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POLYMER-MODIFIED SLURRY SEAL

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INTRODUCTION

A conventional slurry seal is a mixture of well-graded fine aggregate (1/4 inch), mineral filler, emulsified asphalt, and water applied to a pavement as a surface treatment. Slurry seals generally are used as a uniform application across the full-width of the pavement. This article is about a recent entry into the American slurry seal scene: polymer-modified slurry seals (Fig. 1). Polymer-modified slurry seals differ from conventional slurry seals in that a coarser size of aggregate may be used, and the slurry can be placed in greater thickness. The slurry cures and develops strength and toughness faster because of the polymer-modified asphalt base used in making the emulsion. They are not recommended for full-width surface sealing except in high traffic areas or in intersections where stopping, starting, and turning movements would cause problems with a conventional seal coat. They also provide an alternative to HMAC overlays where build-up needs to be kept to a minimum. [Ref. 12]. One good example is Ralumac, which is a brand name for a polymer-modified slurry seal.

Ralumac was developed in Europe in response to a need for a quick, low cost, effective method of dealing with wheel ruts and for restoration of skid resistance. Before Ralumac was introduced, the usual method for dealing with wheel ruts was milling the road and applying a full-width overlay. This method involved expensive adjustments to shoulders, guard rails, inlets, manholes, and bridge dams.

Raschig Inc., an experienced elastomer chemical producer in Ludwigschafen/Rhein, West Germany, is credited with the development of Ralumac. It has been used in Western Europe since 1976 to fill wheel ruts and resurface main arterial highways [Ref. 6]. The Germans have used Ralumac as their major maintenance tool on their Autobahn system for several years. Ralumac was introduced in the United States in 1980 by Hyway Asphalt in Salina, Kansas [Ref. 6]. Oklahoma Department of Transportation (OKDOT), Pennsylvania Department of Transportation (PennDOT), and Arkansas Highway and Transportation Department (ARHTD) have reported success with it. However, California Transportation Department (Caltrans) reported significant contractor-

Photo courtesy of Koch Materials, Inc.

FIG. 1: Polymer-modified slurry seal, prior to breaking.

INSIDE...

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related construction problems and rejected it.

Polymer-modified slurry seals, like Ralumac, have been gaining wider acceptance in Texas. Some district personnel have hailed these seals as the missing link between seal coats and hot mix overlays. District 25 (Childress) was the first district to use Ralumac in Texas about five years ago. Since then, polymer-modified slurry seals have been used in Districts 2, 9, 13, 14, 15, and 18 under a wide variation of traffic conditions including urban and rural interstates, and both high and low volume farm-to-market roads. The two major reasons these districts have used polymer-modified slurry seals have been to improve skid resistance and to fill ruts (Fig. 2). In some sections, they were used to control flushing and reflective cracking as well.

Most districts have expressed an interest in using polymer-modified slurry seals, but would like to know more about what experiences others have had using this type of seal. This article presents some of the experiences of Texas' districts, along with information collected from other states.

Photo courtesy of Koch Materials, Inc.

FIG. 2: Used to improve skid resistance on high volume.

WHAT IT IS

The polymer-modified slurry seal consists of the following ingredients:

(a) Emulsified Asphalt — Texas Special Specification 3557 states that the asphalt emulsion used shall be a cationic slow setting type, designated as CSS-1P. The SS designation means that it is suited for mixing with aggregate. The emulsion is to be modified with an approved latex rubber. Natural rubber latex was the type originally used, but other types which will result in a high softening point binder (one that maintains toughness at elevated road temperatures) can be used. Item 3557 also states that the emulsified asphalt should cure sufficiently at a relative humidity of not more than 50 percent and an ambient air temperature of at least 75°F to allow traffic onto it within one hour. The distillation residue of the modified emulsion must contain a minimum of 2.0 percent rubber solids by weight. The emulsified asphalt should not exhibit any separation after mixing.

(b) Mineral Aggregate — Hard, high polish, slow-wearing aggregate like crushed traprock, crushed granite or crushed sandstone should be used. The aggregate should be free of excessive fines and of clay, loam or other organic substances. The aggregate should not experience a weighted loss of more than 25 percent when subjected to the four-cycle soundness test using magnesium sulfate (Item 3557). The largest size aggregate particles pass through the 3/8 inch sieve. Various sources suggest that the aggregate should demonstrate an abrasion loss of less than 35 percent by weight [Ref. 2], a freeze/thaw resistance of not greater than 10 percent after 10 cycles [Ref. 7], and a sand equivalent of not less than 65 [Ref. 2]. Originally, the aggregate for Texas projects was known as Joplin Chat from Joplin, Missouri. Now a local source of aggregates, sandstone from Marble Falls, is being used.

(c) Mineral Filler — Any mineral filler shall be an approved non-air entrained portland cement Type 1, which is free of lumps. One-and-a-half to 3 percent of mineral filler to dry weight of aggregate can be used [Ref. 1].

(d) Water — Should be potable and free from harmful soluble salts. Carbonate and bicarbonate ions suppress the formation of a stable cationic emulsion.

The optimum combination of components is to be determined by a mix design which, under present specifications, is furnished by the contractor. The emulsified asphalt content will be selected so as to provided an optimum laboratory-compacted density within the range of 94 to 97 percent. The residual asphalt in the slurry must be in the range of 6 to 9 percent by weight or 13.5 to 23 percent by volume of dry aggregate.

HOW IT WORKS

In polymer-modified slurry seals, cationic emulsions are used for several reasons. Firstly, cationic emulsions have a great affinity for all types of damp aggregate whether they are basic or acidic. Secondly, cationic emulsions tend to release water faster than anionic emulsions resulting in a fast break and a rapid cure. Thirdly, cationic emulsions possess good antistripping properties [Ref. 8].

Two important properties of a cured polymer-modified slurry seal are its high temperature stability and its lower cold temperature flexibility. The addition of the proper polymer effectively increases the softening point of asphalt approximately 20°F.

Breaking or setting refers to the process by which the asphalt drops out of suspension and plates itself on the surface of the aggregate to form a continuous film of asphalt. For breaking to occur, the asphalt must separate itself from its water phase. Breaking or setting time is defined as the rate of separation of the asphalt globules from the water phase. Deposition of asphalt is accelerated if the aggregate has a high surface charge.

Curing, as opposed to setting, involves the dissipation of the water from the mixture so that complete bonding between the asphalt and aggregate will occur. The polymer-modified emulsion is a thixotropic mix, which is chemically triggered during mixing to control the set time. This chemical reaction, which is indicated by a change in pH of 2 during the mixing to a pH of 10 during the spreading, gives the mix a quick set, strength and stability [Ref. 9]. By controlling the setting time, the curing process is accelerated which yields a quick strength gain. Most of the bonding strength is derived from the loss of the emulsifying water although there is some contribution from electrochemical forces during the initial breaking of asphalt. The water film can be displaced by evaporation, pressure (rolling), or absorption into the aggregate or pavement [Ref. 8, p16].

There are two main ways of controlling breaking and curing. One is the introduction of some fines, especially high pH fines such as portland cement, to increase the break time. However, as the amount of cement is increased, a point is reached where this effect is reversed, and the break time is reduced because of the large amount of surface area available to the asphalt binder. The second way to control break and set is to use more emulsifying agent which results in more uniform curing by slowing the break time [Ref. 12] in dry, hot weather.

CONSTRUCTION PROCEDURES: OBSERVATIONS AND PROBLEMS

According to Item 3557, placement of polymer-modified slurry seal mixtures should be performed when temperatures are above 50 degrees Fahrenheit and rising. There should be no rain and no possibility of freezing temperatures 24 hours after placement. It is important to ensure that the surface concerned is free of objectionable materials prior to its placement. The surface should be prewetted with water if it is not damp. Tack coating is recommended by some states on portland cement concrete surfaces and on any old and weathered surfaces [Ref. 6, p53]. Any crack which is wider than 3/8 inch should be sealed properly before placement begins. Weak and failed sections of pavement should be repaired because a slurry seal can not be expected to hold a base failure together.

Polymer-modified slurry seal is usually placed by a truck-mounted unit with self-contained aggregate feed bin, cement bin, and separate tanks for water and emulsion (Fig. 3). The mixer should be capable of continuously proportioning and mixing the materials thoroughly prior to discharging them into the spreader box. A mineral filler hopper dispenses the appropriate amount of cement onto the aggregate. A continuous flow, twin-shafted, multibladed pug mill blends the aggregate with the cement prior to the introduction of the emulsion.

An application rate of 23 to 25 lbs/sq yd has been recommended by district personnel for retexturing seals. At least one district has found that a rate of 35 lbs/sq yd resulted in segregation within the mat. However, this was not in a rut-filling application. When filling ruts, up to 40 lbs/sq yd has been used successfully. If the slurry is to be placed at depths exceeding twice the maximum aggregate size, such as for rut filling, a minimum Hveem stability of 35 is required.

The average residual asphalt content for Texas jobs is 7 percent by extraction. Virtually every job has had trouble meeting the 94 to 97 percent density requirement. Most jobs averaged 93 percent of lab density. Trying to increase asphalt content to get the mix to meet density usually resulted in a loss of Hveem stability. Since the 94 to 97 percent density requirement was developed for hot mix asphalt concrete and since satisfactory methods of making samples for testing slurry density have yet to be devised, serious consideration is being given to modifying the density requirement.

The slurry is spread using a special spreader box with a pressurized water system to help disperse occasionally formed lumps of cement and aggregate and equipped with paddles to spread the mix uniformly. A problem encountered at this point by some districts was a tendency for the paddles to cause the mix to break too early while it was still in the spreader box. Increasing the amount of emulsifier or cement will slow the break. Experienced contractors know how to balance the amounts of cement, water, and emulsion to prevent early breaking.

A rubber squeegee or metal strike-off bar screeds the mixture. Sometimes material will begin to build up on the squeegee or bar. Left alone, this material can drag a thin spot in the slurry behind the spreader box or can fall off in chunks. The rear operator should watch for the start of material build-up. Any safe method of removing the material before the build-up becomes critical, without having to stop the paving operation, can be used.

Stopping the paving operation is undesirable for several reasons. One reason is that this is a very fast breaking material and every time a stop is made the spreader box and paddles must be lifted and be thoroughly hosed down to prevent mix from setting up in the box. Lifting the box and repositioning it usually leaves a hump of excess material. More importantly, the fast breaking characteristic means there is little time for handworking this material, making transverse joints very difficult to do well. At best, the transverse joints look like patches. At worst, the transverse joints are noticeable as bumps to the traveling public. One Maintenance Engineer has suggested using torches to heat shovel and rake edges so the curing asphaltic ma-

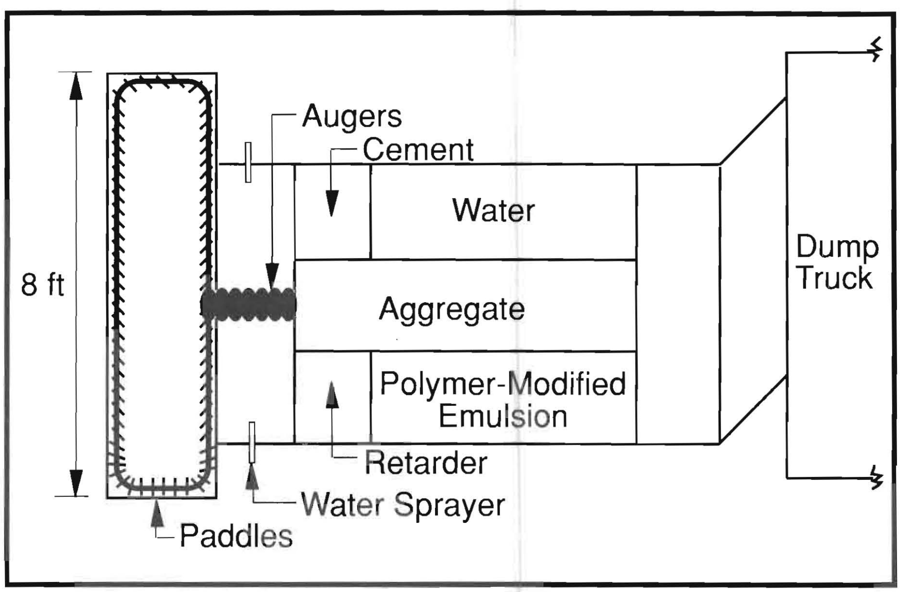

FIGURE 3: Generalized schematic of spreading unit.

terial will become heat softened enough to be more successfully worked by hand. Most districts say they will include a note requiring the use of a straightedge the next time they plan a polymer-modified slurry seal so they can easily reject high joints.

Longitudinal joints can be a problem as well. The special spreader box is variable, from 8 feet to 13 feet, in 1 foot increments. With certain lane configurations, lapped longitudinal joints are the easiest way to get around the fact that the spreader box is not randomly variable. Unfortunately, a lap joint wider than 2 inches can leave a high ridge. Correcting it with hand squeegees often yields an unsightly finished surface, particularly if the crew is more than 40 feet behind the paver. Leaving the longitudinal ridge causes cross sectional problems. The Asphalt Institute suggests waiting to make longitudinal joints until the lane placed first is completely cured [Ref. 8, p55]. The recent opinion among district personnel is to disallow lap joints when specifying the job. However, District 25, with a very experienced contractor, had no joint problems at all.

When filling ruts is the primary reason for using a polymer-modified slurry seal, the favored method of placement is to use a drag box only slightly wider than the rut (Fig. 4). After this application has fully cured, a full lane thin application can be applied for extra skid resistance or for cosmetic purposes.

At least two districts have had problems with the paver operator not being able to hold a true line by sight. In one case, the district had to seal coat the shoulders after the polymer-modified slurry seal was complete to cover the edge crookedness. Several districts have recommended adding a note to the plans requiring use of a stringline. A suitable break and cure time is required to achieve sufficient stability in the mixture prior to turning traffic on to it. One of the major selling points of polymer-modified slurry is the ability to turn traffic onto it in an hour. Texas' special specification requires that the polymer-modified slurry seal be capable of bearing traffic in an hour. A minimum set time of 30 minutes to one hour is usually necessary to prevent excessive damage to the mat. Arkansas HTD, OKDOT, and PennDOT have not reported any problems with tearing or rutting of the mat under traffic when the hour limit was observed. PennDOT did have a section, placed in hot weather, that flushed when traffic was turned onto it within a half hour of its placement.

Photo courtesy of Koch Materials, Inc.

FIGURE 4: A drag box rig used by OKDOT.

Several Texas districts have experienced either tearing or rutting of the mat under traffic turning maneuvers, usually due to cross traffic access when the mat was approximately a half hour old. In several cases, however, turning maneuvers have caused tearing in mats approximately 2 hours old. These problems may well be due to local ambient conditions, particularly humidity, which affect the break and cure rate. Although the general rule of thumb is, "the dryer the day, the better the break and cure," in very hot, dry weather the surface can break too fast. The rubberized surface crusts, holding water in and slowing interior curing. The mat appears to be curing properly, but it isn't. Under hot weather conditions, more emulsifier should probably be added to slow the breaking rate and allow for a more uniform cure. If the project manager has doubts that the slurry seal will be able to cure in an hour under local conditions, do a small section. If it tears or ruts under traffic after an hour's curing, don't place any more without modifying the emulsion break and cure rate. Compaction should not be necessary with polymer-modified slurry seals.

Traffic control plans must take into account the necessary curing time, particularly in complex multilane situations (Fig. 5). Cross traffic control and access is often a problem. PennDOT advocates "Special planning and innovation when considering traffic control methods and devices" [Ref 7, p18]. If only a few, low AADT intersections are involved, water and emulsifying additive can be cut back slightly as the paver approaches the intersection. The intersections are then sanded and can be opened to traffic in approximately twenty minutes. If there are numerous business driveways, an attempt should be made to schedule the work for off-peak times. Scheduling for times of low traffic volumes not only reduces rutting and tearing by cross traffic on the uncured seal coat, it also reduces conflict with local business owners who feel that the operation may be hurting their sales.

EVALUATION

Two factors that play an important role in the performance of polymer-modified slurry seals are experience and quality control [Ref. 6, p52]. Texas districts agree that as both SDHPT personnel and contracting crews gained experience, construction problems lessened, and that most of the problems were of a construction nature, rather than material quality. This observation is borne out by reports from other states indicating that the quality of the overlay work performed generally improved as more experience was acquired. As the technique developed, work delays

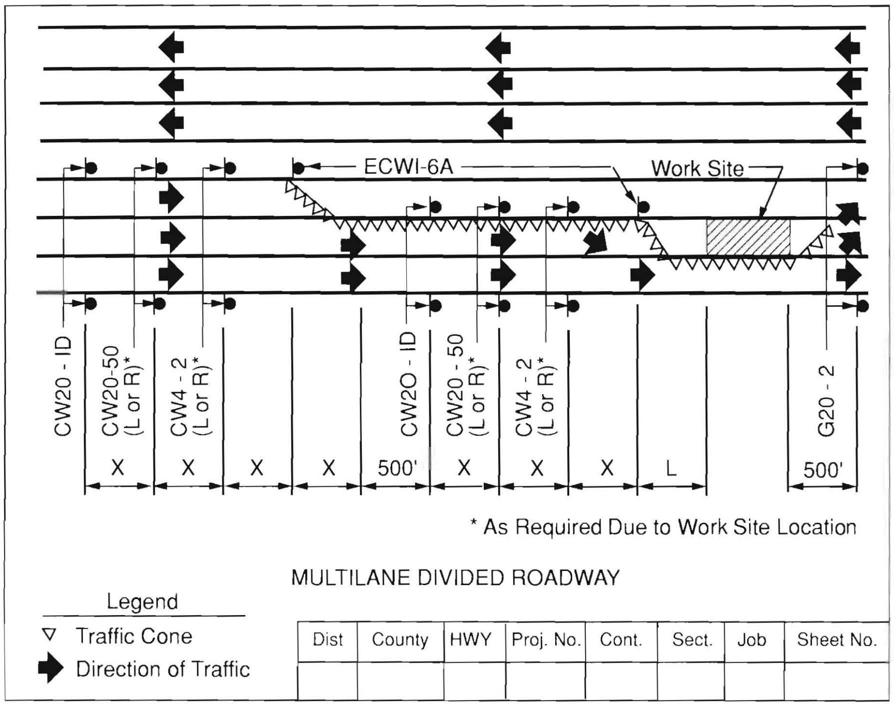

FIG. 5: Traffic control for a multilane divided highway, District 2.

were shortened and uniformity of the finished surface improved [Refs. 5, 6, 7, 13]. Districts that have used Ralumac or similar polymer-modified slurries are positive enough about its resurfacing characteristics, despite some lingering construction technique problems, to be planning future jobs.

Most Texas polymer-modified jobs are less than two years old, so long term performance data is not yet available. The one section in District 25 (Childress) which is 5 years old is reported to have held up well in freeze-thaw conditions, retained satisfactory skid resistance, and resisted rerutting.

Rut Repair Performance

Ralumac performs well as a rut filler (Fig. 6). Ruts up to two inches deep have been filled [Ref. 6, p60], eliminating hydroplaning. PennDOT [Ref. 6, p58] and OKDOT [Ref. 7, p7] report good resistance to rerutting for up to three years following placement. These states indicate that for rut filling applications, Ralumac performs as well or better than any of their other treatments short of major rehabilitation, as does Arkansas State Highway and Transportation Department [Ref.13, p7]. Texas experiences in Districts 2, 15, and 25 are bearing out the other states' reports.

The manufacturer claims that the polymer-modified layer can be feathered without edge raveling, eliminating loose rock problems (as well as the need to raise shoulders to match overlay height). This was shown to be true on the District 15 IH-10 project (Fig. 7) where the thickness varied from about 1/8 inch between wheel paths to about 3/4 inch in the rutted wheel paths [Ref 10].

Skid Resistance Performance

This type of slurry seal also performs satisfactorily in restoring skid resistance. Polymer-modified slurry seals seem to be favored particularly for improving skid resistance in high AADT locations. Based on the available skid data from various Texas projects, the average initial "after" value is 58, and the range of skid values is from 52 to 69. "Before" data is not available for all sections; however, from the sections it is available, the range of "before" skid values is from 13 to 20, the average value being 17. Arkansas [Ref 13, ppA-10 to A-12] reported similar improvements in skid resistance with an average "before" skid value of 47 and an average "after" value of 62 (combined initial and one-year-after data). The range of the Arkansas initial "after" skid data is from 60 to 71. The range for one year after construction was from 56 to 65. PennDOT [Ref 6, pp54-57] and OKDOT [Ref 7, p8] reported improvements in skid resistance, but did not achieve as high values, most likely due to differences in aggregate.

Polymer-modified slurry seals appear to control flushing. District 15 placed 400 to 500 ft of the seal on a flushing section of I-10 immediately upstream of the rut control job. After two hot summers, no excess asphalt has come up to the surface. The Childress sections have not exhibited much flushing in 5 years.

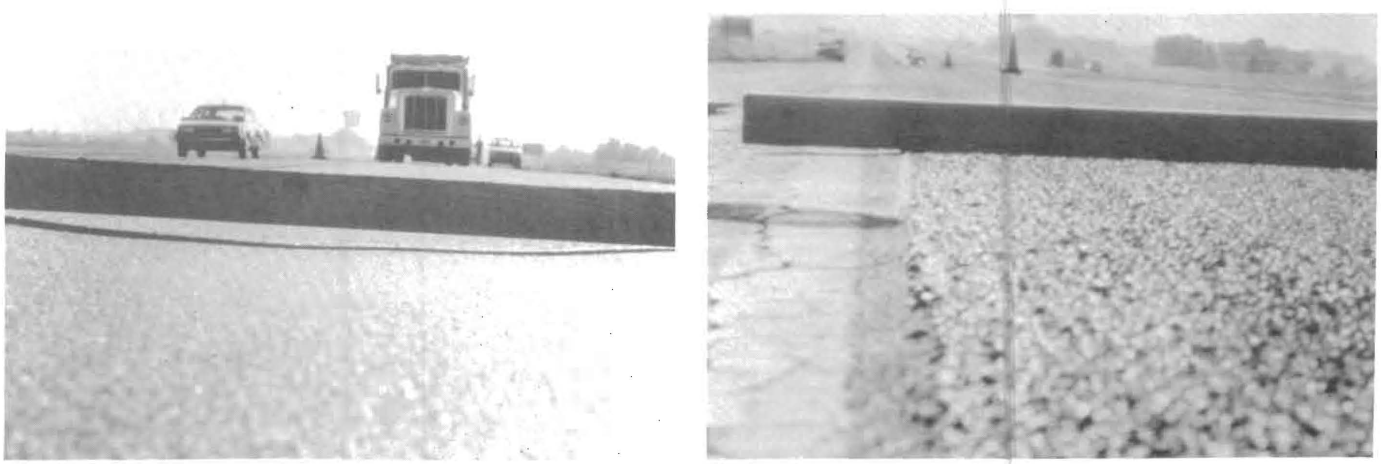

Photo courtesy of Koch Materials, Inc.

FIG. 6: "Before" and "After" on IH-35 (OK).

Crack Repair Performance

The growing consensus is that polymer-modified slurry seals are not very effective in controlling reflective cracking. On the District 15 I-10 rut control section, some reflective cracking has been observed. District 2's newest polymer-modified slurry seal project, a six-lane divided section of US 80/Lancaster Street consisting of an ACP overlaying an existing portland cement concrete pavement, was placed primarily as a retexturing operation. The surface aggregate of the ACP overlay had been polished by traffic. Joints had reflected up through, making the pavement very rough. Also, the gutters inside and out had been almost completely filled by ACP. The District was hoping to solve the cracking at the same time the skid resistance was improved. However, with only one-third of the work completed, due to the thinness of the seal, the joint and crack repair is readily seen through the new construction.

Cost

The unit cost of Ralumac is often three times the unit costs of hot plant mixes. A price range of $.80 to $1.00 per square yard is average for Texas placements. The initial price difference is offset by lower costs in general construction and traffic control due to the speed of the operation and by the fact that polymer-modified slurry seals can be applied as a very thin treatment, using far less material than conventional overlays. These thin treatments also have the benefit of not requiring supplementary adjustments to appurtenances such as curbs, shoulders, drainage inlets, bridge expansion dams, and guardrails. District 15 estimated their 10 mile section on IH-10 cost about half the price of an ordinary hot mix overlay. PennDOT reported 30 to 60 percent reductions in initial construction costs [Ref. 6, p61].

CONCLUSIONS

Polymer-modified slurry seal is not the ultimate cure for all road problems, and D-9 does not recommend that it be used as a substitute for conventional seal coats under ordinary conditions. However, it can be a cost effective, versatile treatment for specialized problems. It has been compared to a "bandage" which can be used to temporarily solve a rutting or skid resistance problem. It is useful in urban areas where high speed operations can alleviate profile problems without adding to peak hour congestion problems. It is also useful in areas of limited vertical clearance where layer thickness due to overlay and seal coat build-up is critical. Although Texas' experience is limited, it appears reasonable to expect at least 4 to 5 years of service out of a polymer-modified slurry seal.

Photo courtesy of Koch Materials, Inc.

FIG. 7: Feathered edge, IH-10, District 15.

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Mr. Bill Tucker, District 15
Mr. Charles Little, District 18
Mr. Terry Keener, District 25

for information on and evaluations of their respective polymer-modified slurry seal sections.

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TRAINING OF MECHANICS

The Southeastern Pennsylvania Transportation Authority (SEPTA) has changed its system of job progression by eliminating seniority as the primary determinant of promotion. Today SEPTA requires training and testing of individuals who desire to advance. Working with the Council for Labor and Industry, SEPTA received several grants from UMTA to create and carry out an automotive training demonstration program. Results of this program are given in *Southeastern Pennsylvania Transportation Authority's Automotive Training Demonstration Program.*

Under the program, classroom training was provided to SEPTA's maintenance mechanics in five major areas of mechanical and maintenance expertise: diesel engines, transmissions, chassis, air conditioning, and electrical systems. The program was a one-time affair; after all of the mechanics had received training, SEPTA would provide training only on an as-needed basis using its own operating funds. The ultimate aim was the development of an apprentice-type program for maintenance mechanics. These programs sought to upgrade knowledge of advanced technology work skills in individuals, to help them remain employable throughout their lives. In recognition of the importance of training, the SEPTA program was eventually expanded beyond mechanics to include foremen and superintendent trainee programs.

The program proved to be highly beneficial and, indeed, the results were good enough to compel SEPTA to continue it. The present program is a tool for advancement that appears to be superior to seniority. It was clear to SEPTA leadership that training cannot be pursued on a contingency basis, implemented only when outside funds are available. To be effective within the transit industry, training must be a vital part of employee development. The realization that training is necessary to get the best out of employees is a hard-won truth.

The report (UMTA-PA-006-0072-87-1; PB87-182085/AS) is available [from the D-10R Technology Transfer Library. Call (512) 465-7644]. *From TRB Newsline 14 (May 1988): 5.*

POTENTIAL IMPACT OF ADVANCED CERAMICS ON CONSTRUCTION

A recent Masters thesis by MIT PACT fellow Ann Brach (who is currently working on her Ph.D.) explored potential applications for advanced ceramics in construction. Many construction industry sectors could accommodate advanced ceramics if current research and building trends continue. Three distinct, but often interrelated, mechanisms may introduce ceramics into construction projects. Ceramics offer unique economic and technical advantages to applications calling for durability and resistance to environmental extremes.

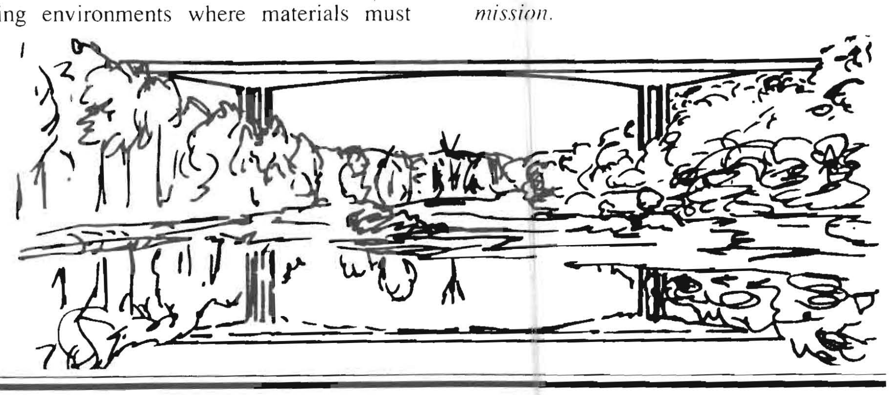
Ceramics specially engineered for specific characteristics such as hardness or resistance to corrosion or heat damage, are used today in the computer, aeronautics, and nuclear industries, among others, where specific applications demand materials with well-defined properties. In contrast, construction projects rely on materials with generalized applications, such as cement and concrete. But more highly engineered materials are used with increasing frequency in construction projects lately. Thus, as materials assume greater importance in construction, and the quickly evolving ceramics field develops better and cheaper products, ceramics may come to play a larger role in the construction industry. Ceramics could improve the performance, overall condition, and reliability of infrastructure or hazardous waste containment and conveyance, and find use as specialized pavements for military or research purposes.

Advanced ceramics use may increase via several mechanisms. The least likely to happen soon is simple substitution for existing materials. Ceramics would have to perform outstandingly well, for instance increase product life by up to ten times, to justify their enormous initial cost.

Ceramics could enter the construction industry through applications in demanding environments where materials must withstand extreme conditions. One could design ceramic materials resistant to the particular hazards of a given application. For instance, a ceramic test stand could withstand the heat of jet engine testing better than conventional stands. Improved performance resulting from ceramics may save money in the long run by reducing maintenance or damage to the function of a facility.

The most exciting and challenging way to use ceramics is through applications which might fundamentally change concepts and approaches in all phases of the construction process from design to final product. To avoid biasing ideas toward current processes or functions, potential applications should be examined on the basis of the unique properties of ceramic materials and the basic processes of construction. For example, ceramic bridge decks could alter the way we design, construct, operate and maintain bridges. A ceramic wearing surface which trapped or impeded chloride ions from de-icing salt could prevent corrosion of underlying steel. Some possibilities could radically change one or more facets of bridge design, construction, operation, or maintenance.

Economic considerations will determine how and when ceramics enter the construction industry, the thesis concludes. Several case studies indicated that the price of engineered ceramics must drop dramatically before they are economically feasible in many applications. The savings they may afford later in the life of a facility should be relatively highly valued by the use of a low discount rate in the analysis of life cycle costs. *From **Construction**, Winter 1988. Published by the Center for Construction Research and Education, Massachusetts Institute of Technology, Cambridge, Massachusetts. Used by permission.*



AESTHETICS AND DESIGN: SOME CONSIDERATIONS

by Luis Ybañez, P.E.
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Bridge Division

Texas is the major designer of prestressed concrete bridges and has been building the most cost-effective structures of any state. Cost of bridge building varies considerably throughout the U.S., from $31 per sq. ft. in Texas (lowest) to $192 per sq. ft. in Washington, D.C. (highest).

In Texas the state highway system contains 32,112 bridges. Another 14,447 have been constructed on city streets and county roads, so that Texas has 46,559 bridges in its inventory. As a comparison, California has 23,442 bridges, and Florida has 10,180. Since Texas has so many existing bridges, some requiring rehabilitation and others total replacement, and being that there are many new ones planned for the future, it becomes necessary that we provide good engineering practice in the design of structures.

This large number requires that we design bridges that are both economical to construct and maintain and are adequately designed to serve their intended function. In addition to these criteria, it is very important that we give due consideration to the aesthetic quality of the structures we design and build, particularly in urban and other high visibility locations.

The bridge design process can be compared to a four-legged table. One leg is for structural adequacy; the structure must carry the loads. The second leg is for functional safety; the structure has to accomplish its job safely. The third leg is cost-effectiveness; the structure should be optimized for reduced cost. The fourth leg is for beauty; the structure must harmonize with its location. Each leg is essential in order for the table to function effectively.

How do you design a beautiful bridge? The responsibility to provide the best possible designs rests in the hands of the bridge designers. Arriving at the proper layout during preliminary design is of utmost importance. Decisions made at this stage impact cost and aesthetics throughout the life of the completed structure. If the wrong choices are made here, no amount of final design "tune-up" can make a poor scheme economical or attractive. For this reason it is important that the most creative and experienced engineers be involved in this step.

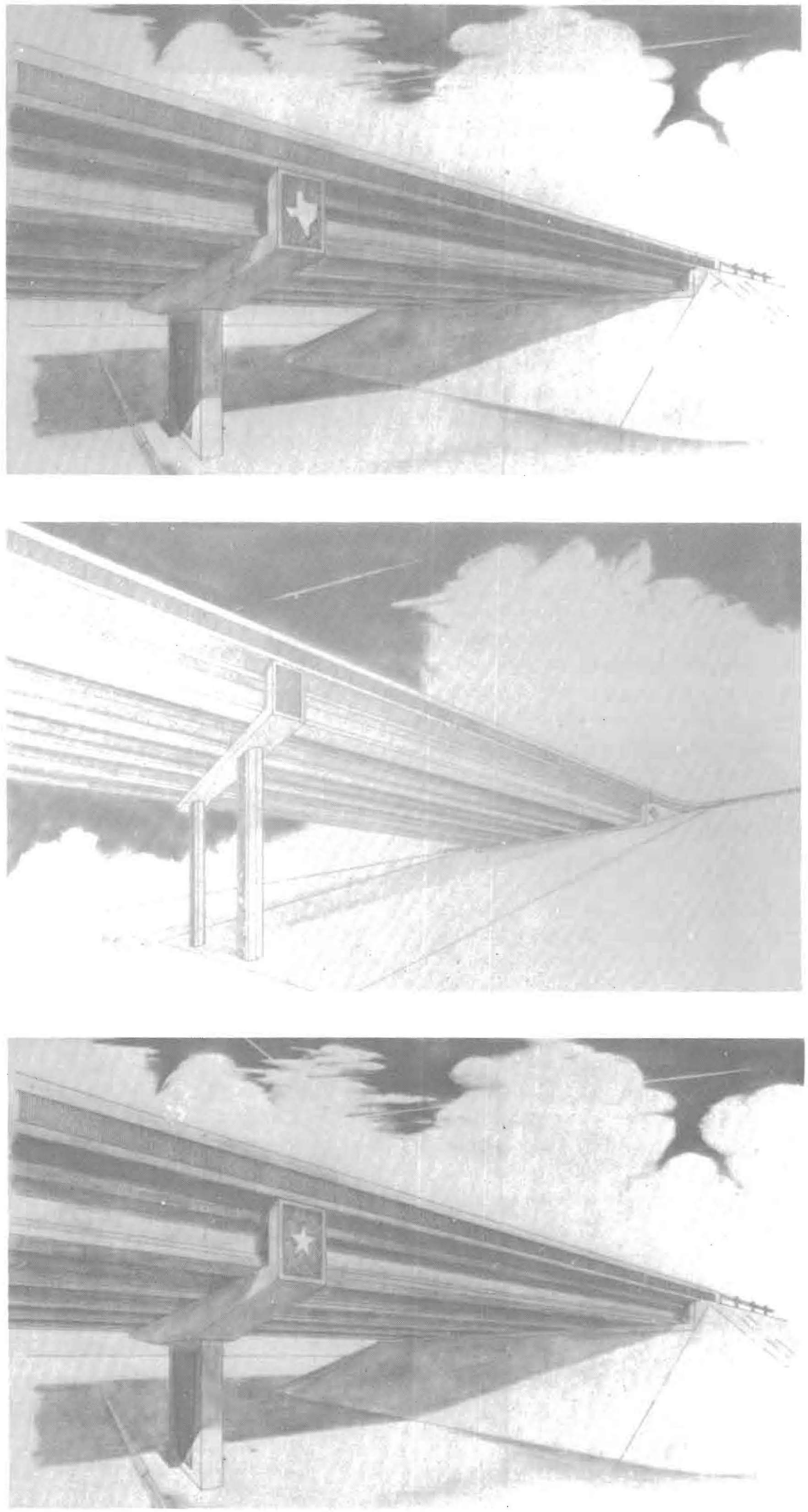

FIG. 1: Three styles of experimental form liners.

To address the challenge of aesthetic quality in bridge design, I would suggest the following: the structure layout and the specific superstructure and substructure shapes should be developed based on the characteristics of the required structure function. We optimize the structure to create simplicity of form, and in this way, determine the most effective span length and column spacing. We try to use the same superstructure cross-section along the length of the bridge to achieve unity of appearance. In the urban areas, we use inverted T-caps in order to minimize the interruption of horizontal lines, and we structure the columns to achieve certain effects by the use of vertical lines or form liners in order to produce striking architectural patterns and textures (Fig. 1). The Bridge Division has a team of engineers studying functional bridge aesthetics. District personnel can call Vernon Harris, Assistant Engineer of Bridge Design [(512) 371-5088; TEX-AN 254-5088], for ideas and help.

What I have said so far is half the solution to having efficient and beautiful bridges. Our interest in permanency of aesthetic bridges should dictate periodic cleaning and adequate maintenance of all structures.

In closing, I would define an aesthetic bridge as being one that is compatible and harmonious with its surroundings; one that does not attract attention, but fits into its environment and looks like it belongs there. People travelling over it should not even realize they crossed a bridge.

EDITOR'S NOTE

In August 1988, Mr. Stotzer directed by letter that, "Projects that are now in the design stage should be reviewed by the Districts for aesthetic quality. If the aesthetics can be improved without a major redesign effort the plans are to be changed accordingly."

Mr. Ybañez's article is the start of a series focusing on aesthetics in design. The future articles will feature actual projects in various districts that have successfully integrated beauty and functionality.

NUCLEAR ASPHALT CONTENT GAUGE FOR ACCURATE, FAST ASPHALT CONTENTS

Excerpted from "Evaluation of the Troxler Model 3241-B Asphalt Content Gauge," (November 1988 Draft Copy), Research Report 1116-1F, by Richard J. Holmgreen, Jr., Thomas W. Kennedy, and William E. Elmore. Conducted for the Texas State Department of Highways and Public Transportation by the Center for Transportation Research, University of Texas at Austin.

INTRODUCTION

Laboratory evaluations performed by the Center for Transportation Research (CTR) and field trials performed in Districts 1, 17, and 20 have shown that the Troxler nuclear asphalt content gauge, Model 3241-B, produces speedy, reliable results if the correct procedures are followed. The procedures are simple enough so that inexperienced personnel can be trained quickly and thoroughly. However, anyone operating the equipment should have completed a "Nuclear Safety Training Course" so that all safety aspects are understood. This is a statutory requirement. The nuclear content gauge (Fig. 1) is a valuable piece of equipment for maintaining quality control in the face of increasing construction and rehabilitation projects and of decreasing experienced personnel due to retirement.

Nuclear asphalt content gauges measure asphalt content of hot mixed asphalt concrete by using the principle of neutron moderation (slowing) by hydrogen atoms. In the Troxler model, a neutron source emits fast neutrons, which are slowed down by the hydrogen in the asphalt. These emitted neutrons are counted during a specified length of time. Using a microprocessor, the Model 3241-B computes the asphalt content from neutron counts and from calibration counts. The count displayed is directly proportional to the amount of hydrogen in the sample. Normally only the hydrogen in the asphalt should be counted, but if proper procedures are not strictly adhered to, hydrogen in moisture may be counted as well, giving a false reading.

With this gauge, after it has been calibrated to the mixture being used, asphalt content can be determined in less than five minutes. It is capable of storing 45 different calibrations in its memory. The gauge does not require the use of hazardous extraction solvents. Also, it satisfies all the requirements of ASTM Method D-4125-83, "Test for Asphalt Content of Bituminous Mixtures by the Nuclear Method." Since it has been proven accurate, it is allowed as an alternate method in the scope of Texas Test Method Tex-210-F by the clause: "Other methods of determining asphalt content of a bituminous mixture which have proven accurate may be used." [Ref. 1]. Currently, the nuclear asphalt content gauge is used by several districts as a supplement to the existing extraction methods.

LABORATORY EVALUATION

To determine the reliability and accuracy of the nuclear asphalt content gauge, the gauge results were compared to extraction results. The two extraction methods were vacuum and centrifugal extraction as set forth in Texas Test Method Tex-210-F [Ref. 1].

The initial part of the evaluation was simply to find out how difficult or easy the machine was to operate from the instruction manual [Ref. 2]. Procedures were followed as outlined in the manual, and the researchers found that the manual was well written and informative. Several operational characteristics and sample variables were investigated. Among them were: background count; calibration; effect of temperature; effect of aggregate type and gradation; and effect of asphalt type and grade.

Background count

Background radiation is an important factor to consider because neutrons from a source other than the gauge can affect the

FIG. 1: The Troxler Model 3241-B.

results by altering the count. The model 3241-B is equipped with a firmware program that will compensate for minor changes in background count occurring between calibration and subsequent measurements. Several background counts were performed in the lab, and it was confirmed that minor fluctuations did not affect the accuracy of the nuclear content gauge. However, both the researchers and the manufacturer recommend that the gauge remain in the same position during the calibration procedure as it was in during the background count.

Calibration

The calibration procedure requires a minimum of two mixtures with different asphalt contents. The laboratory calibration was established using the four asphalt contents of 4.5, 5.0, 5.4, and 6.0 percent which represent the range typically used in Texas. Three different, common Texas asphalts were calibrated at these four contents.

Sample preparation, particularly compacting the material to be measured, is extremely important because the device performs calculations based on volume rather than weight. Therefore, the mix must be uniformly compacted in the sample pan in order to achieve as uniform a density as possible. The study showed that individual sample weights should be as close as possible to aid in maintaining a constant density. The edges and center of the sample should be squared off (Fig. 2). The asphalt must be dispersed throughout the mixture and the aggregate be coated. Simply adding a known quantity of asphalt to the sample pan of aggregate and not mixing it will result in inaccurate readings. This was discovered when the researchers were trying to devise a calibration method faster than the one outlined in the manual.

The effect of "time of count" during calibration was also evaluated. Readings were taken for 1, 4, 8, and 16 minute counts. The maximum difference between the actual asphalt content and the measured content decreased as the time of count increased, though none were very great. The correlation between the actual asphalt content and the measured asphalt content (average of four readings) for each of the four different time counts was very high (Table 1).

TABLE 1: Correlation coefficients for each count time.

Count Time (Minutes)	Correlation Coefficient
1	0.998
4	0.997
8	0.999
16	0.998

(Perfect correlation would be represented by a correlation coefficient of 1.)

Effect of Temperature

The Model 3241-B contains firmware which compensates for the difference between the calibration temperature and the sample temperature. Evaluations were carried out to determine the extent of the compensation. It was discovered that the difference between mixture and input temperatures was not significant for a 5.3 percent asphalt content. However, at higher asphalt contents a change of 50°F can produce a significant difference. This factor should not be a problem since a quick measurement should produce a temperature reasonably close to actual mixture temperature.

Effect of Aggregate

Type of aggregate does not affect the accuracy of the nuclear content gauge, although the amount of moisture present in the aggregate does, since the hydrogen in water slows the emitted neutrons down exactly like the hydrogen in asphalt.

Variation in gradation does affect the accuracy of the reading, but not greatly. For example, the researchers found that a 10 percent increase in material on the No. 10 sieve produced a maximum of 0.2 percent difference in the asphalt content reading. While the difference is not large, it does illustrate the need for proper samples.

Effect of Asphalt

A change in asphalt source can affect the nuclear gauge readings since the hydrogen content of different asphalts can vary significantly. If there is a change in asphalt source, the nuclear gauge must be recalibrated to the new asphalt to ensure accurate results.

FIELD EVALUATIONS

The field evaluations involved four projects in three districts. Three projects used Type D mixtures and the fourth, a Type B. The results were compared with those obtained from vacuum or centrifugal extraction methods.

Background count

Background radiation varies more in the field than under permanent lab conditions. Therefore, background count was found to be extremely important to accurate reading in the field. The location and placement of the gauge must be carefully considered. It should not be placed close to a large volume of water such as a water cooler or distilled water source, nor should it be placed near other potential sources of hydrogen such as solvents. Any of these can significantly alter the readings. Once the background count has been established, the gauge should not be moved nor should sources of hydrogen be placed nearby.

Calibration

Field calibration *must* be performed with field materials. Once the calibration has been made, it should remain effective until the materials change. Periodic calibration checks, performed with samples of known asphalt content, are a good idea when a particular calibration is used over an extended time.

Nuclear gauge measurement vs. extraction measurements

For each project, a nuclear measurement and an extraction were used to determine the asphalt content of the mixtures. Comparisons between the results proved the accuracy of the nuclear gauge (Table 2). One very relevant point in the comparison is that the retention needs to be included with the extraction measurement, since the nuclear asphalt content gauge is a

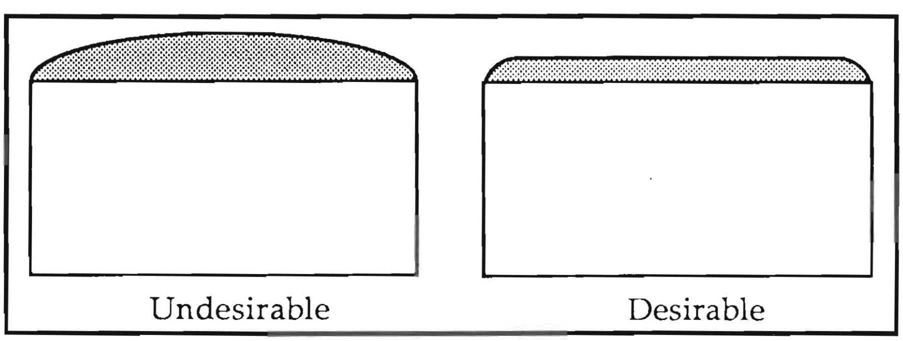

FIGURE 2: Placement of sample in pan before compacting.

more sensitive test and measures all the asphalt present. In one field project, the nuclear gauge was giving readings inconsistent with field extractions. Samples were taken at this location and returned to the lab for extraction. The extraction performed in the main laboratory supported the nuclear gauge results. Errors were corrected in the field laboratory extraction method. After that, the gauge and the extractions were in agreement. This is a strong indication that the model 3241-B nuclear content gauge will produce reliable results in the field if the correct procedures are followed.

CONCLUSIONS

The following conclusions can be made based on the results of Research Report 1116:

1. The operator's manual is easy to understand. It should be studied by the operator to better understand the operation and safety aspects of the nuclear content gauge. While there is no radiation hazard to the operator when proper handling procedures are followed, a potential hazard does exist if the gauge is not properly used.
2. The calibration procedure must be followed carefully with special attention to the measurement of the asphalt in the calibration sample.
3. The background count is extremely important for the gauge to measure accurate asphalt contents, particularly in the field.
4. A calibration is only good for the exact materials used in the calibration sample. If any of the materials, material quantities or gradation are changed, a new calibration should be performed.
5. Since hydrogen is the element measured by the nuclear asphalt content gauge, different asphalts can produce different counts and different estimated asphalt contents.
6. The retention factor must be calculated in order to compare a nuclear asphalt content gauge measurement with the extraction of a mixture.
7. The nuclear gauge will give satisfactory results in the field when proper procedure is used. It therefore can be used under the clause: "Other methods of determining asphalt content of bituminous mixtures which have proven accuracy may be used;" mentioned in the scope of Texas Test Method Tex-210-F.

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TABLE 2: Average extraction percentage vs. average nuclear gauge percentage

Dst.	Mix Type	Design Asphalt %	Average Extraction Content %	Average Extraction Plus Retention Factor %	Average Nuclear Gauge Content %
1	D	5.8	5.5	5.7*	5.8
17	B	5.6	5.3	5.7	5.7
17	D	5.8	5.3	5.6	5.6
20	D	4.7	4.7	4.8	4.8

* *Retention factor from table, not actually calculated.*

REDUCING DEER/VEHICLE ACCIDENTS

Four years ago, ***Technical Quarterly*** ran an article describing the use of the Swareflex Wildlife Reflector [TQ1-4, "Controlling Deer Movement Across Highways"]. This device, a 6.5-inch by 2-inch red reflector (Fig. 1), is used in series along stretches of road known for numerous deer kills. Statistically, most deer hits occur at night. The angled reflectors bounce the headlight beams of oncoming cars perpendicularly toward the shoulder, effectively "spotlighting" the deer and causing them to freeze while the cars pass. Washington DOT conducted research that indicated that the Swareflex reflector significantly reduced the number of deer/automobile accidents. To account effectively for varying factors such as changing deer population densities, changing traffic patterns, weather changes that might affect migration, etc., WSDOT established four test sections in areas known for white-tailed deer accidents along State Road 395 north of Spokane. These sections of reflectors were alternately covered and uncovered at two week intervals during the late fall to early spring from 1981 to 1984. The difference between the number of deer killed when the reflectors were covered and the number killed when these reflectors were uncovered was statistically significant. Upward to 90 percent reduction in the accident rate was experienced.

Unfortunately, the reflectors cost between $3000 and $5000 per mile. However, Texas has had an average of 4300 animal/vehicle collisions (mainly deer) in the last nine years (Table 1), and the weighted direct cost of animal/vehicle accidents in Texas (1983 dollars) is $7300 for fatal accidents, $6700 for injury accidents, and $1200 for non-injury property

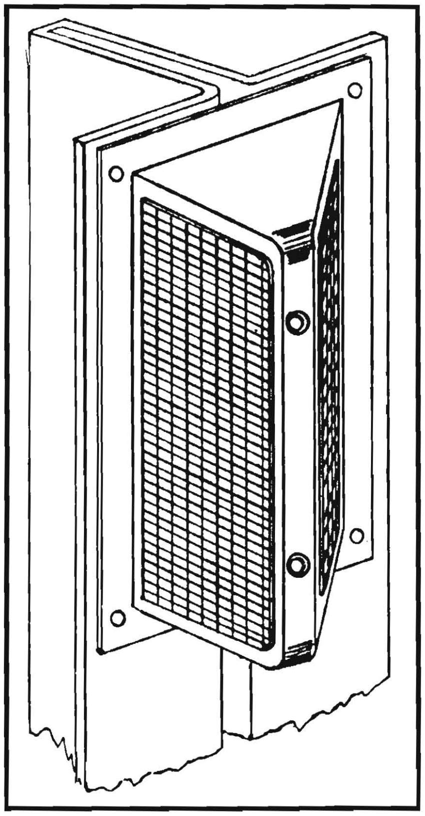

FIG. 1: Swareflex reflector.

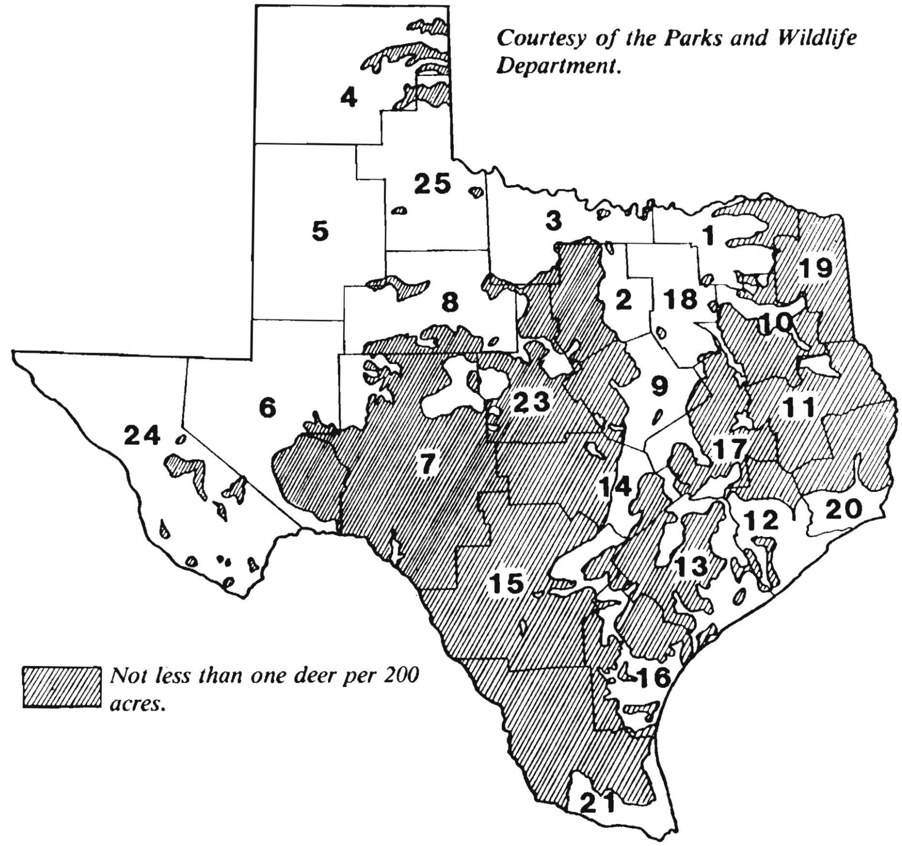

FIG. 2: Distribution of white-tailed deer in relationship to SDHPT Districts.

damage only accidents. These figures do not include the cost of deer carcass disposal, which can be a significant expense in areas near human populations where such disposal is necessary. Districts with suburban sections in areas of heavy deer population (Fig. 2) may well save money, and possibly lives, by installing Swareflex reflectors along sections of roadway where repeat deer/automobile collisions requiring disposal of the deer carcass have occurred. Districts interested in trial installations should contact Lewis Rhodes (D-18STO) at (512) 465-6330, TEX-AN 258-8330 or Wayne White (D-18STO) at (512) 465-6263, TEX-AN 258-8263.

TABLE 1: Annual number of animal/vehicle collisions in Texas (urban, suburban, and rural)

Year	80	81	82	83	84	85	86	87	88
Total	3945	4381	4536	4407	4804	4559	4380	3751	3891
Accidents Involving Fatalities	9	16	12	11	13	13	13	7	9
Involving Injuries	529	662	639	681	794	793	767	651	684
Non-injury	3407	3703	3885	3715	3997	3753	3600	3093	3198
Number of People Killed	10	21	12	15	13	13	13	10	9
Number of People Injured	671	883	860	945	1026	1043	1048	868	901

Courtesy of the Texas Department of Public Safety.

COLD WEATHER CONCRETING TIPS

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INTRODUCTION

Concreting in cold weather poses some unique problems. Low temperatures slow the chemical reaction between water and cement, slowing both hardening and strength gain. Very little cement hydration occurs at temperatures below 40°F. This reason is why the Standard Specifications [Ref. 4] require concrete temperature to be above 50°F: to ensure enough energy to keep the hydration reaction going.

Hydration can be roughly correlated to strength gain. Freezing before full hydration has occurred can reduce the ultimate strength of a concrete placement by up to 50 percent [Ref.1, p137]. If fresh concrete freezes before it gains 500 psi compressive strength (approximately 24 hours in ambient temperatures above 40°F), durability will be reduced. Expanding ice crystals will cause scaling and internal cracking and will leave voids that make the hardened concrete permeable, even though the ultimate strength may be in the normal range. Once the strength is past 500 psi (compressive), however, enough water has gone into hydration that the chance of freeze damage is minimized.

In order to maintain concrete temperature above 40°F, it may be necessary to heat concrete ingredients or to supply external heat to the placed concrete. On the other hand, improper heating of the concrete to keep it from freezing may cause excessive surface evaporation resulting in plastic shrinkage cracking, differential temperatures causing thermal cracking, or flash setting may occur if the water and aggregate are overheated before mixing.

It is the contractor's responsibility to provide protection for the concrete in order to produce concrete equal in quality to that placed during favorable weather. Project engineers, managers, contractors, and inspectors should be familiar with good cold weather concreting practice in order to recognize problems before they become incorrectable (except by removal of the affected concrete). They need to work cooperatively to assure quality concrete.

This article will outline plans and tips for good cold weather concreting practice.

PLANNING

With proper precautions, cold weather concreting is possible. A concrete job needs to have a cold weather plan for batching, placing and curing if concreting is scheduled during months when the anticipated ambient high temperature is below 50°F.

Planning should begin by selecting a mix suitable for cold weather. Design to get past the critical 500 psi point as soon as possible to reduce the chance of freeze damage. Achieving this design criterion may require a reduction (within specification limits) or elimination of fly ash, reduction or elimination of retarder, a slight increase in cement, or the heating of water and/or aggregate. An accelerating admixture may be useful if approved. Air entrainment should be designed into the mix to minimize the possibility of freeze damage. As well as improving durability, entrained air reduces water content and helps absorb the stresses of ice formation within the concrete.

Concrete, when placed, should not be below 50°F [Ref.4, Item 420.11]. This minimum concrete temperature is necessary to keep the hydration reaction going at a rate fast enough to get the 500 psi strength gain within a reasonable amount of time. Be aware that too high an initial concrete temperature causes problems as well: the warmer the concrete relative to the air temperature, the faster the evaporation rate of the mix water, and, therefore, the more likely the concrete will crack due to plastic shrinkage. Also, overheating the mix water and aggregates can cause accelerated chemical action (flash setting) when the cement is added or cause an increase in water demand to achieve a given slump [Ref.2, 3.6]. The temperature of any concrete mix leaving the plant should rarely be warmer than 60 to 70°F in cold weather [Ref. 2, 4.6.2].

Plans should provide that whatever protective gear has been selected (enclosures, windbreaks, portable heaters, insulated forms, or insulated blankets) is on the job site and in good condition before placing starts. Along with its primary function of preventing freeze damage, suitable cold weather protection conserves heat of hydration, thereby allowing strength to develop faster and permitting earlier reuse of forms [Ref.2, 4.6.2].

Some types of protective gear are easier to use than others, and a cold weather plan should take into account the difficulties of the proposed methods. In Texas, polyethylene sheeting and cotton mats are frequently all that are needed to maintain the concrete above 50°F. Such equipment is simple to use and relatively cheap. Heated enclosures are time consuming to construct and difficult to heat correctly without drying the concrete. The plan might assign priorities to various placements in a project based on how critical the completion of a placement by a certain date is to completion of the whole project. These priorities would give the project engineer a good idea of whether to authorize concreting, when faced with ambient temperature conditions below 40°F, and to have the contractor build enclosures or to wait for better weather with a more favorable forecast.

If heated enclosures are elected, plan to vent them. Fuel-fired heaters and internal combustion engines used in heated enclosures must be vented, both for the safety of the crew and for the durability of the concrete. Fresh concrete surfaces will react with carbon dioxide from exhaust fumes to form soft, chalky calcium carbonate. Calcium carbonate causes dusting, scaling, and reduced abrasion resistance.

Plan for fire-fighting equipment on the job site if heated enclosures are being used.

Concrete may be placed when the ambient temperature is above 35°F, as long as it is not in contact with any material coated with frost or having a temperature less than 32°F [Ref. 4, 420.12(2)]. Placing concrete on frozen soil can cause base failure problems because, when thawed, soil is in an expanded condition. Plans should include reworking or removing thawed soil to prevent settlement [Ref.2, p4-58].

Steel, whether it is uninsulated metal forms, protruding reinforcement or metal inserts, conducts heat rapidly from the concrete to the air. Plan to keep areas of concrete in direct contact with metal well above freezing to avoid damage.

For form removal purposes, plan on casting extra flexural test beams in case strength gain is much slower than expected and the first set break below the acceptable minimum. These specimens need to be cured in the same manner as the placements they represent (field cured) [Ref.4, 420.22; Ref.3, p6-17, 6-19; Ref.5]. Lab-cured specimens should not be used to determine a safe strength for form removal. Use the field-cured flexural strength specimens.

Review form removal and reshoring procedures in advance. It is good practice to leave forms in place for as long as possible in cold weather, even within heated enclosures. Forms insulate the concrete from the cold air preventing both drying and thermal cracking.

Plan a pre-placement conference that includes the contractor, project engineer and inspection personnel to ensure that everyone understands what is needed for cold weather procedures established for the placement.

COLD WEATHER PRODUCTION TIPS

Control of mix ingredients' temperatures:

Heating the mix water is the easiest way to bring the mix temperature up to the required minimum because water can store about five times as much heat as can aggregate and cement of the same weight. Mix water should not be heated above 180°F. Heating the mix water can affect the performance of admixtures, such as air entraining agents and water reducers, making them less effective. The temperature of the mix water should be kept uniform from batch to batch. If the mix water and/or the aggregates are heated, the cement cannot be added until the water/aggregate temperature is down to between 50 and 85°F [Ref.4, Item 420.12] in order to avoid flash setting and excessive slump loss. Furthermore, substantially higher concrete temperatures do not afford proportionally longer protection against freezing; the higher the concrete temperature is relative to the air temperature, the quicker the heat is lost to cooling by increased evaporation.

Storage of admixtures should concern the inspector. They should be protected against freezing. Some admixtures deteriorate if they freeze. If an admixture is suspected of having been frozen, it should be sampled and tested before it is used. Admixtures failing to meet specification standards must not be used. [Ref. 2, 3.2.2.4]. Problems with admixtures should be referred to the Materials and Tests Division (D-9).

At ambient temperatures above freezing, it is seldom necessary to heat aggregate. However, thaw aggregate that is frozen in lumps or coated with ice or frost before it is added to the mix. Ice on the aggregate can reduce the mixture temperature below the allowed 50°F minimum. Aggregate needs to be frequently tested for moisture, and the mix water needs to be adjusted accordingly.

If aggregate is heated, the resulting temperature of the stockpile should be uniform. Large temperature variations in the aggregate can cause considerable variation, from batch to batch, in the water demand of the mix to achieve the desired slump. Inspectors should be aware that it is difficult to heat a stockpile uniformly. Be on the lookout for hot and cold spots. It may be necessary to rework the stockpile to even out the temperature.

Hot water or steam circulated in pipes beneath stockpiles or in bins is the recommended method of heating aggregates. Thawing aggregates over a fire built in a metal culvert is acceptable practice for small scale jobs. A fire of coals and low level flames spread over the floor of the culvert heats more uniformly than a miniature bonfire blazing in the center. Exposed aggregate piles should be covered with tarpaulins both to avoid ice formation and to increase heating efficiency. Aggregates should not be heated above 150°F.

The formula by which to figure the temperatures of the various mix ingredients to arrive at a given temperature of concrete is as follows:

$$T = \frac{0.20\,(Ta\,Wa + Tc\,Wc) + Tf\,Wf + Tm\,Wm}{0.20\,(Wa + Wc) + Wf + Wm}$$

Where
- T = Temperature (°F) of concrete
- Wa = Weight in lbs of aggregates (surface dry)°
- Wc = Weight in lbs of cement
- Wf = Weight in lbs of free moisture in aggregates
- Wm = Weight in lbs of mixing water
- Ta = Temperature (°F) of the aggregates
- Tc = Temperature (°F) of the cement
- Tf = Temperature (°F) of free moisture in aggregates
- Tm = Temperature (°F) of mixing water
- 0.20 = Assumed specific heat of dry materials. [Ref.2, 3.6]

Placing, finishing, and curing:

Placing and finishing operations should be well planned and fast paced. Normal expected heat loss during transit and placement can be taken care of by controlling the concrete ingredients' temperature using the temperature formula above as a guideline. Mix delivery should be coordinated with placing operations so trucks do not line up waiting at the site. Delays in delivery or placement can cause delays in finishing and curing protection which will seriously impair the quality of the concrete.

Wind screens can help protect slabs and structures from rapid cooling and from excessive surface evaporation while placing and finishing are going on. Often, instead of erecting full enclosures, insulated forms and combinations of insulating blankets, fiber mats, and polyethylene sheeting (Fig. 1) will keep in enough of the heat of hydration to maintain the surface of the concrete above the specified minimum temperature for the required time period [Ref.4, Items 420.12(2-3), 420.21].

Remember that thin reinforced members, corners, and edges lose heat much more quickly than massive structures such as piers and abutments and, therefore, are much more prone to freezing. Consequently, routine temperature checks to verify that the protection provided is adequate should be taken along the surface of edges and corners or the surface of the thinnest reinforced concrete members. What is adequate protection for these vulnerable parts is normally more than adequate for other portions of the structure. Metal forms, not inside heated enclosures, which do not have built-in insulation, or which have protruding reinforcement or metal inserts should be heavily insulated and temperature monitored routinely as well. Recording thermometers are best for daily monitoring. [Ref. 2, 4.6.2]

Make sure insulation remains appropriate in changing weather conditions. If weather conditions worsen, particularly if wind velocity picks up above 15 mph, insulation thickness may have to be increased. Should ambient temperatures suddenly increase much above the temperatures assumed for the insulation used, some insulation may have to be removed [Ref.1, p.145]. Otherwise, concrete temperatures may become excessive, increasing the probability of thermal cracking when formwork is removed. The surface temperature of insulated concrete in cold weather should not be much above 80°F when read at any routine temperature check. A 35°F temperature differential between interior concrete temperature and surface temperature is about the maximum safe difference [Ref.1, p145].

If enclosures are elected as a means of protecting concrete placements, remember that heated air inside enclosures is likely to be very dry. Concrete within heated enclosures must be kept constantly moist or it will crust, shrink, and crack. Curing compound and/or wet mats should be applied as soon after finishing as possible. While curing compound does not have any insulating effect, it does reduce surface evaporation in a heated enclosure as well as reduce surface carbonation. Ponding as a method of curing in cold weather can only be done if supplemental heating in the enclosure can be arranged to keep the surface of the concrete above 50°F. Live steam piped into an enclosure provides both moisture and heat and is an excellent way to beat cold weather problems [1, p149]. Reducing heat gradually at the end of the required curing period allows the concrete temperature to slowly equalize with the ambient temperature, avoiding thermal shock cracking.

FIGURE 1: Polyethylene sheeting with straw insulation.

In cold weather, curing compound can thicken past the point of easy application. Take precautions in storing it, to avoid increased viscosity. Curing compound should never be heated over open fire.

Form removal:

To be sure no damage of the concrete occurs during cold weather due to form removal, extra test specimens should be made according to Manual of Testing Procedures [Ref.5] during placement and field cured using the same methods that are used on the concrete. Form removal specimens require a minimum of 500 psi flexural strength (center point loading) for weight-supporting forms and falsework for all bridgework and culvert slabs. If none of the test specimens achieve the required minimum strength, forms must remain in place for a total of 14 curing days as defined in the specifications [Ref.4, Item 420.22].

Leaving forms in place for as long as possible in cold weather is good practice. Warm, protected concrete, especially in massive sections, should not suddenly be exposed to air more than 35°F colder than its surface temperature. It may be necessary to loosen forms to allow a more gradual cooling of the concrete face prior to form removal. Similarly, water that is sprinkled on the newly exposed concrete should not be much colder than the surface temperature [Ref.2, 4.9.2]. An inspector should be on hand when forms are removed. He should take the temperature of the concrete surface before the forms are removed to check that thermal cracking will not be a problem.

SUMMARY

Pre-placement planning is very important. The mix design must be appropriate for cold weather. Methods for heating concrete ingredients or supplying heat externally to the concrete placement should be reviewed. Form removal and reshoring procedures should be reviewed in advance. The contractor should have all necessary heating and covering materials on hand to implement the cold weather plan before concreting begins.

Control mix ingredients' temperature to optimize concrete quality. Use wind screens to protect placements from rapid cooling during finishing. Provide enough insulation to maintain the hydration reaction. Perform daily routine temperature checks at critical points such as beneath insulation, on the surface of unformed areas, on corners, and on edges. Record ambient temperature as well. These temperature records let the project engineer know if the insulation selected is adequate. Within heated enclosures, rate of evaporation of surface moisture becomes as critical as if the concreting were being done in

hot weather. Leave forms in place as long as possible in cold weather.

As long as jobs are well planned so that concrete is protected from freezing and heat of hydration is maintained so that sufficient strength is gained, quality concrete can be obtained.

For more information, contact Mr. Gerald Lankes (D-9), TEX-AN 241-7331, (512) 463-7331; Mr. Berry English (D-5), TEX-AN 245-5093, (512) 371-5093; or Mr. Randy Cox (D-5), TEX-AN 254-5090, (512) 371-5090.

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