required milling of the HMA down to the existing concrete and repairing any failures in the concrete.

The geosynthetics will be placed in 500-foot test sections in both lanes in the following sequence of construction: mill off HMA down to concrete, repair concrete failures, seal cracks larger than 1.25 inches, apply underseal (seal coat of Type PB Grade 4 aggregate and AC-15-%TR), spot level pavement using HMA, place 1-inch level-up course of Type D HMA, turn over to traffic for a few months, place geosynthetics, and place 1.5-inch overlay of ½-inch Superpave HMA. Installation of the geosynthetics on this project was originally planned to commence in February of 2001 but was delayed for several reasons. The current plan is to perform all elements of the construction plan through placement of the level-up course in fall of 2001, then place the geosynthetics in the summer of 2002.

Table 13 shows a description of the planned test pavements. Maps showing cracks in the original pavements before milling were prepared and filed. These maps will be used to determine on an annual basis the percent of reflection cracks that appear in the overlay.

Table 13. Description of Test Pavements Planned in the Waco District.

Test Section Number	Material	Limits	Tack Rate (gal/yd^2)	Remarks
1	Paveprep Membrane	105+87.21 – 110+87.21		Placed on top of level-up
2	PetroGrid 4582	110+87.21 – 115+87.21		Placed on top of level-up
3	Pave-Dry 381	115+87.21 – 120+87.21		Placed on top of level-up
4	GlassGrid 8501	120+87.21 – 125+87.21		Placed on top of level-up
5	Additional 1 in. of HMA	125+87.21 – 130+87.21		Placed on top of level-up
6	Saw & Seal	130+87.21 – 135+87.21		Placed on top of level-up
7	Control Section	135+87.21 – 140+87.21		Placed on top of level-up
8	Paveprep Membrane	TBD		Placed directly on old PCCP

VI.3. AMARILLO DISTRICT TEST PAVEMENTS

Test pavements were originally planned for construction in the Amarillo District on SH 136 just northeast of Amarillo in the summer of 2001. However, various delays have pushed construction into the spring of 2001. Details of this project are found in the plans for project number CPM 379-3-19.

This segment of SH 7 is a two-lane, fairly rural facility in a relatively flat plain. The existing structure consists of 12 inches of flexible base, 4 inches of asphalt stabilized base, and 3 inches of asphalt concrete pavement. Construction plans require placement of a 1-inch level-up course of Type D with PG 70-28, reflection cracking treatment, and a 2-inch HMA overlay of Type D with PG 70-28. The geosynthetics will be placed on top of the level-up course in 500-foot test sections in both travel lanes.

A description of the planned test pavements is shown in Table 14. Maps showing cracks in the original pavements before milling will be prepared. These maps will be used to determine on an annual basis the percent of reflection cracks that appear in the overlay.

Table 14. Description of Test Pavements Planned in the Amarillo District.

Test Section Number	Material	Limits	Tack Rate [1] (gal/yd^2)	Remarks
1	Control Section	585+00.00 – 590+00.00	NA	
2	GlassGrid 8501	590+00.00 – 595+00.00	0.0	
3	HATElit C40/17	595+00.00 – 600+00.00	0.10	
4	StarGrid G-PS	600+00.00 – 605+00.00	0.10	
5	Pave-Dry 381	605+00.00 – 610+00.00	0.02	
6	PetroGrid 4582	610+00.00 – 615+00.00	0.25	
7	Bitutex	615+00.00 – 620+00.00	0.25	
8	Additional 1 in. of HMA	621+00.00 – 626+00.00	NA	

[1] Tack material will be PG 64-22.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

VII.1. SUMMARY

The authors conducted an extensive review of literature on studies of geosynthetics for reducing reflective cracking in bituminous overlays, along with a formal survey of engineers in each TxDOT district and an informal survey of certain other knowledgeable individuals nationwide. Mechanistic laboratory testing and analyses were conducted to examine the relative resistance of the three major categories of geosynthetics (fabrics, grids, and composites) in resisting reflection cracking in HMA mixtures. Field tests were established in three locations in Texas with widely differing climates. A summary of significant findings follows.

VII.2. CONCLUSIONS

Based on the review of literature, observations made during the fabrication and testing of the HMA specimens, and analysis of fracture data, the following conclusions appear warranted.

- Performance of geosynthetics in addressing reflection cracking in HMA overlays has ranged from highly successful to disastrous failures. Based on review of the literature, the cost effectiveness of geosynthetics in reducing reflection cracking generally appears to be marginal. Many of the publications reviewed (particularly those related to fabrics) were based on the cost of geosynthetics more than 10 years ago. In recent years, the in-place cost of geosynthetics has become more favorable to paving agencies.
- Generally, the geosynthetics tested in the laboratory consistently increased the number of cycles to failure in the overlay tester.
- Quality assurance tests (Appendix A) were performed on selected laboratory-test beams and compared to the TxDOT job-mix formula (JMF). Extraction

revealed asphalt contents between 4.1 percent and 4.6 percent as compared to the optimum asphalt content of 5 percent. Insufficient asphalt cement produces inadequate film thickness around aggregate particles and decreases the tensile properties of the mixture. The mixture for this investigation was sampled at a production plant and stored in metal containers. Re-heating of the mixture for beam fabrication was necessary which, of course, further oxidized these thin films. These findings are considered the major causes for the relatively low number of cycles to failure recorded during this investigation. The remainder of the quality assurance tests were within acceptable ranges of the JMF.

- Control beams were fabricated with and without an asphalt tack coat (0.05 gal/yd^2) between the overlay and level-up course. Comparing the number of load cycles to failure for these specimens indicates that a thin tack coat increased the number of load cycles by 131 percent (from an average of 2.6 load cycles to 6.0)! Therefore, in typical overlay construction, it follows that the simple addition of a thin asphalt cement tack coat will increase the life of the overlay.
- An analysis of the crack growth regression coefficients, d and e, in Equation 5-2, reveal that lower values of d represent a lower initial crack growth since d represents the distance that the crack travels into the overlay during the first load cycle. The coefficient, e, represents the slope of the log C versus log N curve and is a measure of the rate of crack growth. Smaller values of e indicate slower rates of crack growth. Therefore, a comparison can be made of the relative performance of each geosynthetic tested by comparing crack growth regression coefficients. Extension of overlay life can be achieved with lower values of d and e. Additionally, long-term reduction of crack growth is more dependent on the coefficient, e. With every beam tested, the value of d was lower than the level of the geosynthetic material within the specimen, indicating that the crack stalled at the level of that material. Greater numbers of load cycles to failure were observed with lower values of e.

- An analysis of the pseudo work regression coefficients, a and m, in Equation 5-6, reveal the cumulative amount of work that was expended up to a given number of load repetitions. Therefore, lower values of a are desirable. The coefficient, m, represents the slope of the log W_R versus log N curve and is a measure of the overall resistance to crack propagation. Smaller values of m are desirable and indicate that greater pseudo strain energy (or pseudo work) is required to propagate a reflection crack through an overlay.

- The crack propagation parameters, A and n, determined from a power law regression analysis were plotted in Figure 32. Smaller values of log A are associated with larger values of n. Equation 7-1, similar to the form stated by Lytton (1989), is an integration of the modified Paris' Law (Equation 5-10), which indicates that small values of A and large values of n will result in longer thermal fatigue life for HMA overlays.

$$\int_0^{N_f} dN = \int_d^t \frac{dc}{A(J_R)^n} \tag{7-1}$$

where:

N_f = the number of load or thermal stress cycles to cause failure

d = the initial crack length, which includes the thickness of the old pavement surface layer

t = the total thickness of the HMA ($= d + d_0$)

d_0 = depth of the overlay

- Plots of measured load versus pseudo displacements (e.g., Figure 33) were produced to determine the rate of change of dissipated pseudo strain energy (or pseudo work) per unit area of crack growth, defined as the pseudo J-Integral.

By considering the affects of the geosynthetic products on the loading and unloading paths of the HMA specimens, a new geosynthetic rating factor, termed reinforcing factor, R, was developed (Equation 5-13).

- The crack speed index, as defined by Equation 5-14, summarizes the interactions of the material properties calculated in this investigation and can be used to compare the relative effectiveness of each geosynthetic material. Smaller values indicate more successful products in reducing the rate of crack growth in HMA overlays. Table 15 provides a ranking of the relative effectiveness of the geosynthetic materials tested, based on the calculated average crack speed index (from Table 10). (It should be noted that, due to variability in the test data, these rankings are not statistically significant.) This ranking indicates that, generally, the stiffer (i.e., higher modulus at low strain) products performed better.

Table 15. Ranking of the Relative Effectiveness of Each Geosynthetic Product in Reducing Reflective Cracking in HMA Overlays as Tested in the Laboratory.

Product Tested	**Average Crack Speed Index**	**Relative Effectiveness (1=best; 8=worst)**
StarGrid GP+F	-0.29	1
GlasGrid 8501	-0.10	2
PaveDry 381	-0.09	3
Bitutex Composite	-0.04	4
PetroGrid 4582	0.04	5
Control (with tack)	0.05	6
HaTelit C40/17	0.12	7
Control (with no tack)	0.63	8

- Limited experimentation indicated that the use of emulsified asphalt as a tack coat for geosynthetics produced a plane of weak shear, which could promote slippage during overlay construction and service.

VII.3. RECOMMENDATIONS

The authors recommend the following based on the information gained from this investigation:

- Appendix F contains guidelines for selection and use of geosynthetics with HMA overlays on flexible, rigid, and composite pavements to reduce reflection cracking. The authors recommend that these guidelines (Appendix F) be printed as a separate document for convenient use by pavement design engineers, construction inspectors, and contractor personnel.
- A computer program (described in Appendix F) was developed as a design check for FPS-19. This design check should be used with alternative overlay scenarios when geosynthetics are being considered for addressing reflection cracking.
- Based on the maximum ram displacement of 0.07 inch, the average crack length, d (refer to Equation 5-2), at the first cycle opening was between 0.2 and 1.0 inch. Therefore, as a basis for overlay design, geosynthetic materials installed primarily to address reflection cracking should not be placed within the overlay below the value of d. To avoid this situation, researchers recommend placement of a ¾-inch to 1-inch level-up course on the existing pavement surface *before* the installation of the geosynthetic material.
- Emulsified asphalt should not normally be used as tack for geosynthetics installed to address reflection cracking in HMA overlays. Proper construction methods should be employed and care should be taken when emulsified asphalt is used as tack coat. Sufficient time should be allotted for breaking and curing. See guidelines in Appendix F.

- When placing a self-adhesive grid to address reflective cracking in an HMA overlay, a tack coat should be applied on top of the grid (i.e., after grid application). The appropriate quantity of tack is that normally used without a grid. Type of tack should be hot applied asphalt cement (not emulsion) of the same grade as that determined for the HMA overlay. Placing any thin overlay without a tack coat could invite delamination from the underlying pavement.
- When ordering geosynthetics, the contractor should specify the desired roll width and length to minimize construction joints and maximize efficiency. The contractor should also consider the maximum roll weight that his application equipment can handle.
- During laboratory testing, cracking patterns occurred in an irregular fashion, due to breaking of cohesive bonds within the HMA, and crack lengths at multiple locations were often difficult to record. Video taping devices should be installed near the specimen to record cracking. This information could be used to monitor and review cracking patterns and could be stored as a permanent record for future review and/or analysis.
- Volumetric properties of the unreinforced HMA mixture should be determined. Equation 5-15 can then be used to predict the slope of the relaxation modulus curve. This value of s can be used to compute A, n, B, and m for any given HMA mixture by using the relations provided in Table 11. These values, in turn, can be used in forward-calculating design methods to predict the rate of crack growth and support the design of an overlay to resist reflective cracking.
- Research needs to be performed to determine the ability of asphalt-impregnated fabrics or composites to reduce intrusion of surface water into a pavement after reflection cracks appear and quantify the benefits, if any, toward preserving pavement structural integrity and smoothness.

The following recommendations are related specifically to changes in TxDOT's geosynthetic specifications.

- Re: DMS-6220, Fabric for Underseals. Both theory and practice indicate that a thicker fabric with a greater asphalt retention may delay cracking longer than a thinner fabric. To achieve as thick an interlayer as possible, the fabric must be saturated with asphalt. Clearly, asphalt retention rate is an important fabric property. Asphalt retention should be at least 0.2 gallons/yd^2; retention is directly related to the fabric weight and thickness. When used as a stress-relieving interlayer, the fabric should generally have a minimum weight of 4.1 ounces/yd^2. It is recommended that TxDOT follow AASHTO M 288-00 and specify a paving fabric with a 101-pound grab tensile strength and 4.1-ounce/yd^2 minimum unit weight. Additionally, heavier fabric will reduce bleed through during construction and the effect of any damage by construction traffic. The cost differential between the AASHTO M 288 recommendation and the current TxDOT specification is only 2 to 4 cents/yd^2. This difference will probably not affect the bid price for installed paving fabric.

When fabric is applied on hot days (>90°F), pavement surface temperatures near prevail. These temperatures can be sufficiently high to keep the asphalt tack liquid enough to partially saturate the fabric during placement and fully saturate the fabric in the wheelpaths of construction vehicles. Tires of HMA haul trucks can become coated with asphalt and will often pick up the fabric. The amount of asphalt tack coat should not be reduced to solve this problem. The following corrective measures should be considered: (1)Hand spread a small amount of HMA mix on top of the fabric in the wheelpath of the haul vehicles. (2) Application of sand is the least desirable choice, as sand will absorb some of the asphalt and defeat its purpose. If sand is used, the quantity should be minimized and the grading should be coarse. (3) Change to a "heavier" grade of asphalt cement for the tack coat material. (4) Shorten the distance between fabric placement and the paving machine. (5) Minimize the number of vehicles on the fabric. Specifications currently allow sand; changing this should be considered.

- Re: Item 356, Fabric Underseal; Item 3203, Geogrid Composite for Pavements; Item 3126, Reinforcement Mesh for Joint Repair; and Item 3031, Joint Underseal. (The general term geosynthetic [used below] may replace fabric or grid or composite in these specifications).

Each of these specifications should include the following instructions related to geosynthetic placement: During pavement construction using a geosynthetic product, a geosynthetic manufacturer's representative should be present on site during the first three days of the period when the geosynthetic item is installed. This requirement would help ensure that the contractor and project inspector have a complete understanding of the installation requirements.

Each of these specifications should include the following instructions related to surface preparation: Cracks exceeding 1/8 inch in width shall be filled with suitable crack filler. Cracks or joints exceeding 1 inch in width should be filled with compacted, fine-grained bituminous mixture or other suitable material even with the existing pavement surface. Faulted cracks or joints with vertical deformation greater than ½ inch shall be leveled using fine grained bituminous mixture or other suitable material. (These recommendations are designed to ensure that the geosynthetic or level-up course will have continuous firm support, which will also assist in proper compaction of the overlay.) Potholes shall be properly repaired as directed by the engineer. Crack filler and patching materials shall be allowed to cure prior to placement of the geosynthetic.

Each of these specifications should include the following instructions related to geosynthetic storage: During storage, geosynthetic rolls shall be elevated off the ground and adequately covered to protect from the following – precipitation, extended exposure to sunlight (ultraviolet [UV] is the damaging factor), temperatures exceeding 160°F (this can occur under dark unventilated covers exposed to direct sunlight), damage by construction equipment or chemicals (e.g., solvents or strong acids or bases), sparks, or flames or any other environmental condition that might damage the geosynthetic. (Soggy geosynthetic rolls are difficult to handle and install and may not adhere adequately to pavement.

Vaporization of this moisture may cause the fabric to bubble and delaminate from the pavement surface.) Rolls should be stored vertically to avoid misshapen rolls.

Each of these specifications should include the following instructions related to geosynthetic joint overlaps: Construction joint overlaps in geosynthetic products shall be 6 inches for transverse joints and 4 inches for longitudinal joints unless a larger overlap is recommended by the geosynthetic manufacturer. (This could prevent manufacturers from claiming that poor performance was due to insufficient overlap of their product.)

Each of these specifications should include the following instructions related to geosynthetic placement: The temperature of the asphalt tack shall be sufficiently high to permit a uniform spray pattern. For asphalt cement, the minimum temperature shall be 300°F. To minimize damage to geosynthetic products containing polypropylene, the distributor tank temperatures shall not exceed 320°F. Placement of the HMA overlay should closely follow placement of the geosynthetic. The temperature of the HMA mixture shall not exceed 320°F. In the event asphalt tack bleeds through the geosynthetic causing construction problems before the overlay is placed, the affected areas shall be blotted using, preferably, HMA mixture. If sand is used for blotting, it should be coarse sand and any excess sand should be removed before placing the overlay.

Each of these specifications should include the following instructions related to construction and trafficking: After application of the geosynthetic, construction and emergency traffic may drive on the geosynthetic material. However, all traffic shall be minimized. To avoid dislodging of or damage to the geosynthetic, turning movements of paver and other vehicles shall be gradual and kept to a minimum. The contractor must ensure that turning or braking vehicles (particularly at intersections and driveways) cause no damage to the geosynthetic. The contractor shall ensure that the geosynthetic is kept clean of mud, dust, and other foreign material. Damaged sections shall be removed and patched at the expense of the contractor.

- Re: Item 3203, Geogrid Composite for Pavements and Item 3126, Reinforcement Mesh for Joint Repair. Some grid products contain a thin, continuous sheet, designed to rapidly develop adequate adhesion to the tack coat during installation and then melt and essentially disappear when the hot overlay is applied. Other grids have thin, permanent fiber strands partially filling the openings designed to adhere the grid to the tack coat. Neither of these form a waterproof barrier. These products should be considered as grids and not composites in these specifications.

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APPENDIX A

JOB MIX FORMULA AND TEST RESULTS

As discussed in Chapter III, a Type D asphalt concrete mixture was obtained from a local production plant in the Bryan District of the Texas Department of Transportation (TxDOT). The following information describes the mixture design, or job-mix formula (JMF), along with the quality assurance tests performed on each of the control beams (labeled C-12, C-24, and C-38) fabricated and tested in this investigation. These tests include bulk specific gravity, rice specific gravity, asphalt extraction, bitumen content, and dry sieve analysis.

TxDOT Type D Job-Mix Formula

This section of the appendix will report on the TxDOT Type D Job-Mix Formula. TxDOTs follows a modified Hveem process for mixing, compacting, and testing of HMA specimens for determining the optimum percent asphalt that meets prescribed specifications limits. The 1993 TxDOT Standard Specifications for Construction of Highways, Streets and Bridges (TxDOT, 1993), hereafter called the Spec book, provides standard specification for various construction-related items. In particular, Item 340 (Hot Mix Asphaltic Concrete Pavement) of the Spec book provides Master Grading requirements for various standard mixture designs. The combined gradation for the Type D mixture along with the Master Grading requirements is listed in Table A1. Tables A2 through A4 provide the results of a dry sieve analysis performed on the control beams. The Federal Highway Administration 0.45 power curve is shown in Figure A1 for the JMF and control beams.

Table A1. Combined Gradation Specifications for TxDOT Type D HMA Mixture.

Combined Gradation

District:	Bryan	CSJ #:	NH 98 (310)	Producer:	A.L. Helmcamp Inc.
County:	Robertson	Design #:	H0013	Spec.Item:	3002
Highway:	SH-6	Contractor:	A.L. Helmcamp Inc.	Type Mix:	D

	Source 1 FULTON "D" ROCK		Source 2 FULTON "F" ROCK		Source 3 VULCAN WASHED SCR		Source 4 S&S FIELD SAND		Source 5 Aggr. Num 5 Lab Num 5		Source 6 Aggr. Num 6 Lab Num 6		Total % 100.0		
Sieve	Bin #1 40.0	Total %	Bin #2 15.0	Total	Bin #3 35.0	Total %	Bin #4 10.0	Total %	Bin #5 0.0	Total %	Bin #6 0.0	Total %	Cumulative Pass	TxDOT Specs.	Individ. Ret.
-	100.0	40.0	100.0	15.0	100.0	35.0	100.0	10.0	100.0	0.0	100.0	0.0	100.0	-	0.0
-	100.0	40.0	100.0	15.0	100.0	35.0	100.0	10.0	100.0	0.0	100.0	0.0	100.0	-	0.0
12.5 mm	100.0	40.0	100.0	15.0	100.0	35.0	100.0	10.0	100.0	0.0	100.0	0.0	100.0	98 - 100	0.0
9.5 mm	86.3	34.5	100.0	15.0	100.0	35.0	100.0	10.0	100.0	0.0	100.0	0.0	94.5	85 - 100	5.5
4.75 mm	3.7	1.5	59.5	8.9	97.8	34.2	100.0	10.0	100.0	0.0	100.0	0.0	54.6	50 - 70	39.9
2.00 mm	0.5	0.2	1.0	0.2	71.3	25.0	99.7	10.0	100.0	0.0	100.0	0.0	35.4	32 - 42	19.2
0.425 mm	0.5	0.2	0.6	0.1	38.5	13.5	99.3	9.9	100.0	0.0	100.0	0.0	23.7	11 - 26	11.7
0.180 mm	0.4	0.2	0.6	0.1	14.8	5.2	46.5	4.7	100.0	0.0	100.0	0.0	10.2	4 - 14	13.5
0.075 mm	0.4	0.2	0.5	0.1	5.1	1.8	7.3	0.7	100.0	0.0	100.0	0.0	2.8	1 - 6	7.4
Pan															2.8

Asphalt Content of RAP in Bin # 1(If Applicable) = ? %

Asphalt Source & Grade: TRIFINERY PG 64-22

NOTES: 1% LIME, CURED UNTIL REACHING 250 DEGREES
MOLDED WT. 955 GRAMS

Table A2. Results of Dry Sieve Analysis for Control Beam C-12.

Sieve Size		Weight Retained	Individual Retained	Cumulative Retained	Cumulative Passing
English	Metric	(g)	(%)	(%)	(%)
1/2"	12.50 mm	0.0	0.0	0.0	100.0
3/8"	9.50 mm	136.3	9.2	9.2	90.8
#4	4.75 mm	474.3	32.0	41.1	58.9
#10	2.00 mm	304.6	20.5	61.7	38.3
#40	0.425 mm	214.2	14.4	76.1	23.9
#80	0.180 mm	162.0	10.9	87.0	13.0
#200	0.075 mm	131.8	8.9	95.9	4.1
Pan		47.8	4.1	100.0	0.0
Subtotal		1471.0			
Ash		12.96			
Washings		0.00			
Subtotal		12.96			
Sum		1484.0			

Table A3. Results of Dry Sieve Analysis for Control Beam C-24.

Sieve Size		Weight Retained	Individual Retained	Cumulative Retained	Cumulative Passing
English	Metric	(g)	(%)	(%)	(%)
1/2"	12.50 mm	0.0	0.0	0.0	100.0
3/8"	9.50 mm	128.5	8.9	8.9	91.1
#4	4.75 mm	552.1	38.1	47.0	53.0
#8	2.36 mm	263.1	18.2	65.2	34.8
#16	1.18 mm	112.8	7.8	73.0	27.0
#30	0.600 mm	54.1	3.7	76.7	23.3
#50	0.300 mm	39.1	2.7	79.4	20.6
#100	0.150 mm	130.8	9.0	88.5	11.5
#200	0.075 mm	92.4	6.4	94.8	5.2
Pan		15.3	5.2	100.0	0.0
Subtotal		1388.2			
Ash		11.30			
Washings		48.00			
Subtotal		59.30			
Sum		1447.5			

Table A4. Results of Dry Sieve Analysis for Control Beam C-38.

Sieve Size		Weight Retained	Individual Retained	Cumulative Retained	Cumulative Passing
English	Metric	(g)	(%)	(%)	(%)
1/2"	12.50 mm	0.0	0.0	0.0	100.0
3/8"	9.50 mm	138.3	9.2	9.2	90.8
#4	4.75 mm	543.2	36.2	45.5	54.5
#10	2.00 mm	276.2	18.4	63.9	36.1
#40	0.425 mm	188.5	12.6	76.5	23.5
#80	0.180 mm	162.4	10.8	87.3	12.7
#200	0.075 mm	130.8	8.7	96.0	4.0
Pan		46.3	4.0	100.0	0.0
Subtotal		1485.7			
Ash		13.02			
Washings		0.00			
Subtotal		13.02			
Sum		1498.7			

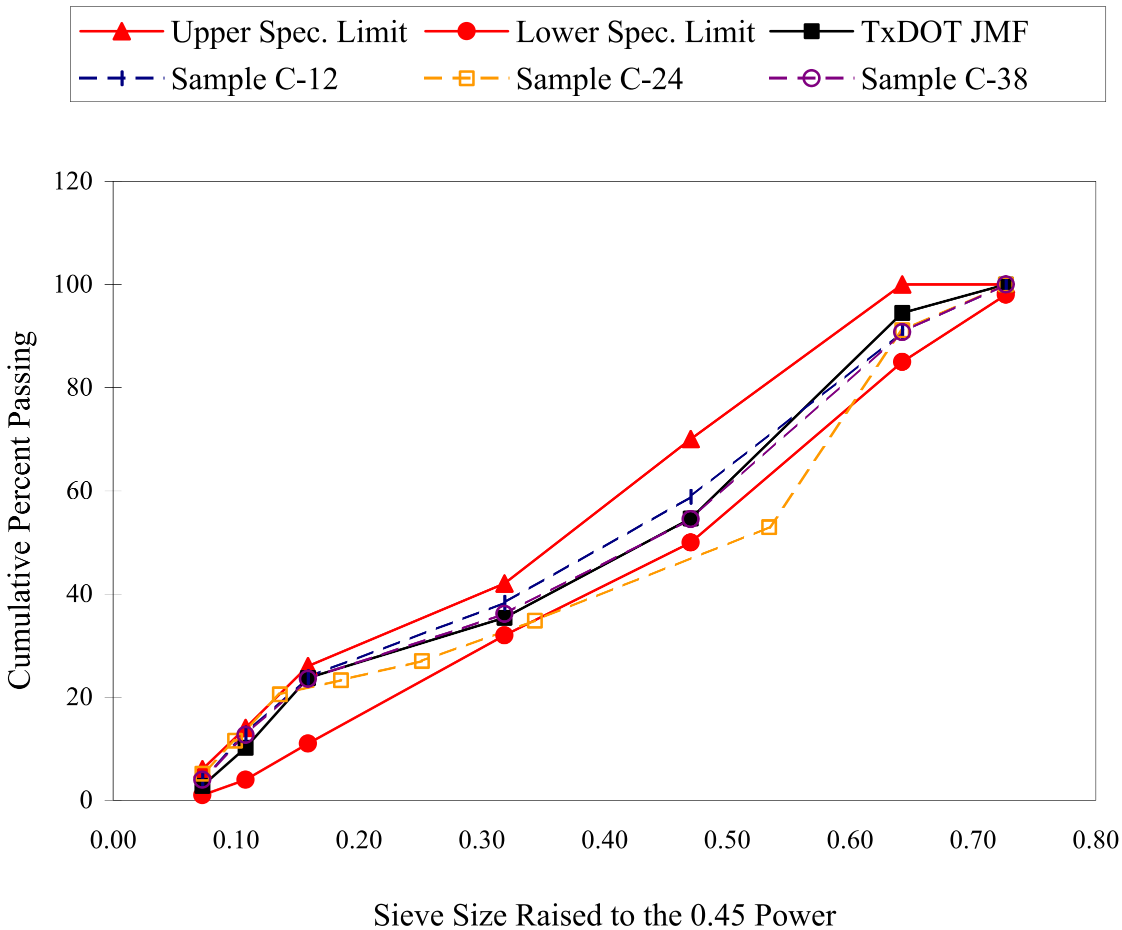


Figure A1. Federal Highway Administration 0.45 Power Gradation Curve.

As described in Item 340.3 of the Spec book, "the mixture shall be designed to produce an acceptable mixture at an optimum density of 96.0 percent" (TxDOT, 1993). From this requirement, the percent asphalt cement to achieve this density is thus defined as the optimum percent asphalt. Additional requirements for minimum percent voids in the mineral aggregate (VMA) is set at 14 percent. Table A5 provides a summary of these values for the Type D JMF.

Table A5. Results of Type D JMF to Obtain 96.0 Percent Optimum Density.

Optimum Asphalt Content	Voids in the Mineral Aggregate (VMA)	Theoretical Maximum Specific Gravity
5%	15.4	2.454

Quality Assurance Testing

The objective of the research was to investigate the relative effectiveness of commercially available geosynthetic products in reducing or retarding reflective cracking in bituminous overlays. The goal of the laboratory fabrication process was to produce compacted beams that were homogenous in nature and contained realistic air void contents when compared to field conditions. Therefore, periodic assurance tests were performed using the control beams and then compared to the above described JMF. Tables A6 through A8 provide the laboratory data and results for the assurance tests. The following equations were used to calculate the values listed in Tables A6 through A8.

Table A6. Bulk Specific Gravities to be Used to Determine Air Void Content.

Sample Container	Date Tested	Sample I.D.	Sample Size	Bulk Specific Gravity			
				Weight (g)	Weight (g)	Weight (g)	
				(dry)	(submerged)	(ssd)	G_{mb}
1	5/23/00	**C-1A**	1 inch	4791.8	2721.9	4820.9	**2.283**
	5/24/00	**C-1B**	1 inch	4764.6	2711.9	4798.7	**2.283**
2	5/30/00	**C-2A**	2 inch	9575.3	5552.3	9581.1	**2.377**
	5/31/00	**C-2B**	2 inch	9591.2	5349.4	9619.3	**2.246**
3	6/01/00	**C-3A**	1 inch	4800.5	2737.6	4815.8	**2.310**
	6/02/00	**C-3B**	1 inch	4788.8	2735.4	4798.2	**2.322**
	6/02/00	**C-3C**	2 inch	9580.4	5490.1	9608.2	**2.326**
4	6/06/00	**C-4A**	1 inch	4803.6	2736.3	4821.4	**2.304**
	6/08/00	**C-4B**	2 inch	9625.3	5532.0	9687.8	**2.316**
20	6/14/00	**C-20A**	1 inch	4795.0	2734.0	4805.5	**2.315**
	6/12/00	**C-20B**	2 inch	9649.3	5560.8	9661.9	**2.353**
	6/16/00	**C-20C**	2 inch	9593.0	5535.7	9612.9	**2.353**
12	8/16/00	**C-12**	3 inch	14190.7	8195.7	14230.1	**2.352**
38	8/16/00	**C-38**	3 inch	14219.2	8244.4	14273.8	**2.358**
24	10/31/00	**C-24**	3 inch	14170.8	8206.9	14222.1	**2.356**

Table A7. Rice Specific Gravities Used to Determine Air Void Content.

Sample Container	Date Tested	Sample I.D.	Weight (g) dry sample	Weight (g) pycn + water)	Weight (g) (pycn + sample + water)	Rice Specific Gravity Lab	JMF	Δ
1	5/22/00	1a	1000.0	2794.0	3387.0	2.457		
	5/22/00	1b	999.0	2855.0	3448.0	2.461		
	5/22/00	1c	999.5	2791.0	3385.0	2.465		
					Average	**2.461**	2.454	-0.007
2	5/23/00	2a	1020.89	2791.82	3395.50	2.447		
	5/23/00	2b	1015.82	2852.76	3452.63	2.442		
	5/23/00	2c	1001.33	2790.24	3381.86	2.444		
					Average	**2.444**	2.454	0.010
3	6/01/00	3a	1145.00	2792.50	3473.50	2.468		
					Average	**2.468**	2.454	-0.014
4	6/07/00	4a	1145.50	2791.50	3472.00	2.463		
					Average	**2.463**	2.454	-0.009
20	6/13/00	20a	1281.30	2790.60	3552.30	2.466		
	6/13/00	20b	1219.75	2852.35	3575.96	2.458		
	6/13/00	20c	1309.54	2788.50	3567.91	2.470		
					Average	**2.465**	2.454	-0.011
12	8/17/00	12a	1268.90	2847.80	3600.70	2.459		
	8/17/00	12b	1224.32	2852.20	3578.00	2.456		
	8/17/00	12c	1218.00	2789.20	3512.90	2.464		
					Average	**2.460**	2.454	-0.006
38	8/17/00	38a	1225.30	2847.80	3574.40	2.457		
	8/17/00	38b	1232.10	2852.20	3583.20	2.459		
	8/17/00	38c	1254.90	2789.20	3534.00	2.460		
					Average	**2.459**	2.454	-0.005
24	2/21/01	24a	1125.70	2828.70	3500.40	2.480		
	3/06/01	24b	1026.40	2846.30	3458.70	2.479		
	3/06/01	24c	1031.50	2858.90	3474.50	2.480		
					Average	**2.480**	2.454	-0.026

Table A8. Results of Extractions of Bitumen Content for Control Beams and JMF.

Test Method A				
	Sample C-12	**Sample C-38**	**Sample C-24**	
Date Tested	8/17/00	8/18/00	2/21/01	
Total Sample, W_1	1561.0	1572.3	1510.0	
Moisture Content, W_2	0.0	0.0	0.0	
Final Filter, a	14.4	14.9	15.2	
Original Filter, b	13.0	13.0	13.3	
Fines in Filter, A	1.4	1.9	1.9	(a-b)
Pan+Extracted Aggregate, c	1665.2	1760.6	-	
Pan, d	190.3	274.3	-	
Extracted Aggregate, B	1474.9	1486.3	1434.3	(c-d)
Total Extracted Aggregate, W_3	1476.3	1488.2	1436.2	(A+B)
Determining mineral matter using Ashing Method				
Dish+Ash per 100 mL, e	111.6	111.4	136.7	
Dish, f	110.5	110.5	135.8	
Ash per 100 mL, C	1.1	0.9	0.9	(e-f)
Total Solvent, D	1200.0	1480.0	1250.0	
Total Ash, W_4	13.0	13.0	11.2	(CxD)/100
Bitumen Content				
Measured, extract & recover	**4.6%**	**4.5%**	**4.1%**	
Optimum, TxDOT JMF		**5%**		

$$\text{Bulk specific gravity} = \frac{W_{dry}}{W_{SSD} - W_{sub}} \qquad \text{(A-1)}$$

$$\text{Rice specific gravity} = \frac{W_{dry}}{\left(W_{dry} + W_{pycometer+water} - W_{pycometer+sample+water}\right)} \qquad \text{(A-2)}$$

AASHTO T164/ASTM D2172, *Quantitative Extraction of Bitumen from Bituminous Paving Mixtures*, was utilized to determine the bitumen content. Equation A-3 (see Table A8 for variable descriptions) was used to calculate the bitumen content.

$$\text{Bitumen Content} = \frac{(W_1 - W_2) - (W_3 + W_4)}{(W_1 - W_2)} * 100 \qquad \text{(A-3)}$$

The following equations were used to calculate the values listed in Table A9.

$$\text{Volume of air voids} = \left[1 - \left(\frac{\text{Bulk specific gravity}}{\text{Rice specific gravity}}\right)\right] * 100 \qquad \text{(A-4)}$$

Volume of effective asphalt content

= (bulk specific gravity) * (effective asphalt content) (A-5)

Volume of Voids in Mineral Aggregate (VMA)

= (volume of air voids) + (volume of effective asphalt content) (A-6)

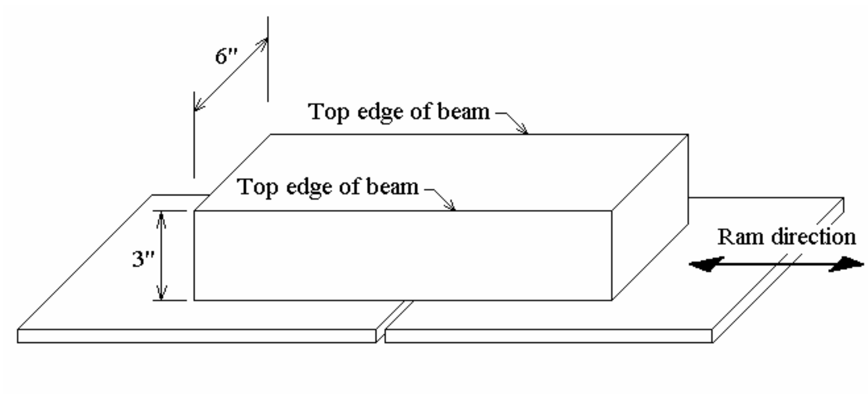
Table A9. Determination of VMA for Control Specimens.

Sample I.D.	Bulk Specific Gravity	Volume of Air Voids	Asphalt Content	Absorption (assume)	Effective Asphalt Content	Volume of Effective Asphalt Content	Volume of Voids in Mineral Aggregate (VMA)
		(%)	(%)	(%)	(%)	(%)	(%)
C-12	2.352	4.39	4.6	0	4.6	10.8	15.2
C-38	2.358	4.08	4.5	0	4.5	10.7	14.7
C-24	2.356	4.99	4.1	0	4.1	9.8	14.7

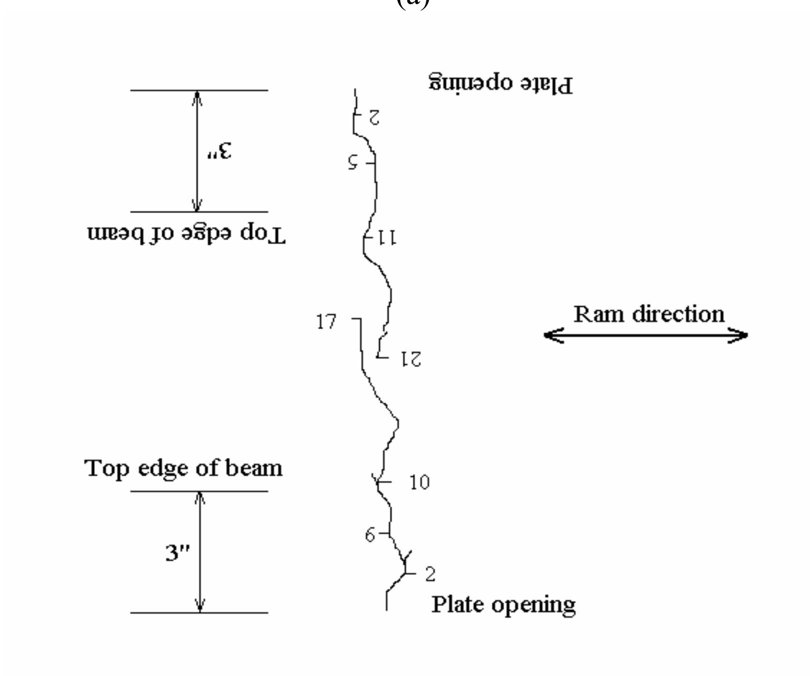
APPENDIX B

EXAMPLE OF LABORATORY TEST BEAM

Figure B1 is an example of a tested specimen used to illustrate the tracing orientation and layout in relation to the specimen and ram direction. Cleveland (2001) contains actual tracings for all beam tests conducted. His figures are reduced copies of cracking patterns from the original beam tracings used to document and measure crack lengths with corresponding load cycles.



(a)



(b)

Figure B1. Illustration of (a) Specimen Orientation and (b) Tracing of Crack Lengths and Load Cycles.

APPENDIX C

GRAPHS AND CHARTS FROM TESTS ON BEAMS USING TTI OVERLAY TESTER

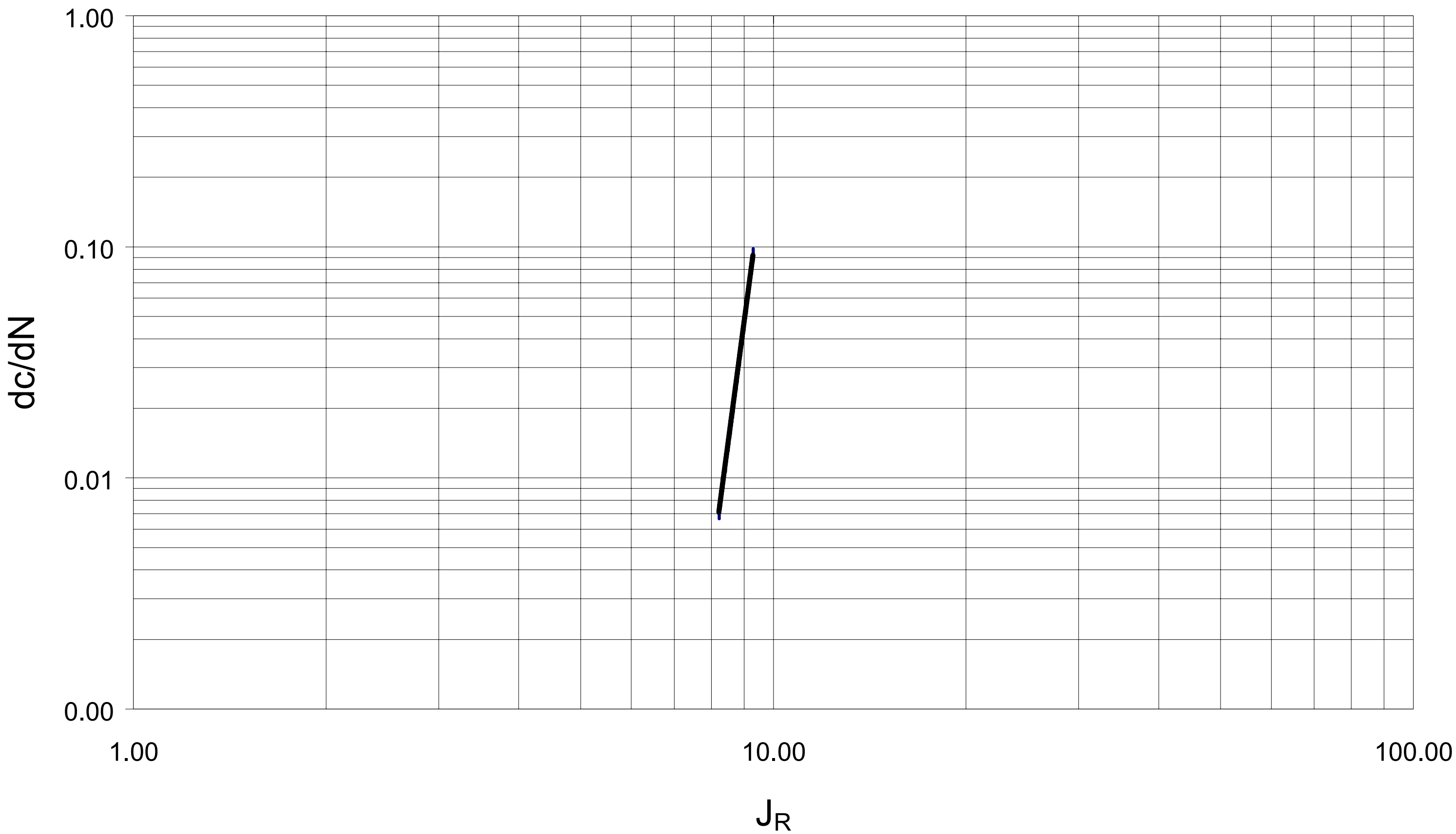


Figure C1. Rate of Crack Growth (dc/dN) versus the Pseudo J-Integral (J_R) for Specimen B-5.

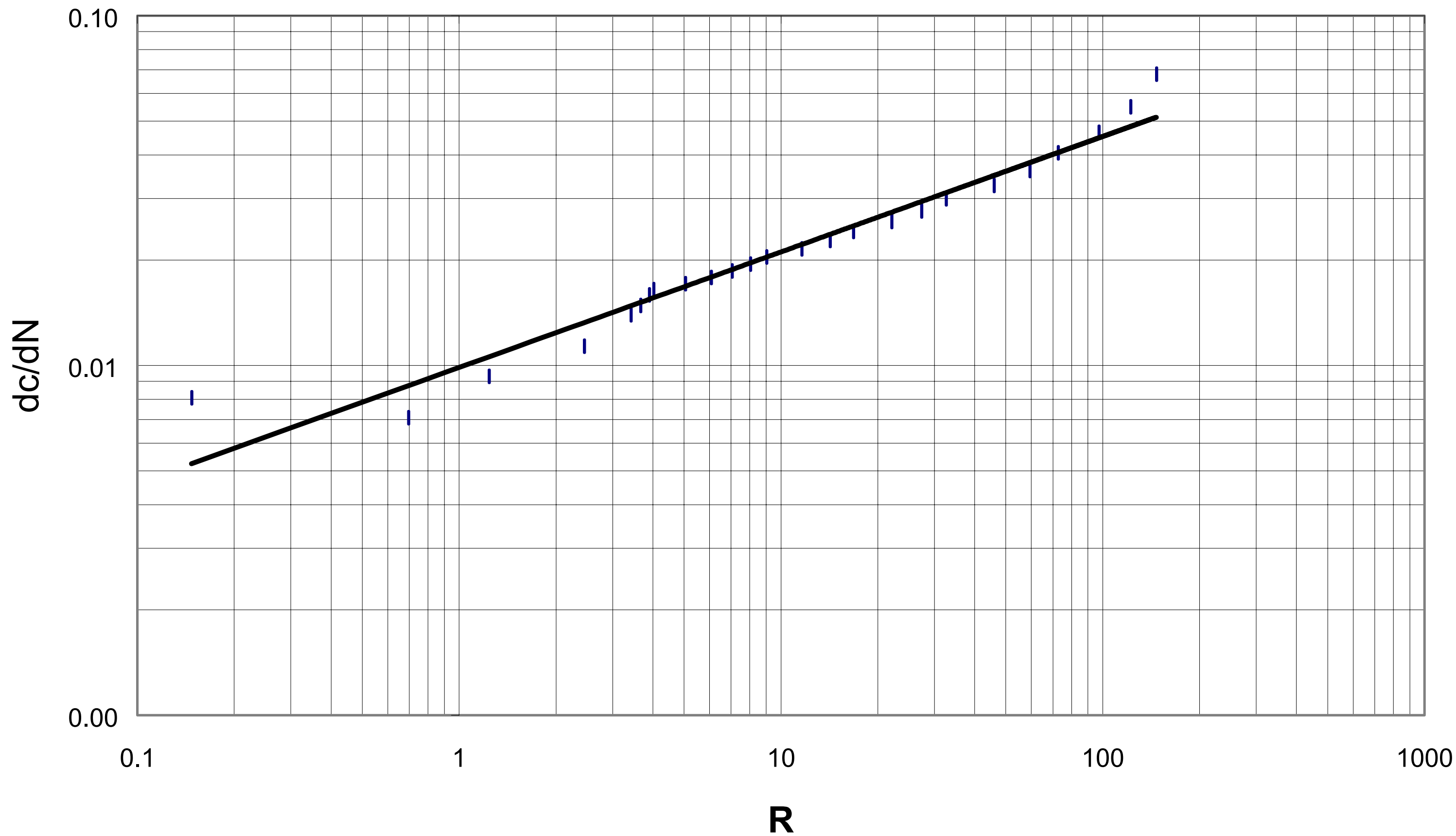


Figure C2. Rate of Crack Growth (dc/dN) versus the Reinforcing Factor (R) for Specimen B-5.

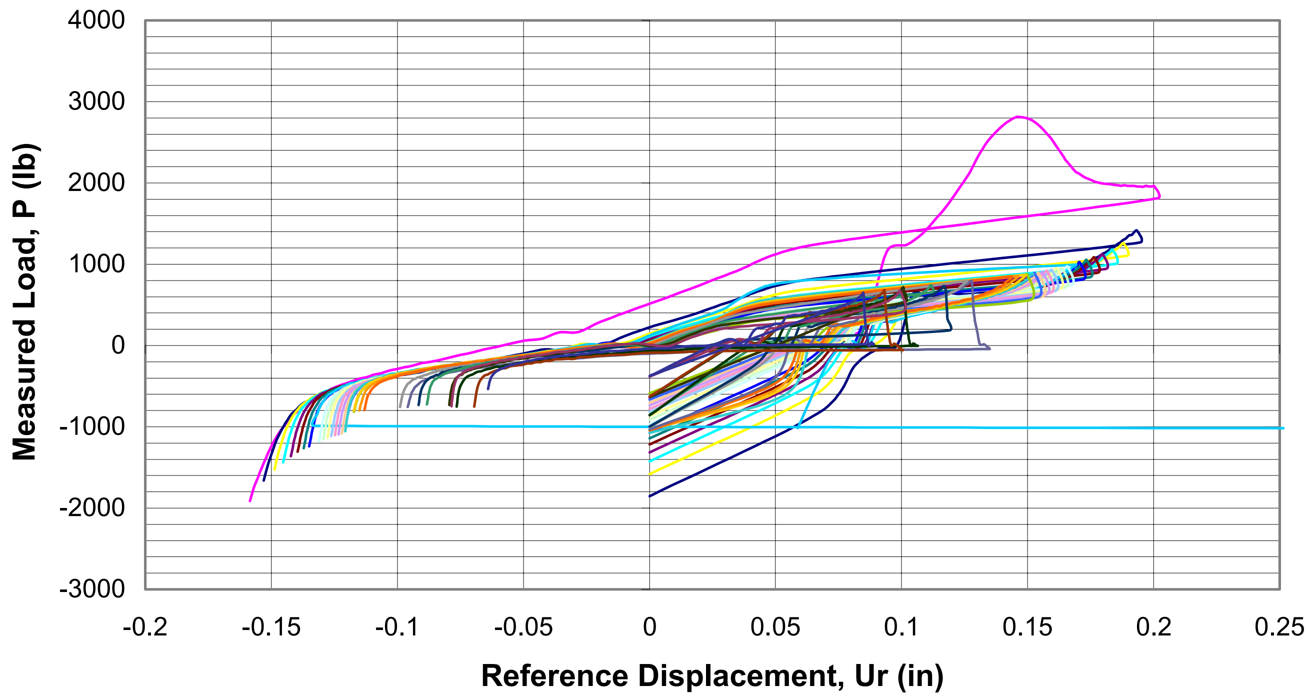


Figure C3. Measured Load versus Reference Displacement used to Calculate Pseudo Strain Energy for Specimen B-5.

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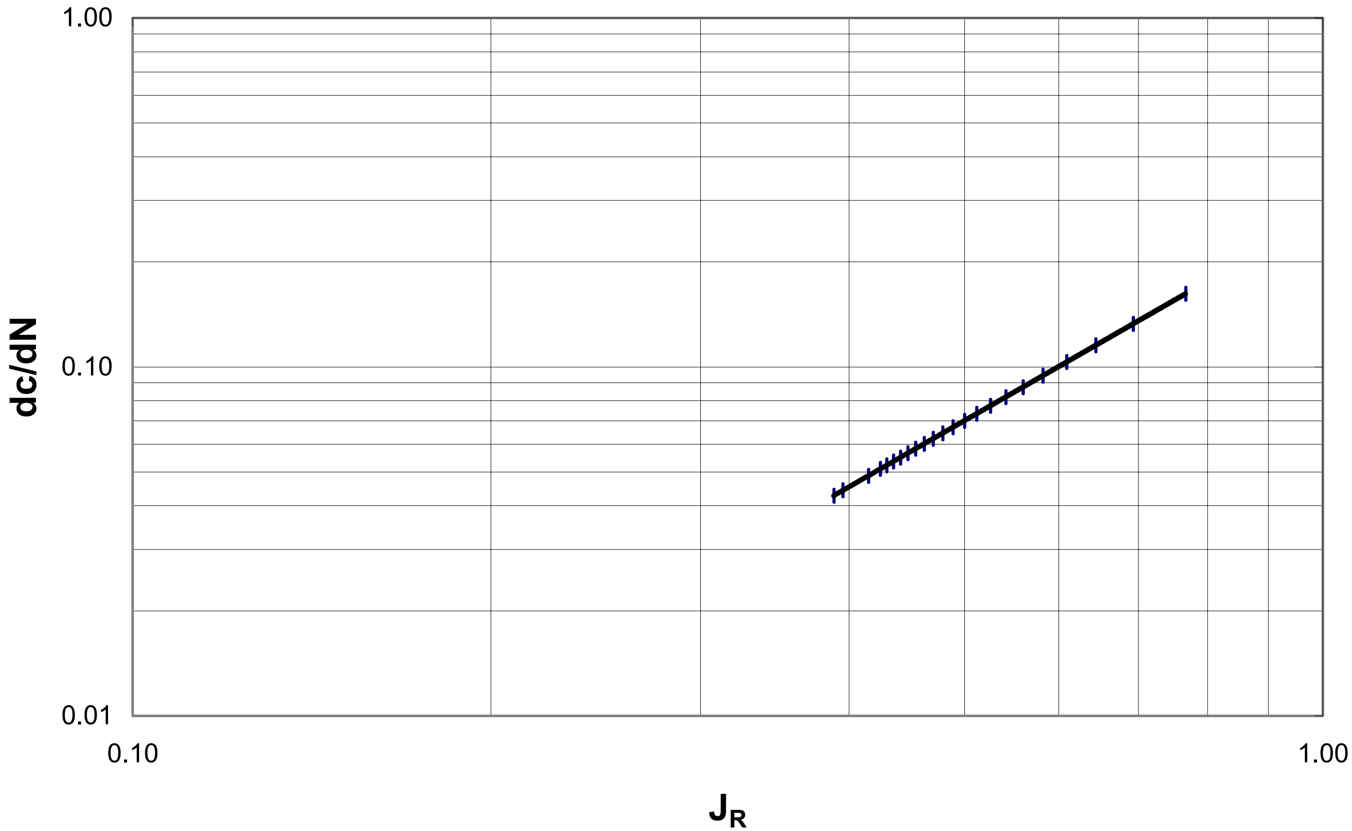

Figure C4. Rate of Crack Growth (dc/dN) versus the Pseudo J-Integral (J_R) for Specimen PD3-6.

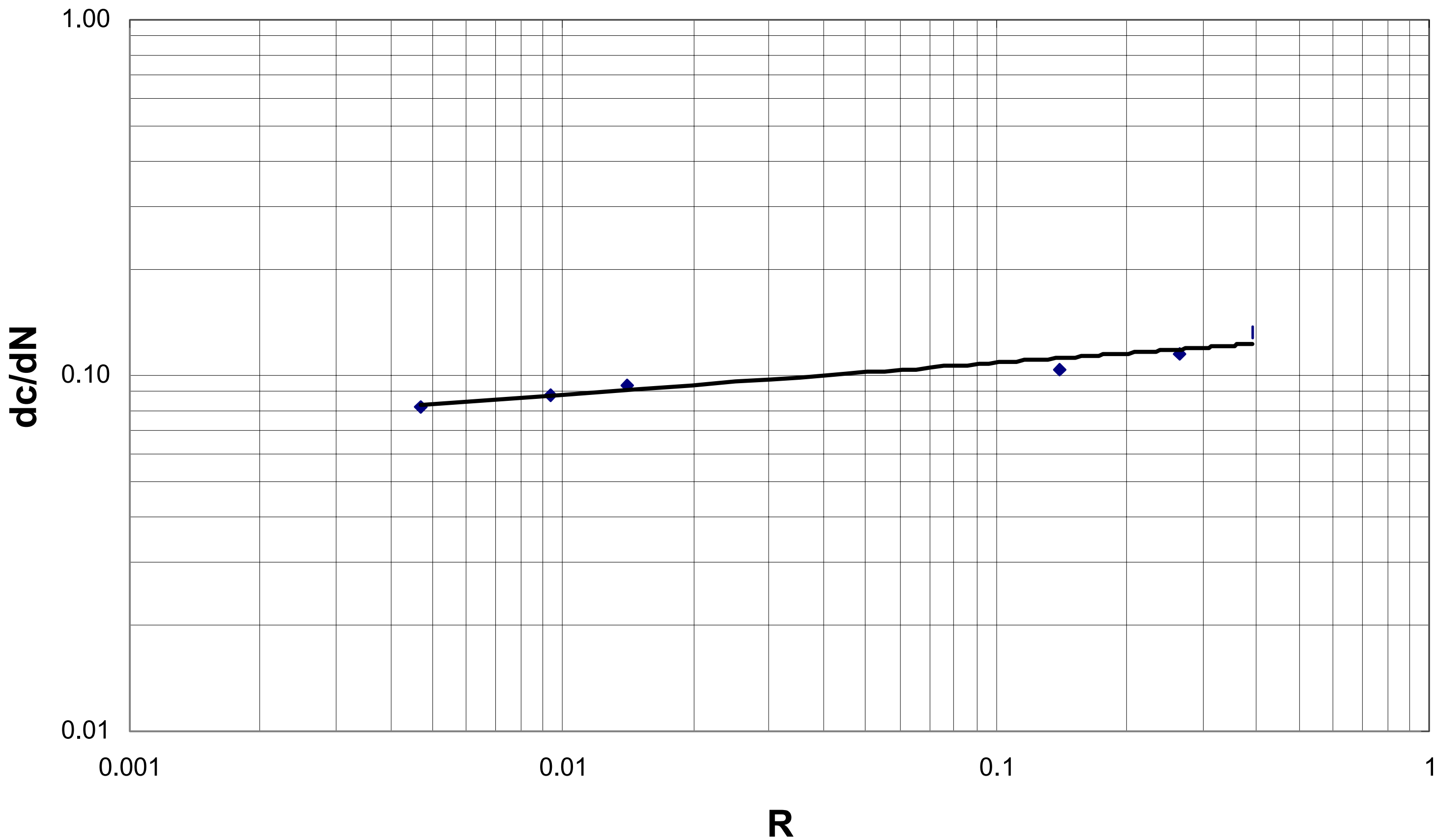

Figure C5. Rate of Crack Growth (dc/dN) versus the Reinforcing Factor (R) for Specimen PD3-6.

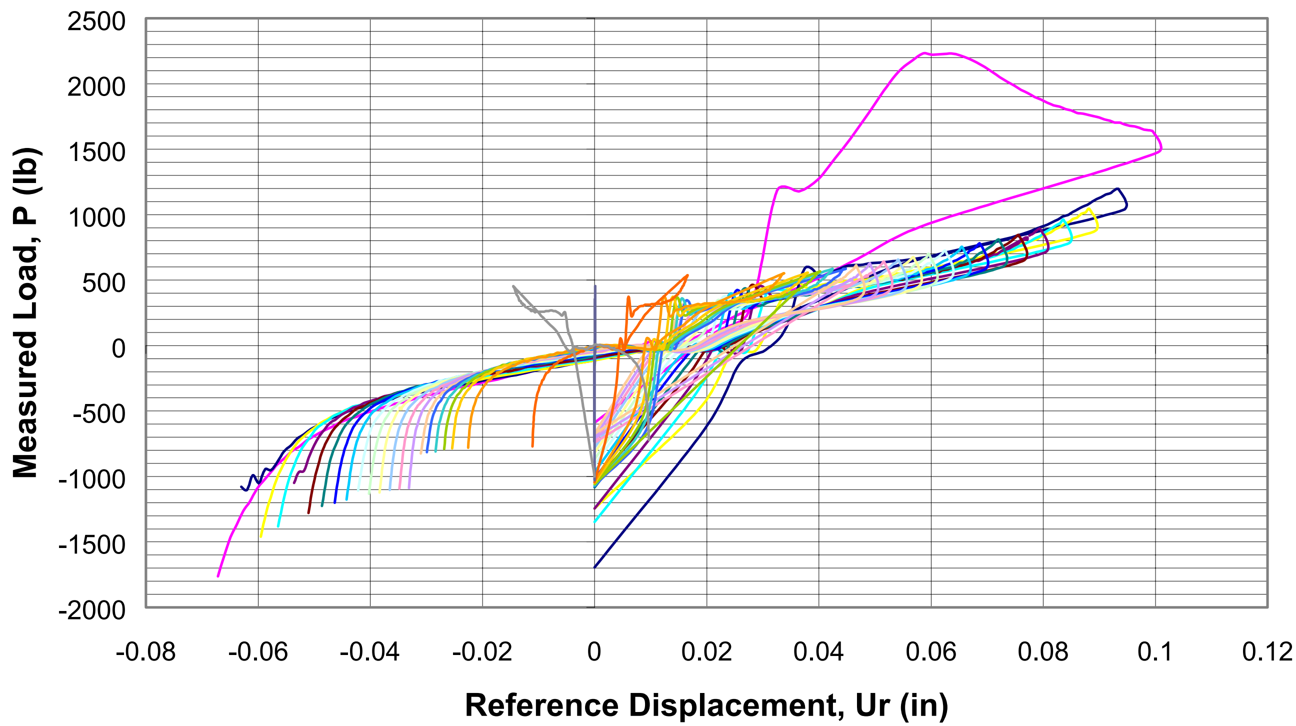

Figure C6. Measured Load versus Reference Displacement used to Calculate Pseudo Strain Energy for Specimen PD3-6.

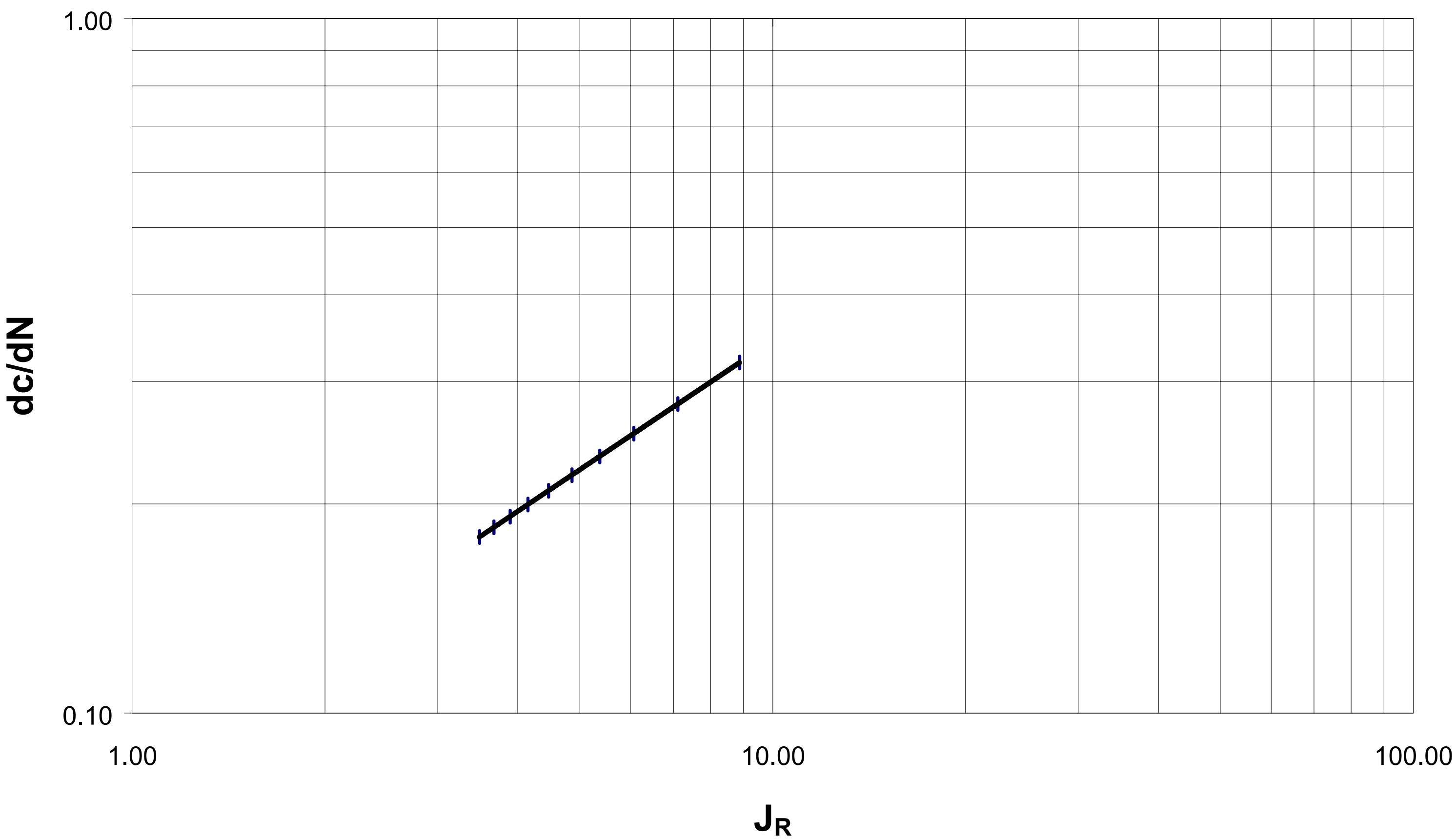

Figure C7. Rate of Crack Growth (dc/dN) versus the Pseudo J-Integral (J_R) for Specimen HC-7.

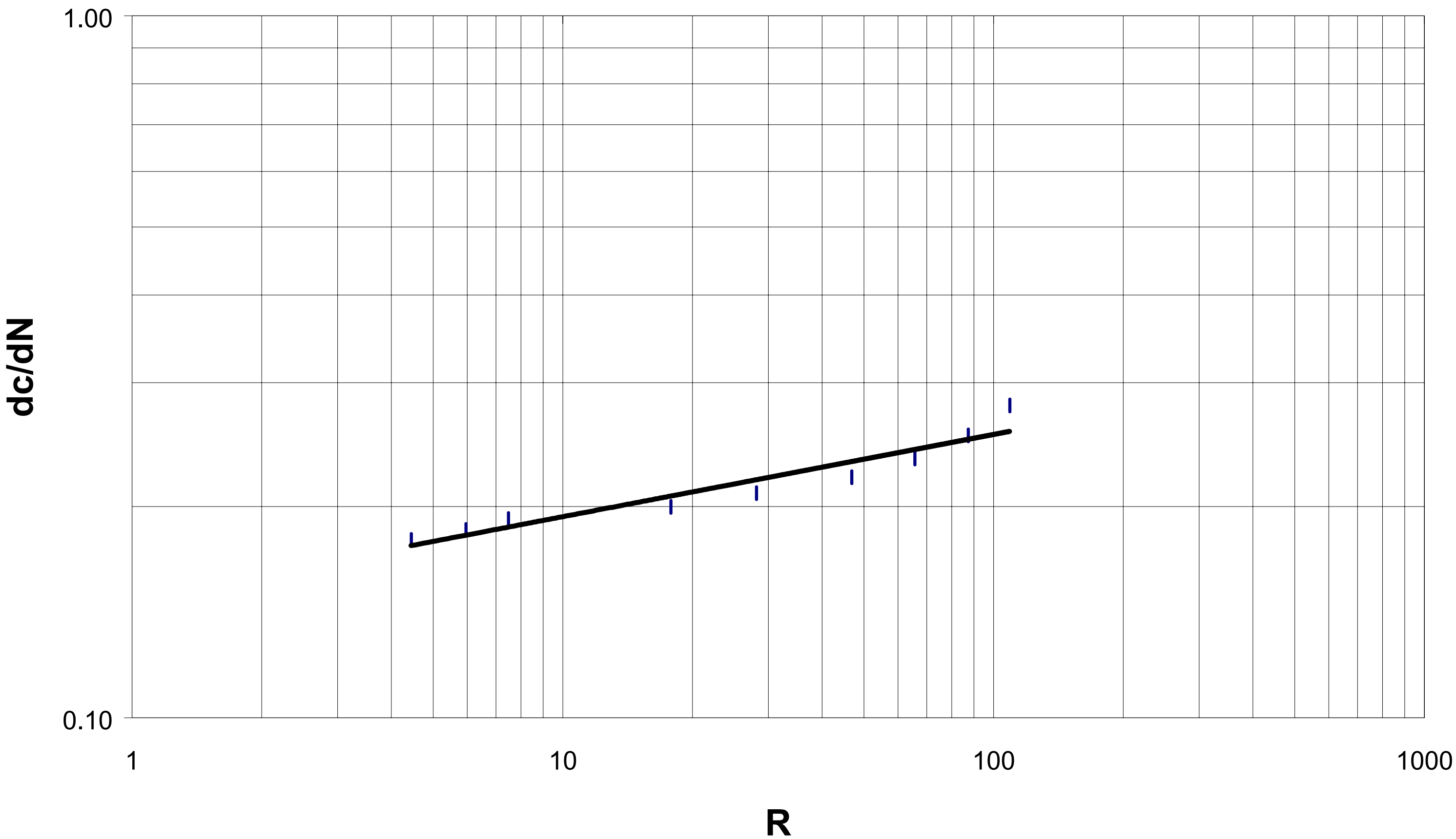

Figure C8. Rate of Crack Growth (dc/dN) versus the Reinforcing Factor (R) for Specimen HC-7.

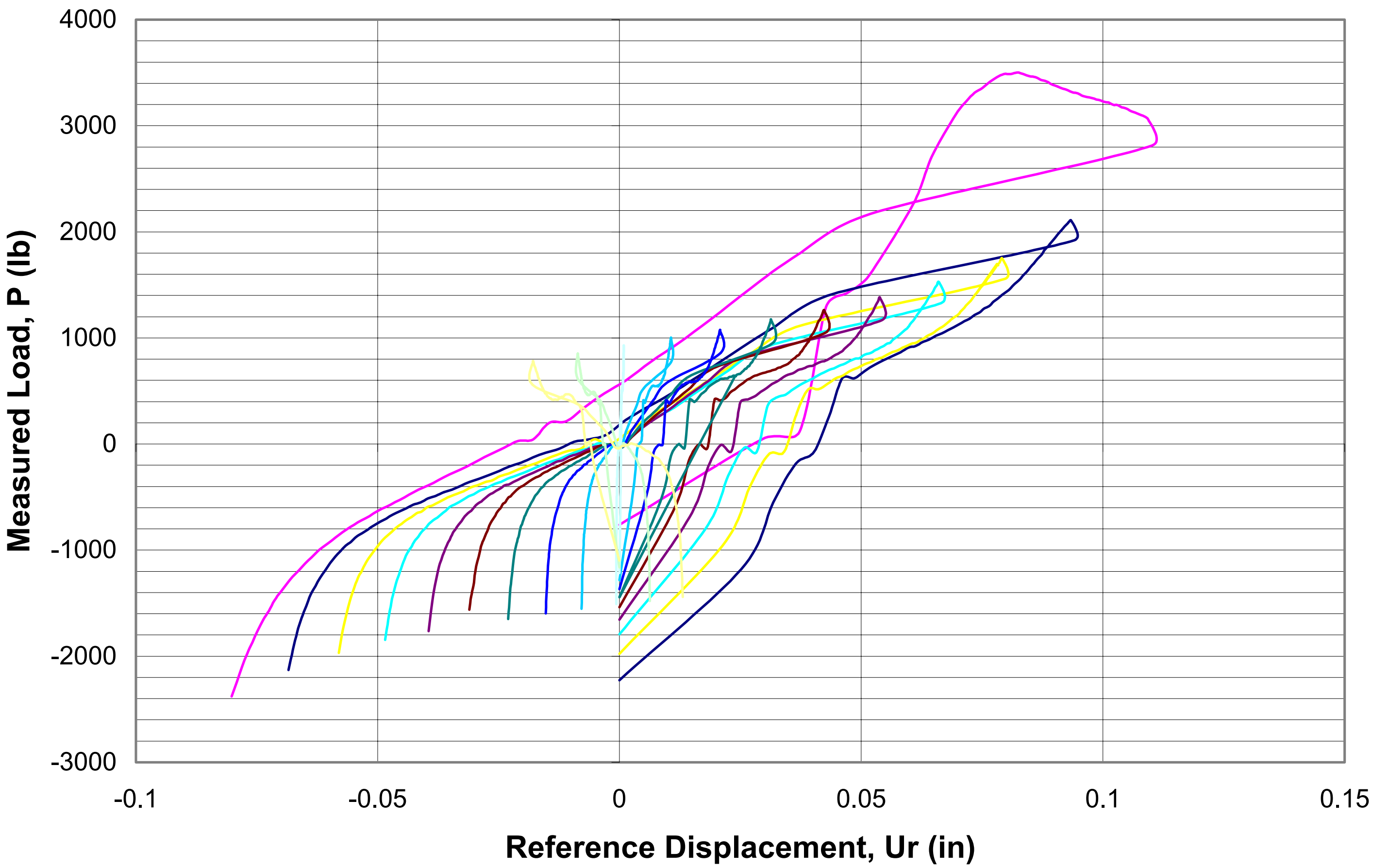

Figure C9. Measured Load versus Reference Displacement used to Calculate Pseudo Strain Energy for Specimen HC-7.

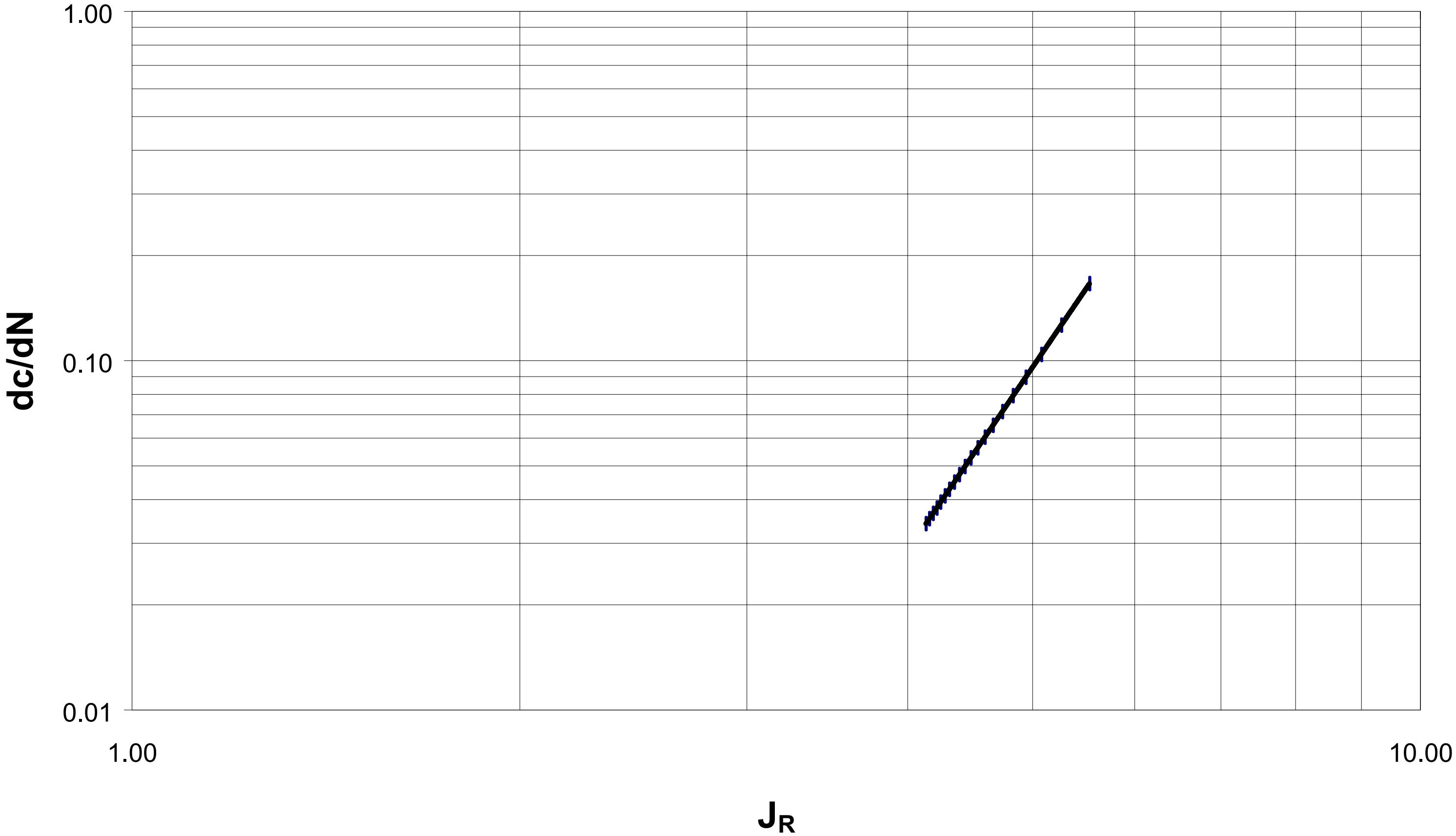

Figure C10. Rate of Crack Growth (dc/dN) versus the Pseudo J-Integral (J_R) for Specimen PG2-8.

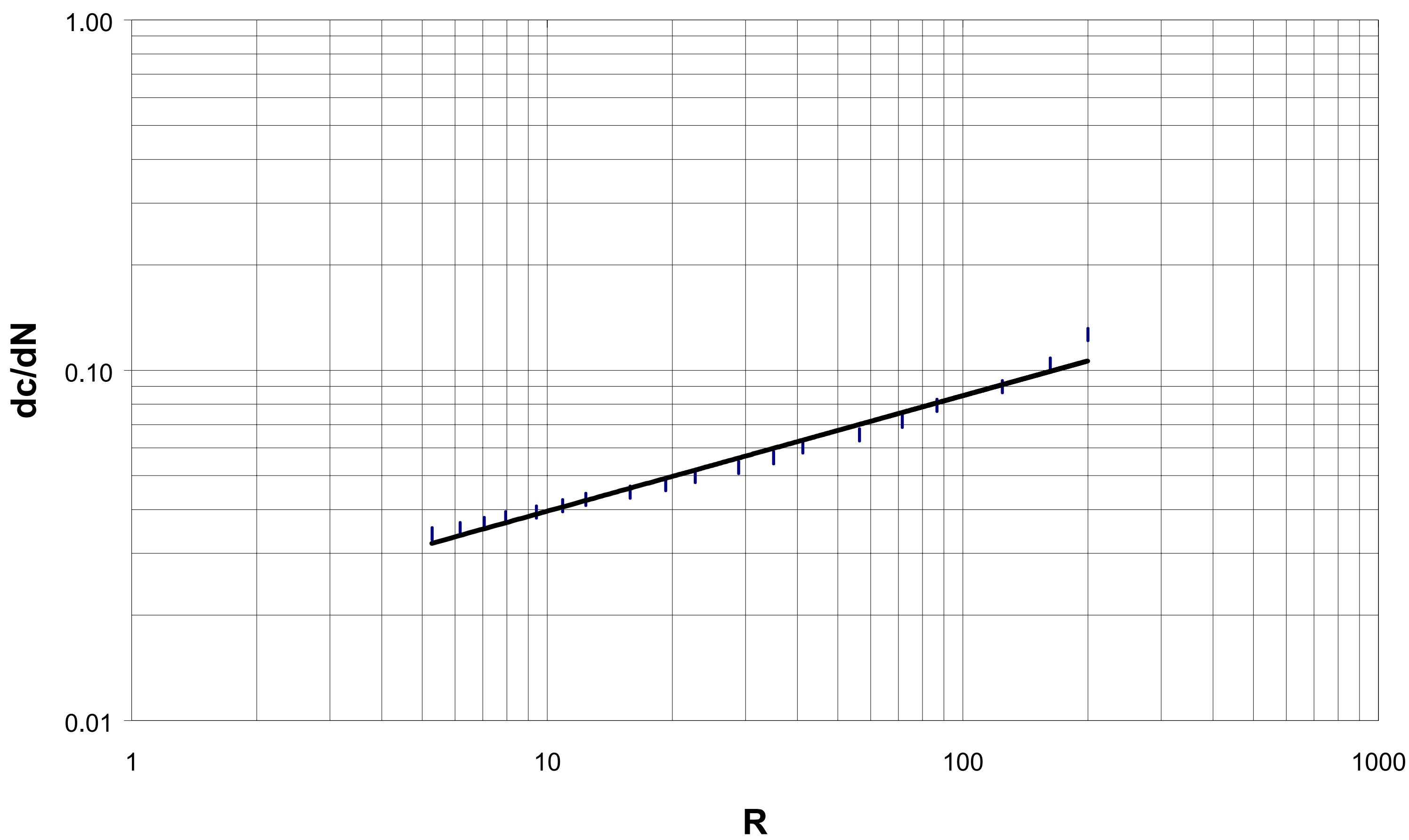

Figure C11. Rate of Crack Growth (dc/dN) versus the Reinforcing Factor (R) for Specimen PG2-8.

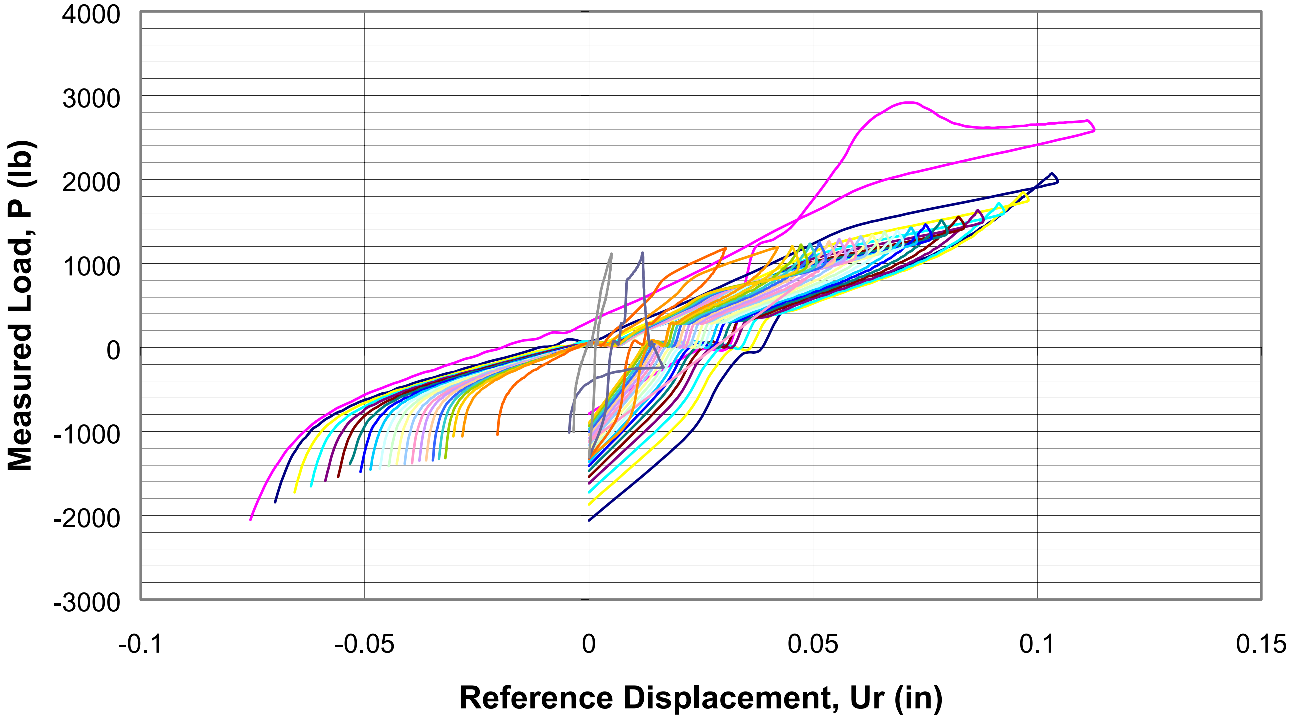

Figure C12. Measured Load versus Reference Displacement used to Calculate Pseudo Strain Energy for Specimen PG2-8.

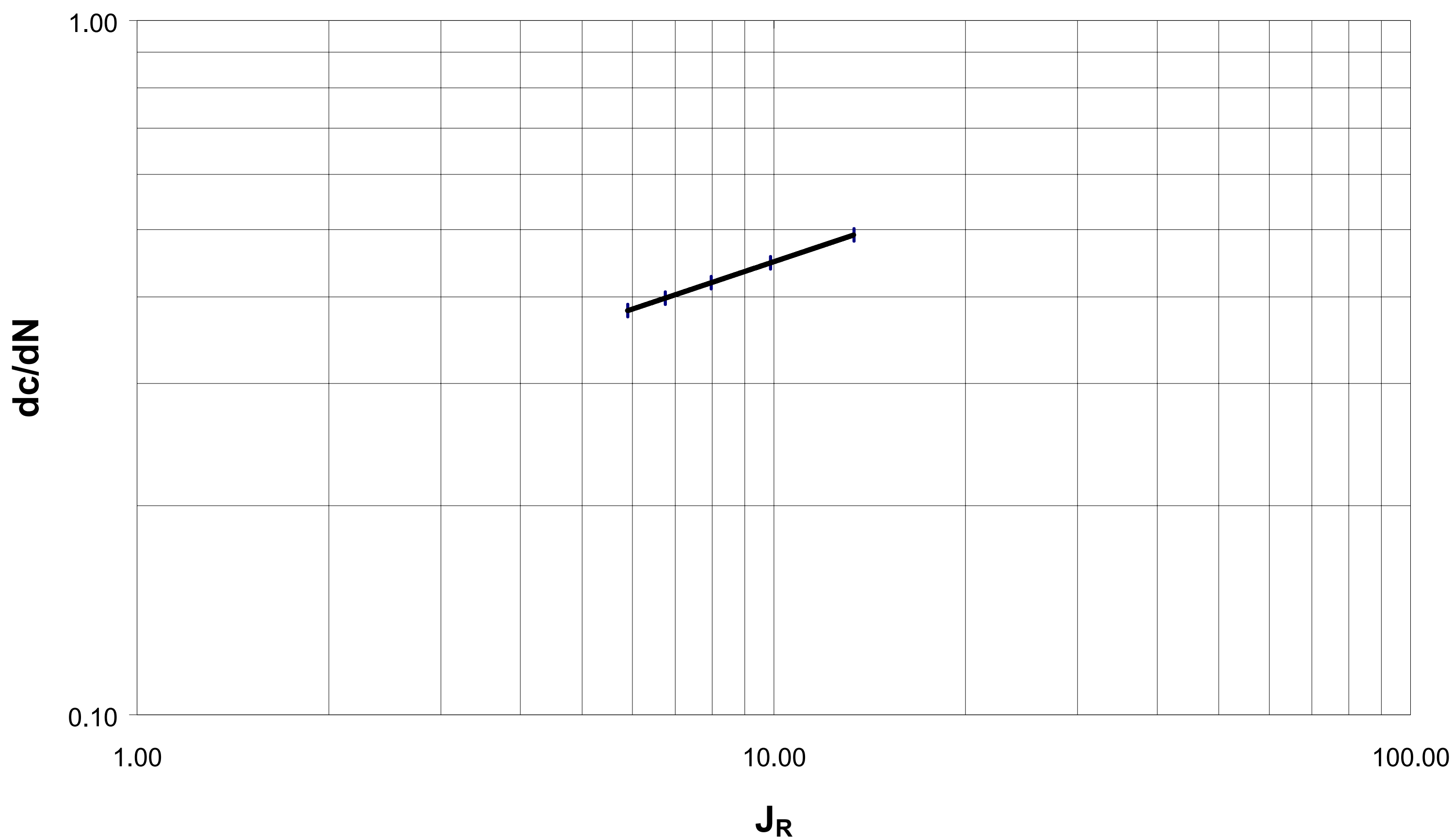

Figure C13. Rate of Crack Growth (dc/dN) versus the Pseudo J-Integral (J_R) for Specimen C-9.

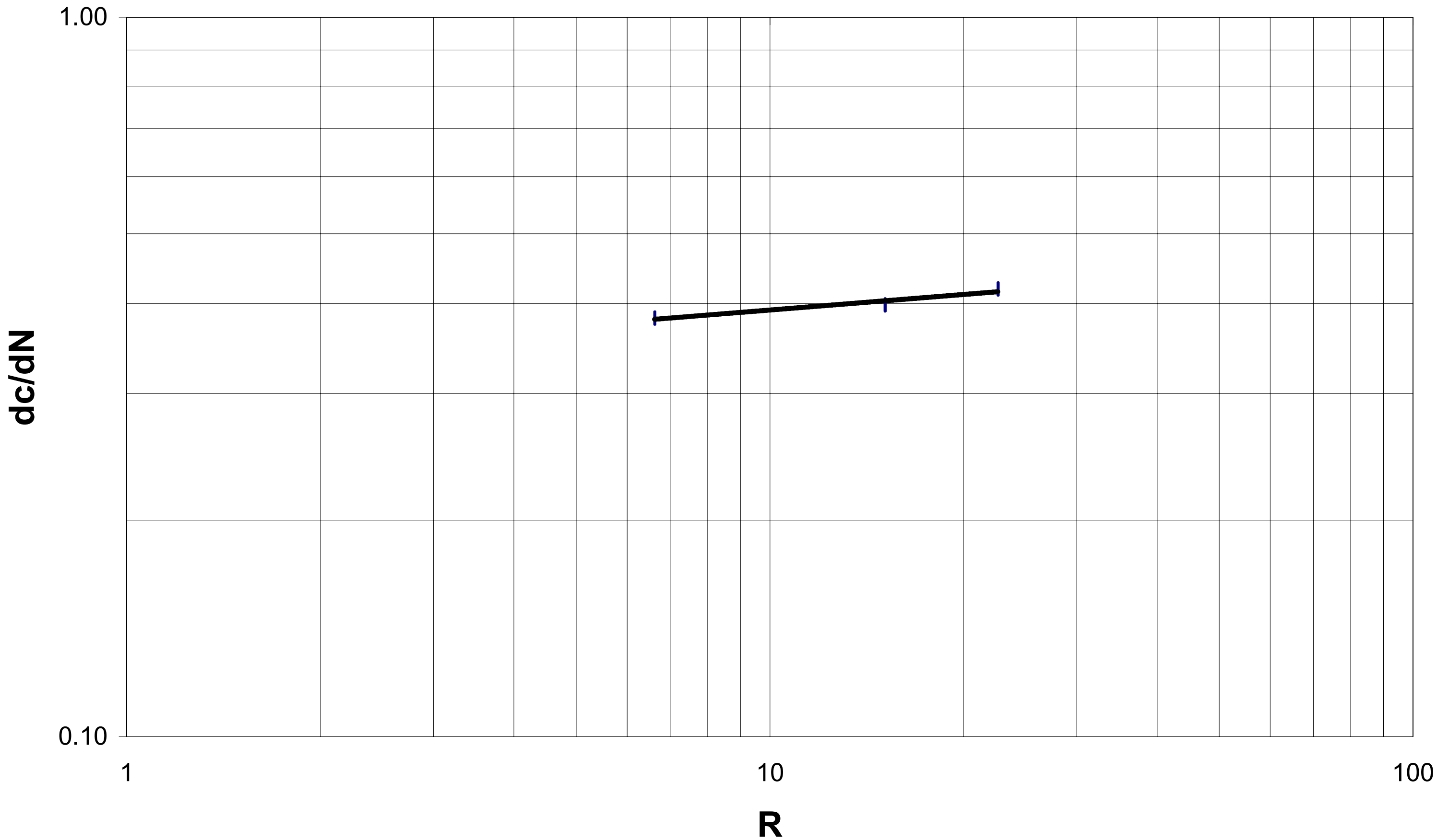

Figure C14. Rate of Crack Growth (dc/dN) versus the Reinforcing Factor (R) for Specimen C-9.

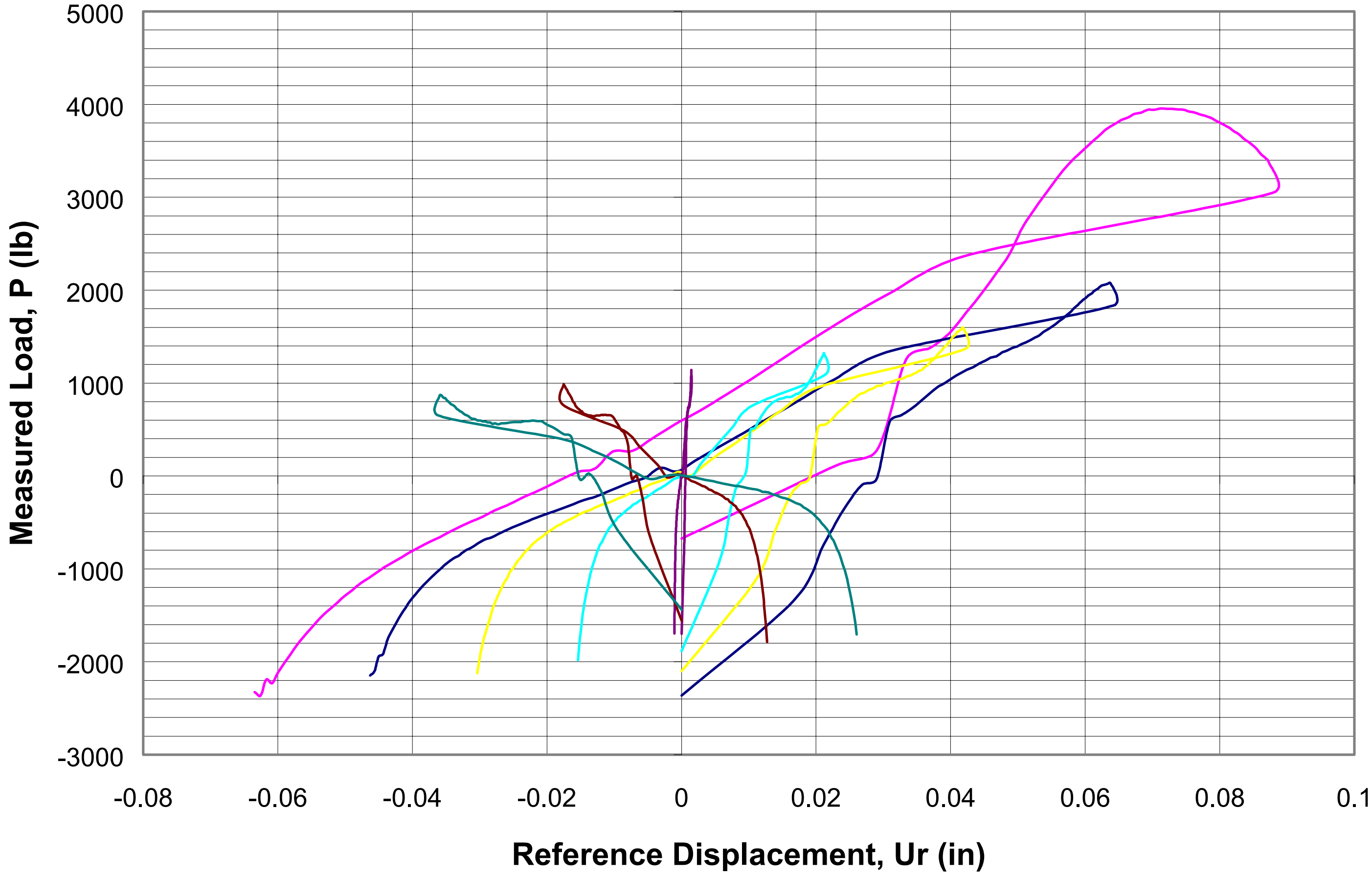

Figure C15. Measured Load versus Reference Displacement used to Calculate Pseudo Strain Energy for Specimen C-9.

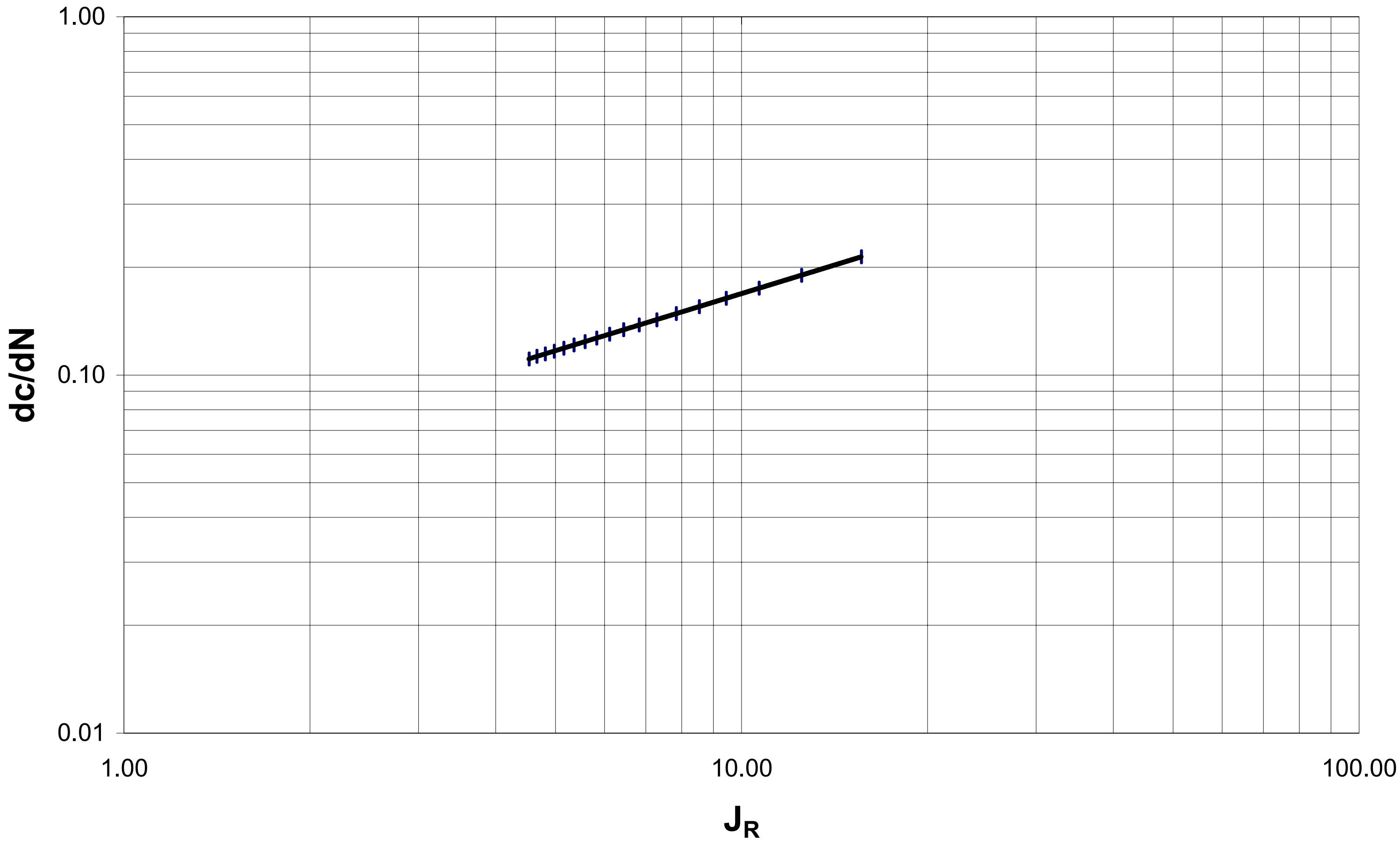

Figure C16. Rate of Crack Growth (dc/dN) versus the Pseudo J-Integral (J_R) for Specimen S-10.

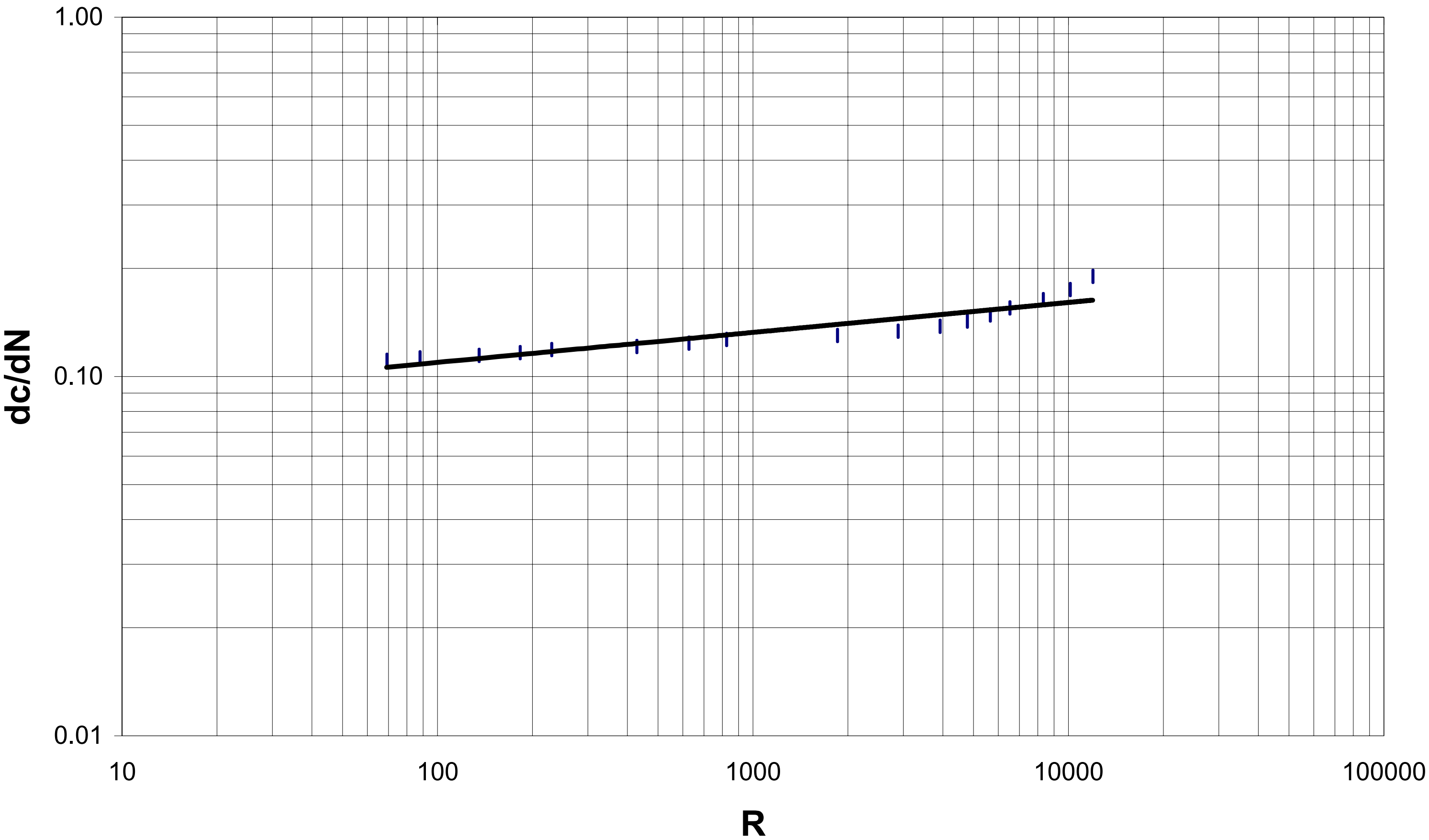

Figure C17. Rate of Crack Growth (dc/dN) versus the Reinforcing Factor (R) for Specimen S-10.

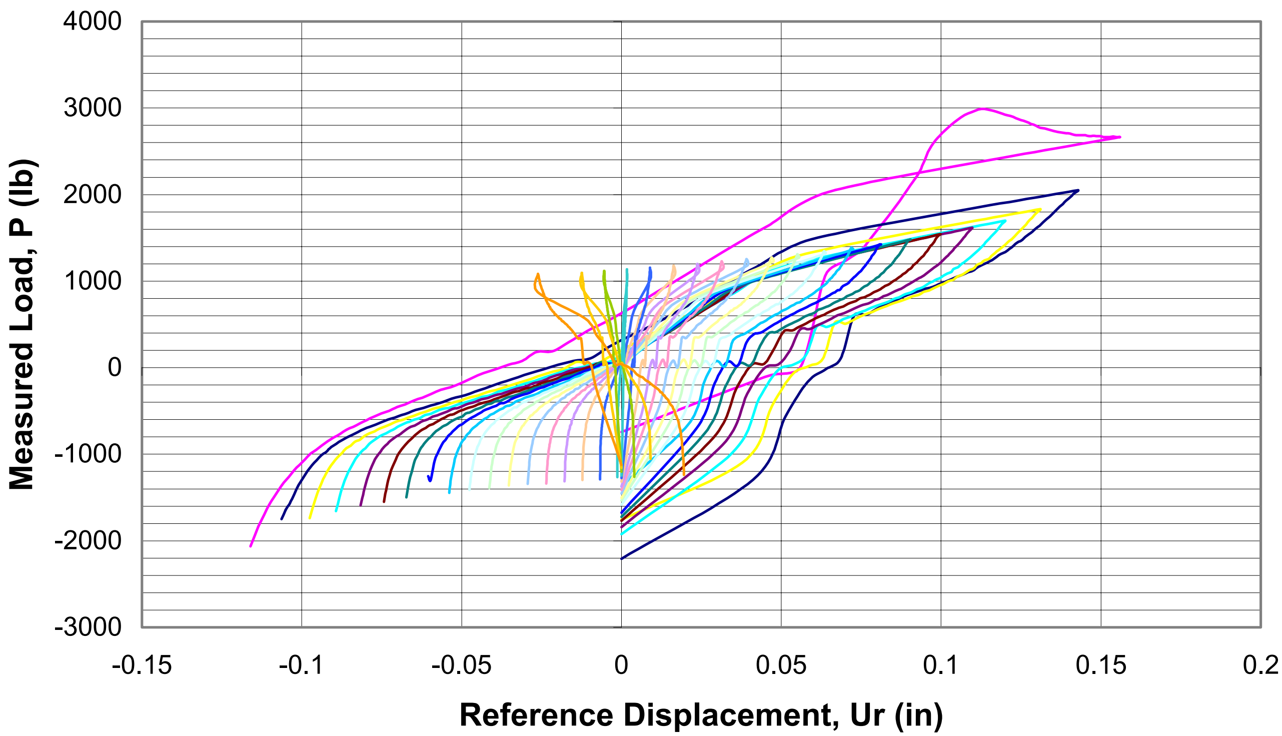

Figure C18. Measured Load versus Reference Displacement used to Calculate Pseudo Strain Energy for Specimen S-10.

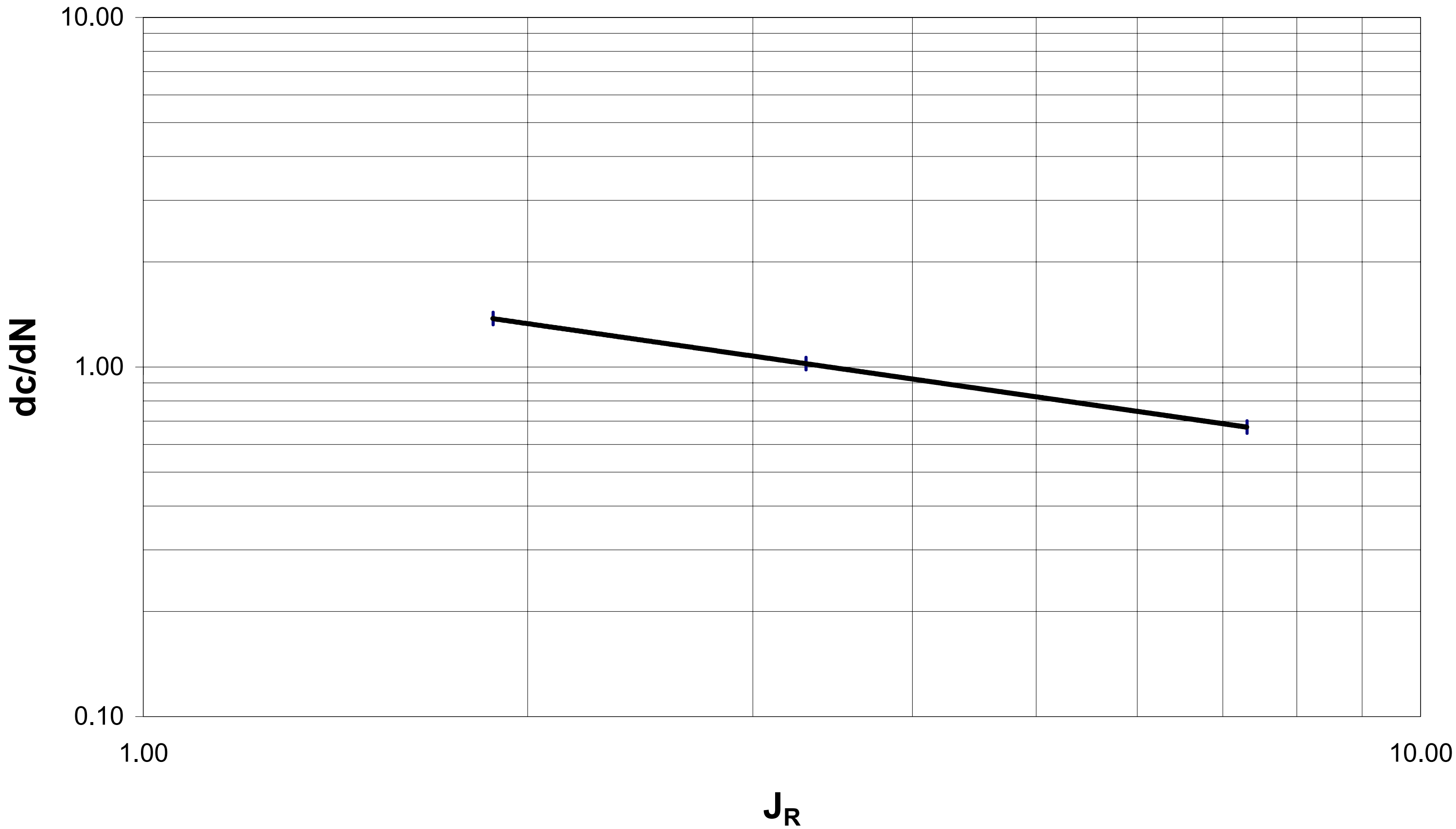

Figure C19. Rate of Crack Growth (dc/dN) versus the Pseudo J-Integral (J_R) for Specimen G-11.

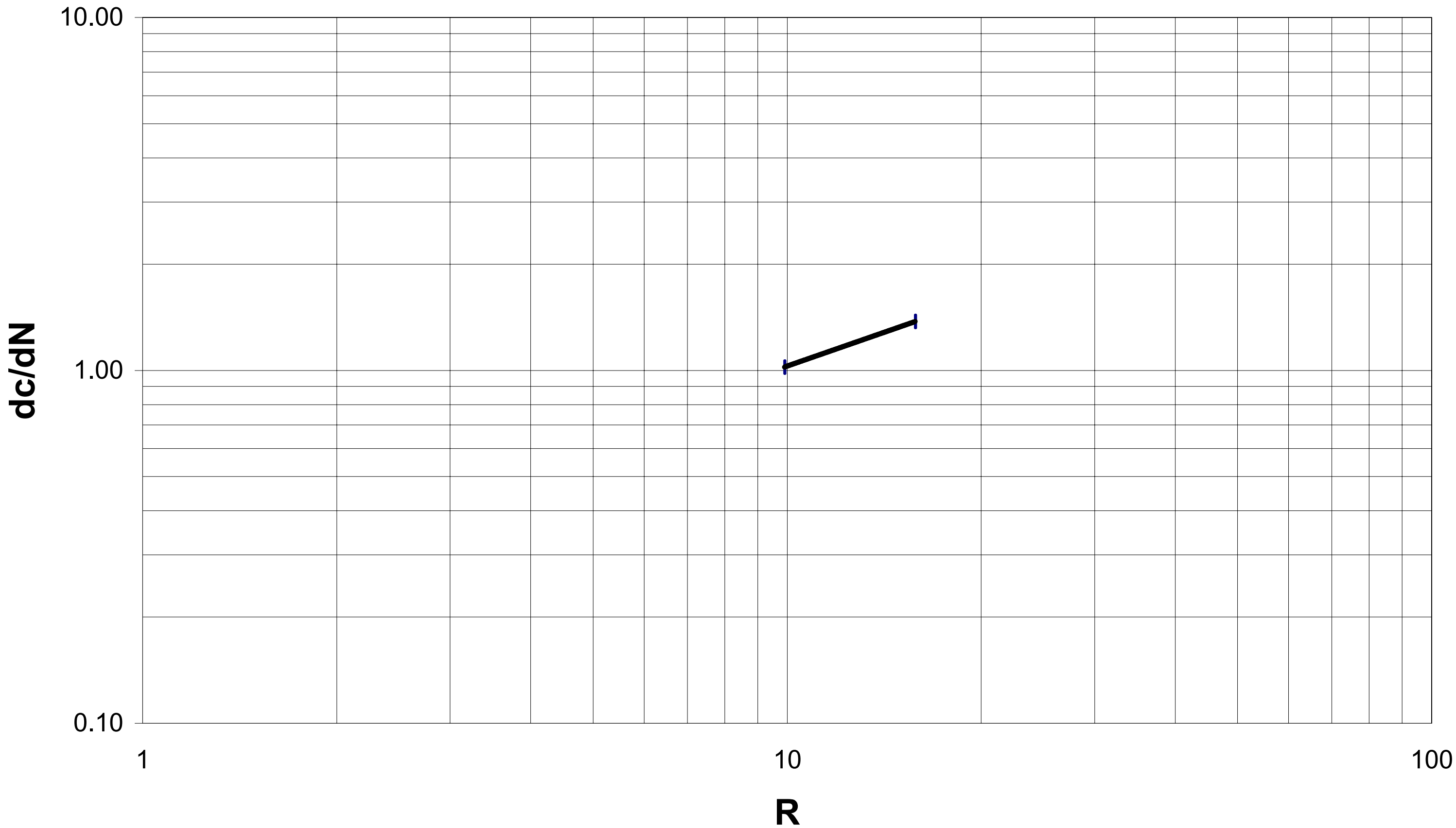

Figure C20. Rate of Crack Growth (dc/dN) versus the Reinforcing Factor (R) for Specimen G-11.

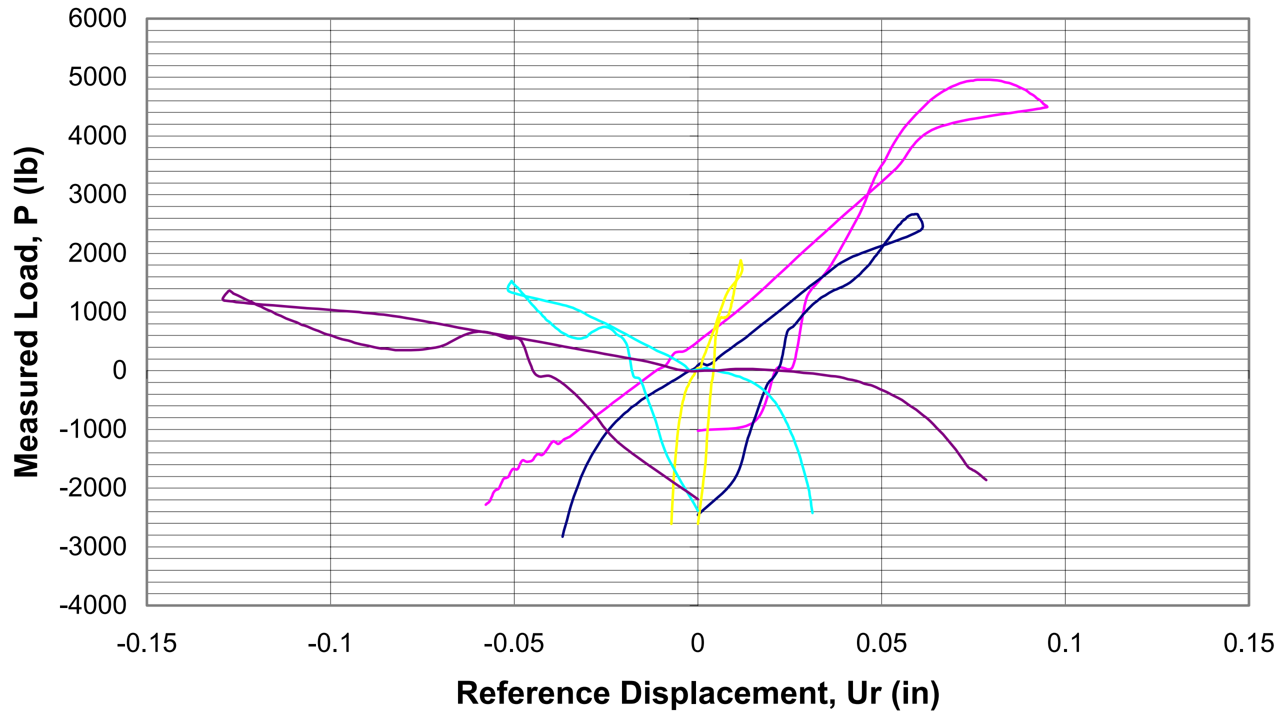

Figure C21. Measured Load versus Reference Displacement used to Calculate Pseudo Strain Energy for Specimen G-11.

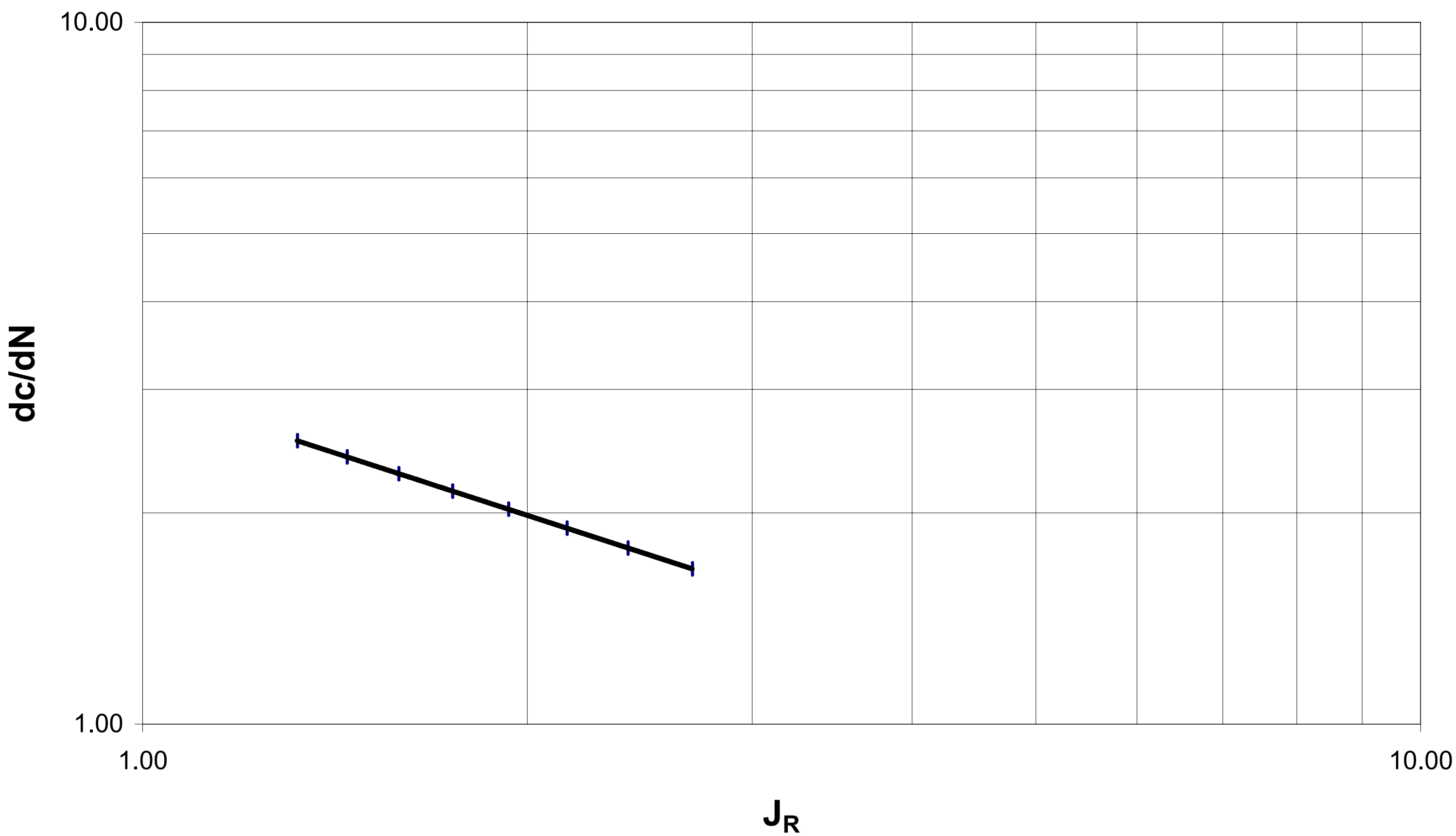

Figure C22. Rate of Crack Growth (dc/dN) versus the Pseudo J-Integral (J_R) for Specimen C-12.

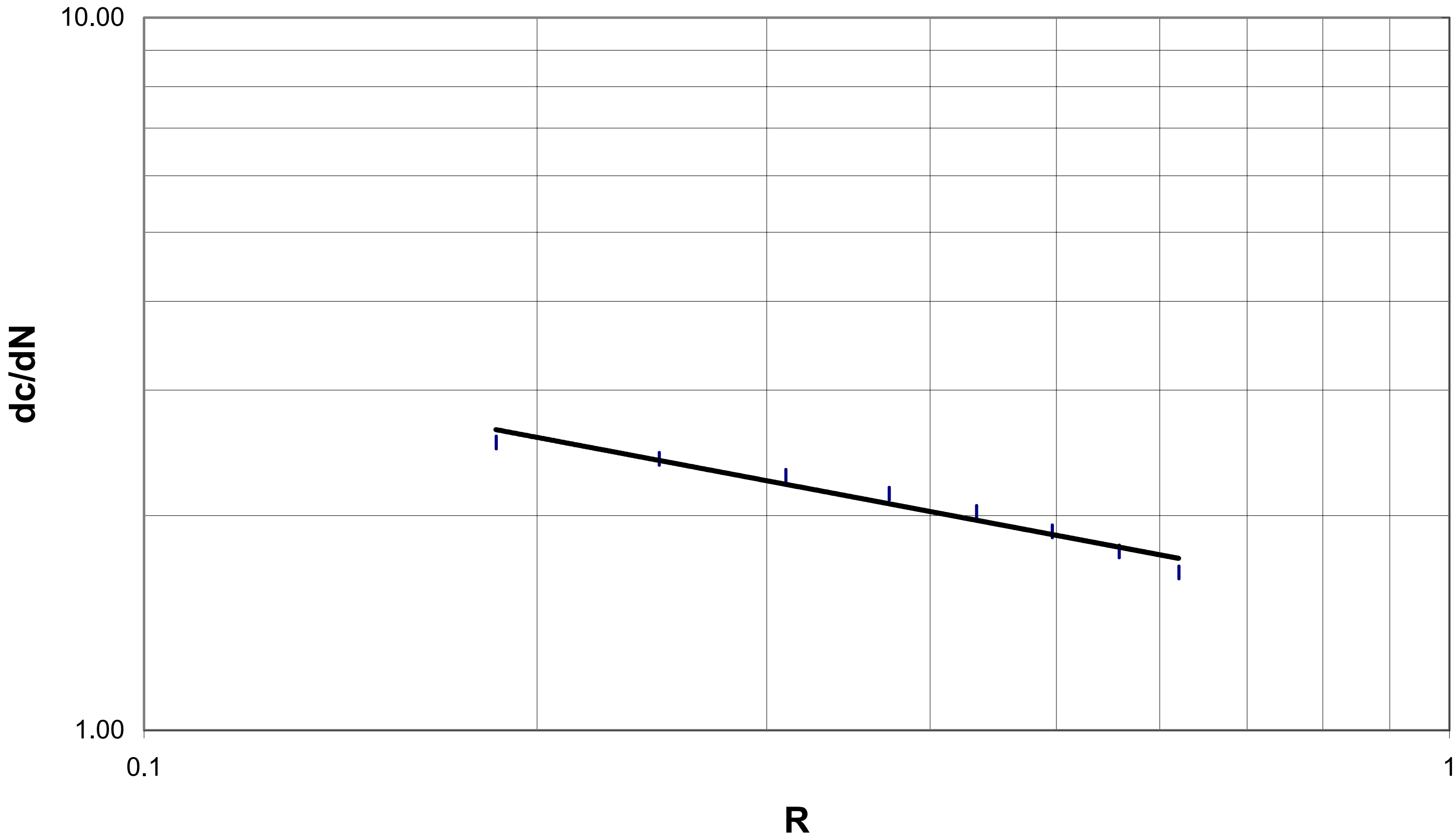

Figure C23. Rate of Crack Growth (dc/dN) versus the Reinforcing Factor (R) for Specimen C-12.

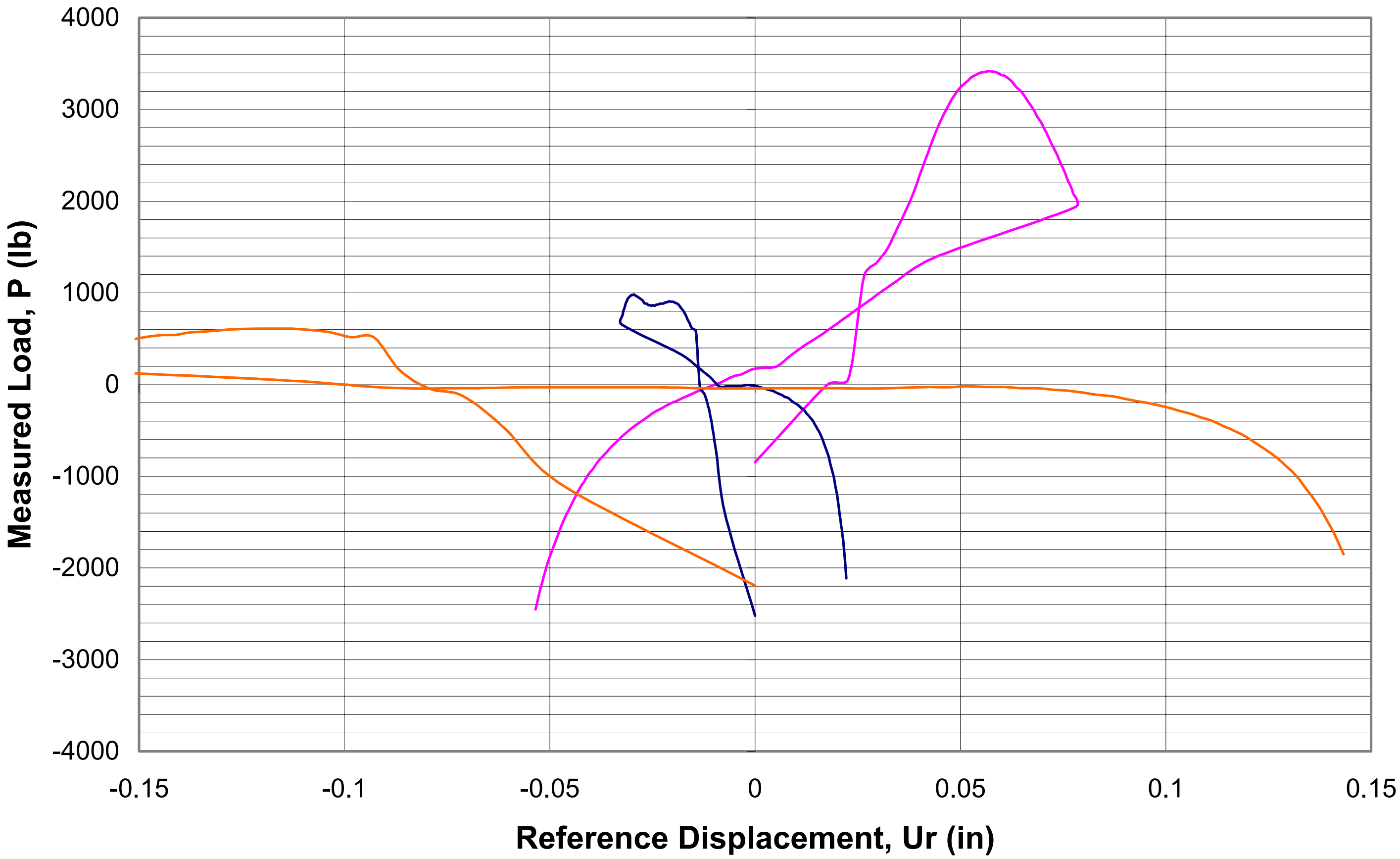

Figure C24. Measured Load versus Reference Displacement used to Calculate Pseudo Strain Energy for Specimen C-12.

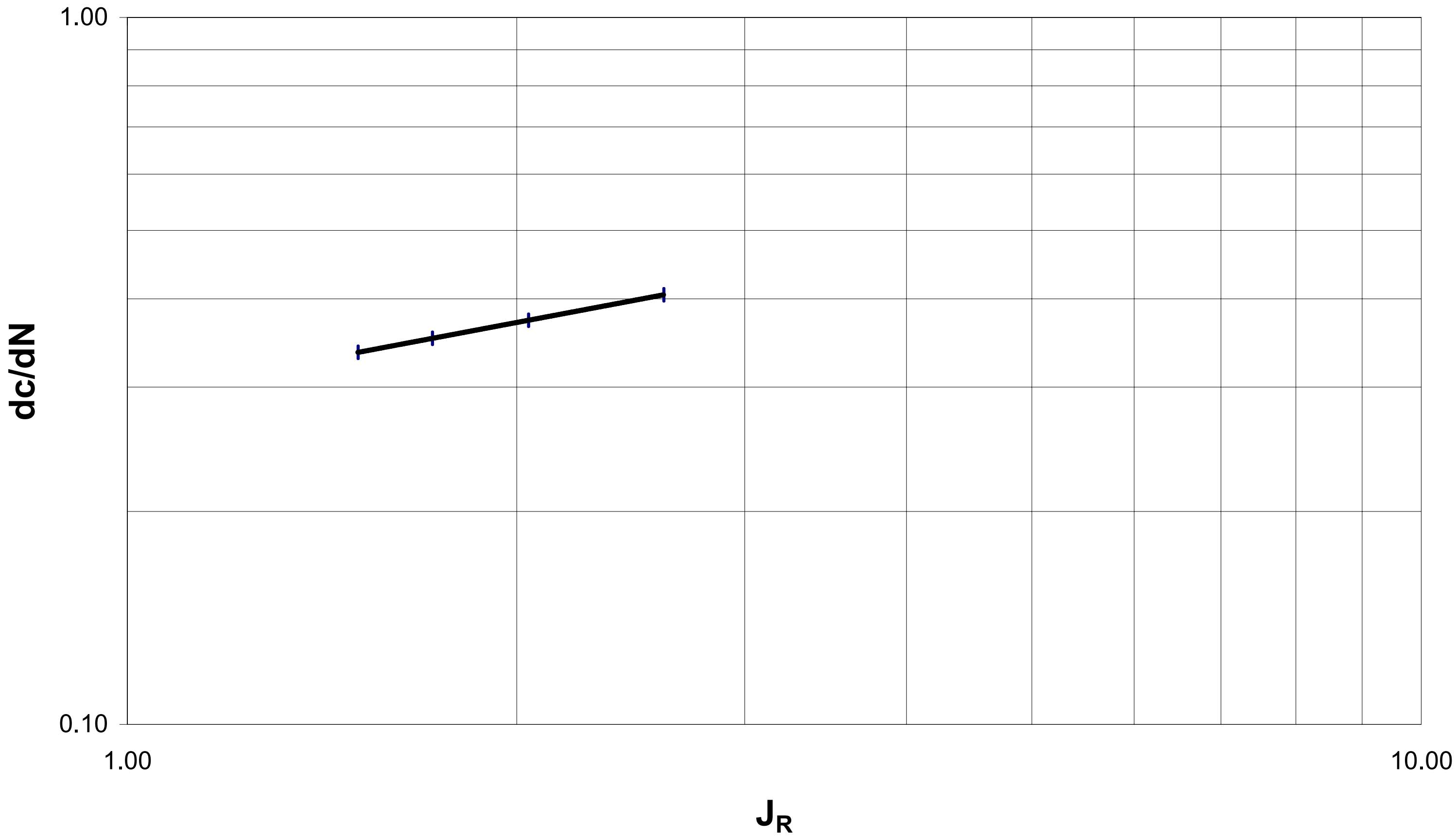

Figure C25. Rate of Crack Growth (dc/dN) versus the Pseudo J-Integral (J_R) for Specimen B-25.

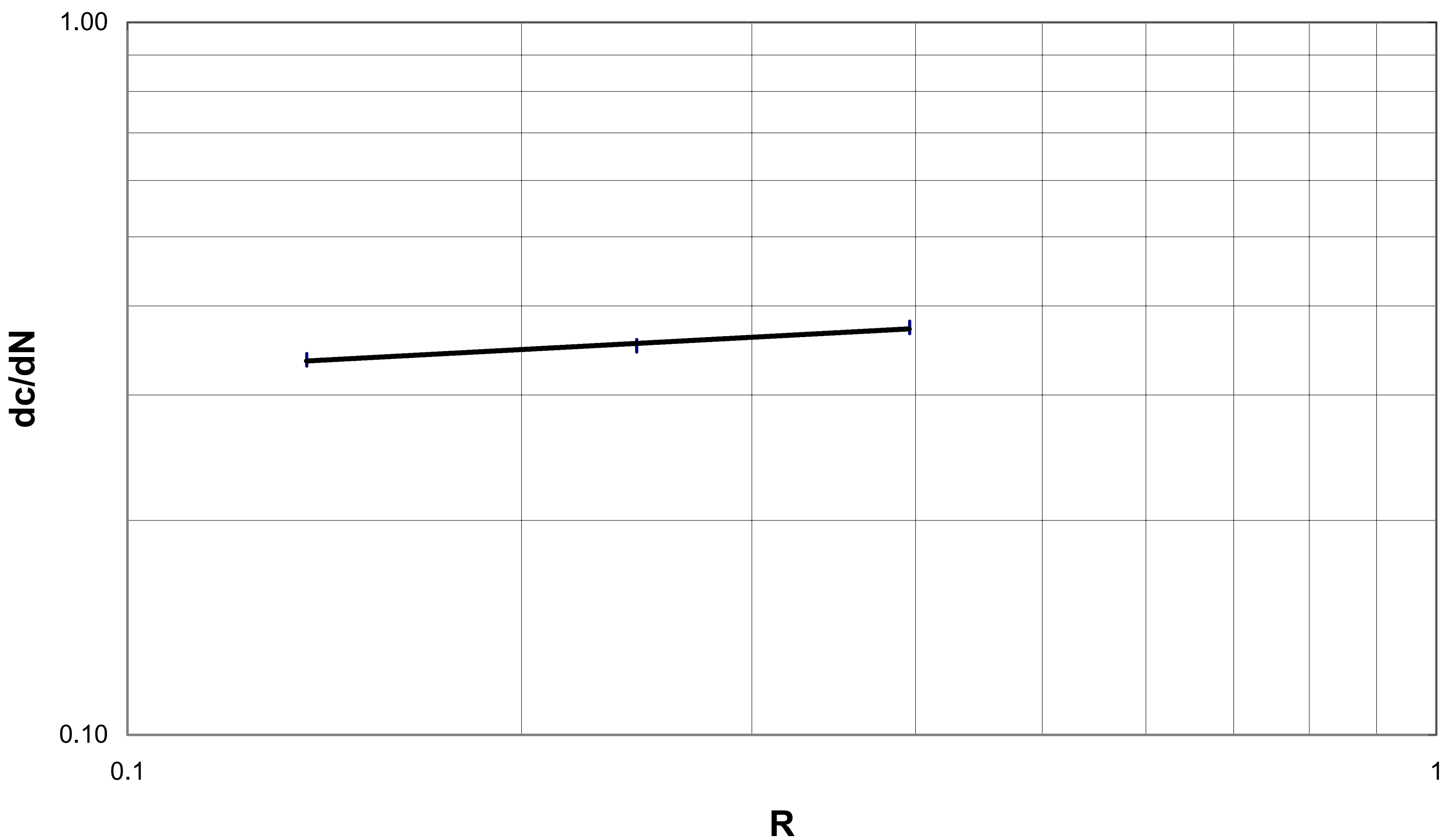

Figure C26. Rate of Crack Growth (dc/dN) versus the Reinforcing Factor (R) for Specimen B-25.

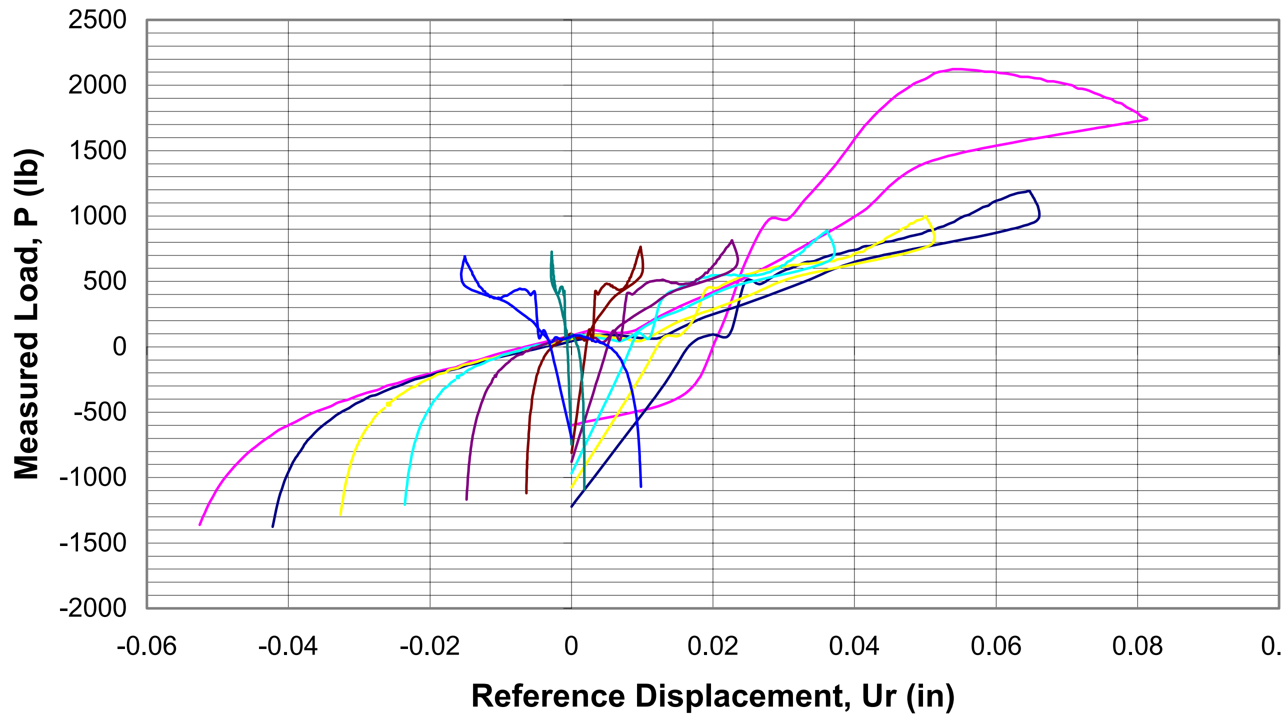

Figure C27. Measured Load versus Reference Displacement used to Calculate Pseudo Strain Energy for Specimen B-25.

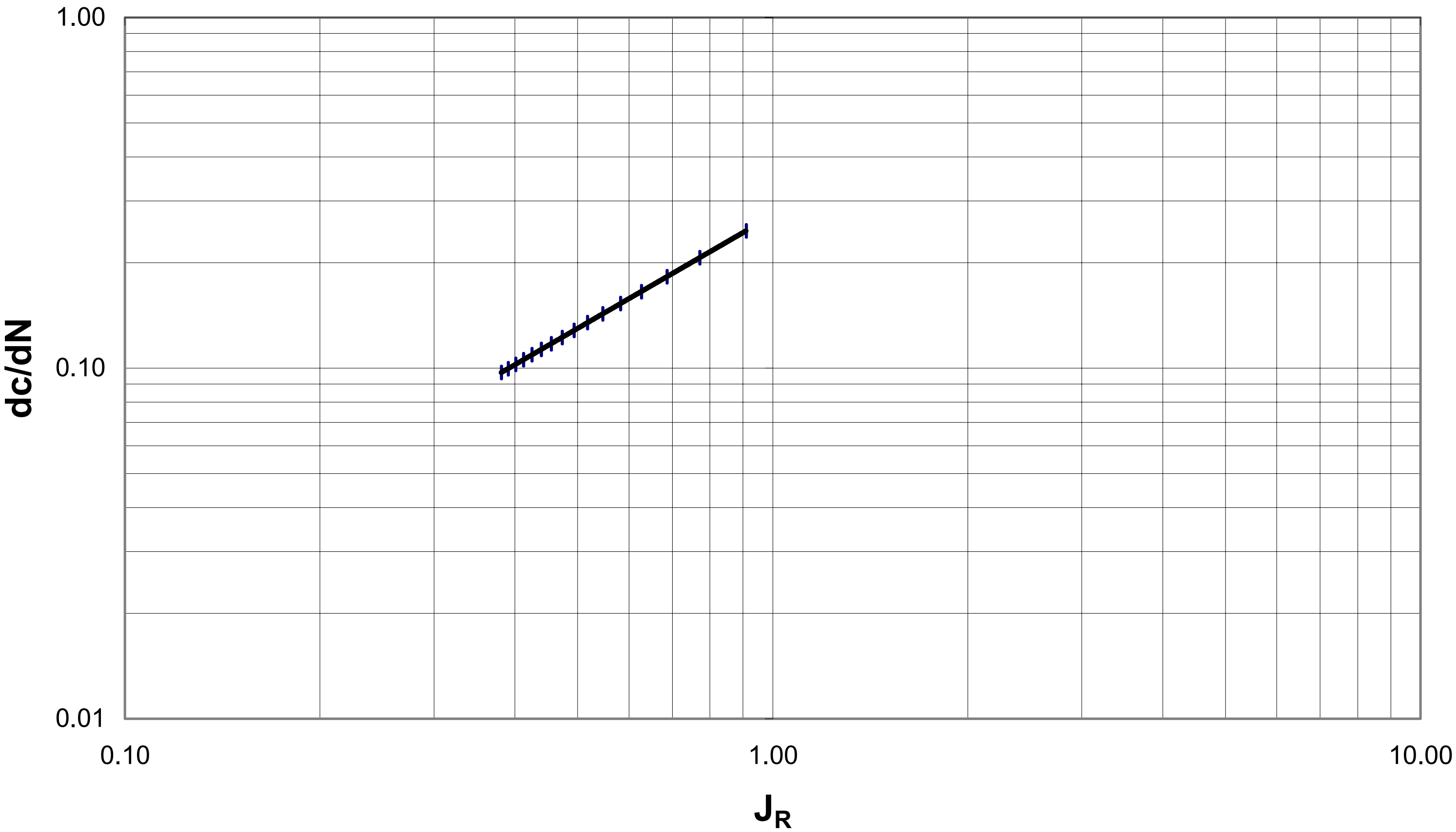

Figure C28. Rate of Crack Growth (dc/dN) versus the Pseudo J-Integral (J_R) for Specimen PD3-14.

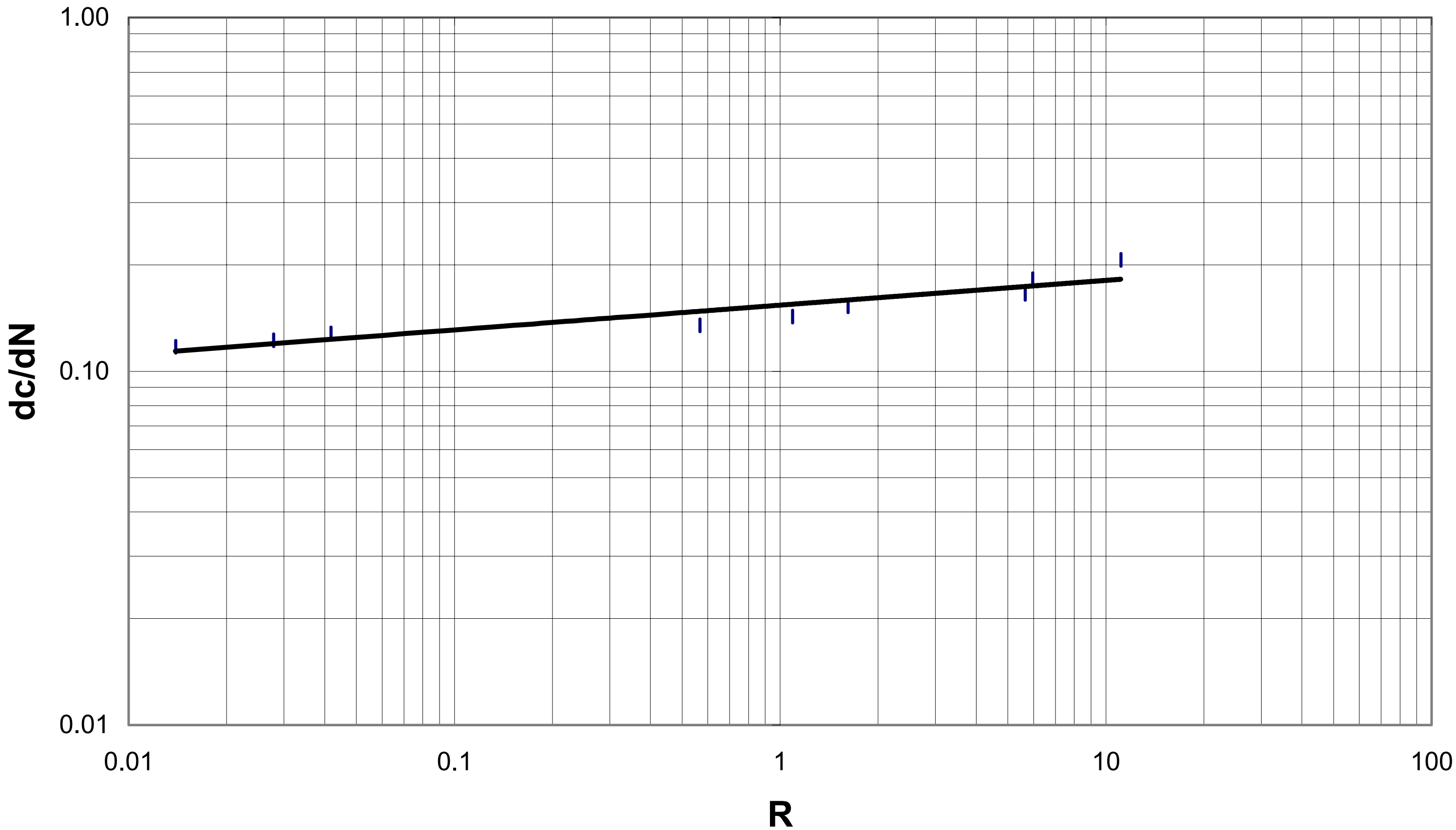

Figure C29. Rate of Crack Growth (dc/dN) versus the Reinforcing Factor (R) for Specimen PD3-14.

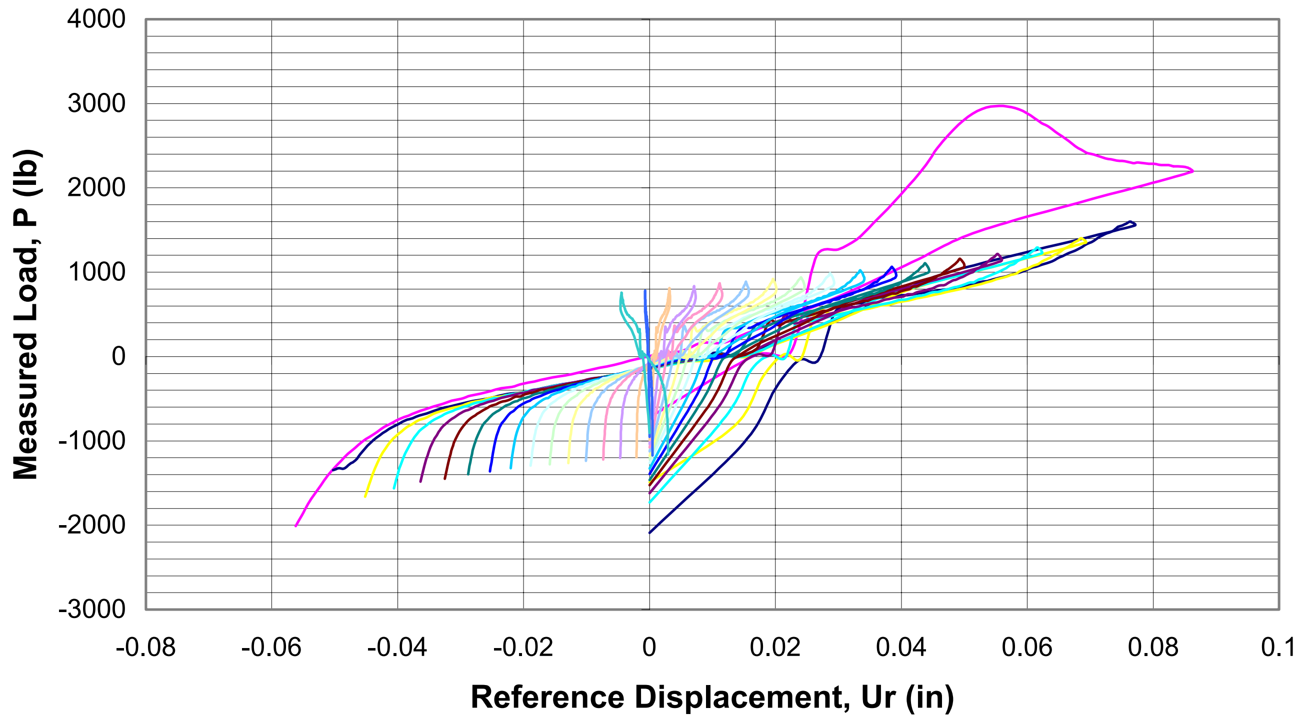

Figure C30. Measured Load versus Reference Displacement used to Calculate Pseudo Strain Energy for Specimen PD3-14.

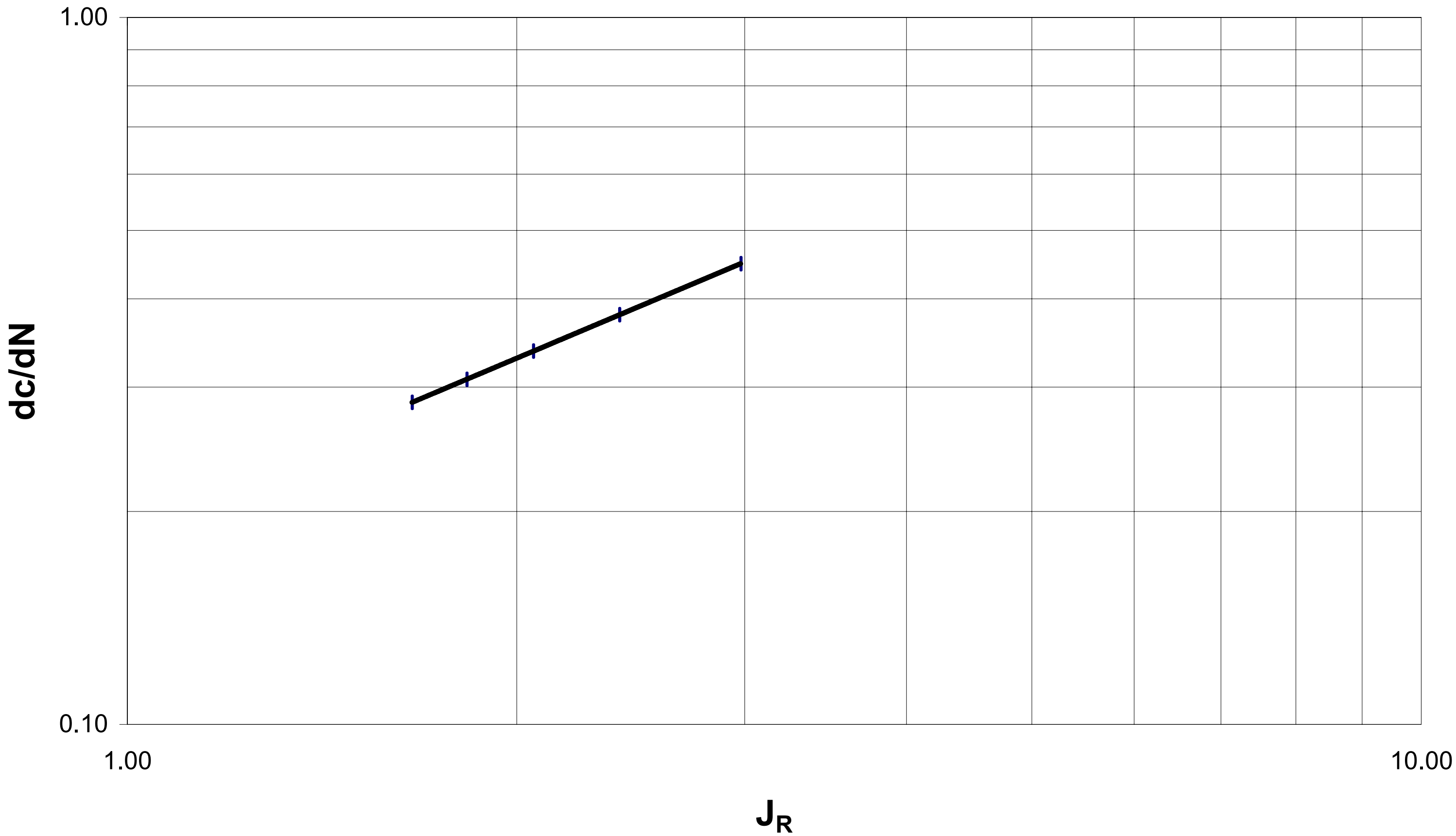

Figure C31. Rate of Crack Growth (dc/dN) versus the Pseudo J-Integral (J_R) for Specimen HC-32.

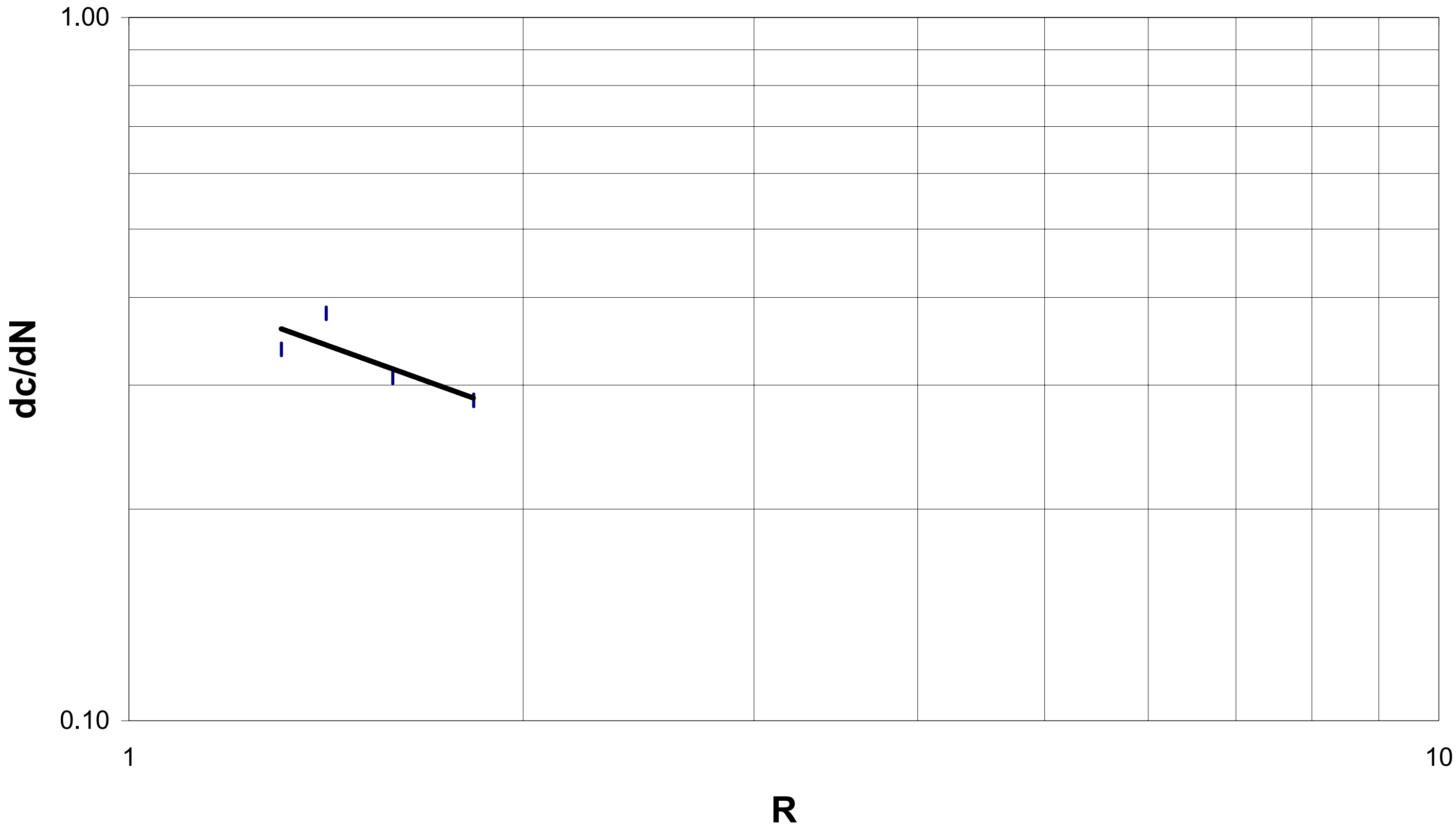

Figure C32. Rate of Crack Growth (dc/dN) versus the Reinforcing Factor (R) for Specimen HC-32.

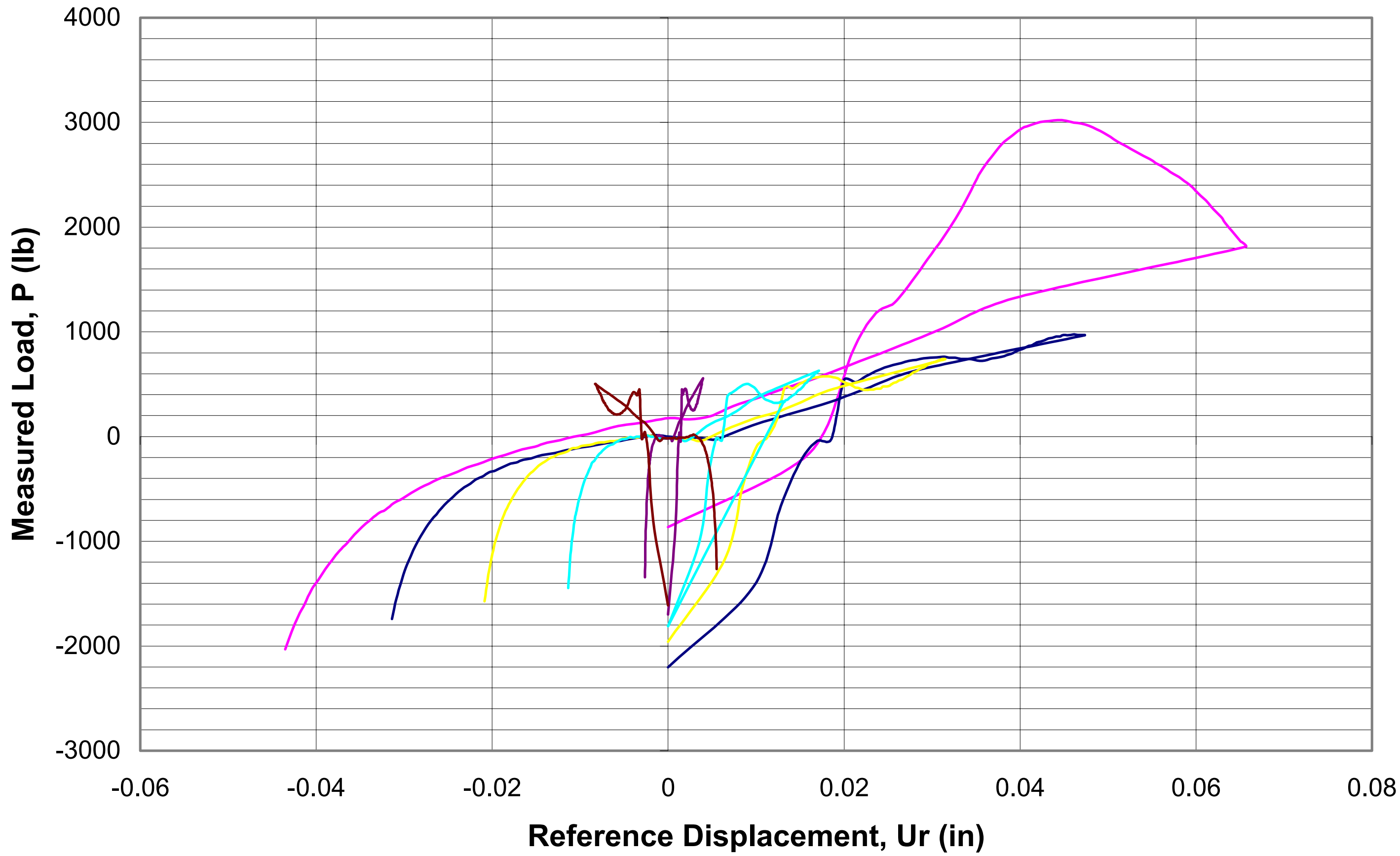

Figure C33. Measured Load versus Reference Displacement used to Calculate Pseudo Strain Energy for Specimen HC-32.

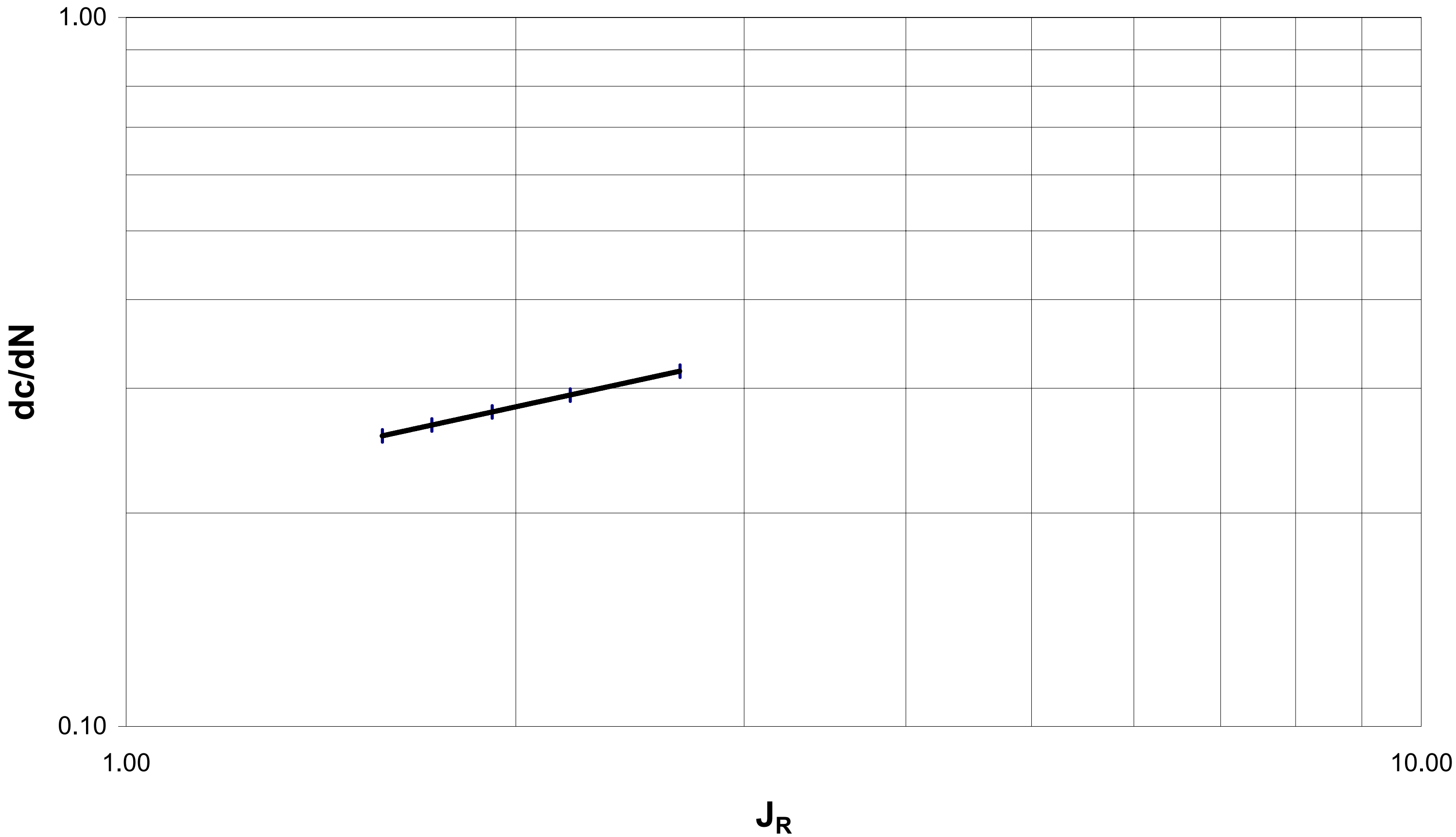

Figure C34. Rate of Crack Growth (dc/dN) versus the Pseudo J-Integral (J_R) for Specimen PG2-18.

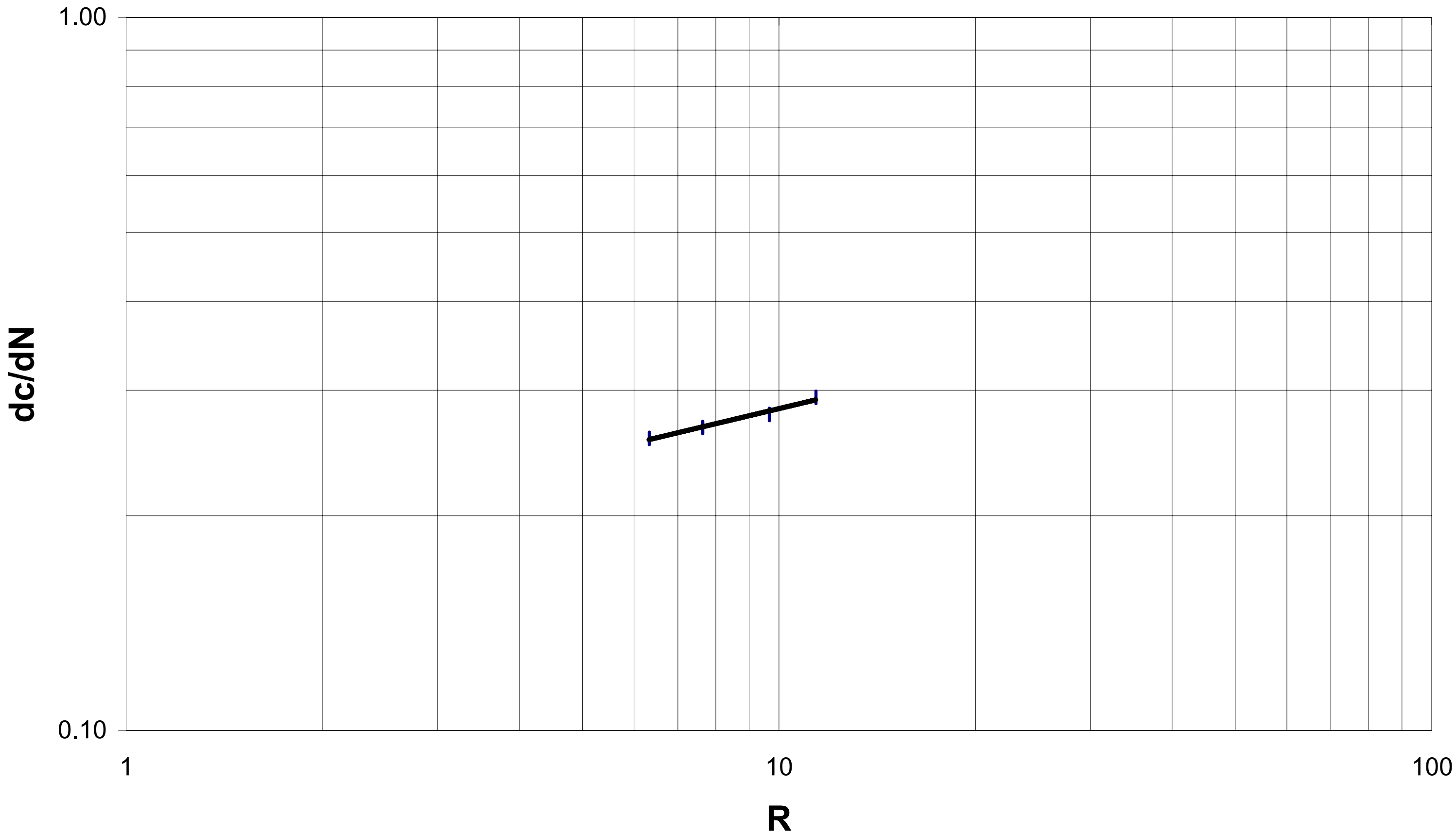

Figure C35. Rate of Crack Growth (dc/dN) versus the Reinforcing Factor (R) for Specimen PG2-18.

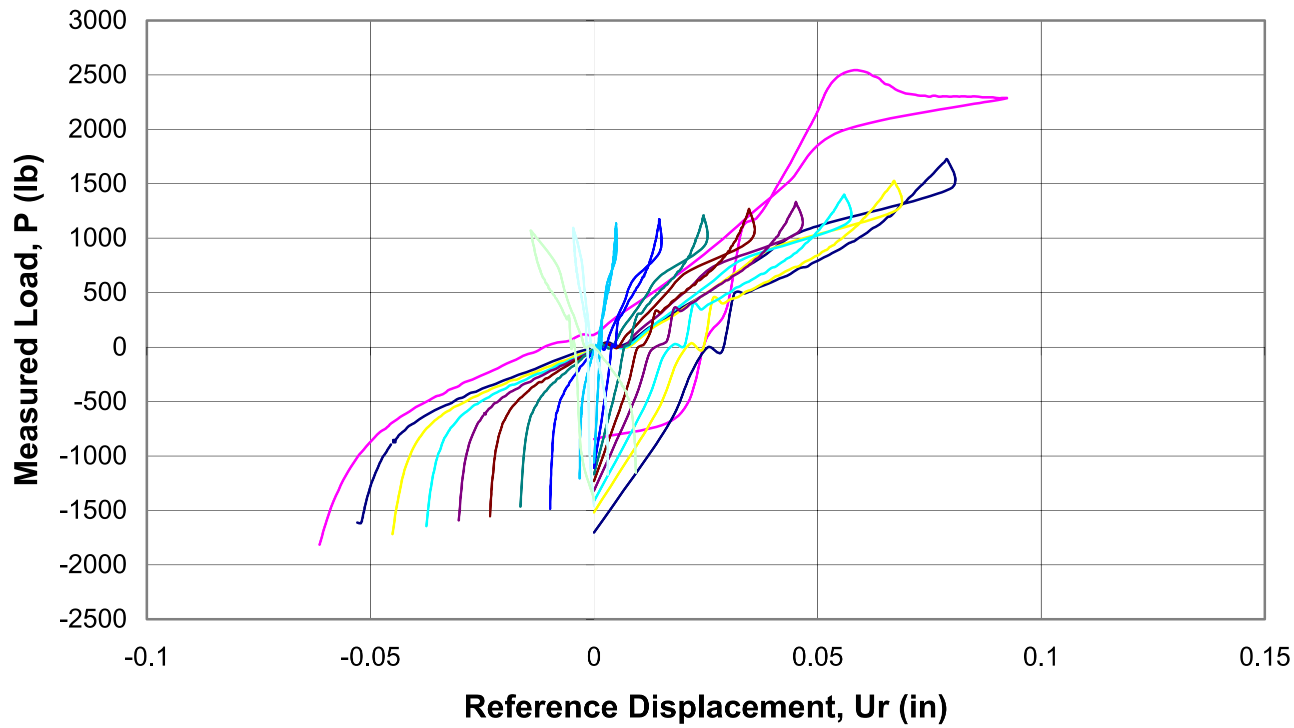

Figure C36. Measured Load versus Reference Displacement used to Calculate Pseudo Strain Energy for Specimen PG2-18.

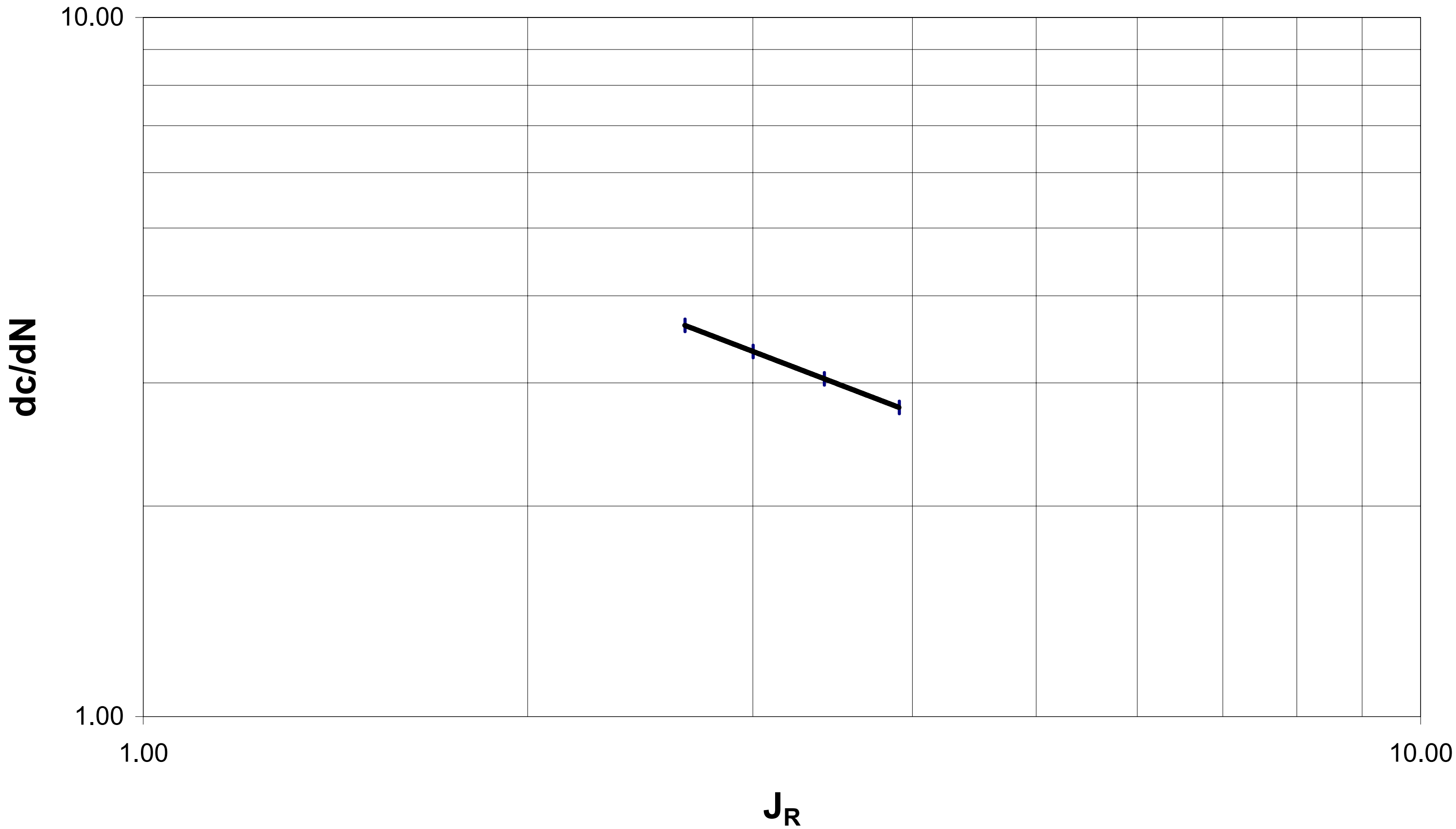

Figure C37. Rate of Crack Growth (dc/dN) versus the Pseudo J-Integral (J_R) for Specimen C-38.

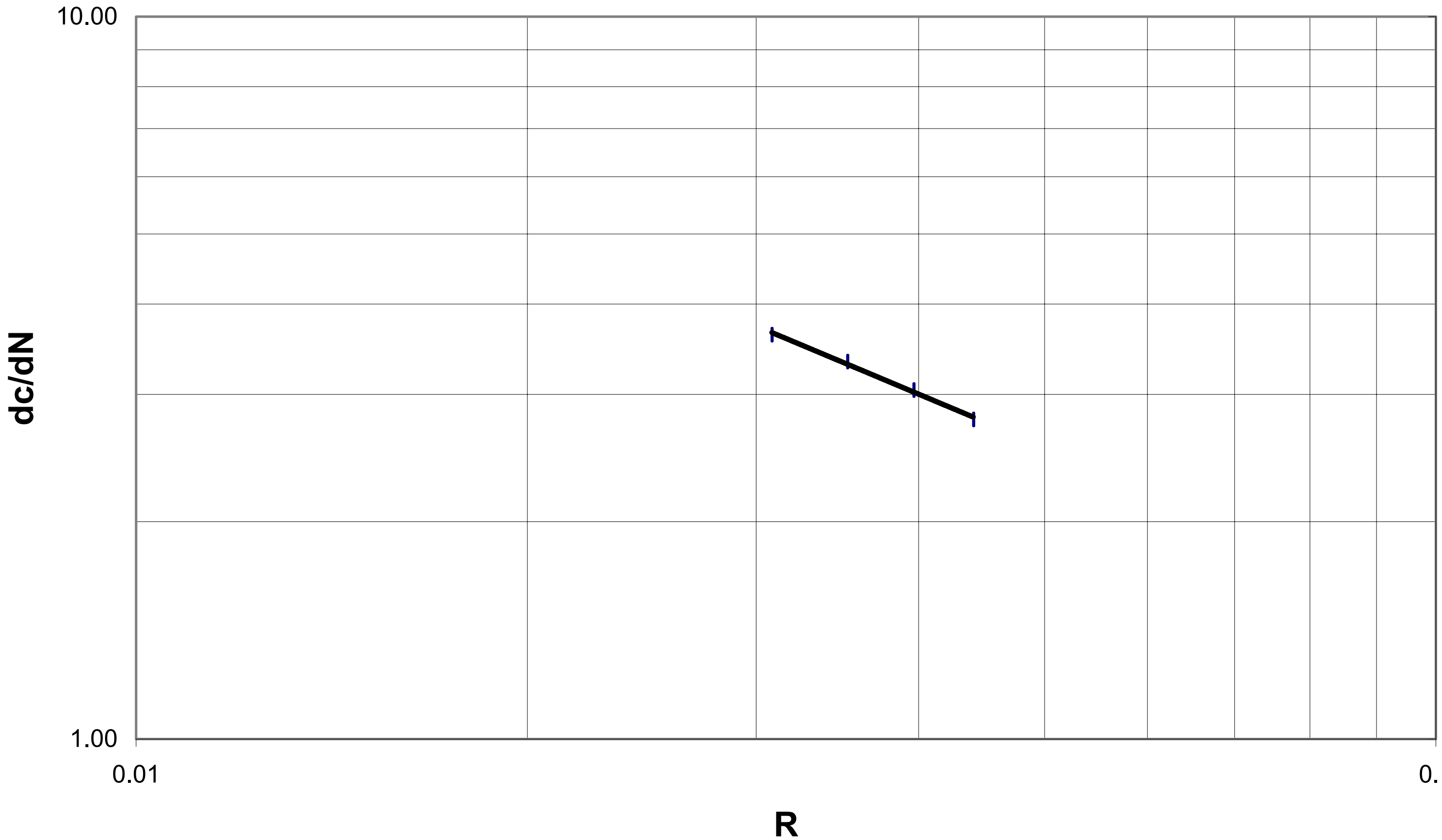

Figure C38. Rate of Crack Growth (dc/dN) versus the Reinforcing Factor (R) for Specimen C-38.

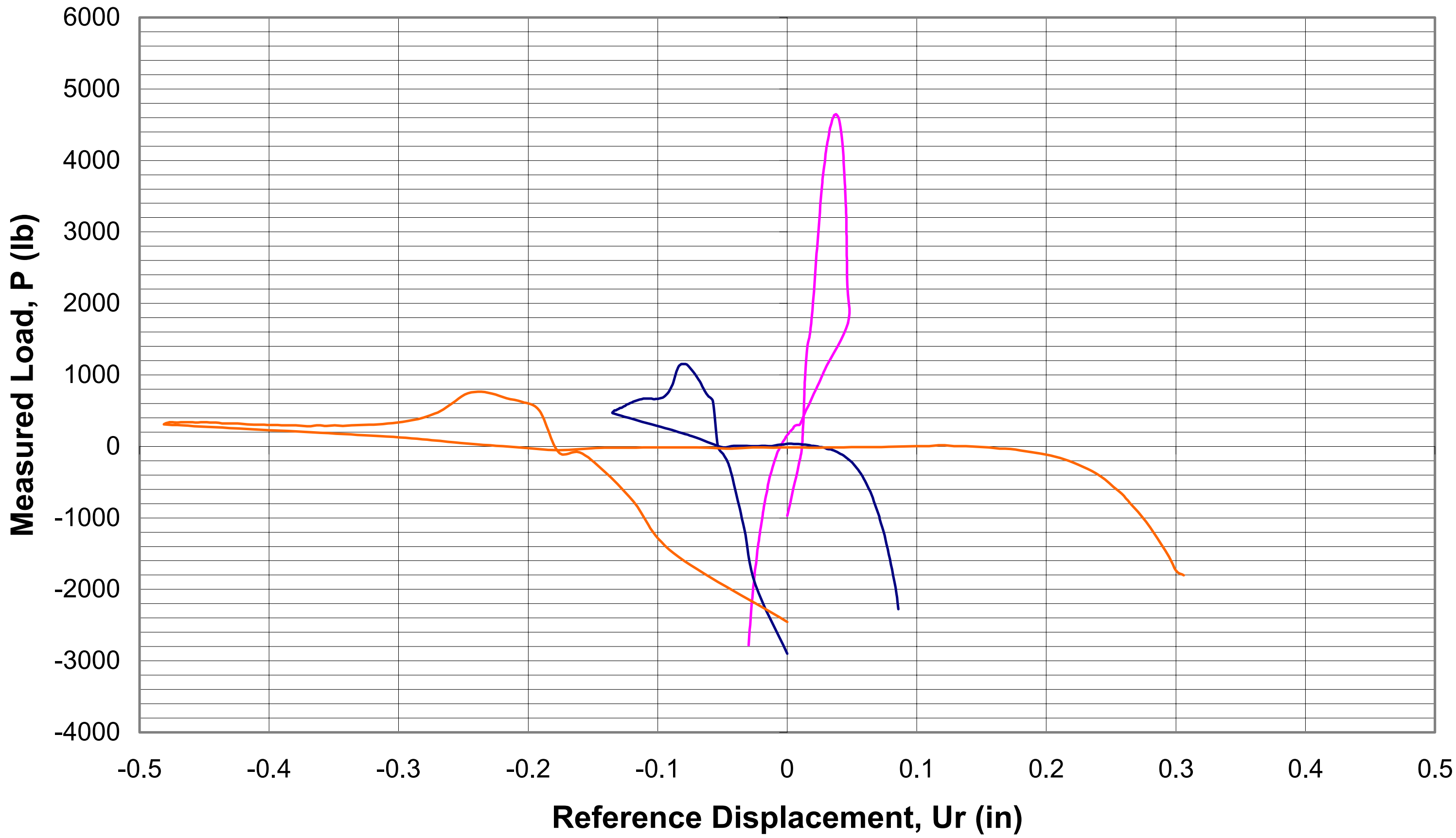

Figure C39. Measured Load versus Reference Displacement used to Calculate Pseudo Strain Energy for Specimen C-38.

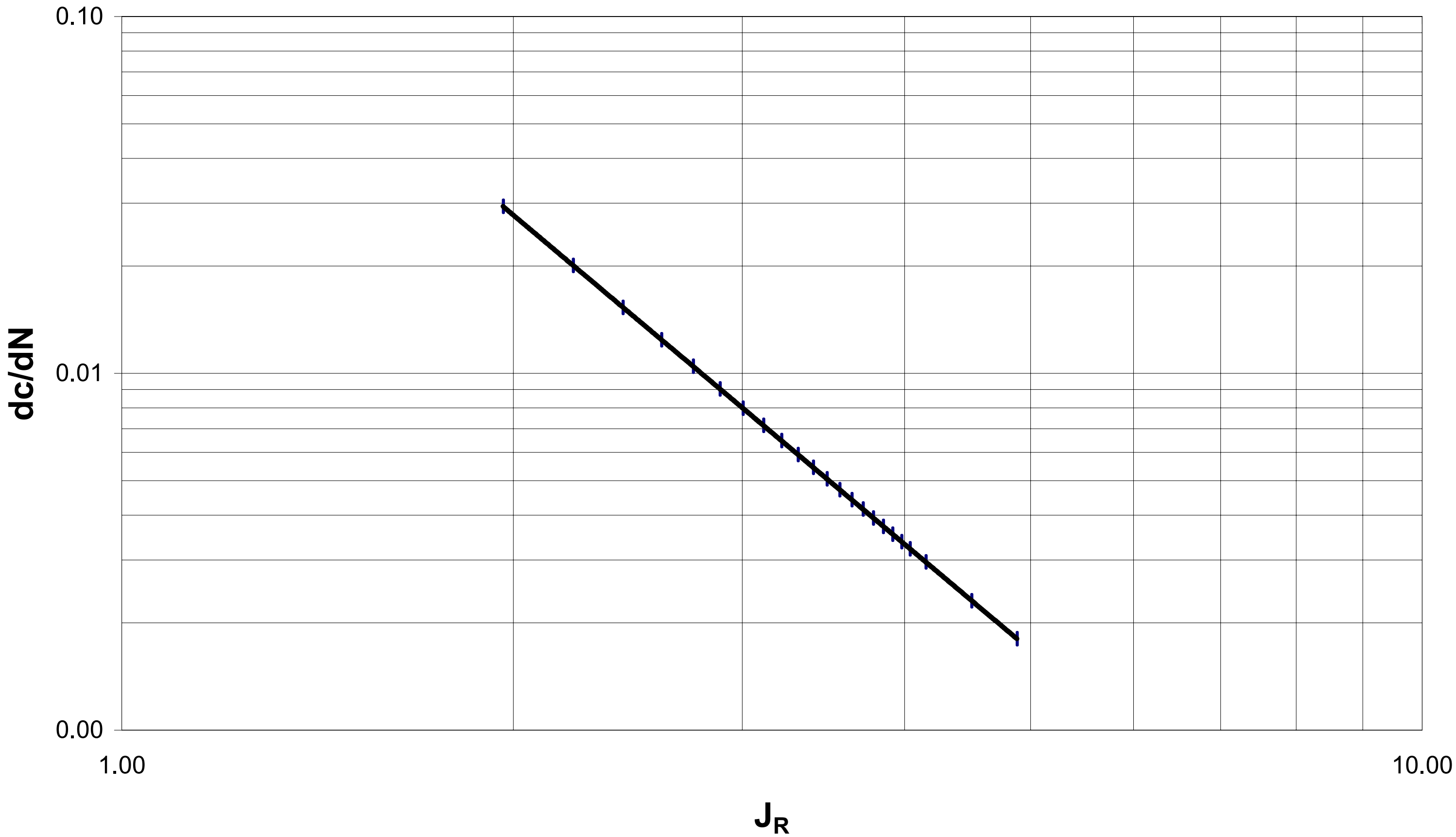

Figure C40. Rate of Crack Growth (dc/dN) versus the Pseudo J-Integral (J_R) for Specimen S-28.

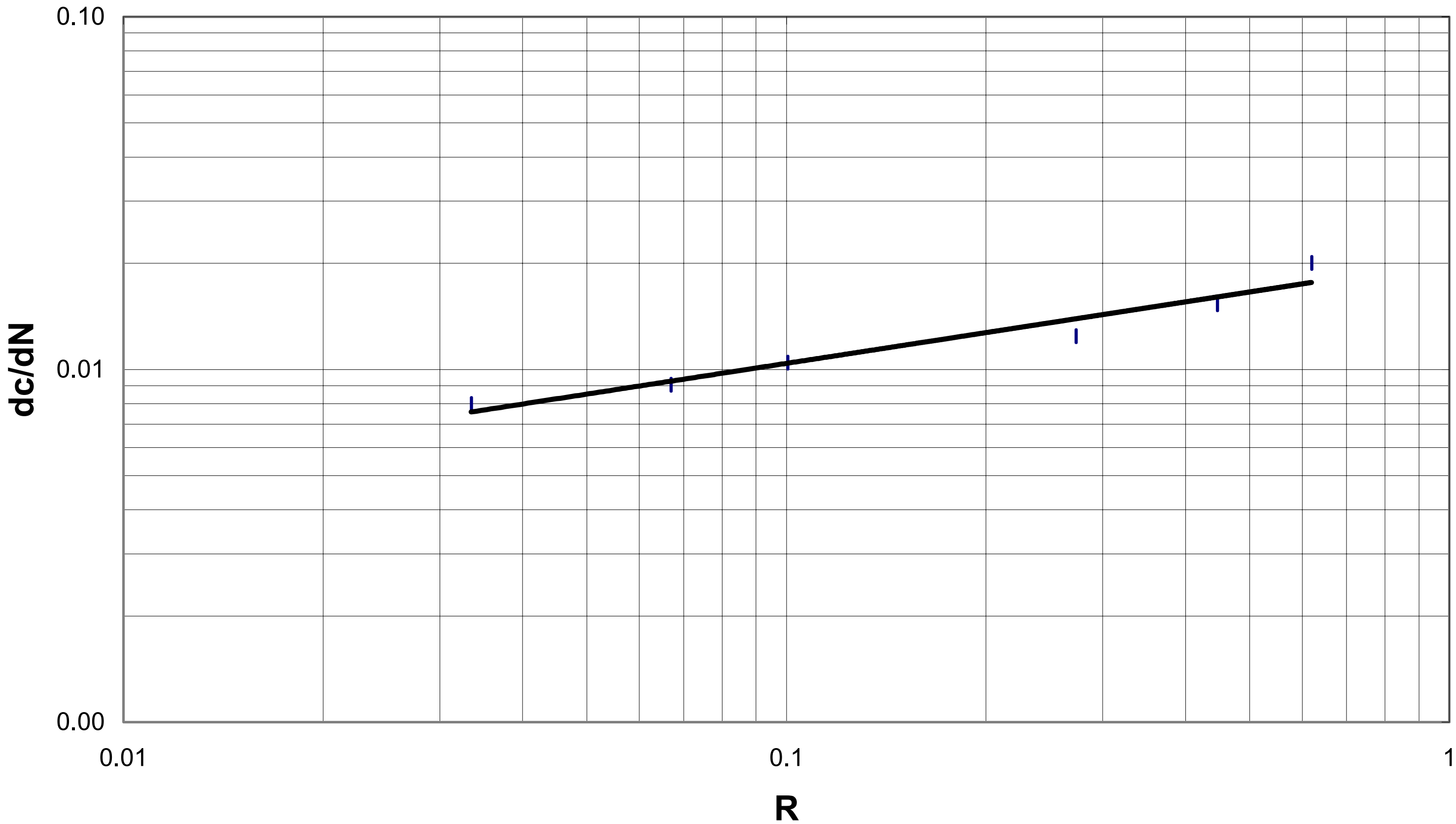

Figure C41. Rate of Crack Growth (dc/dN) versus the Reinforcing Factor (R) for Specimen S-28.

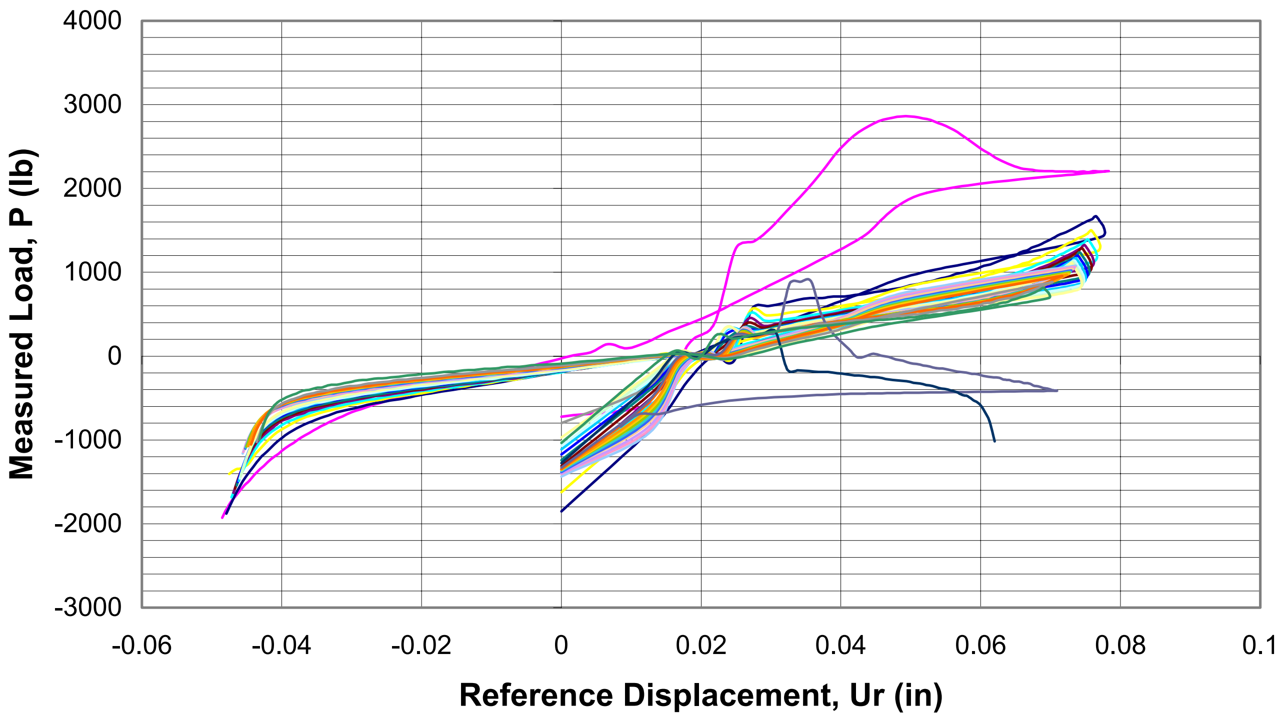

Figure C42. Measured Load versus Reference Displacement used to Calculate Pseudo Strain Energy for Specimen S-28.

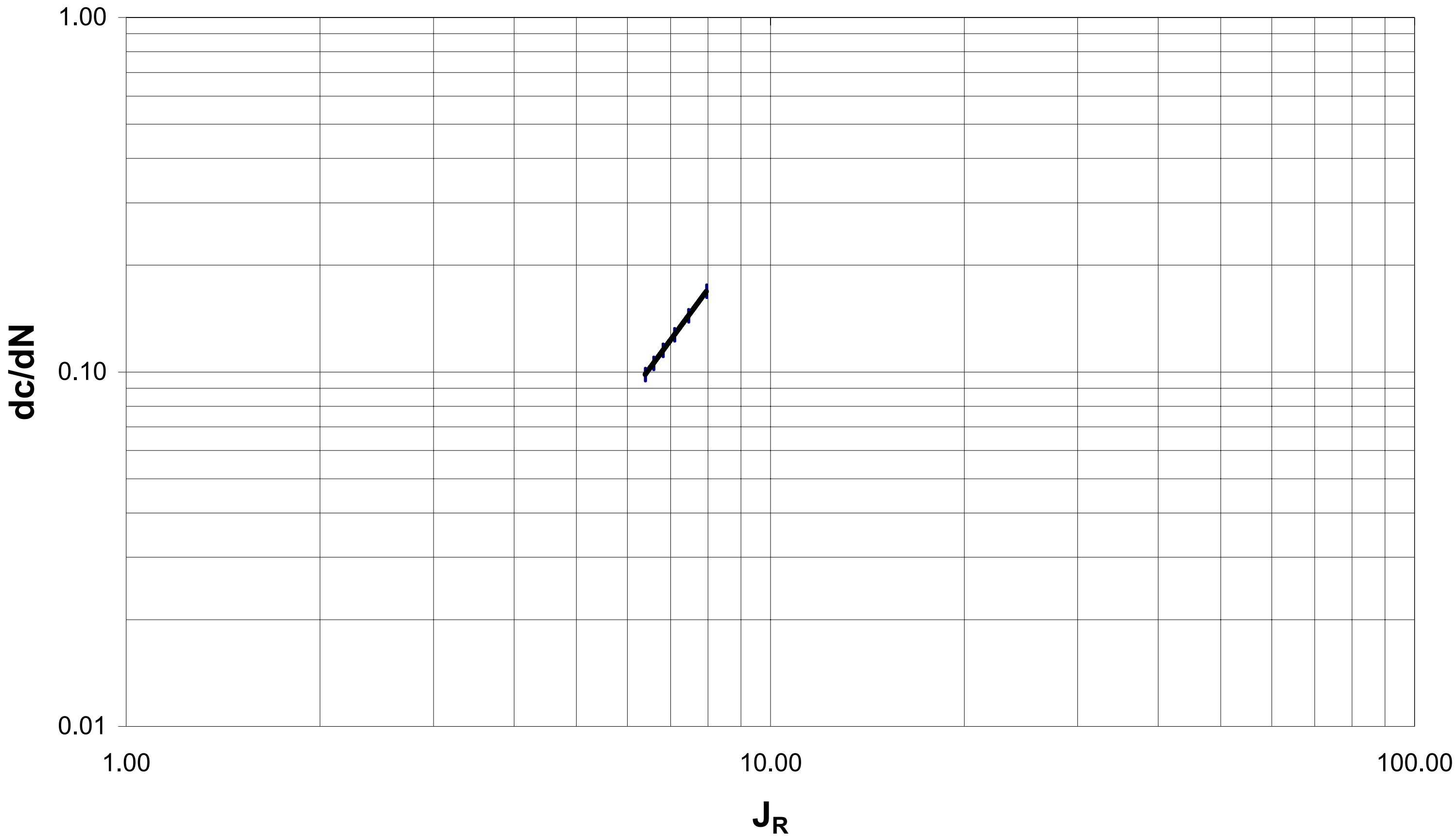

Figure C43. Rate of Crack Growth (dc/dN) versus the Pseudo J-Integral (J_R) for Specimen G-35.

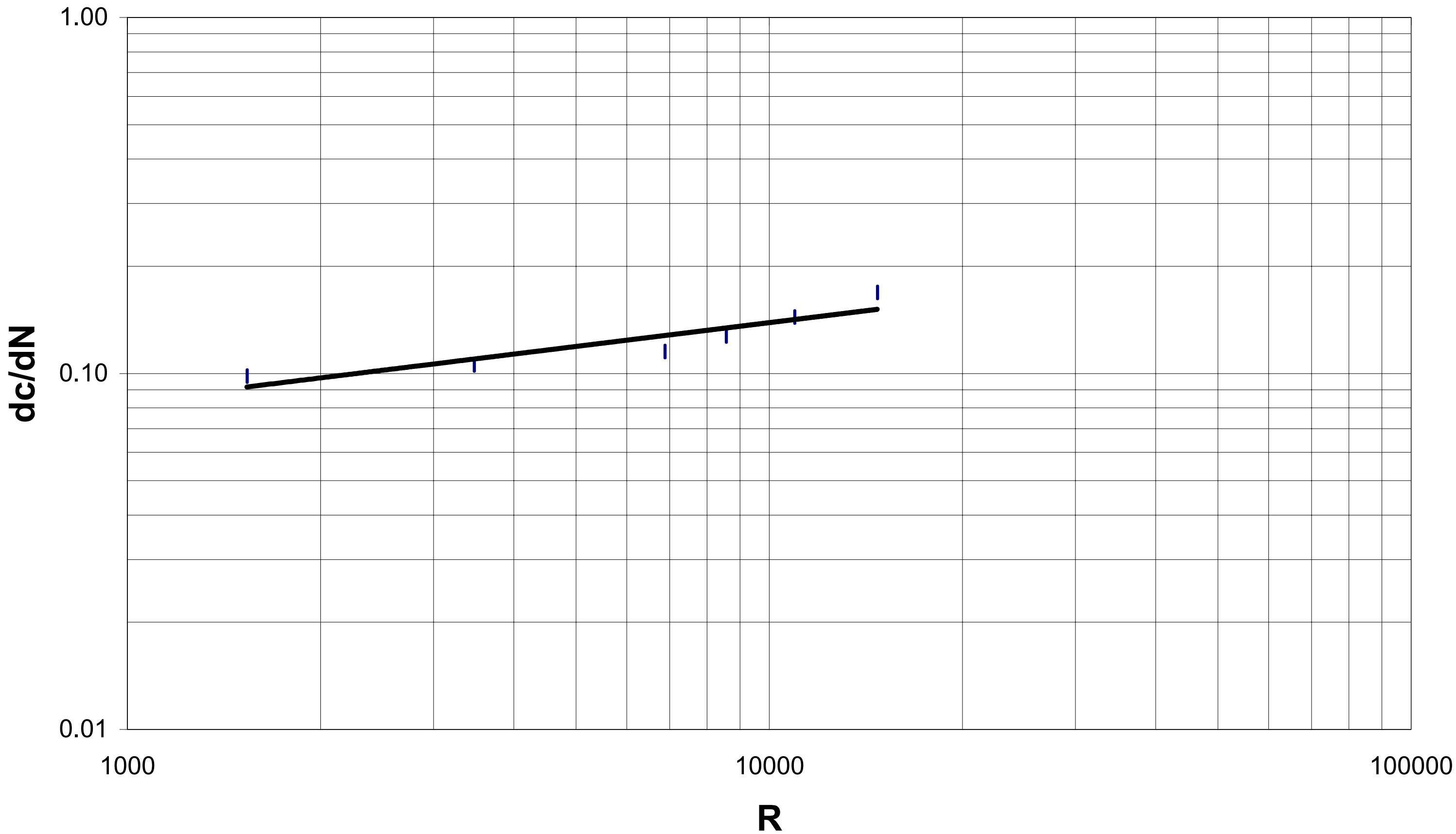

Figure C44. Rate of Crack Growth (dc/dN) versus the Reinforcing Factor (R) for Specimen G-35.

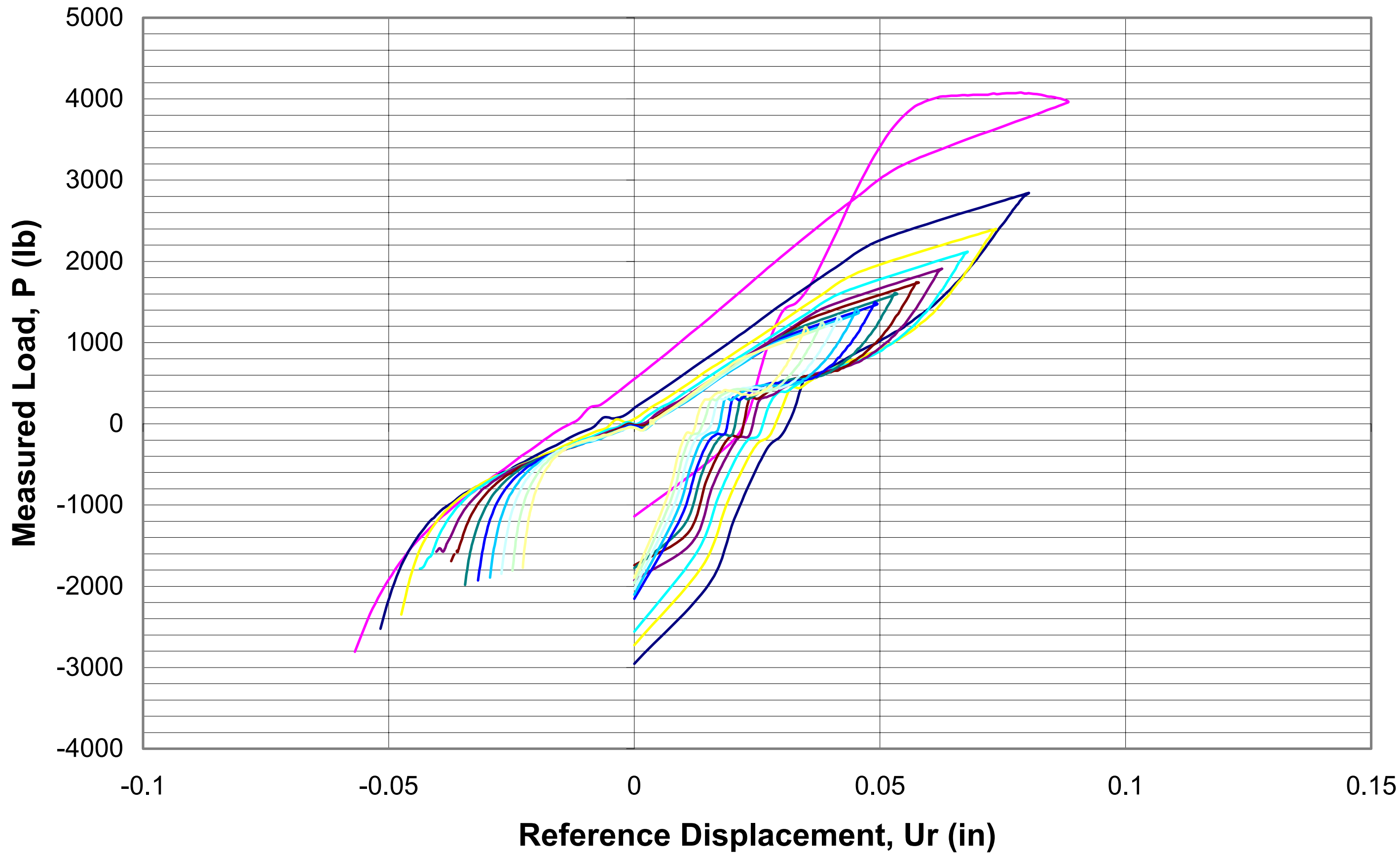

Figure C45. Measured Load versus Reference Displacement used to Calculate Pseudo Strain Energy for Specimen G-35.

APPENDIX D

CASE HISTORIES FOR LOOP 12 (DALLAS DISTRICT) AND IH 35 (LAREDO DISTRICT)

Case History – Loop 12

TxDOT Dallas District

General

In 1998, the Dallas District of the Texas Department of Transportation (TxDOT) rehabilitated Loop 12, or Northwest Highway, in Dallas County. This roadway was experiencing severe reflective cracking in the HMA overlay that was placed over a jointed concrete pavement with 15-foot transverse joint spacings. Roadway expansion limitations and high traffic volumes prohibited the district from performing extensive reconstruction. Therefore, the district decided to use an alternative rehabilitation technique of using a geocomposite material with a thin HMA overlay. This type of geosynthetic material and rehabilitation procedure has been purported to aid in the reduction of reflective cracking in HMA overlays when placed over existing distressed asphaltic or jointed concrete pavements.

In short, the eastbound direction of Loop12 experienced severe reflective cracking of all transverse joints immediately after the geocomposite material was installed. As a result of this and other failures in the state, Mr. Michael Behrens, P.E., issued a memorandum on August 14, 2000, (Exhibit D1) advising all districts to "suspend the use of geocomposites for asphalt concrete pavement reinforcement until the research is completed and issues of performance and benefit are answered." This case history is written to provide information and lessons learned from this project and provide recommendations for future use of geosynthetic products. This case history is divided into two sections according to plan development and control-section-job (CSJ) identifications.

Project CSJ: 0353-05-098 From Douglas Avenue to Boedeker Street

In November of 1998, the Northwest Dallas Area Office let plans to rehabilitate 2.2 miles of Loop 12 (Northwest Highway) from Boedeker Street West to Douglas Avenue as shown in Figure D1. To orient the reader, Douglas Avenue is just east of the

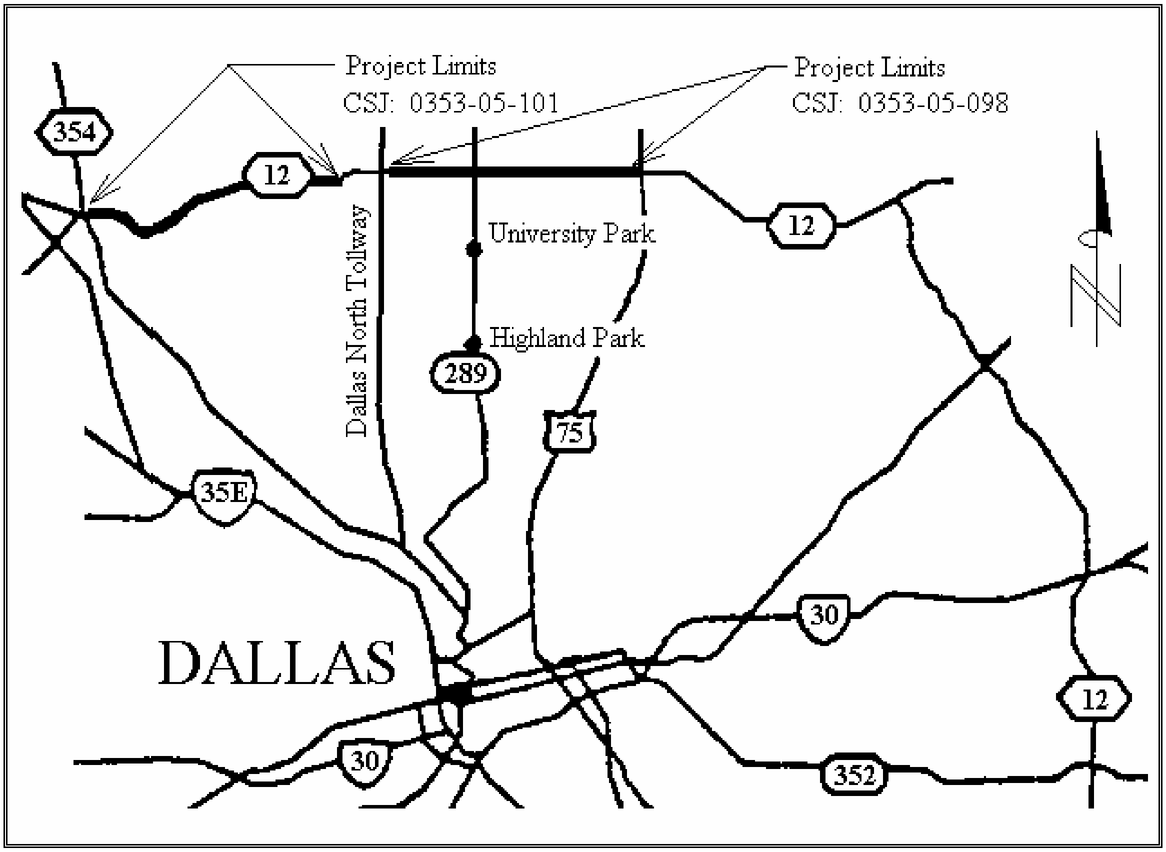

Figure D1. Site Map for Loop 12 in Dallas County, Texas Indicating Project Limits.

Dallas North Tollway, US 289 is called Preston Road, and Boedeker Street is just west of US 75.

The existing roadway consisted of a 64-foot curb and gutter (72 feet including turning lanes) divided urban arterial roadway with a variable-width raised center median. The existing pavement structure consisted of a 10-inch jointed concrete pavement – contraction design (CPCD) with 1.5 inches of an HMA surface course. Due to joint movement of the underlying concrete pavement, substantial reflective cracking existed within the HMA layer as shown in Figure D2.

Total reconstruction to remove the underlying concrete pavement was considered improbable due to right-of-way constraints in this heavily urbanized area of Dallas. Additionally, high traffic volumes (see Table D-1) existed on this roadway that would undoubtedly exacerbate reconstruction efforts. Therefore, plans were developed

Figure D2. Existing Reflective Cracking on Northwest Highway.

Table D1. Traffic Data for LOOP 12 in Dallas County, Texas.

Travel Lane Direction	Data Limits	Average Daily Traffic (ADT)	20-year 18-kip Equivalent Single Axle Loads (ESAL) x 10^6
Eastbound	from Tollway to Boedecker	25,000 to 28,500	3.521 to 4.492
Westbound	from Boedecker to Tollway	25,000 to 28,500	3.521 to 4.492

for rehabilitation that included milling the existing HMA surface, performing full-depth concrete repairs and joint waterproofing, as necessary, placement of a geocomposite material, and placement of a 2-inch Type C HMA overlay.

The geocomposite material used during construction was Bitutex Composite manufactured by Synteen USA. This material is constructed of a woven/coated polyester grid with a nonwoven fabric material attached. This material is attached to the existing jointed concrete pavement using AC-20 tack coat at an application rate of 0.25 gallon per square yard. Special Specification 3129 was used on this project as the governing specification. This specification is similar to SS 3168 (Exhibit D2) that was used on project CSJ: 0353-05-101 Denton Drive to West of Midway Road. The asphalt cement for the Type C surface course was specified as a PG 76-22.

Eastbound Construction Procedures

The following steps were used to rehabilitate the eastbound direction of Loop 12.

1. Mill the existing 1.5-inch HMA to the concrete surface.
2. Perform full-depth concrete repairs according to Standard Specification Item 361 and plan details, as needed.
3. Waterproof joints in concrete pavement (24-inch width) according to Special Specification 3024 as needed.
4. Clean existing surface and apply AC-20 tack coat to the concrete surface at the application rate of 0.25 gal/yd^2.
5. Install Bitutex Composite material with nonwoven fabric side down.
6. Place and compact 2 inches of Type C HMA surface course.

The roadway was opened to traffic prior to the application of the tack coat and geocomposite material. Consequently, construction personnel observed that the concrete spalled at the joints as shown in Figure D3 (scale exaggerated). When the geocomposite material was spanned across the joints, a void was produced. As a result, there was not 100 percent bond between the geocomposite material and the concrete surface. This, along with compaction equipment and traffic loading, caused high shear stresses, and immediate reflective cracking occurred at all of the transverse joints as shown in Figure D4.

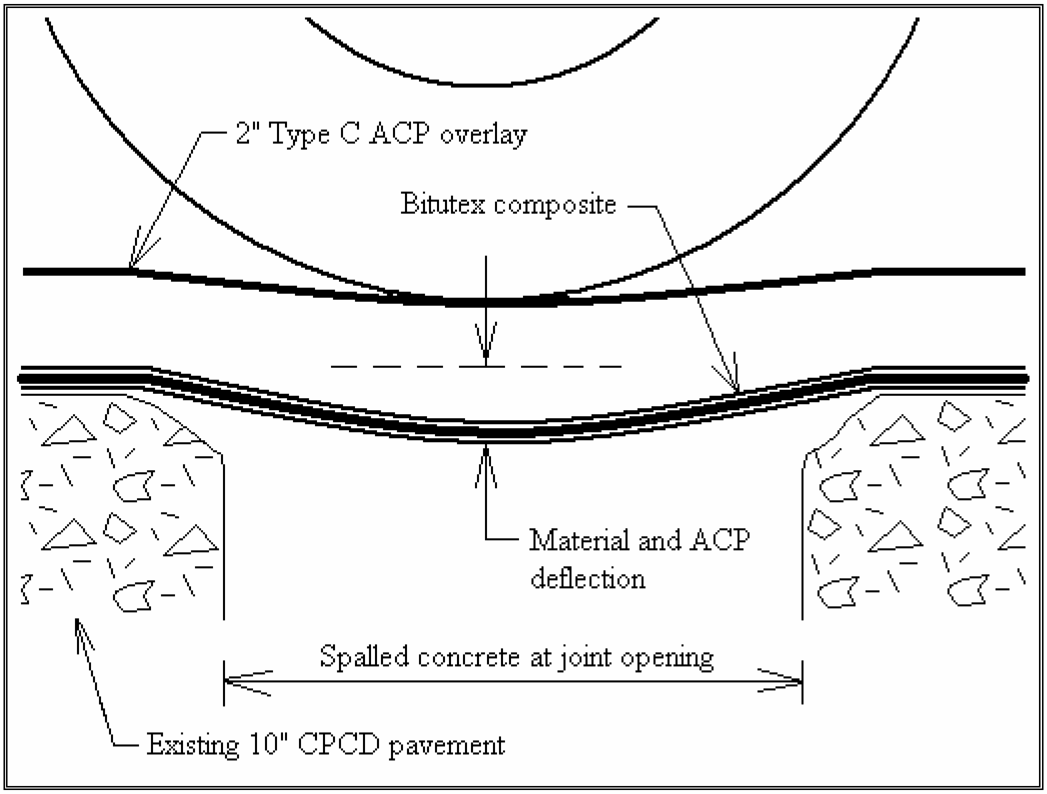

Figure D3. Schematic of Deflection of Geocomposite Material over Concrete Joint.

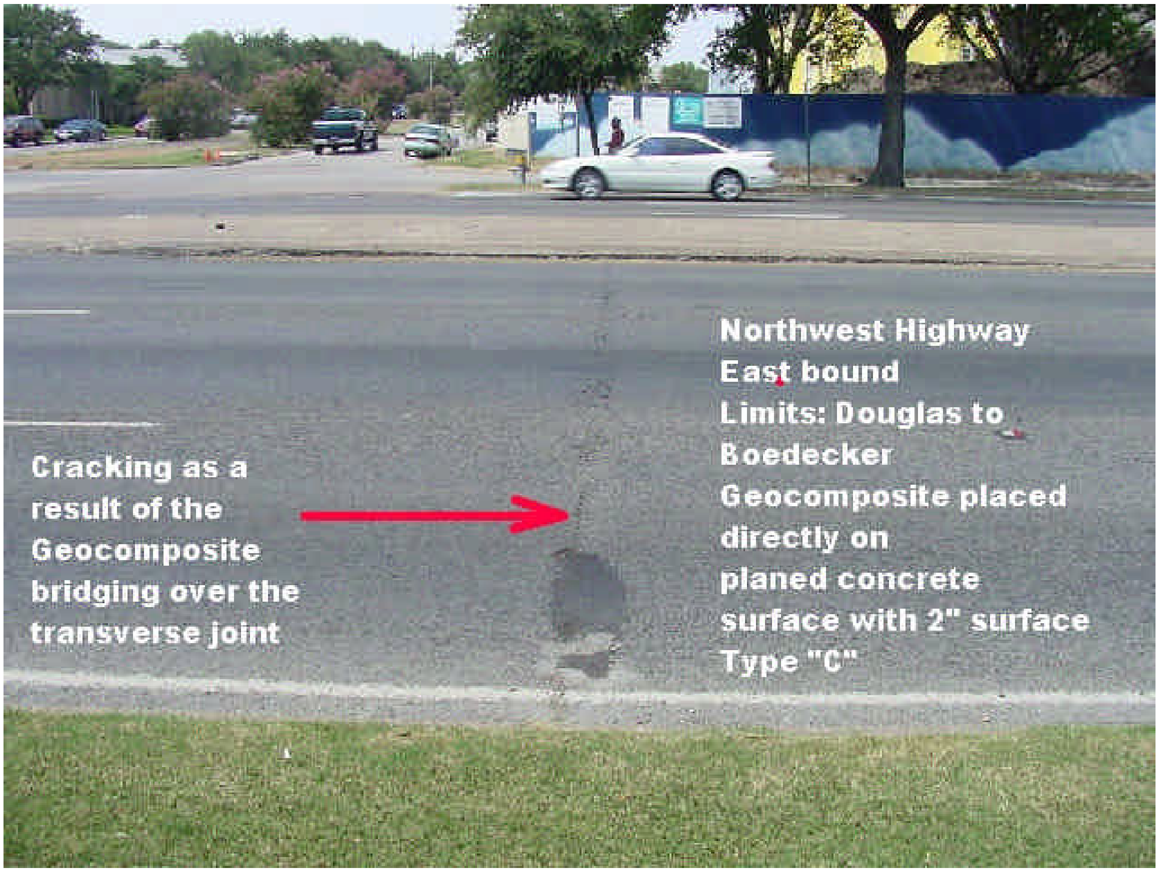

Figure D4. Transverse Reflection Cracks in the Eastbound Direction of Loop 12.

Westbound Construction Procedures

During the westbound construction phase of Loop 12, a decision was made to place a 3/4-inch Type D level-up course to provide a smooth, void-free area for which to install the geocomposite material. As anticipated, the fine-grained mixture filled in the voided areas. When the geocomposite material was placed on this firm, level foundation, reflective cracking at the transverse joints, to date, has been eliminated. Figure D5 shows the transverse cracks in the eastbound direction stopping at the median opening where the ¾-inch level-up course was placed in the westbound direction. After approximately two years of service, reflective cracking in the westbound direction has not been observed as shown in Figure D6.

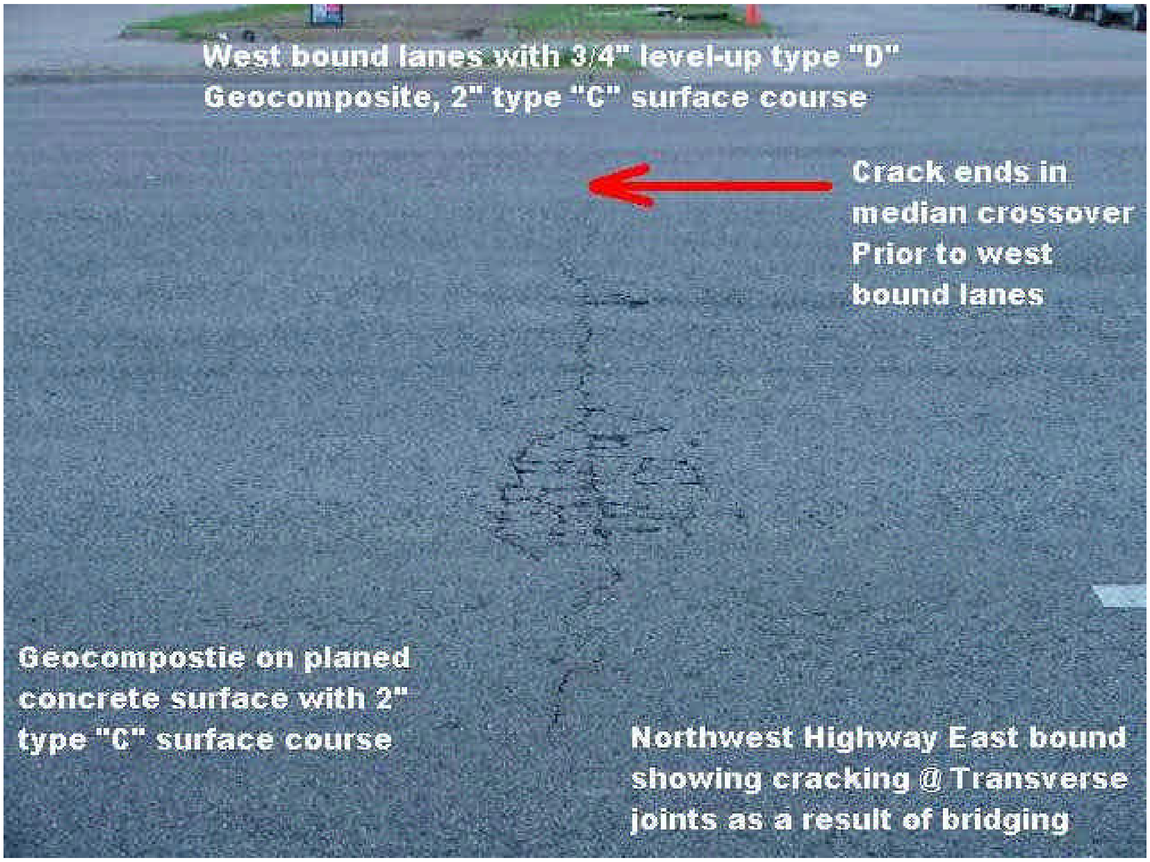

Figure D5. Transverse Cracks Stopping Due to Placement of Level-up Course.

Project CSJ: 0353-05-101 Denton Drive to West of Midway Road

Due to the success of the westbound construction on the previous project, the Northwest Dallas Area Office decided in November 1999 to rehabilitate an additional 2.6 miles of Loop 12 from Denton Drive to West of Midway Road. Referring to Figure D1 for this project location, US 354 is called Harry Hines Boulevard, Denton Drive is just east of US 354, and Midway Road is west of the Dallas North Tollway. The existing pavement structure and construction procedures were identical to project CSJ 0353-05-098 except that the 3/4-inch Type D level-up course was specified in the plans.

Figure D6. Westbound Direction of Loop 12 after One Year of Service.

During the letting phase of this project, concerns arose over the geocomposite material specification, which resulted in the geocomposite being removed from the plans. Therefore, the roadway was constructed with a 3/4-inch Type D HMA level-up course followed by a 2-inch Type C HMA surface course. Figure D7 shows the reflective cracks that occurred after approximately six months of service.

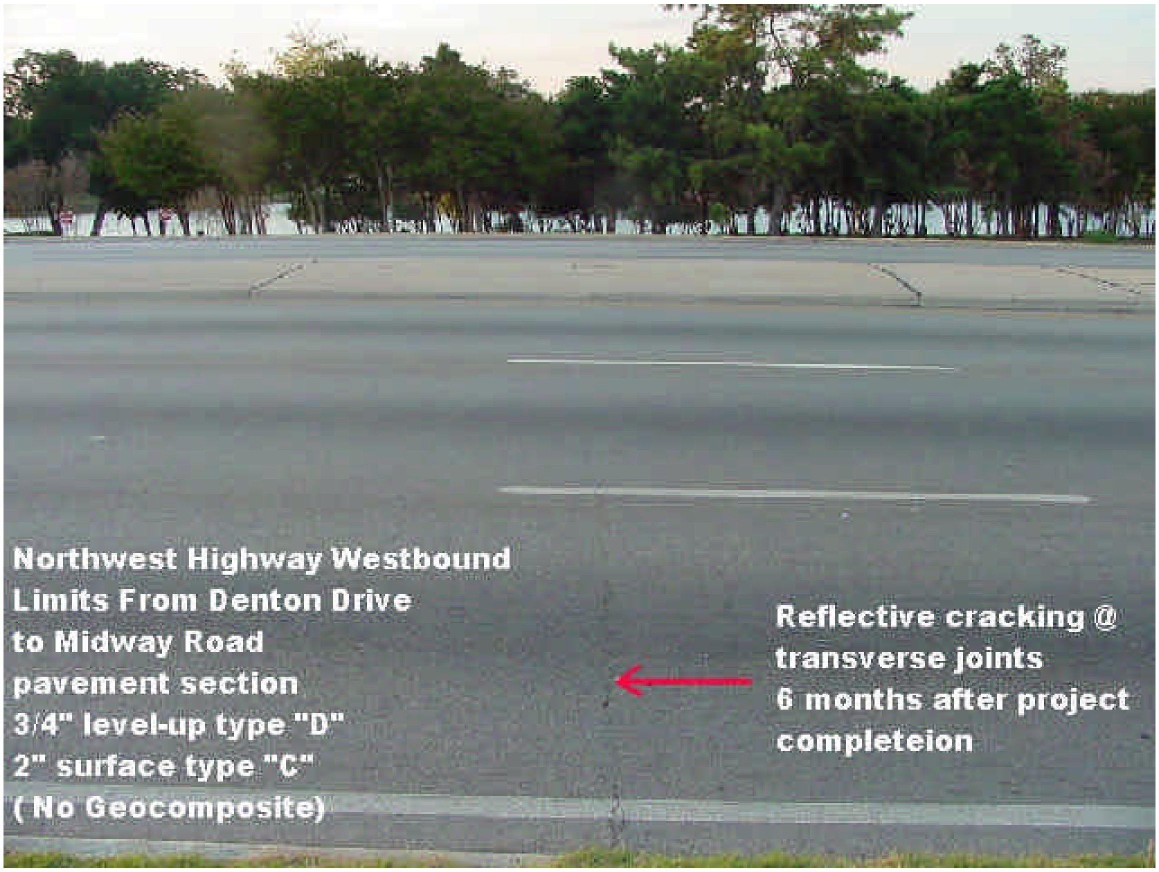

Figure D7. Transverse Cracking with a Level-up Course and Without Geocomposite.

Lessons Learned

Use of a level-up course

From this limited evaluation, it appears that the ¾-inch level-up course, placed prior to the installation of the geocomposite material, helped reduce reflective cracking at the transverse joints. Further, there is other research to support the use of a level-up course when using geosynthetic materials. The term 'geosynthetic material' is used here to categorize the three general types of paving interlayers, namely grids, fabrics, and composites.

Researchers at the Texas Transportation Institute at Texas A&M University have performed research to identify the optimum geosynthetic placement location within a pavement layer for the reduction of reflective cracking. They found that the material gave the best performance when placed in the lower third of the pavement layer. With the use of 3-inch overlays, this guidance translates into the construction of a 1-inch level-up course followed by the placement of the geosynthetic material and a 2-inch final surface course. Likewise, some geosynthetic manufacturers will specify, for maximum performance, a minimum of 1.5 to 2.0 inches of overlay in conjunction with a level-up course when using their product. Use of the aforementioned construction procedures is in agreement with their recommendations.

Much of the research mentioned was performed using a fracture mechanics based approach. Although these concepts can become quite complicated, the explanation of two simple equations can provide further insight into answering why a level-up course is needed. The first is the fundamental fracture law governing the rate of crack growth in a material, given as Equation D-1 and termed Paris' Law.

$$\frac{dc}{dN} = A(\Delta K)^n \qquad \text{(D-1)}$$

where:

$\frac{dc}{dN}$	=	the rate of crack growth
c	=	the crack length
N	=	the number of load applications
ΔK	=	the change of stress intensity factor during loading and unloading
A, n	=	fracture parameters for asphalt mixture

This equation defines the rate of crack growth as a function of the fracture properties of the material as well as changes in stress intensity at crack tips. Based on experimentally measured fracture properties of the HMA reinforcement system, changes in stress intensity determine the rate at which cracks will grow in the material.

An explanation of the left side of Equation D-1 will clarify the use of a level-up course. In the most recent research for TxDOT, laboratory specimens were produced that had a 1-inch level-up with a geosynthetic material attached and a 2-inch overlay. These specimens were subjected to thermal expansion and contraction stresses using a fatigue-testing machine called the TTI Overlay Tester. As the specimen was placed in tension, fracture occurred that formed cracks that were physically measured for each load application. Crack length, c, was then plotted on the y-axis with the corresponding load application, N, on the x-axis using a log-log scale. A best-fit power law regression analysis produced the general form of the second equation below.

$$c(N) = dN^{e} \qquad \text{(D-2)}$$

where: d = a regression constant representing the average crack length at the first cycle opening (i.e. the y-intercept of the log c versus log N curve)

e = the slope of the log c versus log N curve

Previous, as well as the aforementioned, research has shown that when specimens are tested with the geosynthetic material installed, the value of 'd' has varied from 0.2 to 1.0 inch (crack length, as measured from the bottom of the specimen). The significance of this is that, even with the geosynthetic installed, the HMA will crack on the first thermal fatigue cycle between the values shown. Therefore, it is advised to place the geosynthetic material higher than these values in the pavement structure. The placement of a level-up course prior to the installation of the geosynthetic material will satisfy this condition. More importantly, the same research has shown that when placed directly on the old pavement surface the material adds practically no life to the overlay. This statement is certainly confirmed when considering the pavement failure in this case history.

The placement of a level-up course provides other benefits when using geosynthetic materials. First, there is a better bond between the geosynthetic and the level-up as compared to the geosynthetic and an irregular, dusty, and/or pitted surface. When the existing surface is irregular, the in-place geosynthetic will likely contain more wrinkles than with a level-up course. Second, the main purpose of a geosynthetic material is to provide high strength to the surrounding pavement at low levels of strain. This cannot be achieved if the material is not properly bonded. Any voids between the geosynthetic and the irregular surface will greatly increase the speed and intensity of the reflective crack as well as provide a plane of potential slippage.

Preparation of the existing surface

There are certain measures that must be taken to ensure that the existing surface is properly prepared before the application of geosynthetic materials. Inadequate preparation will certainly decrease the effectiveness of the materials and inevitably lead to decreased pavement performance. The first step is to ensure that the existing pavement is structurally sound. Visual observations should be made to detect areas of obvious distress. The primary mechanism of failure for these areas should be investigated and defined. For example, rutting in the pavement can be due to inadequate mixture properties or associated with deeper layers that have become overstressed and consolidated.

To distinguish mixture rutting from deep layer rutting, cores can be taken and mixture properties analyzed. Other tests such as the Asphalt Pavement Analyzer (APA) or the Hamburg wheel-tracking device can be used to indicate whether the mixture is prone to moisture susceptibility or rutting. The Falling Weight Deflectometer (FWD) can be used to define the strength of the underlying pavement layers for areas associated with deep layer rutting. For jointed concrete pavement, FWD can be used to determine the load transfer efficiency across the joints. Research has indicated that, if this efficiency is not above 80 percent, then load transfer must be restored before the geosynthetic material is applied. Full depth concrete repair, as used in the Loop 12 project, can be used to restore load transfer. Ground Penetrating Radar (GPR) could also be used to locate moisture and define other properties within the layers. The main objective is to define the failed areas and to bring the strength of the pavement structure to the same level as the surrounding good pavement layers.

Most, if not all, manufacturers will advise against placing geosynthetic materials on milled surfaces. The same concept of an irregular surface and inadequate bonding applies. Any geosynthetic product that contains a fabric component requires the application of a tack coat to bond the material to the existing surface. Since the milled surface will hold asphalt cement in the grooved surfaces, care must be taken to provide adequate residual asphalt and thus proper adhesion of the material. Additionally, research indicates tack coat rates for HMA pavements should be slightly above the optimum rate supplied by the manufacturer to satisfy the "hunger" of the existing pavement layer. The proper rate in these cases is based on the existing porosity of the pavement and can usually be determined using field judgement. If bleeding occurs through a geosynthetic product, then the tack coat rate should be reduced.

Conclusions and Recommendations

From this limited study of the construction procedures performed and material specifications used in the Dallas District, the following conclusions and recommendations are made.

- The jointed concrete pavement was milled and repaired, but the joints were spalled due to trafficking.
- During the eastbound construction phase, the geocomposite material was placed directly on the milled surface, spanned across the spalled joints, which created a voided area whereby bonding was not fully achieved.
- Higher shear stresses due to deformation from compaction and/or trafficking caused immediate reflective cracking at all transverse joints in the eastbound direction.
- Construction procedures were changed during the westbound construction phase to include a ¾-inch Type D HMA level-up course. This material filled in the spalled areas and provided for a smooth surface on which the geosynthetic was installed. As a result, the material achieved full bonding with the concrete surface.
- After nearly two years of service, reflective cracking has not been recorded in the Loop 12 westbound pavement direction (Project CS: 0353-05-98).
- An adjacent project was constructed using the same type and thickness of HMA level-up and overlay but without a geocomposite material. Reflective cracking occurred after approximately one year of service.

- Underlying principles have been given in this study that suggest the use of a level-up course when using geosynthetic materials to reduce reflective cracking in HMA overlays over existing asphaltic or jointed concrete pavements.
- A proper assessment of the primary mechanisms of pavement failure must be established before determining a course for rehabilitation. This assessment will provide supporting documentation and proper rationale for selecting the appropriate method, which may or may not include the use of geosynthetic materials.

EXHIBIT D1

Texas Department of Transportation

MEMORANDUM

TO: District Engineers August 14, 2000

FROM: Michael W. Behrens, P.E.

SUBJECT: Use of Geocomposite for ACP Reinforcement

Geocomposites for Asphaltic Concrete Pavement (ACP) reinforcement are reinforcing grid structures attached to non-woven fabric similar to fabric underseal. Manufacturers claim these materials provide two functions:

1) reinforcement of the ACP making it less prone to reflective cracking, especially over concrete pavement, and

2) provide a moisture-proof layer, when saturated with asphalt upon installation, preventing moisture penetration into the pavement structure.

These materials have been used in several projects in the last few years. There have been at least two instances where the use of a geocomposite in the ACP layer may have contributed to premature failure of the road surface.

The Texas Transportation Institute is currently conducting a research project studying geotextiles, of which geocomposites are a subset. This memorandum is to advise districts to suspend the use of geocomposites for ACP reinforcement until the research is completed and issues of performance and benefit are answered.

Any questions you may have regarding these materials can be directed to Mr. Darren G. Hazlett, P.E. in the Construction Division at 512-465-7352.

cc: Thomas Bohuslav, P.E., CST
Katherine Holtz, P.E., CSTM
Darren Hazlett, P.E., CSTM

Original signed by M. W. Behrens, P.E.

EXHIBIT D2

1993 Specifications CSJ 0353-05-101

SPECIAL SPECIFICATION

ITEM 3168

GEOCOMPOSITE PAVEMENT REINFORCING

1. Description. This Item shall govern for furnishing and placing a geotextile consisting of a composite of woven polyester grid and non-woven polyester paving fabric as manufactured by Synteen USA, Inc., or approved equal, in accordance with the details shown on the plans and the requirements herein.

2. Materials.

   (1) Non-Woven Fabric. The fabric shall meet the requirements of Departmental Materials Specification D-9-6220, "Fabric For Underseals".

   (2) Woven Polyester Grid. The polyester grid shall meet the following requirement when sampled and tested in accordance with Test Method TEX-621-J.

Test	Requirement
Tensile Modulus @ 2% Elongation*	14,000 lb/ft 19,950 lb/ft

*Determined as a secant modulus without offset allowances.

   (3) Asphalt Cement. Asphalt cement shall be of the grade shown on the plans or as designated by the Engineer and shall meet the requirements of Item 300, "Asphalts, Oils and Emulsions".

   (4) Sand or Screenings. Sand or screenings shall meet requirements as shown on the plans or approved by the Engineer.

3. Construction Methods. The area of which the fabric and grid composite is to be placed shall be cleaned of dirt, dust, or other deleterious material by sweeping or other approved methods. Asphalt cement shall be applied on the clean surface by an approved self-propelled pressure distributor. The distributor shall apply the asphalt cement, at the application rate of 0.25 gallons per square yard, evenly and

smoothly under a pressure necessary for proper distribution. The Contractor shall provide all necessary facilities for determining the temperature of the asphaltic material.

Calibration of the distributor shall be in accordance with Item 316, "Surface Treatments." All equipment used in storing or handling asphalt cement shall be kept clean and in good operating condition at all times, and they shall be operated in such a manner that there will be no contamination of the asphalt cement. The Contractor shall provide and maintain a recording thermometer to continuously indicate the asphalt cement temperature at the storage heating unit.

The Engineer will select a temperature of application within the limits recommended in Item 300, "Asphalts, Oils and Emulsions". The Contractor shall apply the asphalt at a temperature within 15°F of the temperature selected.

The geocomposite shall not be applied when the air temperature is below 60°F and falling, but may be applied when the air temperature is above 50°F and is rising, the air temperature being taken in the shade away from artificial heat. In addition, the geocomposite shall not be applied when the temperature of the surface on which the material is to be placed is below 60°F. Neither the asphalt cement nor the geocomposite shall be placed when general weather conditions, in the opinion of the Engineer, are not suitable.

Asphalt cement shall be applied ahead of the fabric-grid composite placement in widths approximately six (6) inches wider than the fabric-grid composite, unless otherwise directed by the Engineer. The fabric grid composite shall be applied with waterproofing membrane side down and the reinforcing grid side up. The asphalt cement shall be applied at the approximate rate shown on the plans or as directed by the Engineer.

String lines shall be set for alignment as required by the Engineer.

Immediately upon application of the asphalt cement, the fabric-grid composite shall be aligned and carefully broomed and/or rolled onto the asphalt cement with equipment approved by the Engineer. The fabric grid composite shall be applied with waterproofing membrane side down and the reinforcing grid side up. In the event the initial alignment is not satisfactory and causes the fabric-grid composite to wrinkle during placement, the material shall be cut and realigned overlapping the previous material and proceeding as before. If the edges of the fabric tend to be displaced because of air currents, the Engineer may require that the edges be secured to the pavement at 15 foot intervals. In the event this procedure does not prove satisfactory, the work will be suspended until conditions are more favorable.

All transverse joints shall be overlapped a minimum of six (6) inches. Laps shall be in the direction of travel when traffic is allowed directly on the fabric-grid composite. In lapping joints, the top material shall be folded back to allow application of a light coat of asphalt cement. The top material is then placed back onto the asphalt cement, broomed and squeegeed out smoothly. Rolling and/or brooming the geocomposite into the asphalt cement at the joints shall be accomplished in such a way that air bubbles which form under the material will be removed. This may be accomplished by brooming from the center of the fabric toward the outer edges. The geocomposite shall be neatly cut and contoured at all joints as directed by the Engineer.

Adjacent longitudinal rolls of the geocomposite shall overlap a minimum of four (4) inches. Additional asphalt cement shall be applied to make these longitudinal joints.

Turning of equipment shall be gradual and kept to a minimum to avoid damage to the fabric-grid composite. When required by the Engineer, the material shall be covered with a thin layer of clean sand or clean crusher screenings at a rate sufficient to absorb any excess asphalt cement.

4. Measurement.

(1) Asphalt Cement. Asphalt cement will be measured at the point of application on the road in gallons at the applied temperature. The quantity to be measured for payment shall be the number of gallons used, as directed by the Engineer, in the accepted underseal portion of the geocomposite.

(2) Geocomposite. The Geocomposite will be measured by the square yard based on the calculated quantity shown on the contract plans with no allowance made for overlapping at joints.

This is a plan quantity measurement Item and the quantity to be paid for will be that quantity shown in the proposal and on the "Estimate and Quantity" sheet of the contract plans, except as may be modified by Article 9.8. If no adjustment of quantities is required, additional measurements or calculations will not be required.

5. Payment. The work performed and materials furnished in accordance with this Item, and measured as provided under "Measurement", will be paid for at the unit prices bid for "Asphalt" and "Geocomposite". These prices shall each be full compensation for cleaning and preparing the existing pavement; for furnishing, preparing, hauling and placing all materials, including sand or crusher screenings; for all freight involved; for all manipulation, including rolling and brooming and for all labor, tools, equipment and incidentals necessary to complete the work.

Case History – IH 35
TxDOT Laredo District

General

The Laredo District of TxDOT requested a forensic investigation of premature failures of two different pavement sections on Interstate Highway 35 (IH 35) in La Salle County. This roadway is located in the southwestern desert region of Texas. Beginning in November of 1999, a forensic investigation was performed by various personnel within TxDOT's Construction Division, and a final report was submitted in May of 2000. These two projects were constructed using full-depth rehabilitation procedures and were between one and two years old when the failures occurred. One of the pavement sections included a geocomposite material which, according to the final report, contributed to the premature failure of the pavement surface. As a result of this and other failures in the state, Mr. Michael Behrens, P.E., issued a memorandum on August 14, 2000 (Exhibit D1) advising all districts to "suspend the use of geocomposites for HMA reinforcement until the research is completed and issues of performance and benefit are answered." This case history summarizes and examines the findings of the forensic report and provides additional information on the use of geocomposite materials in this type of rehabilitation technique.

Background

The two pavement sections on IH 35 are labeled as the North Section and South Section as shown in Figure D8. This is a divided four-lane roadway having a grassed medium. Figures D12 through D20 show the existing and proposed typical sections. Each of the plan view sections has labels indicating the typical section number; these numbers correspond to the typical section numbers.

The primary reason for performing the forensic investigation was to determine the source(s) of rutting, shoving, and pavement cracking in both lanes (most noticeable in outside lanes) of the South Section (CSJ: 0018-02-045), as shown in Figure D9 below. In addition, the North Section (CSJ: 0018-01-055) was exhibiting rutting primarily in the outside lanes. A geocomposite material was applied in the South Section between the

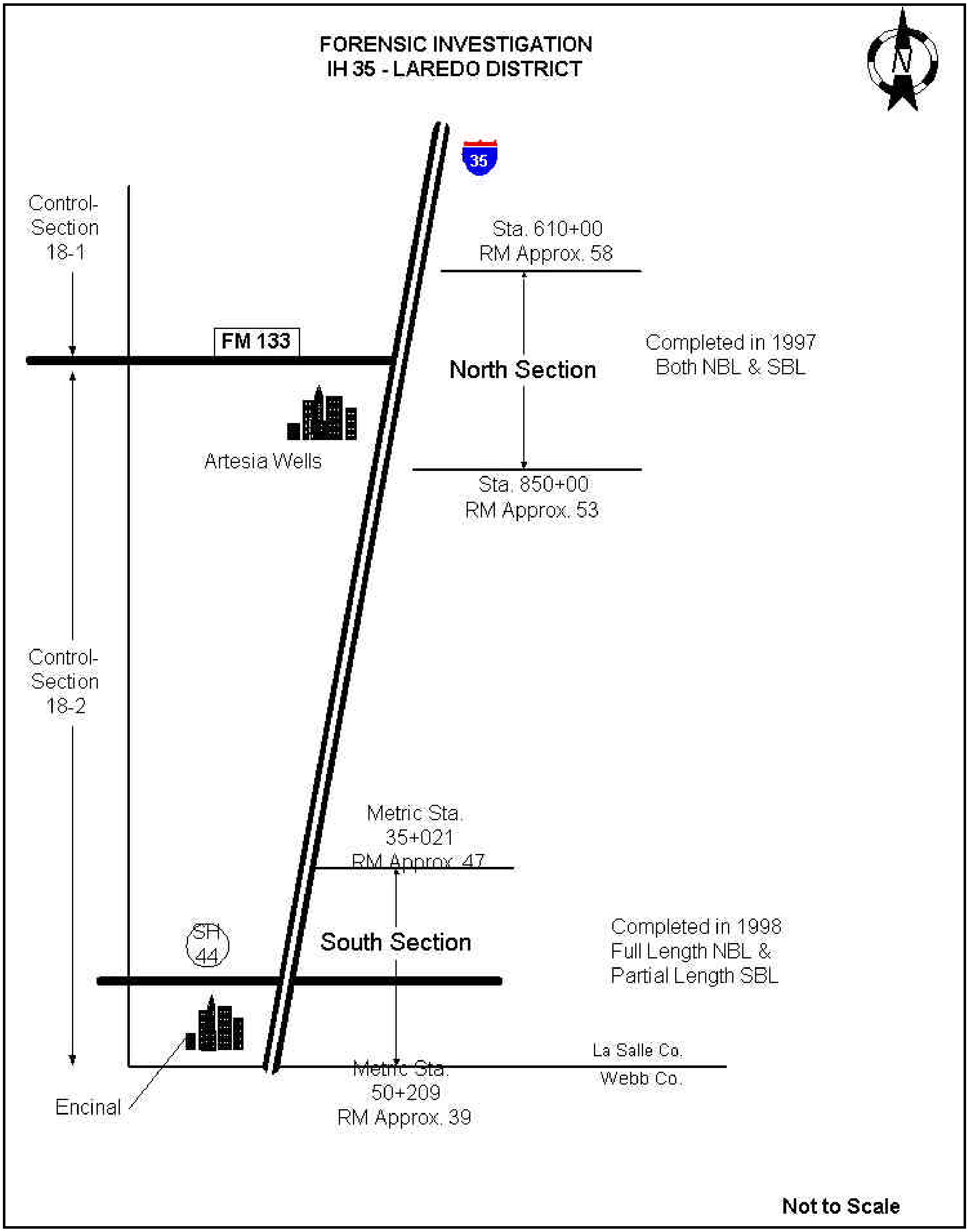

Figure D8. Site Plan of Interstate Highway 35 (IH 35) for Forensic Investigation.

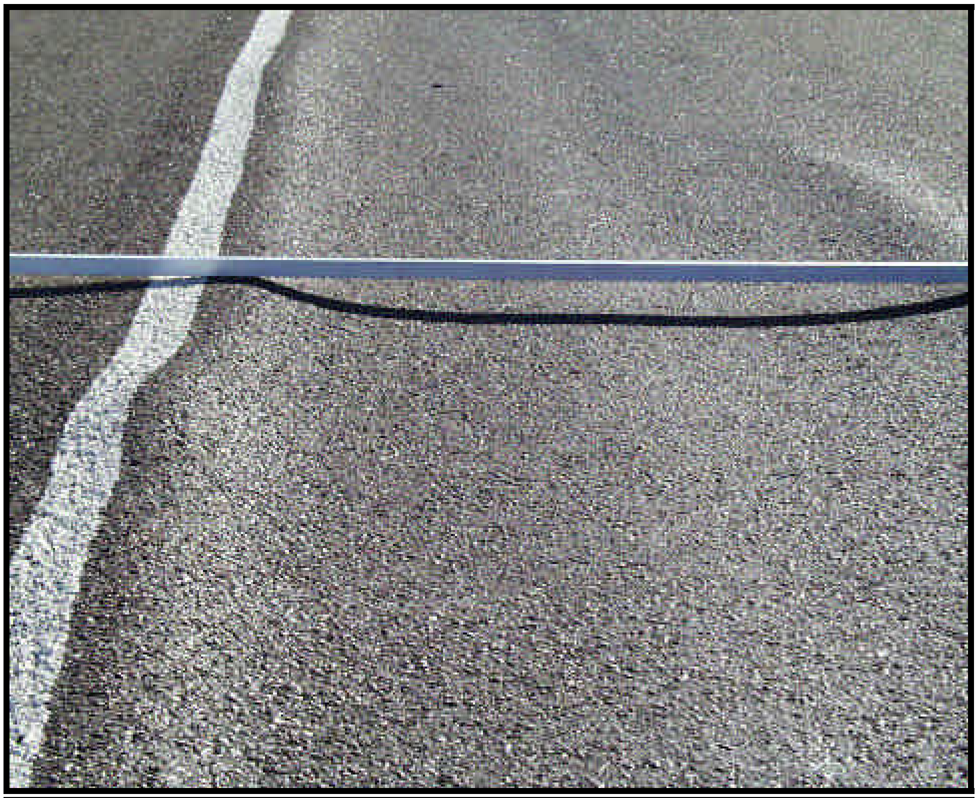

Figure D9. Shoving and Rutting in the Type D HMA Surface Course (North and South Sections of IH 35).

Type B HMA level-up and Type D HMA surface course as shown in Figures D19 and D20. Specific purposes of the forensic investigation were to:

1. identify the pavement layer(s) responsible for the distresses, and
2. recommend short-term and long-term corrective action to the district.

The final forensic report presented an in-depth study of the materials, construction, pavement condition, visual observations, field-testing, laboratory testing, and analysis of the data collected during the investigation. One should examine the final report for a complete discussion of these items. Listed below are the major findings and recommendations for both sections of roadway as taken directly from the forensic report.

Major Findings and Recommendations

CSJ: 0018-02-045 (South Section)

1. The severe rutting and shoving between Sta. 40+495 and Sta. 42+589 was attributed to the lack of bond between the asphalt concrete surface layer and the geocomposite fabric underseal (see Figures D10 and D11). Contributing factors included geocomposite trapping moisture beneath the fabric, stripping in HMA surface and base layers, low crushed aggregate face count in HMA and low in-place density in the HMA base layer.
2. Rutting in areas without geocomposite was due to stripping in HMA base layer and consolidation of HMA surface layer. Contributing factors included low in-place density in Type B layer and low crushed face count.

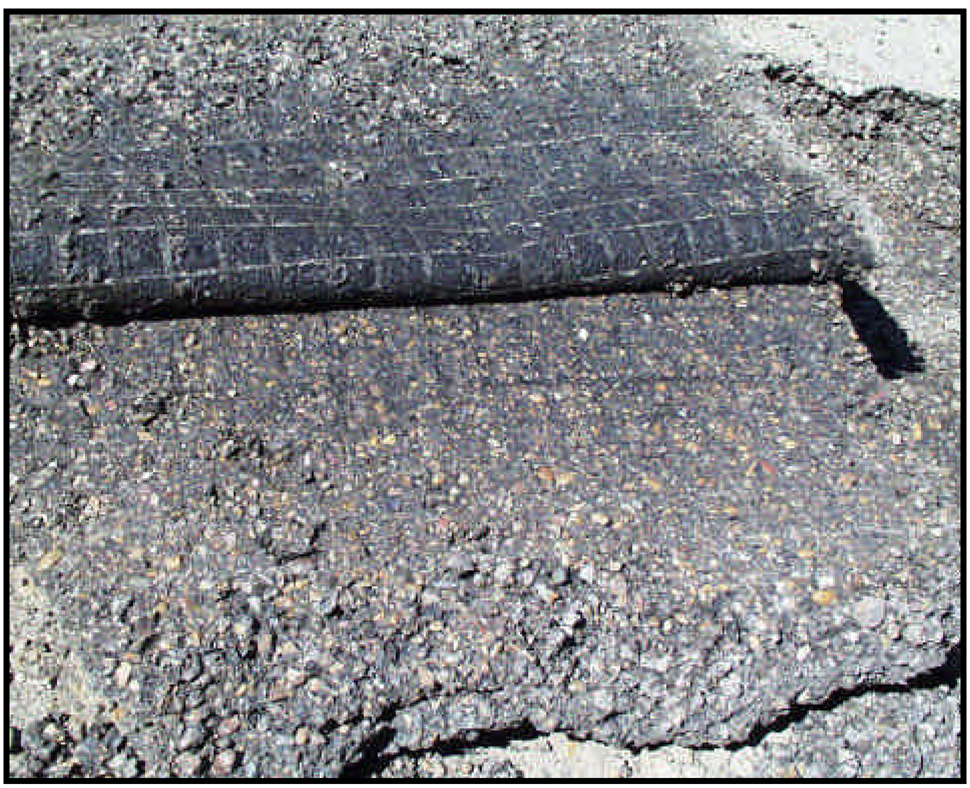

Figure D10. Geocomposite Material Delaminating from Lower Type B HMA Layer.

Figure D11. Stripping of Underlying Type B HMA Layer.
(Note indentions from geocomposite material.)

3. Base did not contribute to the premature distresses observed.
4. HMA in both layers met mixture design gradation requirements.
5. Rain during construction could have trapped moisture within the pavement structure due to the "bath-tub" effect of an inlay.

Recommendations

Mill and replace HMA pavement for the entire length of northbound lanes. Consider milling and replacing a minimum depth of 4 inches of HMA. Full-depth milling and replacement is recommended. An overlay placed on the current unstable pavement would likely deform. When possible, avoid inlay-type rehabilitation techniques on facilities with heavy truck traffic. Consider using mixtures with good stone-on-stone contact of coarse aggregate for interstate highways (e.g., SMA, PFC, Stone-Filled, CMHB, Superpave). Specify Hamburg Wheel Tracking test for mixtures placed on Interstate Highways. Require job control testing to monitor crushed face count of aggregates.

CSJ: 0018-01-055 (North Section)

1. Rutting in northbound and southbound lanes was due to stripping and consolidation of HMA surface layer. Contributing factors included low in-place density in Type D layer, rain during construction, and low crushed-face count of aggregate in HMA.
2. Longitudinal and transverse cracking in southbound lanes was due to debonding of HMA base layers. Another contributing factor could be high stiffness of the base that may have induced shrinkage cracks. Top 3 to 4 inches of the base is softer indicating retention of moisture in the upper strata.
3. HMA in both layers met mixture design gradation requirements.
4. Rain during construction could have trapped moisture in the pavement structure due to the "bath-tub" effect of an inlay.

Recommendations

Mill and replace HMA for the entire length of the project. Consider milling and replacing a minimum depth of 5 inches of HMA. Full-depth milling and replacing of HMA is recommended. An overlay placed on the current unstable pavement would likely deform. When possible, avoid inlay-type rehabilitation methods on heavy truck traffic facilities. Consider using mixtures with good stone-on-stone contact of coarse aggregate for interstate highways (e.g., SMA, PFC, Stone-Filled, CMHB, Superpave). Specify Hamburg Wheel Tracking test for mixtures placed on Interstate Highways. Require job control testing to monitor crushed face count of aggregates.

Observations

The purpose of this case history is to provide a summary and observations on the findings of the forensic investigation of IH 35 involving a geocomposite material. A geocomposite was used on the South and not the North section, as shown in Figure D8. It seems apparent, when comparing the South and North sections, that stripping was prevalent in *both* sections due to the low crushed-face count of the aggregate in the HMA and the low in-place density in the HMA base layer. In other words, the pavement structure had major problems regardless of the presence of the geocomposite material. It should be stated that the geocomposite material probably exacerbated the stripping phenomenon. This case can be argued since the non-woven fabric material is held in place with a thick layer of tack coat (approximately 0.25 gallons per square yard). This material forms an impermeable layer that more than likely trapped water in the pavement structure formed by the inlay construction technique.

When using a geocomposite or a fabric material alone, to reduce reflective cracking, the user must be aware of the potential problems associated with trapping water in the pavement layers. The fabric backing on some geosynthetic materials is meant to form a waterproofing barrier. In this investigation, the recommendations clearly state that the construction of an inlay project should be avoided on heavy truck traffic facilities due to the aforementioned problems. This can be taken one step further by stating that, whenever the possibility exists for trapping water in a pavement structure, the construction technique or materials should change immediately. The use of a grid product (without a non-woven fabric attached) would be more ideally suited in these situations since an impermeable layer will not be created. The grid will allow the pavement to "breathe" and thus the probability of stripping may be reduced.

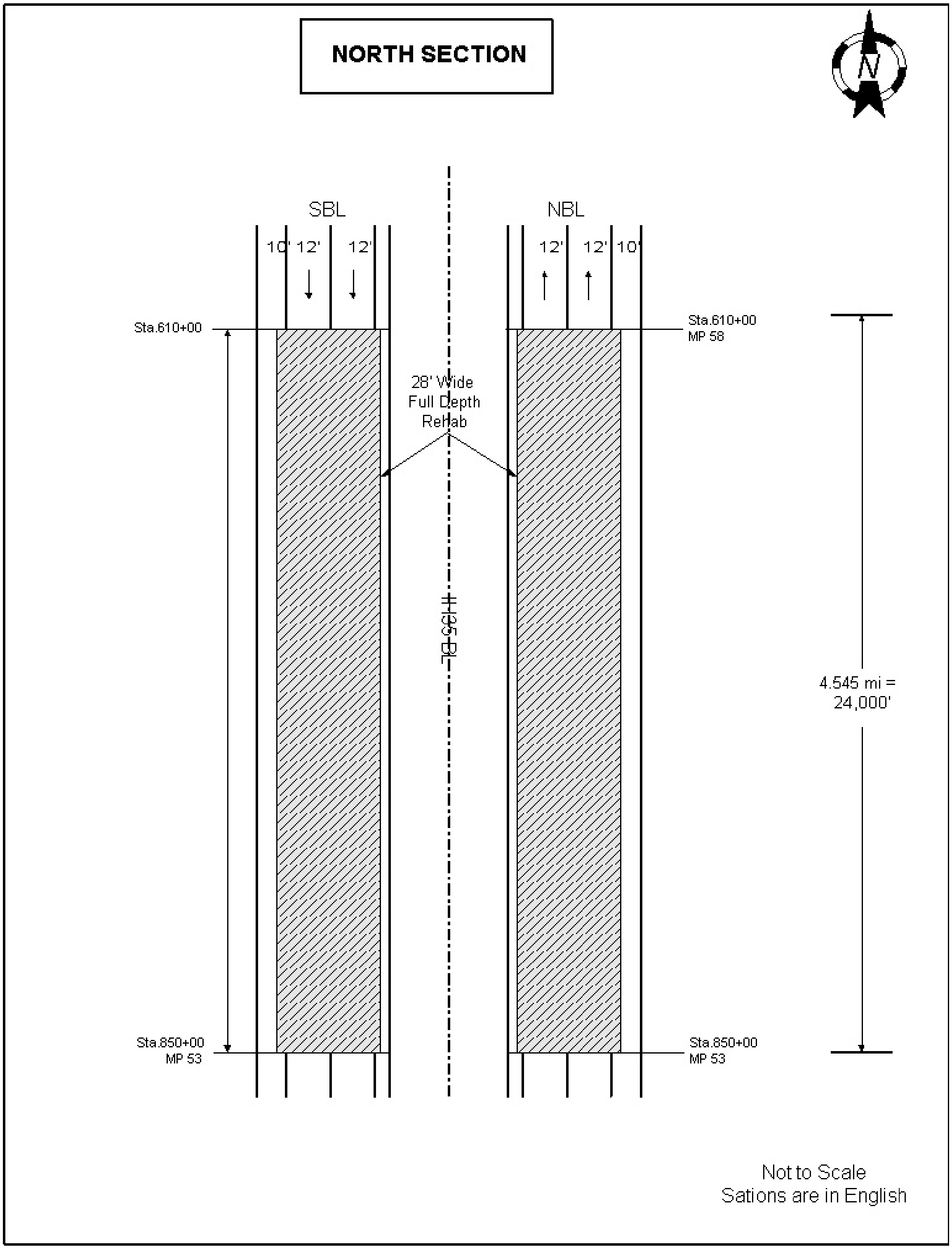

Figure D12. Plan View of North Section of IH 35 in Laredo District.

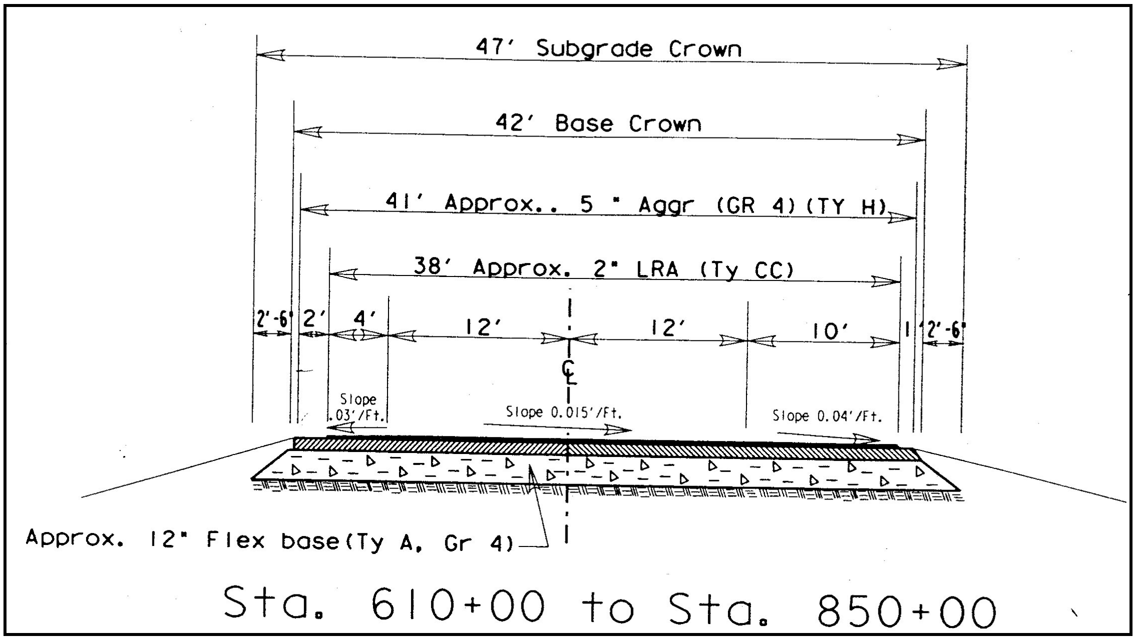

Figure D13. Existing North Typical Section of IH 35 in Laredo District.

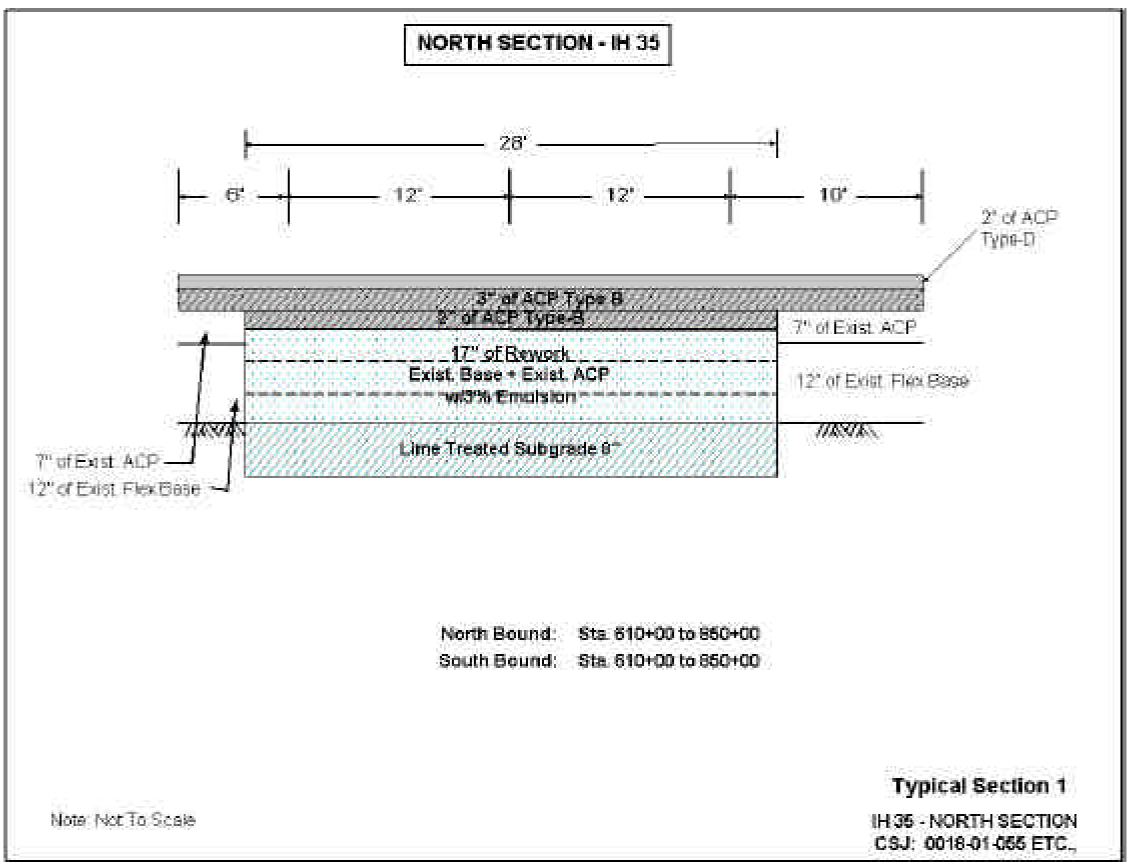

Figure D14. Proposed North Typical Section of IH 35 in Laredo District.

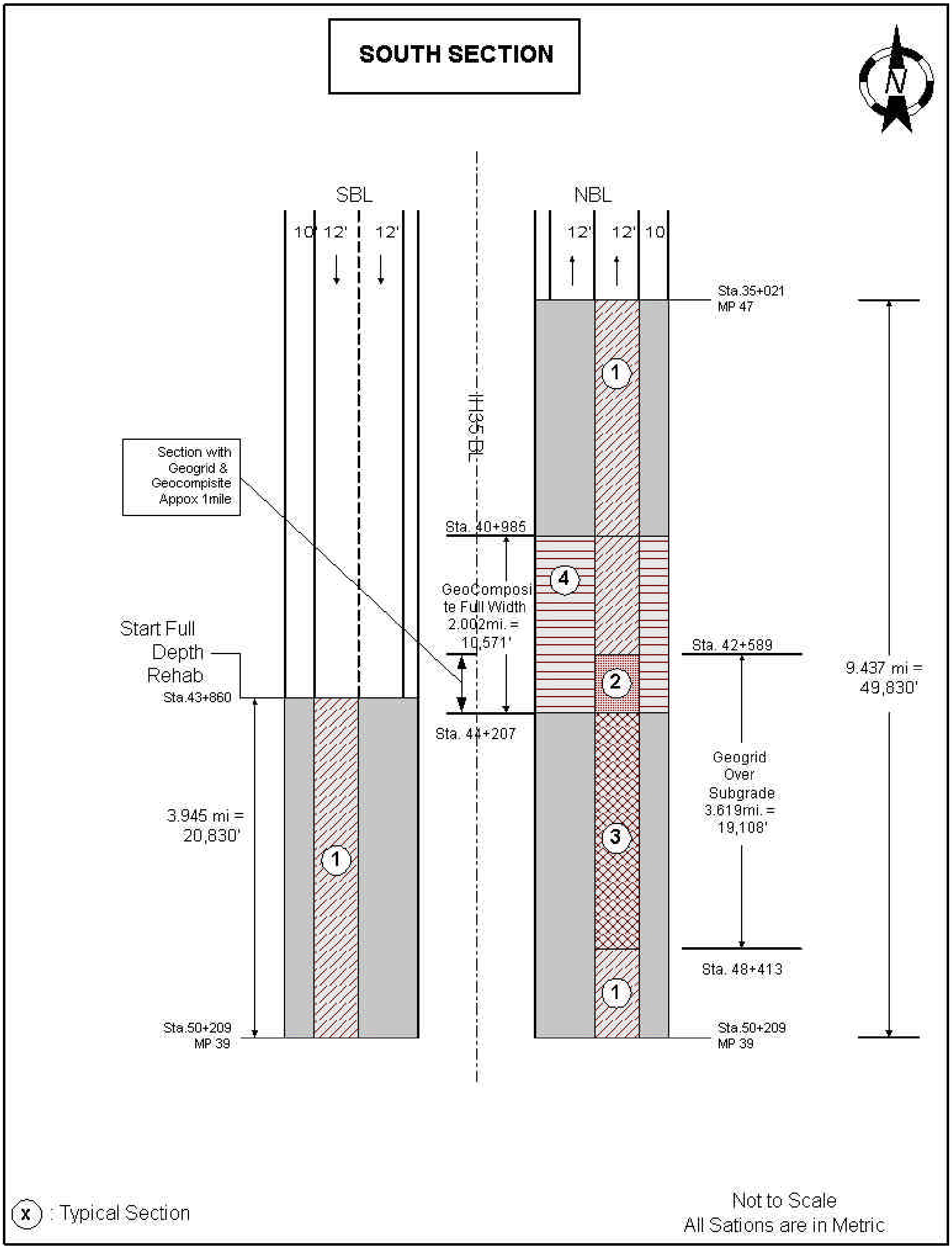

Figure D15. Plan View of South Section of IH 35 in Laredo District.

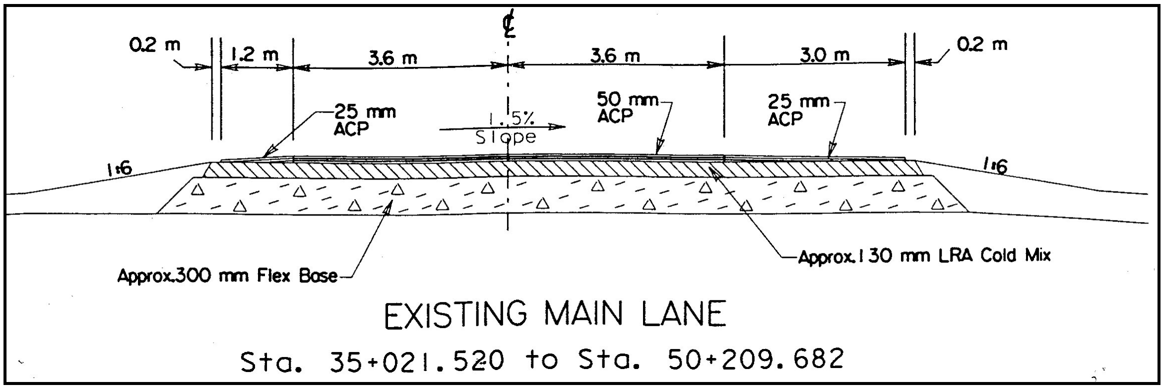

Figure D16. Existing South Typical Section of IH 35 in Laredo District.

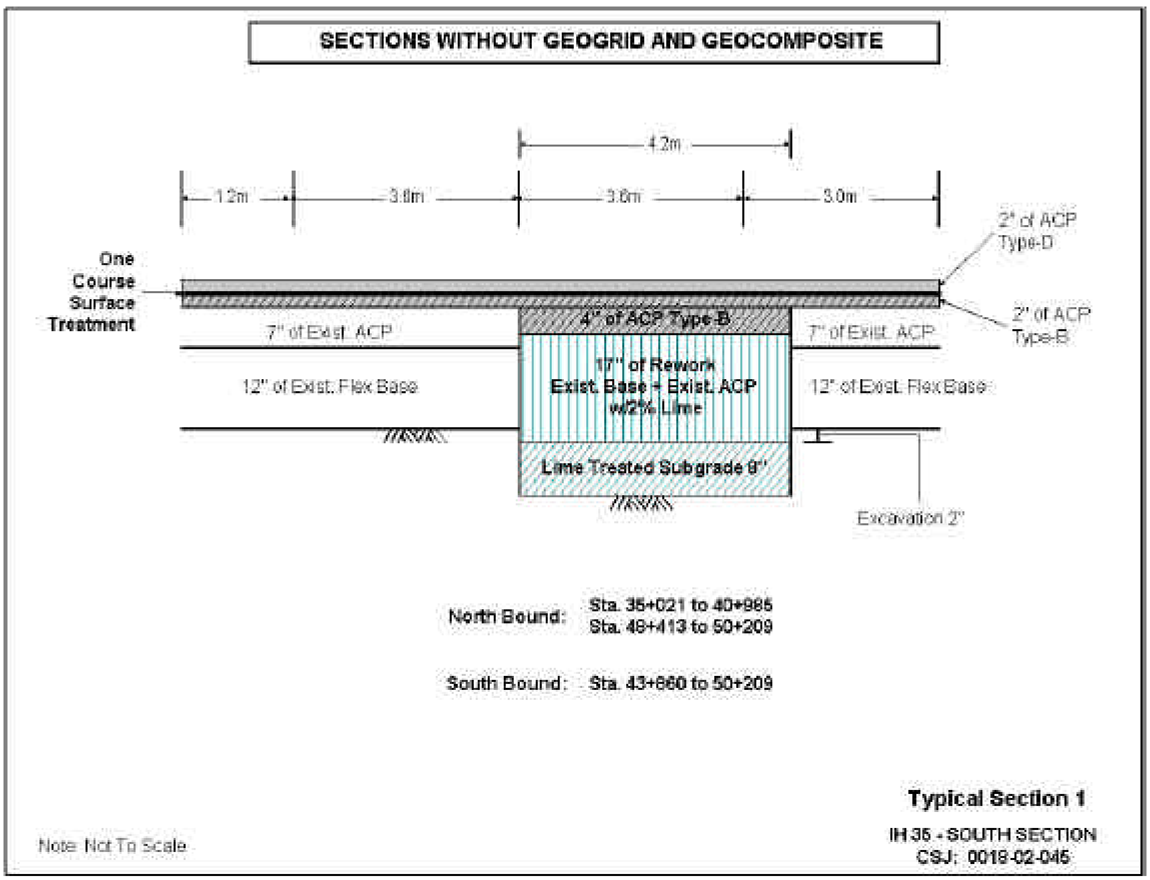

Figure D17. Proposed South Typical Section 1 of IH 35 in Laredo District.

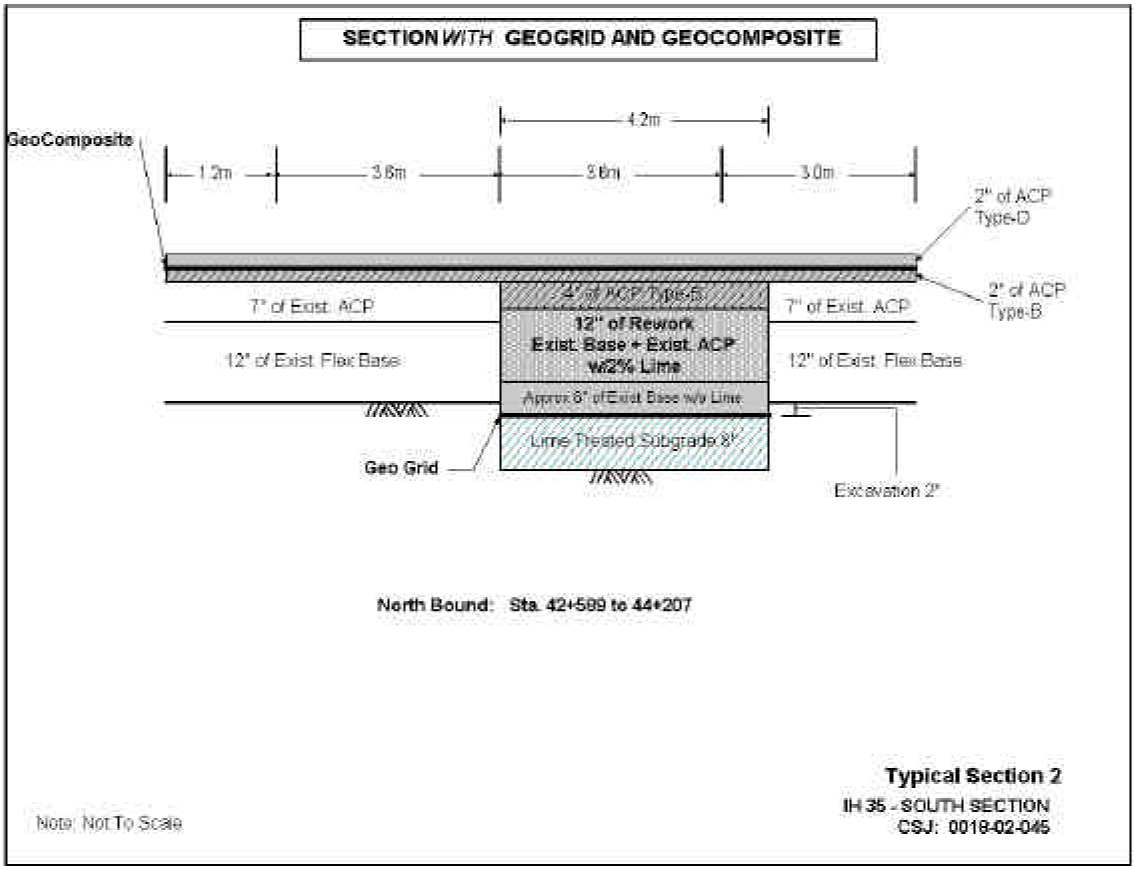

Figure D18. Proposed South Typical Section 2 of IH 35 in Laredo District.

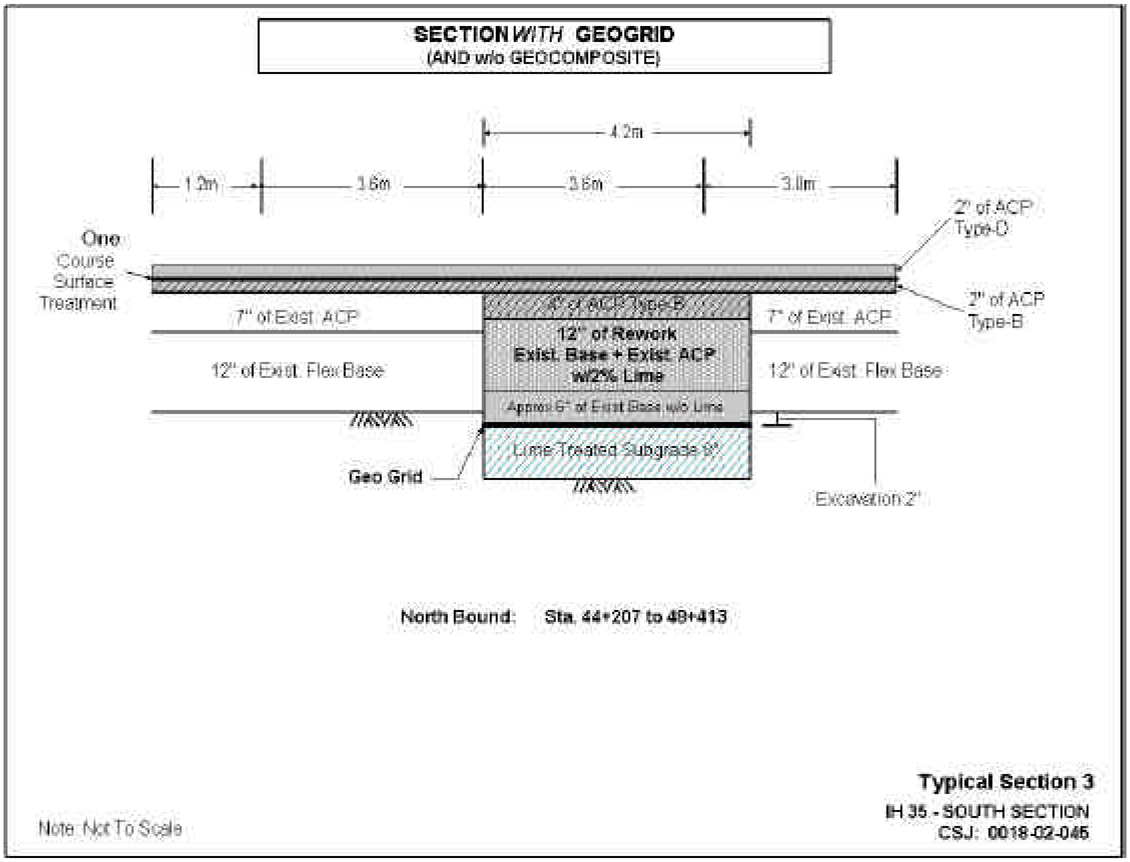

Figure D19. Proposed South Typical Section 3 of IH 35 in Laredo District.

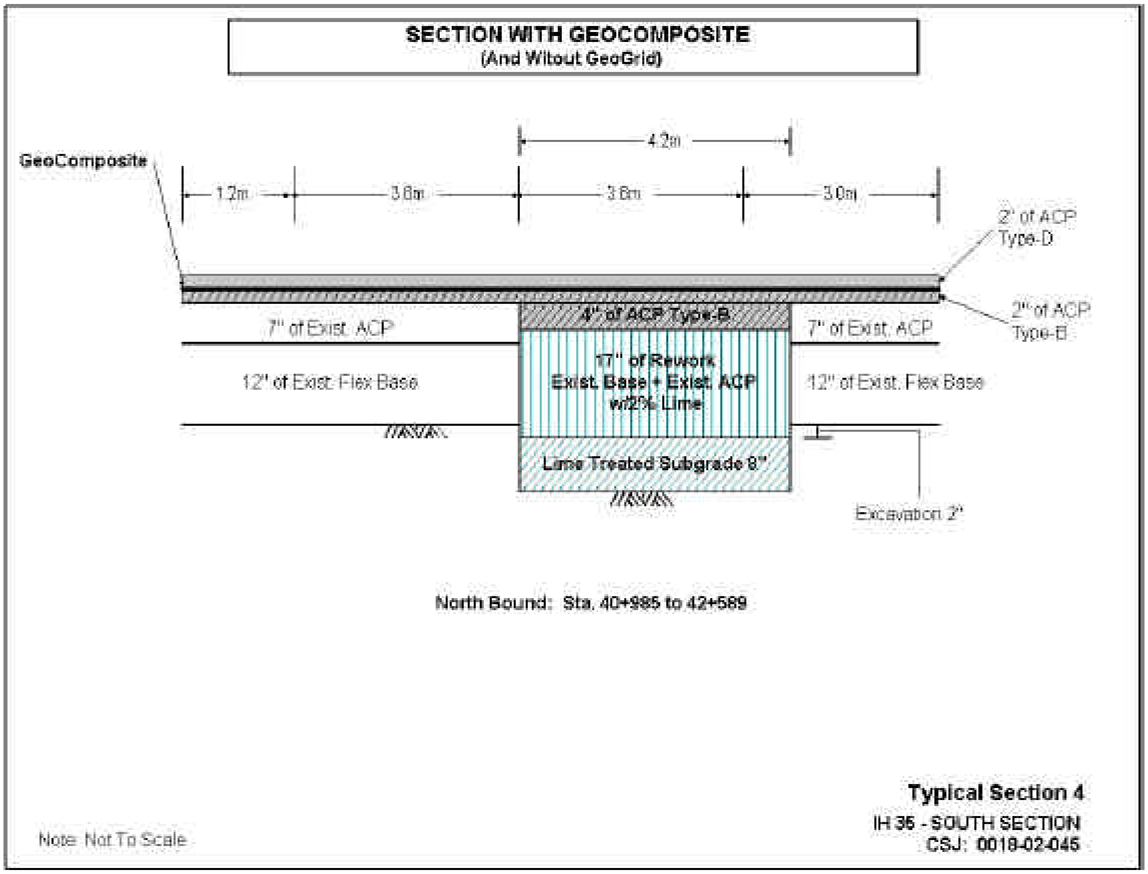

Figure D20. Proposed South Typical Section 4 of IH 35 in Laredo District.

APPENDIX E

SUMMARY OF FINDINGS FROM STATEWIDE QUESTIONNAIRE

SUMMARY OF FINDINGS FROM STATEWIDE QUESTIONNAIRE

To better assess the use and success of geosynthetic materials for reducing or retarding reflective cracking in HMA overlays, the research team sent a questionnaire to all 25 districts within the Texas Department of Transportation (TxDOT). The major focus of this questionnaire (Exhibit E1) was to document the following:

1. the number of projects using a geosynthetic within a district,
2. typical underlying pavement structures,
3. techniques used to prepare the existing pavement,
4. the use of geosynthetic materials (grids, fabrics, or composites),
5. thickness of HMA overlays,
6. construction problems, and
7. performance issues.

The questionnaire was sent to each district engineer for dissemination on September 15, 2000, with a requested completion date of October 13, 2000. Twenty-one of the twenty-five districts completed and returned the questionnaire, and their responses are summarized in Table E1 below. Most of the districts have used some type of geosynthetic product from the mid 1980s to the mid 1990s. Most responded that construction records and personnel associated with these projects were difficult to locate. Therefore, some of the districts that stated that there was no use of geosynthetic materials may simply not be aware of their use. Nonetheless, significant information and general trends can be gained from this questionnaire. Questionnaire responses should provide useful information to TxDOT's engineering, construction, and maintenance staff on the use of these products within the state of Texas.

Table E1. Summary of Findings from TxDOT District Questionnaire (21 of 25 districts responded)

District	Projects in District	Existing Roadway	Mill Existing Surface	Seal/Level-up	Geosynthetic Material	Overlay Thickness	Construction Comments	Performance Comments
Beaumont	1 reported	JCP with ACP overlay	No	0-2.5" Gr 4 seal coat / None	Fabric	1.5" Type C	Wrinkles in fabric	No observations-new project
Bryan	Several	JCP with ACP overlay	Yes. 8"	Sealed / 2" Type C level-up	Grid	4" CMHB Type C	5' width placed on transverse joints	Ride quality reduced at joints
El Paso	Will not use							
San Angelo	Not used							
Amarillo	None known	4" Flexible	Yes. 1-2"	None / None	Fabric	1.5" (type not specified)	No problems encountered	100% reflected in less than 1 year
Lufkin	Project 1	JCP with ACP overlay	Yes. 1"	None / 1" level up	Grid	2" CHMB Type C	No problems encountered	No cracks after 9 months No difference in ride quality
	Project 2	4" Flexible	No	Heavy tack / None	Fabric	4" Type D	No problems encountered	No cracks in control and fabric section.
Odessa	1 reported	4.25" Flexible	Unknown	None / 1" Type D level-up	Unknown	1.75" Type D	Not aware of problems	District believes that normal rehab procedures work better than that of geotextiles
Dallas	13 projects	JCP with ACP overlay	Yes. 2-4"	LW aggregate seal coat / 2-4" level-up	Fabric	2" Type C with 2% latex	2' wide strips placed over joints	Much less reflective cracking; probably delayed by one year
	* Project 14	JCP with ACP overlay	Yes. 3" avg	None / 3/4" Type D level-up	Composite	2" Type C	Refer to case history	Refer to case history
	Project 15	JCP with ACP overlay	No	Sealed / 4" ASB level-up	Fabric	1" Type D	None indicated	Perceived to perform satisfactorily. Intrusion of water has been improved but ride quality was not improved.
	Project 16	JCP with ACP overlay	Yes. 4"	None / 2" level-up	Fabric	2" Type D	Fabric placed full-width due to extensive cracking. Level-up placed due to rough surface of concrete.	Project is performing satisfactorily. Method is cost-effective for pumping areas where base failures are frequent. Pavement smoothness is improved.
Yoakum	1 reported	JCP with ACP overlay	Yes. 4"	Hot rubber seal / 1.5" Type C	Membrane	1.5" Type C	Tack coat problems. Tires picking up material.	Six months after installation, there were more reflective cracks than were before the project. Has not improved water intrusion and ride quality is worse.
Waco	1 reported	Flexible	No	Not available	Fabric	1-1.5" (type not specified)	Not available	Discontinued use of geotextiles indicates dissatisfaction
Lubbock	6 projects	Flexible	No	None / 0.5" Type D level-up AC-5, 2% latex	Fabric	1.5" Type C	Unknown	Fabric underseals are used to slow the appearance of reflective cracking. Used within district to seal the pavement from water intrusion.
Tyler	1 reported	JCP with ACP overlay	Yes. 4-5"	One-course surface treatment / No level-up	Fabric	2.5" Type B (base) and 2" Type C (surface)	1' strip placed over joints. Not aware of problems	Less cracking is apparent with the use of the material.

* See case histories for this project

Table E1. Summary of Findings from TxDOT District Questionnaire (21 of 25 districts responded) (Continued).

District	Projects in District	Existing Roadway	Mill Existing Surface	Seal/Level-up	Geosynthetic Material	Overlay Thickness	Construction Comments	Performance Comments
Atlanta	Project 1	Flexible	Yes. 2"	None / None	Composite	2" (type not specified)	No problems encountered	75% to 90% reduction of reflective cracking. Has helped in water intrusion but no difference in ride quality.
	Project 2	JCP with ACP overlay	No	Existing seal coat for all three products	1. Fabric 2. Grid 3. Membrane	4" Type B (base) One course surface treatment 1.5" Type D (surface)	1. Place full-width. No problems encountered. 2. Small widths placed over all joints. No problems encountered. 3. Product melted and slipped under hot ACP and would roll-up under equipment Manufacturer recommends self-adhesive. product over that which requires tack.	1. 100% reflective cracking within 1 year. 2. 100% reflective cracking within 1 year. 3. No cracking observed. District notes that manufacturers 2 and 3 advised against small widths over joints prior to construction.
Wichita Falls	2 projects	JCP with ACP overlay	No	None / 3/4" Type D level-up	Fabric	1.5 - 2" Type D	Unknown	Unknown
Laredo	2 projects	Flexible	No	Seal coat / None	Grid	Project 1: 1.5" Type D Project 2: 2.0" Type D	No problems encountered	No reflective cracking in both projects since 1997. Product performs well if manufacturers procedures are followed.
	* Project 3	Flexible	No	None / None	Composite	2" Type D	No problems encountered	No reflection cracking noticed. Rutting and shelling started in one year. Composite may create a moisture barrier which will harm the pavement structure. Grids have been used with success and in areas with composite, the whole project failed due to stripping.
Brownwood	1 reported	Not stated	Not stated	Not stated	Fabric	Not stated	Used in early 1970s and not much since	Fabric placed over alligator cracks seemed to work well. Has not worked well over longitudinal, tranverse, or block cracking. District does not plan on using geotextiles in the future.
Corpus Christi	Not used							
Abilene	1 reported	Flexible	Not stated	Not stated	Composite	1.5" Type D	Material was rejected by district for not meeting department specifications	Not specified
Pharr	Several	Not stated	Not stated	Not stated	Fabrics	Not stated	Have used in the early 1980s and not much since.	Not specified
Houston	1 reported	JCP with ACP overlay	Yes. 4"	One-course surface treatment / 1.5" Type D level-up	Grid	1.5" Type D	None indicated	Overlay delaminated within a few weeks of trafficing. The grid disintegrated and the surface mix was loose.
	5 projects contained in district report	JCP with ACP overlay	Varies	Not stated	Fabric and Membrane	1.75-2" ACP	Information contained in 1985 and 1992 reports. Strips from 12" to 24" have been used along with full-width applications.	Success has varied from project to project.
Fort Worth	7 projects contained in district report	JCP with ACP overlay	Varies	Not stated	Fabric and Membrane	1.75-2" ACP	Information contained in 1985 and 1992 reports. Strips from 12" to 24" have been used along with full-width applications.	Success has varied from project to project.
Austin	Not used							

* See case histories for this project

The following provides a summary of the findings from the questionnaire.

1. Seventeen districts reported having used geosynthetic products.
    a. Dallas, Lubbock, Houston, and Fort Worth Districts reported six or more projects. The Dallas District has the most experience and/or documented use of geosynthetics.
    b. Four districts have reported either no use or unknown use.
2. Existing pavement type - Fourteen districts have used geosynthetics for rehabilitation of HMA over JCP pavements; whereas, nine districts have used this technique with flexible pavements.
3. Preparation of existing pavement has consisted of:
    a. eight projects with milling and seal/level-up placed,
    b. two projects with milling and NO seal/level-up placed,
    c. seven projects that have NOT been milled but a seal/level-up placed,
    d. one project with NO milling and with NO seal/level-up placed, and
    e. three projects with unknown pavement preparation information.
4. Recent construction projects incorporating geosynthetics indicate the following breakdown: 15 with fabrics, 5 with grids, 4 with composites, and 4 with membranes.
5. HMA overlay thickness have varied from:
    a. Type C - 1.5 inches to 2 inches
    b. CMHB - 2 inches to 4 inches
    c. Type D - 1 inch to 4 inches (normally 1.5 inches to 2 inches)

The preceding summary illustrates that TxDOT has constructed many projects using various types of geosynthetic products. Most projects involved rehabilitation of old jointed concrete pavements (JCP) in which the joints have reflected through an HMA overlay(s). As stated earlier, most of these projects were constructed between 1985 and 1995. In general, fabrics were introduced to the pavement reinforcing market before grids. Likewise, grids were introduced somewhat before composites. This coincides with the predominate use of fabric installations (15) over that of grids (5) and composites

(4). Once again, these data represent the best knowledge of the individual completing the questionnaire.

Since not all pavement conditions are identical, surface preparation techniques have varied from project to project. Surface preparation guidelines are provided in the *Guidelines for Using Geosynthetics* in Appendix F of this report. It is worth reiterating the need for a level-up course prior to installing geosynthetic products. As described in the case history for Loop 12 in Dallas, the HMA level-up provided substantial additional life to the overlay (3/4-inch level-up over JCP + geocomposite + 2-inch overlay). In short, the level-up course separates the joint and the geosynthetic material, thus reducing the shear stresses in the overlay above the joint. Additional benefits of placing a level-up include a better bond between the geosynthetic and the level-up as compared to the geosynthetic and an irregular surface. On the relatively smooth surface of a level-up, the goesynthetic can be placed with fewer wrinkles than on an irregular surface. <u>Any</u> voids between the geosynthetic and the irregular surface will greatly increase the speed and intensity of the reflective crack as well as provide areas for potential slippage. As a result, the full benefit of a geosynthetic cannot be realized without a level-up course.

The questionnaire showed that the average overlay thickness, *independent* of the geosynthetic material, was 2 inches. Ideally, the overlay thickness should be determined based on a structural pavement design using the existing substrate conditions. Within TxDOT, structural pavement designs are performed using a flexible pavement design computer program called FPS-19. The overlay design option within FPS-19 provides the required thickness of HMA to meet certain loading conditions based on the condition of the underlying materials. In contrast, no formal overlay thickness design is performed when addressing routine preventive maintenance projects. In these situations, if the pavement is considered structurally sound, distress in the surface course is corrected by placing a nominal thickness of HMA overlay. The overlay thickness is normally based on local experience and/or available funding. The inclusion of a geosynthetic product in the pavement structure compounds the problem of determining the ideal overlay thickness.

Questions have been raised, such as, "If I add a geosynthetic material during construction, would the thickness of the required overlay decrease?" To answer this question, TTI prepared a reflective cracking pavement design program for use by the Department. This program provides a design check against reflective cracking for overlays that are determined using the FPS-19 program. The designer takes the required overlay thickness (output of FPS-19) and performs a design check to indicate the number of days that the pavement will last (with a geosynthetic material included) in terms of reflective cracking for a medium level of severity. This program therefore circumvents the previous question. The overlay thickness is designed from a structural standpoint and then checked to see how well it performs. If the performance is inadequate, then the designer has the option of varying the input parameters (product type, overlay thickness, etc.). In essence, the designer is analyzing the overlay thickness and choosing the best alternative for the specific field conditions.

The final portion of the questionnaire focused on construction and performance issues. In terms of construction, most districts reported no major problems with the installation of grid and composite materials and only minor problems with the installation of fabric materials. In some cases, materials that required tack coat rolled up on the tires of construction equipment. Guidance is given for these situations in the *Guidelines for Using Geosynthetics* portion of this report. Some districts reported that a manufacturer's representative was on site during installation of the geosynthetic and the paving operations. This is obviously desirable and might even be advisable to place in the construction general notes for districts/contractors that are unfamiliar with geosynthetic application.

Performance of geosynthetics has varied. A particular type of geosynthetic product that might have had a success in one district has shown a complete failure in another district. A differentiation of success of one particular geosynthetic type over another cannot be made based on the results of this questionnaire. This conclusion on performance, although disappointing, should not come as a complete surprise. The use of geosynthetics for reducing reflective cracking is not an intuitive science. One reason is because the medium in which the material is used (e.g., HMA) is highly variable. It is simply not easy to state that one should increase or decrease the overlay thickness because a geosynthetic material is added to the system.

Lytton et al. (1993) describe HMA as behaving as a linear elastic or viscoelastic material at low temperatures and as a nonlinear elasto-visco-plastic material at high temperatures. Additionally, the performance enhancement of HMA by the addition of a geosynthetic product is highly a function of the loading conditions (bending and shear caused by traffic), weather (expansion and contraction stresses induced by thermal changes), and material properties of the geosynthetic (modulus, percent elongation, etc). Reflective cracking performance will change if any one of these changes. It is therefore essential that all projects be *designed* based on the existing field conditions and materials specified. The correct combination of materials, which is different for each project, should be selected to achieve the level of performance desired by the user. This is where the reflective cracking design check within FPS-19 can be useful. This program provides a design check, but can also be used as an analysis tool to determine the optimum overlay system (thickness and geosynthetic type) based on such input parameters as traffic, site temperature variations, and tack coat usage.

EXHIBIT E1

Research Questionnaire

Texas Department of Transportation Research Project 0-1777
Field Synthesis of Geotextiles in Flexible and Rigid Pavement Rehabilitation Strategies Including Cost Considerations

Research Team

Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3135

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Dr. Robert L. Lytton, P.E. Professor, Texas A&M University Director, Center for Infrastructure Engineering (979) 845-2407	Mr. Gregory S. Cleveland, P.E. Texas Department of Transportation Graduate Research Assistant (979) 458-4148

Instructions for completing questionnaire

The questions in this survey pertain to the use of geotextiles (fabric, grid, or composites) under hot-mix asphalt overlays to reduce or retard reflective cracking in two classifications of pavement construction:

- Asphalt Concrete Pavement, and
- Jointed Concrete Pavement

If applicable, we ask that you make additional copies and complete this questionnaire for each roadway where geotextiles have been used in your district.

Due date for completed questionnaire

Please complete this survey by **October 13, 2000** and return to the attention of Gregory Cleveland at the address above.

Thank you in advance for your valuable input to this research effort.

Project Goal

The ultimate goal of this study is to evaluate geotextiles placed under or within a hot-mix asphalt (HMA) overlay to reduce the severity or delay the appearance of reflection cracks. TxDOT is in need of rational methodologies for selecting and installing geotextiles for paving applications. This is currently done based primarily on local experience within a district or a willingness to try a product that appears to have merit.

Definitions

Reflection cracking: Propagation of an existing cracking pattern from the old pavement into and through a new overlay.

Geotextile: Fabrics, grids, or composites (a grid with a nonwoven fabric attached).

Questions:

1. Name:
   District:
   Job Title:
   Telephone number:

2. Description of highway where geotextile(s) was used.
   - Interstate, freeway, arterial, urban, rural, etc.:
   - Name of highway:
   - County:
   - Limits:

3. Please indicate the preexisting underlying pavement type.

   - Asphalt concrete pavement
   - Jointed concrete pavement

4. Describe the existing pavement structure before the geotextile and overlay was placed.

   - Thickness of:
     - ACP
     - Concrete Pavement
   - Flexible base
     - Thickness
     - Lime treated
     - Cement treated
     - Aggregate type
     - Approximate percentage of stabilizer used

Subbase
- Thickness
- Lime treated
- Cement treated
- Aggregate type
- Approximate percentage of stabilizer used

Subgrade
- Thickness
- Lime treated
- Cement treated
- Aggregate type
- Approximate percentage of stabilizer used

5. Describe the distresses in the existing pavement before placing geotextile and overlay. Please indicate the size (e.g., 1/8", 1/4"), spacing (e.g., approximately every 15'), and amount (e.g., 25% of outer lane) for each applicable distress below.

<u>Asphalt Concrete Pavements</u>
Alligator (fatigue) cracking
Block cracking
Edge cracking
Longitudinal cracking
Reflection cracking at joints
Transverse cracking
Rutting (location/depth)
Shoving (location/severity)
Lane-to-shoulder dropoff
Lane-to-shoulder separation
Water bleeding and pumping
Other

<u>Jointed Concrete Pavements</u>
Corner breaks
Durability "D" cracking
Longitudinal cracking
Transverse cracking
Joint seal damage of transverse joints
Spalling of longitudinal joints
Spalling of transverse joints
Blowups
Faulting of transverse joints and cracks
Lane-to-shoulder dropoff
Lane-to-shoulder separation
Patch/ Patch deterioration
Water bleeding and pumping
Other

6. Was any testing performed to access the amount of distress and/or reason to rehabilitate? Please summarize major findings.

   Falling Weight Deflectometer
   Ground Penetrating Radar
   Dynamic Cone Penetrometer
   Cores/ Trenching
   Calculation of load-transfer efficiencies across joints
   PMIS scores
   Roughness (profilograph?)
   Maintenance history
   Other
   Comments:

7. Was the decision to use geotextiles based on local experience or the suggestion of geotextile manufacturers?

8. What are the district's normal rehabilitative procedures? Please describe methods and usual overlay thickness.

9. Describe the type of geotextile applied.

   Fabric
      type
      manufacturer
   Grid
      type
      manufacturer

   Composite
      type
      manufacturer

Describe the construction procedures used before installing the geotextile.

Was the existing surface milled? (indicate depth)

Was the existing surface sealed? (indicate method)

Were any concrete repairs made? (indicate procedures)

Was a level-up course of HMA applied? (indicate type and depth)

What type of tackcoat was used? (e.g., emulsion, liquid ac)

What was the tackcoat application rate in gal/sy?

10. What was the type and thickness of HMA overlay?

11. Describe any problems associated with the construction of such products. Please indicate any changes made during the construction process.

12. Was a geotextile manufacturer consulted and/or present during the design and installation of the geotextile? Please indicate company contact information.

13. Indicate the approximate reduction (i.e., percentage, more, less, same) in reflection cracking resulting from the installation of the geotextile. Indicate approximate time frames for which observations were made (e.g., after one year, the reflection cracking is the same as the underlying pavement, etc.).

14. What is your opinion of geotextile used to reduce reflective cracking in overlays as compared to other rehabilitative measures you have used (refer to question no. 8) within your district on similar types of pavements and/or substrate conditions

15. Do you believe the product is performing to the district's satisfaction?

16. Are you aware of any geotextile test pavement sections within your district? Have these pavements been monitored or has data been documented?

17. Are you aware of any forensic reports which attribute pavement failure to the use of geotextiles?

18. What was the unit bid cost for the geotextile (per square yard or per linear foot)? Do you feel the costs associated with this method of rehabilitation are advantageous, as compared to other methods which you have described earlier?

19. Do you believe the geotextile has helped reduce intrusion of surface water into the pavement structure? If so, has pavement smoothness, or ride quality, been "improved" by the use of the geotextile? Do you have documented proof that the geotextile has improved pavement smoothness?

20. Do you believe the geotextile has contributed to a premature failure in the pavement structure due to stripping?

21. Please make any additional comments for the research team.

Once again, thank you for your input to this research effort!

APPENDIX F

GUIDELINES FOR USING GEOSYNTHETICS WITH HMA OVERLAYS TO REDUCE REFLECTIVE CRACKING

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GUIDELINES FOR USING GEOSYNTHETICS WITH HMA OVERLAYS TO REDUCE REFLECTIVE CRACKING

No current pavement rehabilitation techniques have been shown to *prevent* reflective cracking. Several techniques have demonstrated the ability to reduce reflective cracking. Application of geosynthetics is only one of a number of techniques. Available methods usually fall under one or more of three categories:

1. Reinforcement of the overlay
    a. Thicker overlay
    b. Fiber-reinforced HMA overlay: polyester, polypropylene
    c. Modified asphalt in HMA overlay: tire rubber, neat rubber, polymer, sulfur, carbon black
    d. Compliant HMA mix: PFC w/crumb rubber or SMA
    e. High-modulus grid or composite: fiberglass or polymer
2. Stress relieving interlayers
    a. Stress absorbing membrane interlayer (SAMI): asphalt rubber seal coat
    b. Open-graded HMA interlayers
    c. HMA interlayer containing low-viscosity asphalt
    d. Stone dust bond breaker
    e. Fabric/asphalt interlayer
    f. Heavy-duty membrane
3. Restrengthening of cracked pavement before overlaying
    a. Heater scarification
    b. Spray applications of asphalt rejuvenator

Other methods to address reflection cracking might include: a seal coat applied to the existing pavement, thick large stone open-graded asphalt stabilized layer (Arkansas mix), saw and seal the HMA overlay, and cracking and seating or rubblizing of concrete pavements. This guideline will deal strictly with geosynthetics for reducing reflection cracking.

DEFINITION OF TERMS

"Geosynthetics" are defined herein as fabrics, grids, composites, or membranes. Grids and composites are newer generation materials developed for specific purposes by manufacturers.

Fabrics or geotextiles may be woven or nonwoven and are typically composed of thermoplastics such as polypropylene or polyester but may also contain nylon, other polymers, natural organic materials, or fiberglass. Filaments in nonwoven fabrics are typically bonded together mechanically (needle-punched) or by adhesion (spun-bonded, using heat or chemicals). Paving fabrics typically weigh about 4 to 8 ounces/yd^2. Technically, grids and composites are not geotextiles (Holtz et al., 1998).

Grids may be woven or knitted from glass fibers or polymeric (polypropylene or polyester) filaments, or they may be cut or pressed from plastic sheets and then post tensioned to maximize strength and modulus. Grids typically have rectangular openings from 1/4 inch to 2 inches wide. A grid may have a thin membrane laminated onto it that assists in construction (i.e., attaches to the asphalt tack coat) but is designed to melt and thus disappear when the hot HMA overlay is applied. Additionally, some grids have thin, permanent fiber strands partially filling the openings that adhere the grid to the tack coat without forming a waterproof barrier. Grids are designed to exhibit high modulus at low strain levels such that their reinforcing benefits begin before the protected pavement layer fails in tension.

Composites generally consist of a laminate of fabric onto a grid. For the composite, the fabric provides absorbency (primarily to hold asphalt) and a continuous sheet to permit adequate adhesion of the composite onto a pavement surface; whereas, the grid provides high strength and stiffness. Manufacturers custom design these third-generation products, based on laboratory and field research, to meet the needs of asphalt retention and high initial tangent modulus (i.e., high modulus at low strain levels).

A heavy-duty membrane is a composite system, usually consisting of a polypropylene or polyester mesh laminated on either one or both sides with an impermeable rubber-asphalt membrane. Membranes weigh about 50 to 100 ounces/yd^2. They are typically placed in strips over joints in concrete pavements or used for repair of localized pavement failures.

WHEN TO CONSIDER A GEOSYNTHETIC

Generally, geosynthetics will perform best when used to address load-related fatigue distress manifested by closely spaced random cracks or alligator cracks. To justify a full-coverage geosynthetic, significant random cracking should be prevalent on a significant portion of the project. No specific guidance is available. More widely spaced cracks and/or joints in PCCP can be addressed using a geosynthetic strip product (heavy-duty membrane). However, widely spaced transverse cracks and joints often exhibit large movements, making reflective cracking difficult to impede.

Geosynthetics can be effective in retarding reflection cracking from low-severity and medium-severity alligator-cracked pavements (Holtz et al., 1998).

Geosynthetics and other types of interlayers will typically perform considerably better in warm and mild climates than in cold climates. There are three ranges of thermal crack opening: (a) from 0 to 0.03 inch, where no geosynthetic is needed; (b) from 0.03 to 0.07 inch, which is the effective range of geosynthetics; and (c) greater than 0.07 inch, which is an opening movement that geosynthetics cannot normally withstand (Lytton, 1989).

The presence of cracks does not necessarily mean that ride quality is low. Cracks can be sealed and the pavement can continue to be used if ride quality is acceptable.

The economics associated with existing techniques for reducing reflection cracking indicate that a crack-treatment program for pavements having light to moderate levels of cracking is usually more cost effective than other available methods (Barksdale, 1991).

Strategies including a geosynthetic, like all others, must be carefully engineered and are not quick, easy solutions suitable for all pavements.

Hot Mix Asphalt Concrete Pavements

In order for geosynthetics to perform satisfactorily, the flexible pavement on which they are placed must be structurally sound. The pavement should have a remaining life of greater than 5 years, as computed by the remaining life routine in Modulus 5.1.

Pavements for which cracking can potentially be delayed by using a geosynthetic exhibit fatigue cracks that are *not* caused by base or subgrade failures or delamination of existing pavement layers. Surface cracks should be less than 1/8 inch wide. No improvement in performance is likely if cracks are greater than 3/8 inch wide. Observations have shown that fabrics are not effective where wide transverse thermal and shrinkage cracks are present (Barksdale, 1991).

When an overlay and fabric are placed over an existing pavement, it often can no longer "breathe" and thus water may accumulate in the old pavement. It is prudent to evaluate the stripping potential of a pavement before placing a fabric/overlay system or any other sealing layer or interlayer. While the old pavement was able to "breathe," moisture susceptibility was not manifested (McKeen and Lytton, 1982).

Geosynthetic products should not normally be placed on a milled surface. A level-up course of HMA should be placed to provide a smooth surface on which to place the geosynthetic. A level-up course will also prolong the appearance of reflective cracking at the overlay surface. Theory (Pickett and Lytton, 1983) and practice (Brewer, 1997) have shown significant benefits from placing a level-up course before placing the geosynthetic.

Portland Cement Concrete Pavements (PCCP)

Jointed Concrete Pavements. In order for geosynthetics to perform satisfactorily, the JCP on which they are placed must be structurally sound. Measures should be taken to minimize joint and crack movements. The load transfer efficiency factor (LTEF) at joints should be 80 percent or greater. LTEF is computed as (AASHTO, 1993)

$$LTEF = (d_u / d_l) \times 100$$

where d_l = deflection on the loaded side

d_u = deflection on the unloaded side

Lateral movements at joints and some cracks in JCP are usually large, and stopping these reflective cracks is particularly difficult. Cracks should be sealed before overlaying.

Geosynthetic strips, which have a thick membrane, may provide an effective seal for several years even after the cracks appear at the overlay surface.

The 1993 AASHTO Design Guide advises that the effectiveness of geotextiles in controlling reflective cracking in HMA overlays over jointed plain concrete and jointed reinforced concrete pavements is questionable. If a geosynthetic is to be used on JCP, this guideline recommends a high-modulus product (such as fiberglass grid) be placed in strips only over the joints. Ideally, the geosynthetic should not be placed directly on the existing JCP. The following should precede placement of the grid: cracks in the concrete larger than 1/8 inch should be filled with crack sealant. A Grade 4 (~1/2-inch maximum size) seal coat (underseal) should be applied to promote good adhesion to the concrete and assist in sealing smaller cracks in the slabs. A level-up course of HMA should be placed to provide a smooth surface on which to place the grid and assist in reducing reflective cracking. Theory (Pickett and Lytton, 1983) and practice (Brewer, 1997) have shown significant benefits from placing a level-up course before placing the geosynthetic.

Cracks in JCP greater than 3/8 inch should not be treated with fabrics without previous crack treatment. Cracks 3/8 inch or wider prevent asphalt tack from "wicking" into the fabric across a crack or joint. Thus, the crack or joint is left open to infiltration of surface water immediately after the old crack reflects through the overlay (Barksdale, 1991).

Continuously Reinforced Concrete Pavements (CRCP). In order for geosynthetics to perform satisfactorily, the rigid pavement on which they are placed must be structurally sound. Since crack spacing in CRCP is usually small, slab movement at the cracks is usually small, and reflective cracks through a HMA overlay are not usually serious problems. If a geosynthetic is to be used on a CRCP, it is advisable to place an HMA level-up course before placing the geosynthetic and the final overlay. Theory (Pickett and Lytton, 1983) and practice (Brewer, 1997) have shown significant benefits from placing a level-up course before placing the geosynthetic.

HMA-Overlaid Concrete Pavements

Geosynthetics are routinely used with new overlays on previously HMA overlaid PCCP, where the original pavement was JCP, JRCP, or CRCP. In addition to controlling reflective cracking, an asphalt-impregnated geotextile can help control surface water infiltration into the pavement and thus minimize associated damage. Moisture can cause loss of bond between AC and PCC, stripping in the AC layers, progression of D-cracking or reactive aggregate distress (in pavements with these problems), weakening of the base and subgrade (Holtz et al., 1998), and frost heave.

ADVANTAGES AND POTENTIAL DISADVANTAGES

Advantages

Moisture is frequently the main source of pavement damage and roughness. Asphalt-impregnated fabrics will control infiltration of surface water into a pavement. Fabrics may remain intact after the asphalt overlay has cracked and provide a moisture barrier. The fabric must be saturated with sufficient asphalt to provide a continuous moisture barrier; insufficient tack will diminish this waterproofing effect. Movement at cracks in some jointed concrete pavements may be large enough to rupture the fabric such that it no longer provides resistance to water flow. If a moisture barrier is justified, fabrics and composites offer this added benefit but grids cannot.

Disadvantages

An asphalt-impregnated fabric or composite can trap water in a pavement. A moisture barrier under a new overlay can be a detriment to its performance, particularly if the overlay is not compacted properly. Rapid premature failures have occurred when a moisture barrier (fabric, seal coat, etc.) was placed on an old pavement then the overlay is insufficiently compacted such that it is permeable to water (Better Roads, 2000; Roads & Bridges, 2000). Surface water enters the permeable overlay and is trapped by the impermeable layer. Subsequent kneading and scouring action by traffic in the presence of the water causes rapid failure of the overlay. This problem is compounded when the overlay is also an inlay (sometimes termed the “bathtub” effect). One paper (Marienfeld and Baker, 1999) stated, “The level of compaction is not as critical to achieving low permeabilities when a paving fabric moisture barrier is used." Based on personal observations, the authors disagree with this statement. Compaction of dense-graded HMA is always important for achieving proper density and minimum permeability. A permeable dense-graded HMA overlay over a moisture barrier can result in rapid failure, particularly during freeze-thaw conditions (Button, 1989).

In addition, water vapor rising from below due to evapo-transpiration can accumulate just under a moisture barrier and, if the HMA mixture in that vicinity is water susceptible, it can suffer significant damage. Distress will develop first in the wheelpaths due to repetitive loading by traffic on the weakened pavement layer and progress rapidly.

Fabrics have been found ineffective in reducing reflection of thermal cracks. Pavement overlay systems have had limited success in areas of heavy rainfall and regions with significant freeze-thaw cycles. (FHWA Manual, 1982)

SELECTION OF A GEOSYNTHETIC

Geosynthetics currently available include fabrics, grids, and composites. There are several widely varying products within each of the three categories. Fabrics made using polypropylene or polyester are most common. Fabrics have been made of other products (nylon, glass, combinations of materials) but they are usually more expensive. Polypropylene begins to melt at a temperature of about 325°F. Therefore, when using polypropylene products, the temperature of the paving mixture should not exceed 325°F when it contacts the geosynthetic.

When ordering geosynthetic products, the contractor should specify width of rolls to accommodate pavement lane width or his plans for geosynthetic placement. Improper roll width can result in significant lost time, excessive construction joints, and waste of material. The contractor should also consider the maximum roll weight that the application equipment (typically a specially equipped small tractor) can handle. Excessive roll weight may cause the roll core to sag thus producing wrinkles during geosynthetic placement.

Fabrics

Nonwoven paving fabrics typically exhibit relatively low moduli and thus can mobilize only limited stress at low strain levels. Fabrics have demonstrated mixed results in reducing reflective cracking by acting as a stress-absorbing interlayer. There is evidence that an asphalt-impregnated fabric will resist intrusion of surface water into the base even after reflective cracks appear at the pavement surface. Some Department engineers believe this reduction of water in the base/subgrade reduces localized swell and thus helps maintain pavement smoothness.

In theory, using a thicker fabric should result in lower stresses at the tip of a crack than using a thinner one. Therefore, the thicker layer should be more effective in delaying reflection cracking. The full thickness of the nonwoven fabric must be saturated with asphalt. Clearly, asphalt retention rate is an important property. Asphalt retention should be at least 0.2 gallons/yd^2; it is directly related to the fabric weight and thickness. When used as a stress-relieving interlayer, the fabric should generally have a minimum weight of 4.1 ounces/yd^2 (AASHTO M 288-00). Both theory and limited evidence indicate that a thicker fabric with a greater asphalt retention may delay cracking longer than a thinner fabric. Additionally, heavier fabric will reduce bleed through during construction and reduce the effect of any damage by construction traffic. The maximum practical weight for a paving fabric is about 6 oz/yd^2 to allow proper asphalt saturation in the field.

Manufacturers may recommend certain lightweight fabrics as having appropriate qualities. In these instances, advice should be sought from the Materials & Tests Section, Construction Division.

Full-width fabrics should be limited to use on flexible pavements where there is extensive random cracking and waterproofing of the pavement is needed and justified. Widespread alligator cracking often indicates structural failure, which must be addressed by major rehabilitation efforts. A fabric/seal coat or fabric/overlay to address structural problems should be considered only a short-term solution. If widespread alligator cracking is due to surface aging of asphalt and not structural failure, full-width fabric may be an inappropriate treatment; rejuvenation or surface recycling may be more appropriate. Strip fabrics are recommended for use on widely spaced cracks and joints where a prolonged waterproofing interface is desired. Waterproofing may limit base and subgrade movement due to freeze-thaw action or expansive soils. Fabrics have not demonstrated good success in reducing reflection of thermal (transverse) cracks in flexible pavements and joints in concrete pavements.

Grids

Grids typically exhibit much higher moduli than fabrics and logically should take on more stress at low strain levels. Grid systems serve primarily as a reinforcing interlayer. To act as overlay reinforcement, a grid must be tightly stretched, or slightly pretensioned, and it must have sufficient stiffness. Typical grids used as overlay reinforcement exhibit stiffnesses varying from 80 to >1000 lb/inch. However, only the stiffest grids can act as overlay reinforcement (Barksdale, 1991).

Some grids contain a thin, continuous sheet, designed to assist in installation (i.e., adhere to the tack coat) that melts when the hot overlay is applied. Other grids have thin, permanent fiber strands partially filling the openings that adhere the grid to the tack coat. Neither of these products forms a waterproof barrier. These products should be considered as grids and not composites.

Composites

Composites may offer benefits of both fabrics (stress-relieving interlayer) and grids (reinforcement). Composites are recommended for use on pavements where both reinforcement and waterproofing are desired.

Membranes

Heavy-duty membranes should serve as both a waterproofing membrane and a stress-relieving interlayer. The mastic membrane should provide both reduced permeability and be sufficiently soft and thick to act as a stress-relieving interlayer. Membranes are relatively expensive and are normally placed in strips over joints or cracks. In some systems, the membrane is bonded to the old pavement when temperatures exceed 70°F, by simply removing a protective film on the back of the membrane and placing it over the prepared joint. In other systems, an adhesive tack coat must be applied to the pavement before placement of the membrane.

Storage

During storage, geosynthetics should be protected from precipitation, extended exposure to sunlight, temperatures exceeding 160°F, sparks/flame, and chemicals. Geosynthetics containing any polymer will degrade upon prolonged exposure to sunlight. They should be protected from direct sunlight even if the geosynthetic is marked UV stabilized. Water-soaked materials are cumbersome and may not readily adhere to an asphalt tack. If rolls have taken on water, the core may not be strong enough to support the geosynthetic during placement. Geosynthetics should be stored in such a manner to avoid misshapen rolls.

COST CONSIDERATIONS

The in-place costs of geosynthetics and other methods to address reflection cracking are influenced by: (a) the specific product used, (b) the quantity to be placed, (c) local experience with its installation, (d) local labor costs, and (e) the general condition of the market place. The in-place cost of fabrics has fallen significantly since the early 1980s, apparently due to stiff competition and, perhaps, improved contractor experience and acceptance of geosynthetics. In 1991, NCHRP Synthesis 171 offered the following rule of thumb: The in-place cost of a full-width paving fabric is roughly equivalent to the cost of about 0.5 to 0.6 inch of asphalt concrete (Barksdale, 1991).

Under favorable conditions (many of which are described herein), some geosynthetic products can delay reflection cracking in an asphalt overlay about two to four years longer than a similar overlay without a geosynthetic. Reflection cracks are usually sealed through a maintenance program. Such maintenance costs and any delays by a geosynthetic are reasonably easy to quantify, and should be considered when the cost of different design alternatives are analyzed. An estimate of the probability of success should be included in all economic analyses. NCHRP Synthesis 171 indicated that, under favorable conditions, the probability of success of a paving fabric will be about 60 to 65 percent. The use of geosynthetics and other techniques should, at a minimum, be compared with the cost of using an overlay of similar thickness with a crack-sealing program. Thicker overlays can also be used as a basis for comparison (Barksdale, 1991).

A simple approach is to determine or estimate the performance equivalency between two alternatives and directly compare their costs. California DOT indicated a paving fabric interlayer may be equivalent to about 1.2 inches of HMA in retarding reflective cracking. Using typical in-place costs, a fabric interlayer is about 50 percent of the cost of 1.2 inches of HMA (Holtz et al., 1998), and this assumes a 100 percent success rate. Considering a 65 percent probability of success, the economic advantage of using paving fabrics appears to be somewhat less unless the potential benefits of reduced water infiltration and resultant improved ride quality are considered. One should obtain realistic cost data for the particular situation and estimate a reasonable probability of success.

Determination of cost effectiveness of products in pavements typically requires several years. As a result, information on cost effectiveness of the newer grids and composites is not currently available in the literature.

Heater scarification is an alternative for addressing reflective cracking. The decision to use a geosynthetic or heater scarification for controlling reflective cracking may come down to economic conditions for the particular project. The two procedures are not equivalent. Heater scarification may be used in conjunction with a geotextile to provide, for practical purposes, a 1-inch leveling course. In this case, heater scarification must compete with a new leveling course in order to be the most cost-effective alternative. When a pavement exhibits large spaces between thermal cracks (e.g., greater than about 15 to 20 feet, depending on the temperature regime), crack movement due to thermal variations and traffic is expected to exceed the capability of a fabric to effectively control reflective cracking. In this case, it seems reasonable to heater scarify the old pavement rather than or in addition to installing a geosynthetic. Again, heater scarification is competing with new overlay material. If heater scarification reduces the overlay thickness and/or maintains the required grade, it may be cost effective.

PAVEMENT DESIGN CONSIDERATIONS

Overlay Thickness

Overlay thickness for both flexible and rigid pavements should be determined as if the geosynthetic interlayer is not present. Generally, overlay thickness should not be reduced from that determined by standard methods when using a geosynthetic. When overlay thickness is reduced based on contributions of the geosynthetic, it should not be reduced to less than four times the size of the largest aggregate in the HMA overlay mixture nor less than 1.5 inches.

Avoid the use of thin (< 2 inches) or inadequately compacted overlays with fabric, particularly on high traffic volume facilities. Stage construction is not recommended. That is, a thin overlay should not be constructed with plans for placing another thin overlay in a few years. Data and experience suggest that a minimum overlay thickness of 2 inches should be used with or without paving fabrics (Barksdale, 1991).

Overlays less than 1 ½-inch thick cool rapidly and, thus, are difficult to compact to the required density. A poorly compacted overlay may exhibit high permeability and allow water to become trapped on top of a fabric interlayer. Trapped water can lead to stripping and freeze-thaw damage in the overlay, which will appear prematurely as cracks in the wheel paths and will deteriorate rapidly.

Overlay Type

Normally, only dense-graded, well-compacted, low permeability HMA mixtures should be used as overlays over fabrics or composites. Beneath permeable HMA mixtures (e.g., PFC or OGFC), a waterproof fabric must he placed at a drainable grade so that surface water drains out of the overlay. For milled inlays proper drainage must be provided. Permeable overlays, such as poorly compacted mixtures with interconnected voids, should not be permitted. CMHB mixtures have shown significant permeability when first placed and, therefore, should not be used over a waterproofing fabric or composite. A poorly compacted overlay over a waterproof membrane (asphalt-impregnated fabric) can trap and hold water. Retained water can cause rapid failure of the overlay due to freezing and/or stripping of the asphalt. Overlay damage during or after freezing and while holding water is exacerbated by traffic loadings.

Flexible Pavements

The recommended steps (Barksdale, 1991) in developing an overlay design for flexible pavements where a paving fabric is a potential candidate are given below. Details have been modified to accommodate TxDOT circumstances.

Pavement Condition Evaluation. A general pavement condition survey is valuable in establishing the type, severity, and extent of pavement distress. Such information is needed to develop required repair strategies and the overlay design strategy. Candidate pavements should be divided into segments. Non-destructive surveys, including visual distress, ground penetrating radar (GPR), deflection (FWD), or seismic (SPA), are possible tools to establish where these divisions should be made. For each segment, determine extent and severity of cracking (longitudinal, transverse, alligator, block, random), rutting, patching, potholes, flushing, raveling, etc. Crack widths should be measured. TxDOT has existing systems for rating pavement condition.

A tentative conclusion should then be drawn as to whether a geosynthetic is a suitable candidate in the rehabilitation scheme. If a formal pavement condition survey is not performed, at a minimum, the type, extent, and level of cracking should be established.

Structural Strength. Overall structural strength of the pavement should be evaluated, along its length, using the falling weight deflectometer (FWD). The pavement should have a remaining life of greater than 5 years, as computed by the remaining life routine in TxDOT's Modulus 5.1.

Base / Subgrade Failure. Areas that have experienced base or subgrade failures should be identified. There should be no evidence of severe load associated distress (e.g., alligator cracking < 5 percent, no deep ruts or failures). When nondestructive testing devices are not available, proof loading of the pavement with a loaded truck has also been used to identify structurally weak areas. Reflection cracking will not be significantly delayed by geosynthetics in areas that have base/subgrade failures.

If base failure areas are limited, they should be repaired by removal and replacement. If base failure areas are extensive, rehabilitation alternatives other than geotextiles should be considered. If all failed base/subgrade areas are repaired and no other types of distress are present, geotextiles will probably not cost-effective improvements in performance.

Remedial Pavement Treatment. The results of the pavement condition survey and deflection measurements should be used to develop a pavement repair strategy for each segment.

Overlay Design. A realistic overlay thickness must be selected to ensure a reasonable overlay life. Using geosynthetics with thin, under-designed overlays, which lead to significant reflection cracking in three to five years, or less, will not justify the use of a geosynthetic.

Performance Monitoring. To develop a data bank of performance histories with geosynthetics, performance monitoring during construction and service of the overlay is highly desirable. Constructing a control section without the geosynthetic, with all other items equal, will provide valuable comparative data for future decisions. Without a control section, the so-called test has no value.

Using FPS-19 Design Check for the Effect of Geosynthetics

A modification of the flexible pavement design program, FPS-19, has been offered by TTI to permit a design check for the expected reflection cracking life of an overlay with and without selected generic reinforcing geosynthetics. If this design check is selected, the designer must put in some additional data concerning (1) the existing pattern of reflection cracking of the old pavement surface, (2) the temperature variations in the area of the project, (3) whether a tack coat will be used with the geosynthetic, and (4) what the typical aggregate interlocking factor is expected to be from experience in the project area. The design check then uses the traffic and asphalt layer data that were originally input to the FPS-19 program to predict the life of the overlay to reach the medium severity level of reflection cracking.

In the design check for reflection cracking, three levels of aggregate interlocking factor are used: high, medium, and low. Subjective rankings are used because measured data from a deflection survey may not always be available at the time when the overlay is being designed. The load transfer efficiency factor (LTEF) from a deflection survey is directly related to the aggregate interlocking factor. The LTEF is the ratio of the deflection on the unloaded side of a crack divided by the deflection on the loaded side of the same crack. The relationship between the LTEF and the aggregate interlocking factor is as follows:

Range of LTEF	Aggregate Interlocking Factor
0.80 – 1.00	High
0.50 – 0.80	Medium
0.00 – 0.50	Low

In the absence of any measured deflections on a prospective project site, a medium aggregate interlocking factor is a prudent choice.

The options that the designer will have in selecting reinforcing materials are:

- no reinforcing geosynthetic,
- woven/coated polyester grid with non-woven fabric composites,
- woven/coated fiberglass grid with fabric woven composite,
- polypropylene non-woven fabric, or
- coated fiberglass grid.

The properties of these products that are used in the design check are averages of typical products that are commercially available in each category of material. As a result, the predicted reflection cracking life of the overlay is an approximate estimate of how each generic product will perform under the expected traffic and weather.

The design check will have default data for each of the input data that the designer is required to provide so that it is possible for the designer to simply accept the default data or to modify it as personal experience or judgment indicates. The default data are as follows:

- annual average temperature: 72°F;
- daily temperature drop: 20°F;
- transverse crack spacing in old pavement: 10 feet;

- tack coat used with geosynthetic? Yes; and
- aggregate interlocking factor: Medium.

As a good rule, the overlay should be designed to last as long against reflection cracking as the FPS-19 program predicts it should last under the expected traffic while resisting fatigue cracking, rutting, and roughness (loss of serviceability index). In order to achieve this, the designer may need to experiment with the thickness of the overlay to achieve this balanced design.

There are many options for the design of overlays with reinforcing geosynthetics, most of which have been experimented with for decades. From both experience and analysis, it has been found that there are numerous construction and performance benefits to applying a ¾ to 1 inch thick leveling course on top of the old pavement before placing the geosynthetic and then placing the remainder of the designed thickness of the overlay on top of the geosynthetic. For this reason, the design check for reflection cracking automatically assumes that the geosynthetic will be placed on top of a 1-inch leveling course and the reflection cracking life is calculated on that basis.

According to the design check, reflection cracks will begin to appear in a 2-inch thick overlay without any reinforcing in about 250 to 400 days, depending upon a number of factors such as traffic level, crack spacing in the existing pavement, aggregate interlocking factor, stiffness of supporting layers, and nightly temperature drops. Alternatively, initiation of reflection cracks in a similar overlay of the same thickness with reinforcing will occur in about 500 to 1200 days (a time increase of 2 to 3 fold), depending upon the product and the quality of its placement.

Rigid Pavements

The process (Barksdale, 1991) for determining candidate rigid pavements for rehabilitation with overlays having a geosynthetic is generally similar to that previously described for flexible pavements. Vertical joint deflection surveys should be performed to determine if grout injection or joint repairs are necessary. Joint deflections can be conducted using FWD, Rolling Dynamic Deflectometer, or proof rolling with a loaded truck. Geosynthetics should not be used when vertical joint deflections exceed 0.008 inches unless corrective measures are taken to reduce joint movements.

Horizontal thermal joint movement should be less than about 0.05 inch. Because horizontal joint movement is approximately proportional to slab length, thermal joint movements will increase as joint spacing increases. Careful attention must be given to performing the required remedial measures, including joint cleaning and resealing, patching, grouting, joint repair, slab replacement, etc. (Barksdale, 1991).

Overlay thickness should not be reduced when a geosynthetic interlayer is employed.

OVERLAY CONSTRUCTION WITH A GEOSYNTHETIC

Surface Preparation

Before application of a geosynthetic, the existing pavement should be thoroughly cleaned using a broom and/or compressed air and should be dry. Fill cracks exceeding 1/8 inch wide with appropriate crack sealant. Fill cracks exceeding 1 inch wide with a fine-grained bituminous mixture. Faulted cracks or joints with vertical deformation greater than ½ inch should be leveled using fine-grained bituminous mixture or other suitable material. These recommendations are designed to ensure that the geosynthetic or level-up course will have continuous firm support, which will assist in proper compaction of the overlay and allow continuous tack coat application to uniformly saturate the geosynthetic product. Potholes should be properly repaired even with the existing pavement surface. Crack filler and patching materials should be allowed to cure prior to placement of the geosynthetic.

Importance of a Leveling Course

Apply a leveling course to uneven, rutted, or extremely rough surfaces. For best results, place a level-up course (0.75 to 1 inch thick), whenever possible, before placing the geosynthetic. This will maximize performance of the geosynthetic in reducing reflective cracking. Both observation and analysis have shown that it is important to place a leveling course before placing a geosynthetic to further retard the appearance of reflection cracks. The leveling course does several important things to promote success of the overlay including providing a smooth surface on which to place a geosynthetic and a fresh, unoxidized surface to which the geosynthetic or new overlay can bond. The leveling course can also establish a drainable grade, when necessary, on which to place the geosynthetic. Placing a geosynthetic (and particularly a fabric) directly on an old or even a milled surface can cause wrinkles, which can themselves reflect upward to the surface of the overlay. Grids also benefit from being placed on a smooth surface because it makes the installation much easier, provides maximum adhesion, allows the reinforcing strands to be placed flat to mobilize their strength and stiffness at small deformations, and provides new material both above and below the grid so that compaction will press aggregates down through the grid apertures to lock the grid in place.

Theory and practice indicate that the life of an overlay can be shortened by placing a grid directly on the old pavement surface, whether it is milled or not, and then placing the overlay on top of it. Typically, the life of the overlay is shortened if the overlay thickness is between 2 and 5 inches thick and no leveling course is used beneath the grid. In such cases, analysis shows that, in this range of total thickness of overlay, the use of a leveling course can provide an overlay reflection cracking life that is 20 to 100 times longer than it would be if a grid were placed directly on the old pavement surface

Because the movement at cracks and joints in jointed concrete pavements is relatively large, a level-up course is highly recommended.

Tack Coat Selection and Application

Selection of proper tack material and application rate is one of the most important aspects in construction and performance of geosynthetic interlayers. One should consult the particular geosynthetic manufacturer's installation manual. Hot asphalt cement (AC) is usually recommended as tack for geosynthetics. Tack coat should be applied uniformly at the specified rate using a calibrated asphalt distributor truck. The tack coat should be sprayed approximately 4 inches wider than the geosynthetic. Common field problems with tack coat applications include proper temperature control, clogged or leaking spray bars or nozzles, application of too much or too little material, and nonuniform distribution.

Tack application temperatures are generally about 290°F to a maximum of 325°F. Temperature of the tack when the geosynthetic is placed can be critical. Polypropylene may be damaged or shrink at temperatures above about 300°F (Button et al., 1983). Optimum temperature for embedment of fabric is 180°F to 250°F. One must install fabric while asphalt is still tacky. However, if fabric is embedded in asphalt that is much hotter than 180°F (particularly in hot weather), the fabric may become prematurely saturated and cause construction problems (e.g., fabric pick-up, slippage). A noncontact thermometer is useful in determining binder temperature.

Tack rate should not be reduced to solve construction problems. Such reductions can cause subsequent system failure.

Weight tickets and tank gauges may not be sufficiently accurate for checking tack rate. Tack rate should be verified using preweighed, thin pans placed directly in the path of the distributor truck. The pans can be recovered after passage of the distributor truck and weighed to compute the tack application rate. If measured tack rate is different from specified rate, it should be appropriately adjusted before further use. Application spot checks should be conducted periodically and be used to verify weight tickets and calibrated stick measurements.

Insufficient tack rate is the leading cause of poor fabric interlayer performance and failure (AIA, 1999). Insufficient tack will result in unsaturated fabric, which can lead to overlay slippage and/or debonding and will not provide waterproofing.

Emulsified asphalt is not normally recommended as tack for geosynthetics. If , however, emulsified asphalt is used, it should be allowed to break and set before the geosynthetic is placed. Placement should be followed immediately by pneumatic rolling to minimize disruption by wind or traffic. A larger quantity of emulsion is required as compared to AC (to yield the proper amount of residue) and the viscosity of emulsion is lower than AC (and stays lower longer). This may cause problems with runoff, particularly on sloped or undulating pavements. If emulsified asphalt is used as tack, it should not be diluted with water. The inspector should ensure the emulsion has not been diluted. When calculating tack coat shot rate, recall that emulsion is only about 65 percent asphalt, therefore, tack rate must be adjusted upward by dividing it by the asphalt content (percentage) of the emulsion: (e.g., emulsion shot rate = desired asphalt tack rate/0.65).

Fabrics. The design tack coat application rate for a particular fabric is normally provided by the manufacturer/supplier. Type of tack should be hot applied asphalt cement (not emulsion) of the same grade as that determined for the HMA overlay. Although emulsified asphalts have been successfully used as tack for fabrics, they develop bond strength more slowly than asphalt cement, and debonding on windy days has been reported. Cutback asphalts should never be used for fabric tack, because the solvent can remain for extended periods and weaken the polymer.

Tack coats for fabric application are relatively heavy and should be applied uniformly with a calibrated distributor truck. Insufficient or excessive asphalt tack applied for fabric adhesion can result in overlay failures due to slippage at the fabric interface, especially in areas of high shear forces during periods of hot weather. Excessive tack can cause slippage of the paving machine or subsequently migrate to the pavement surface and appear as flushing in the wheelpaths. Low-viscosity asphalts are more susceptible to this bleeding than higher viscosity materials.

Tack coat should be applied using relatively long shot lengths. Start-stop operations less than a few hundred feet yield highly variable asphalt application rates. Shot lengths equal to fabric roll lengths (about 300 feet) are convenient for some operations. Greater lengths are encouraged provided the freshly sprayed asphalt does not become contaminated with dust or other foreign material. Starting and stopping on paper will reduce the buildup of asphalt at the overlapping sites.

Grids. Grids or mesh products often do not have enough continuous surface area to adhere tenaciously to an asphalt tack coat. Some grids are fastened to the existing pavement by methods other than asphalt tack. Some grid products have a self-adhesive backing. Therefore, tack may or may not be necessary to fasten a grid to the existing pavement. Generally, one should follow the manufacturer's recommendations for tacking grids. However, keep in mind that the interface between the existing pavement and the new overlay often needs tack to prevent delamination and thus slippage due to vertical and horizontal traffic loads. Placement of a light tack coat onto the mesh after installation should minimize potential slippage and/or debonding but may cause construction problems.

Placing a thin overlay without tack (particularly on a high-traffic facility) is inviting slippage and/or debonding problems. When placing a self-adhesive grid product for use with an overlay on an old pavement surface (i.e., not a new level-up course), a tack coat should be applied on top of the grid (i.e., after grid application) to ensure adequate adhesion at the interface. The appropriate quantity of tack is that normally used without a grid or slightly more. Type of tack should be hot applied asphalt cement (not emulsion) of the same grade as that determined for the HMA overlay. If the grid is placed on a new level-up course, the tack coat may not be necessary.

Composites. Typically, the tack coat selection and application guidelines for fabrics apply to composites.

Membranes. Membranes may or may not require tack coat. If a tack is required, it may be a proprietary product.

Placement of Geosynthetics

An experienced crew using a small tractor rigged for handling geosynthetic rolls should be specified for geosynthetic placement. Such a crew can move much faster than the paving train. To avoid placing traffic on geosynthetic, no more geosynthetic should be placed than can be overlaid the same day. Manual placement should be disallowed except in small areas where equipment may have difficulty maneuvering.

As the geosynthetic is spread onto the asphalt tack coat, it must be aligned and smoothed to remove wrinkles and folds. Some wrinkling of geosynthetics during installation is unavoidable due to curves and undulations in the pavement surface. Folds that result in a triple thickness must be slit with a knife and overlapped in a double thickness. Wrinkles can be a source of premature cracking in the overlay due to compaction without firm support or possibly due to shrinkage (polypropylene products) (Button et al., 1983).

A 4-inch to 6-inch overlap is suggested at all longitudinal and transverse joints. Overlaps should be in the direction of paving to avoid fabric pick-up by sticky tires. It is necessary to apply additional asphalt tack at these locations to ensure proper saturation and bonding. For this purpose, emulsified asphalt can be applied using a hand sprayer, brush, or mop.

Traffic will damage geosynthetics and may cause delamination from the pavement surface prior to overlay placement. Geosynthetics significantly reduce pavement surface friction and can present skidding hazard, particularly during wet weather. Significant traffic should never be allowed on geosynthetics. If trafficking is necessary, speed should be strictly controlled to 25 mph. If significant trafficking is necessary, an alternative to geosynthetics should be considered.

To avoid displacement or damage to geosynthetics while turning construction equipment, turning should be gradual and kept to a minimum. Parking of construction equipment on a completed geosynthetic/asphalt tack interlayer, even for short periods, should be avoided.

Geosynthetics should not be placed during rainfall or when rain is expected. Rainfall before, during, and after placement can result in severe debonding and even loss of the geosynthetic. Geosynthetics can be successfully employed on highly textured surfaces such as freshly milled pavement. Milled surfaces may require additional tack coat; this can be accomplished by pretacking any milled surfaces (e.g., next to curbs). In urban areas subject to high shear forces (e.g., at intersections), a highly textured surface may help decrease the probability of slippage. However, on highly textured surfaces, geosynthetics are more subject to damage by rainfall and traffic.

Fabrics. The bonded or glazed side of a fabric is better to drive on than the fuzzy side (i.e., less damage). The fuzzy side should be placed next to the tack coat. This practice will provide the highest bond strength and best slippage resistance.

When fabric is applied on hot days (>90°F), pavement surface temperatures near 160°F may prevail. These temperatures can be sufficiently high to keep the viscosity of asphalt tack low enough to partially saturate the fabric during placement and fully saturate the fabric in the wheelpaths of construction vehicles. Tires of HMA haul trucks can become coated with asphalt and will often pick up the fabric. The amount of asphalt tack coat should not be reduced to solve this problem. The following corrective measures should be considered:

1. First, allow the tack to cool longer before placing fabric.

2. Alternatively, hand spread a small amount of HMA mix on top of the fabric in the wheelpath of the haul vehicles.
3. Application of sand is the least desirable choice, as sand will absorb some of the asphalt and defeat its purpose. If sand is used, the quantity should be minimized and the grading should be coarse.
4. Change to a "heavier" grade of asphalt cement for the tack coat material.
5. Shorten the distance between fabric placement and the paving machine.
6. Minimize the number of vehicles on the fabric.

Cool weather construction may require the use of a lightweight rubber tired roller to properly attach the fabric to the tack coat. Rolling is preferred over a short shot length to solve the cool weather fabric adhesion problem. Excessive rolling should be avoided.

High winds can be problematic during application of fabrics particularly on a highly textured milled surface. Limited pneumatic rolling of a fabric immediately after application will maximize adhesive strength and minimize its disruption by wind and construction traffic. Pneumatic rolling on a steep grade or cross slope can result in slippage at the pavement fabric interface if the asphalt tack is still hot.

Construction joints in geosynthetics should generally follow the manufacturer's instructions. Additional tack hand-applied on transverse fabric overlaps or applied by distributor on longitudinal overlaps can reduce disruption by wind and construction traffic. Emulsified asphalt is suitable for securing fabric overlaps at construction joints.

Grids and Composites. Placement of grids and composites are generally similar to placement of fabrics. They should be tensioned during placement using a specially equipped tractor or laid flat to maximize their reinforcement effects.

Membranes. Membranes are thicker and heavier than fabrics and grids and are usually placed by hand in strips along pavement joints or cracks.

Placement of HMA Overlay

An HMA overlay can be placed immediately after placement of a geosynthetic using conventional equipment and techniques. No cure time is necessary. The HMA mixture should be no less than 250°F nor greater than 325°F as it exits the paving machine. The minimum temperature is required to obtain adequate density of the overlay and pull the binder up through the fabric. The maximum temperature is required to avoid damage to geosynthetics containing polypropylene. If in-place density specifications are met, typically, heat and rolling will have occurred to achieve fabric saturation.

On hot days, premature saturation of the fabric may occur. Therefore, it may be necessary to broadcast a thin layer of HMA mix in front of the paving machine in the wheelpaths of haul trucks and the paving machine to prevent fabric "pick-up."

If the installed geosynthetic should get wet due to rainfall, the overlay should not be placed until all free water is removed. The fabric surface may be slightly damp but one should not be able to squeegee any free water out of the geosynthetic. If an overlay is placed over excess moisture, the resultant steam will not permit adequate bond of the interlayer system and could lead to overlay problems. (Marienfeld and Baker, 2001)

A minimum compacted overlay thickness of 1.5 inches is required as the first lift over a geosynthetic. If the thickness of the overlay is tapered toward the edges, at the thinnest point, it should not be less than 1.5 inches. Thinner overlays will not generate enough heat to draw the asphalt up into the paving fabric to produce a well-bonded interlayer. (Marienfeld and Baker, 2001)

Project Inspection

Table F1 contains a suggested generalized checklist for geosynthetic/overlay placement.

Table F1. Inspection Checklist for Geosynthetic Product Placement.
(Modified after California DOT, 1981)

Primary Work

1. Sample geosynthetic, and send to Materials and Tests Division.
2. Store geosynthetic in area protected from sun and water.
3. Determine grade of asphalt to be used for tack coat and obtain a sample.
4. Determine the rate of application of tack coat.

Preparation of Old Pavement

1. Sweep surface clean.
2. Seal cracks larger than 1/8 inch or place leveling course.
3. Fill cracks larger than ½ inch with fine graded asphalt mixture.
4. Repair rough, uneven, or unstable areas, large spalls, and potholes.
5. Place level-up course.

Application of Asphalt Binder

1. Check application rate and temperature of asphalt and obtain a sample.
2. Watch for poor asphalt spread practices such as:
   a) frequent stops and starts
   b) spread overlaps
   c) nonuniform spread
3. Test binder application rate on roadway using preweighed, thin pans.

Geosynthetic Placement

1. Ensure minimal wrinkles or folds in geosynthetic (or bubbles in fabrics).
2. Avoid excessive overlaps in geosynthetic; follow specifications or manufacturer's recommendations.
3. Insure that geosynthetic follows proper alignment.
6. Geosynthetics have different characteristics on each side. Ensure it is placed with the proper side downward.
5. If bleeding of tack coat occurs, broadcast small amount of asphalt concrete (not sand) on geosynthetic in wheelpaths to prevent construction vehicle tires from sticking.

Overlay Placement

1. Discourage lengthy windrows of asphalt concrete.
2. Ensure proper temperature of asphalt concrete behind paving machine.
3. After compaction, displace HMA and expose some geosynthetic to confirm adequate saturation by tack coat (if appropriate).
3. Encourage expeditious, thorough rolling of asphalt concrete overlay.
4. Ensure specified density of overlay.

The following items are recommended for comprehensive inspection of geosynthetic interlayers:

- noncontact thermometer,
- geosynthetic knife,
- scale capable of 0.01- to 0.02-gram increments,
- calculator,
- tack coat calculator reference chart,
- test units (for measuring binder rates), and

POTENTIAL CONSTRUCTION PROBLEMS

In hot weather (pavement temperatures >120°F), asphalt tack may bleed through fabrics. Vehicles can splash asphalt onto their painted surfaces. Construction traffic can become sticky and pick up fabric, in severe cases wrapping the fabric around the tires or axles. Bleeding can be exacerbated by excessive pressure applied by the brush on the fabric application tractor.

Incomplete fabric saturation can occur due to insufficient tack application rate, overlay temperature, and/or overlay compaction.

If wet fabric is applied or if fabric is applied on damp pavement, blistering can occur due to vaporization of moisture underneath the asphalt-impregnated fabric. Pavement that has recently received rainfall but has a dry surface can retain enough moisture to cause blistering. If blisters appear, workers should eliminate them by using a lightweight rubber-tired roller before overlaying.

Wrinkles in geosynthetics can occur due to uneven pavement surface, improper alignment during placement, damaged rolls, and/or curves in the roadway.

PERFORMANCE MONITORING

To develop a data bank of performance histories when geosynthetics are employed, performance monitoring during the construction period and service life of the overlay is highly desirable. The primary areas of interest are reflective cracking and road roughness. Clearly, the most meaningful results will come from a special monitoring study where cracks in the old pavement are carefully mapped rather than depending on routine PMIS data.

Constructing a control section without the geosynthetic, with all other items equal, will provide valuable comparative data to assist future decisions. Without a control section, the so-called test has no value and, in fact, can be misleading.

MILLING /RECYCLING PAVEMENTS CONTAINING GEOSYNTHETICS

A few problems have been reported when recycling pavements containing a geosynthetic interlayer. Hot milling and, particularly, heater scarification can cause problems when a geosynthetic is present; however, cold milling does not usually present problems. The cold pavement holds the geosynthetic while the milling machine tears it out in small pieces. Chisel milling teeth rather than conical teeth and slower forward speed can be used to produce the smallest geotextile pieces. Thick fabrics or strong plastic grids may interfere with any milling process.

A typical 4-ounce/yd^2 polymeric fabric milled with HMA does not normally have a significant affect on mixture properties, construction operations, or mix plant stack opacity.

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APPENDIX G

RECOMMENDED NEW SPECIFICATIONS FOR FABRICS, GRIDS, AND COMPOSITES FOR REDUCING REFLECTION CRACKING

ITEM 356

FABRIC UNDERSEAL

356.1. Description. Furnish and place fabric underseal in a longitudinal, full-road-width application or over pavement joints.

356.2. Materials.

A. Longitudinal, Full-width Underseal.

1. **Fabric.** Provide fabric meeting DMS-6220, "Fabric for Underseals." Use roll widths shown on the plans or as approved.
2. **Asphalt.** Provide the grade of asphalt shown on the plans and in accordance with Item 300, "Asphalts, Oils, and Emulsions."
3. **Blotter.** Provide screenings, natural sand, or other materials as approved.

B. Pavement Joint Underseal. Provide material in accordance with DMS-6260, "Reinforced Fabric Joint Underseal." Use roll widths as shown on the plans or as approved.

C. Fabric Storage. Store and cover the fabric rolls elevated off the ground. Store rolls vertically to avoid misshapen rolls.

356.3. Equipment. For longitudinal full-width underseal, provide applicable equipment in accordance with Item 316, "Surface Treatments."

356.4. Construction. Apply fabric underseal when air temperature is above 50ºF and rising. Do not apply fabric underseal when air temperature is 60ºF and falling. In all cases, do not apply fabric underseal when surface temperature is below 60ºF. Do not apply when, according to the Engineer, weather conditions are not suitable. Measure air temperature in the shade and away from artificial heat.

A. Longitudinal, Full-width Underseal.

1. **Surface Preparation.** Prepare the surface by cleaning off dirt, dust, or other debris. Set string lines for alignment, if required. Remove existing raised pavement markers in accordance with the plans. When shown on the plans, remove vegetation and blade pavement edges. Fill cracks exceeding 1/8 inch in width with an approved crack filler. Fill cracks exceeding 1 inch in width with a fined grained bituminous mixture or other approved material. Ensure crack sealing material is flush with the existing pavement surface. Repair faulted cracks or joints with vertical deformation greater than ½ inch with a fine grained bituminous mixture or other approved material. Ensure crack filler and patching materials are cured prior to the placement of the fabric underseal.
2. **Asphalt Binder Application.** Apply:
   - with an asphalt distributor unless otherwise approved,
   - at the rate shown on the plans or as directed,
   - within 15°F of the temperature selected by the Engineer not to exceed 320°F,
   - approximately 6 in. outside the fabric width,
   - with paper or other approved material at the beginning and end of each shot to construct a straight transverse joint and to prevent overlapping of the asphalt.

Unless otherwise approved, match longitudinal joints with the lane lines. The Engineer may require a string line, if necessary, to keep joints straight with no overlapping. Do not contaminate asphalt binder.

3. **Fabric Placement.** Unless otherwise directed, furnish the Engineer with manufacturer's recommendations for fabric installation. If required by the Engineer, ensure a fabric manufacturer's representative is present on site during the first three days of the fabric placement. Immediately after asphalt binder application, align the fabric and broom or roll it in place. If skewed alignment occurs, cut the fabric, overlap the cut fabric to create a transverse joint, and begin application again. Roll or broom fabric onto the asphalt binder in a manner that prevents air bubbles from forming under the fabric. If wind prevents proper adherence of the fabric to the asphalt binder, especially at the edges, provide an alternate means of securing the edges to the pavement. Cease underseal application if the Engineer determines that wind conditions prevent proper placement.
   a. **Transverse Joints.** Overlap transverse joints a minimum of 6 inches with the top layer in the direction of traffic. At transverse joints, secure ends of overlapping fabric layer by nailing or other approved means.
   b. **Longitudinal Joints.** Overlap longitudinal joints a minimum of 4 inches. Apply additional asphalt binder to make longitudinal joints.

Apply blotter as directed to the top of the underseal to absorb excess asphalt binder. If sand is used for blotting, remove excess before placing the overlay. Ensure fabric is kept clean of mud, dust, and other foreign material. Minimize turning movements of paving machinery. Minimize braking from vehicles by installing appropriate signs at intersections and driveways. Remove and patch damaged sections. No payment will be made for repair work.

B. Pavement Joint Underseal.

1. **Surface Preparation.** Remove dirt, dust, or other debris from all joints, and the area on both sides of the joint, which will be in contact with the installed underseal. Other preparation for proper adherence may be required as shown on the plans.
2. **Fabric Placement.** For transverse pavement joints, do not allow joints or laps in the underseal material. Minimize underseal material joints in longitudinal pavement joints and do not allow overlap. Remove any protective coatings from the self-adhering layer of the fabric underseal. Center the fabric width over the joint. Apply fabric to the joint with a minimum of 5 in. on each side or as specified on the plans. Roll fabric in place to ensure adherence of the self-adhering binder. Do not allow air bubbles under the fabric.

356.5. Measurement.

A. Longitudinal, Full-width Underseal.

1. **Asphalt Binder.** Asphalt binder will be measured as follows:
   a. **Volume.** Volume measurements will be made at the point of application on the road as gallons used at the application temperature, as directed, in the accepted fabric underseal.

b. Weight. Weight measurements will be by the ton in accordance with Item 520, "Weighing and Measuring Equipment." At the end of the project, deduct any remaining material from quantities delivered to determine pay quantities.

2. Fabric. Fabric will be measured by the square yard based on the calculated quantity shown on the plans with no allowance for overlapping at joints.

"Fabric" is a plans quantity measurement item. The quantity to be paid will be the quantity shown in the proposal, unless modified by Article 9.8, "Plans Quantity Measurement." Additional measurements or calculations will be made if adjustments of quantities are required.

B. Pavement Joint Underseal. Pavement joint underseal will be measured by the foot, at the widths specified in the plans.

"Pavement Joint Underseal" is a plans quantity measurement item. The quantity to be paid will be the quantity shown in the proposal, unless modified by Article 9.8, "Plans Quantity Measurement." Additional measurements or calculations will be made if adjustments of quantities are required.

356.6 Payment. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" are paid for at the unit prices bid for "Asphalt Binder" and for "Fabric" or "Pavement Joint Underseal." These prices are full compensation for cleaning and preparing the existing pavement, including removal of raised pavement markers; furnishing, preparing, hauling, and placing materials, including blotter; manipulation, including rolling and brooming; and equipment, labor, tools, and incidentals.

SPECIAL SPECIFICATION

31xx

REINFORCING GRID FOR JOINT REPAIR

1. **Description.** Install a reinforcing grid in accordance with the details shown on the plans to prevent reflective cracking of transverse and longitudinal joints in asphaltic paving overlay mixtures.

2. **Materials.**
   (1) **Reinforcing Grid.** Provide grid meeting DMS-62xx, "Reinforcing Grid for Joint Repair." Use roll widths shown on the plans or as approved.
   (2) **Asphalt.** Provide the grade of asphalt for tack coat as shown on the plans and in accordance with Item 300, "Asphalts, Oils, and Emulsions."
   (3) **Packaging Requirements.** Ensure each roll of grid is packaged individually in a suitable wrapper to help protect from damage due to ultra-violet light and moisture during normal storage and handling.
   (4) **Storage Requirements.** Store material in dry covered conditions free from dust. Store vertically to avoid misshapen rolls.
   (5) **Identification Requirements.** Label or tag such that the sample identification can be read without opening the roll packaging. Label each roll with the manufacturer's name, job number, loom number, production date and shift, tare weight of packaging material, width and length of grid on the roll, and net weight of the grid.
   (6) **Safety Precautions.** Gloves are recommended to prevent contact with the material.

3. **Equipment.** For longitudinal full-width reinforcing grid, provide applicable equipment in accordance with Item 316, "Surface Treatments."

4. **Construction.** Apply reinforcing grid when air temperature is above 50ºF and rising. Do not apply grid when air temperature is 60ºF and falling. In all cases, do not apply grid when surface temperature is below 60ºF. Do not apply when, according to the Engineer, weather conditions are not suitable. Measure air temperature in the shade and away from artificial heat. Cease reinforcing grid installation if the Engineer determines that weather conditions prevent proper placement.
   (1) Surface Preparation. Prepare the surface by cleaning off dirt, dust, or other debris. Set string lines for alignment, if required. Remove existing raised pavement markers in accordance with the plans. When shown on the plans, remove vegetation and blade pavement edges. Fill cracks exceeding 1/8 inch in width with approved crack filler. Fill cracks exceeding 1 inch in width with a fined grained bituminous mixture or other approved material. Ensure crack sealing material is flush with the existing pavement surface. Repair faulted cracks or joints with vertical deformation greater than ½ inch with a fine grained bituminous mixture or other approved material. Ensure crack filler and patching materials are cured prior to the placement of the level-up paving mixture.
   (2) Asphalt Binder Application. Apply:
      (a) with an asphalt distributor unless otherwise approved,
      (b) at the rate shown on the plans or as directed,

(c) within 15°F of the temperature selected by the Engineer not to exceed 320°F,
(d) approximately 6 in. outside the reinforcing grid width,
(e) with paper or other approved material at the beginning and end of each shot to construct a straight transverse joint and to prevent overlapping of the asphalt. Unless otherwise approved, match longitudinal joints with the lane lines. The Engineer may require a string line, if necessary, to keep joints straight with no overlapping. Do not contaminate asphalt binder.

(3) Level-Up Paving Mixture. Place and compact a fine-grained paving mixture as a leveling course in accordance with the specifications shown on the plans. Unless otherwise shown, the compacted target lift thickness is between 3/4 and 1 inch.

(4) Reinforcing Grid Placement. Unless otherwise directed, furnish the Engineer with manufacture's recommendations for reinforcing grid installation. If required by the Engineer, ensure a manufacturer's representative is present on site during the first three days of the grid placement.

(a) Installation. Apply asphalt binder at the rate shown on the plans, unless otherwise directed. Install grid either by hand or mechanical means under sufficient tension to eliminate ripples and provide sufficient adhesion to avoid dislodging of the grid. Should ripples occur, these must be removed by pulling the grid tight or in extreme cases, for example, in tight radius, by cutting and laying flat. A sharp knife may be used for cutting. Roll the grid surface with a rubber coated drum roller or pneumatic tire roller to seat grid. Tires must be cleaned regularly with an approved asphalt-cleaning agent.

(b) Transverse Joints. Overlap transverse joints in the direction of the paver a minimum of 3 inches with the top layer in the direction of traffic. If required, apply additional asphalt binder to secure overlapping grid layer.

(c) Longitudinal Joints. Overlap longitudinal joints a minimum of 1 inch. If required, apply additional asphalt binder to make secure overlapping grid layer.

After the rolling is completed, construction and emergency traffic may drive on the grid. Minimize turning movements of paving machinery. Minimize braking from vehicles by installing appropriate signs at intersections and driveways. Remove and patch damaged sections. No payment will be made for repair work.

All grid placed in a day shall be covered with asphaltic concrete the same day, within permissible laying temperatures, and compacted in accordance with applicable specifications as shown on the plans.

5. **Measurement.** The reinforcing grid will be measured by the linear foot of joint or crack repaired or by the square yard of the actual area complete in place. No allowance will be made for overlapping at joints.

6. **Payment.** The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Reinforcing Grid for Joint Repair" of the type specified and by the width for the linear foot measurement. This price shall be full compensation for cleaning the existing pavement; for furnishing, preparing, hauling and placing all materials; for all

manipulation, including rolling, and for all labor, tools, equipment and incidentals necessary to complete the work

SPECIAL SPECIFICATION

32xx

GEOGRID-FABRIC COMPOSITE FOR PAVEMENTS

1. Description. This Item shall govern for furnishing and placing a geogrid-fabric composite pavement reinforcing material in accordance with the details shown on the plans.

2. Materials.

(1) Geogrid-Fabric Composite. Provide geogrid-fabric composite meeting the requirements of Departmental Materials Specification DMS-62xx, "Geogrid-Fabric Composite for Pavements."

(2) Asphalt. Provide the grade of asphalt for tack coat as shown on the plans and in accordance with Item 300, "Asphalts, Oils, and Emulsions."

(3) Blotter. Provide screenings, natural sand, or other materials as approved

(4) Packaging Requirements. Ensure each roll of geogrid-fabric composite is packaged individually in a suitable wrapper to help protect from damage due to ultra-violet light and moisture during normal storage and handling.

(5) Storage Requirements. Store material in dry covered conditions free from dust. Store vertically to avoid misshapen rolls.

(6) Identification Requirements. Label or tag such that the sample identification can be read without opening the roll packaging. Label each roll with the manufacturer's name, job number, loom number, production date and shift, tare weight of packaging material, width and length of geogrid-fabric composite on the roll, and net weight of the geogrid-fabric composite.

(7) Safety Precautions. Gloves are recommended to prevent contact with the material.

3. Equipment. For longitudinal full-width reinforcing geogrid-fabric composite, provide applicable equipment in accordance with Item 316, "Surface Treatments."

4. Construction. Apply reinforcing geogrid-fabric composite when air temperature is above 50ºF and rising. Do not apply geogrid-fabric composite when air temperature is 60ºF and falling. In all cases, do not apply geogrid-fabric composite when surface temperature is below 60ºF. Do not apply when, according to the Engineer, weather conditions are not suitable. Measure air temperature in the shade and away from artificial heat. Cease reinforcing geogrid-fabric composite installation if the Engineer determines that weather conditions prevent proper placement.

(1) Surface Preparation. Prepare the surface by cleaning off dirt, dust, or other debris. Set string lines for alignment, if required. Remove existing raised pavement markers in accordance with the plans. When shown on the plans, remove vegetation and blade pavement edges. Fill cracks exceeding 1/8 inch in width with approved crack filler. Fill cracks exceeding 1 inch in width with a fined grained bituminous mixture or other approved material. Ensure crack sealing material is flush with the existing pavement surface. Repair faulted cracks or joints with vertical deformation greater than ½ inch with a fine grained bituminous mixture or other approved material. Ensure crack filler and patching materials are cured prior to the placement of the level-up paving mixture.

(2) Asphalt Binder Application. Apply:

(a) with an asphalt distributor unless otherwise approved,

(b) at the rate shown on the plans or as directed,

(c) within 15°F of the temperature selected by the Engineer not to exceed

(d) approximately 6 in. outside the reinforcing geogrid-fabric composite width,

(e) with paper or other approved material at the beginning and end of each shot to construct a straight transverse joint and to prevent overlapping of the asphalt.

Unless otherwise approved, match longitudinal joints with the lane lines. The Engineer may require a string line, if necessary, to keep joints straight with no overlapping. Do not contaminate asphalt binder.

(3) Level-Up Paving Mixture. Place and compact a fine-grained paving mixture as a leveling course in accordance with the specifications shown on the plans. Unless otherwise shown, the compacted target lift thickness is between 3/4 and 1 inch.

(4) Geogrid-Fabric Composite Placement. Unless otherwise directed, furnish the Engineer with manufacture's recommendations for reinforcing geogrid-fabric composite installation. If required by the Engineer, ensure a manufacturer's representative is present on site during the first three days of the geogrid-fabric composite placement.

(a) Installation. Apply asphalt binder at the rate shown on the plans, unless otherwise directed. Install geogrid-fabric composite either by hand or mechanical means under sufficient tension to eliminate ripples and provide sufficient adhesion to avoid dislodging of the geogrid-fabric composite. Should ripples occur, these must be removed by pulling the geogrid-fabric composite tight or in extreme cases, for example, in tight radius, by cutting and laying flat. A sharp knife may be used for cutting. Broom and/or roll the geogrid-fabric composite surface with a rubber coated drum roller or pneumatic tire roller to seat geogrid-fabric composite. Tires must be cleaned regularly with an approved asphalt-cleaning agent.

(b) Transverse Joints. Overlap transverse joints in the direction of the paver a minimum of 3 inches with the top layer in the direction of traffic. If required, apply additional asphalt binder to secure overlapping geogrid-fabric composite layer.

(c) Longitudinal Joints. Overlap longitudinal joints a minimum of 4 inches. If required, apply additional asphalt binder to make secure overlapping geogrid-fabric composite layer.

Apply blotter as directed to the top of the geogrid-fabric composite to absorb excess asphalt binder. If sand is used for blotting, remove excess before placing the overlay. After the rolling is completed, construction and emergency traffic may drive on the geogrid-fabric composite. Minimize turning movements of paving machinery. Minimize braking from vehicles by installing appropriate signs at intersections and

driveways. Remove and patch damaged sections. No payment will be made for repair work.
All geogrid-fabric composites placed in a day shall be covered with asphaltic concrete the same day, within permissible laying temperatures, and compacted in accordance with applicable specifications as shown on the plans.

5. Measurement.

(1) Asphalt Binder. Asphalt binder will be measured as follows:

(a) Volume. Volume measurements will be made at the point of application on the road as gallons used at the application temperature, as directed, in the accepted geogrid-fabric composite for pavements.

(b) Weight. Weight measurements will be by the ton in accordance with Item 520, "Weighing and Measuring Equipment." At the end of the project, deduct any remaining material from quantities delivered to determine pay quantities.

(2) Geogrid-Fabric Composite. Geogrid-fabric composite will be measured by the square yard based on the calculated quantity shown on the plans with no allowance for overlapping at joints.

"Geogrid-Fabric Composite" is a plans quantity measurement item. The quantity to be paid will be the quantity shown in the proposal, unless modified by Article 9.8, "Plans Quantity Measurement." Additional measurements or calculations will be made if adjustments of quantities are required.

6. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" are paid for at the unit prices bid for "Asphalt Binder" and for "Geogrid-Fabric Composite." These prices are full compensation for cleaning and preparing the existing pavement, including removal of raised pavement markers; furnishing, preparing, hauling, and placing materials, including blotter; manipulation, including rolling and brooming; and equipment, labor, tools, and incidentals.