Vol. 6, Issue 1, October 1990.

TECHNICAL QUARTERLY

An Exchange of Ideas
Editor:
Kathleen M. Jones

MOWER-THROWN OBJECT ACCIDENTS

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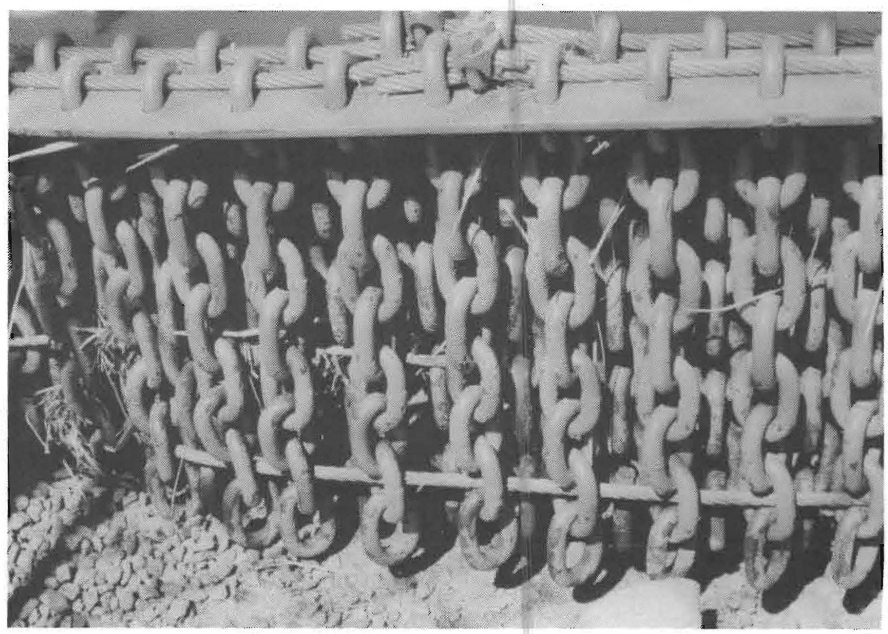

FIGURE 1: The safest configuration: cables strung through chains.

INTRODUCTION

The incidence of tractor mower-thrown object (MTO) accidents involving the public during the maintenance of highways and adjoining rights-of-way has become an ever-increasing problem to the Texas State Department of Highways and Public Transportation (SDHPT). In fact, approximately 20 percent of the 900 insurance claims submitted to SDHPT's insurance carriers in 1984 were directly related to MTO accidents. In an effort to curb accident frequency and severity and improve public relations, SDHPT recently sponsored a research investigation to evaluate the effectiveness of various mower design improvements and identify possible remedial measures to the MTO problem.

More specifically, the objectives of the research investigation were to:

- Study existing SDHPT equipment, mowing practices and accident data together with available reports on mowing practices and equipment of approximately 30 other States.
- Visit mower manufacturers in Texas to review past and present developments related to the reduction of MTO accidents.
- Form a data base to help identify specific patterns in accident causes.
- Recommend changes in equipment design.
- Evaluate the effectiveness of various bat-wing mower design improvements by performing field tests and studies.
- Identify possible remedial measures to reduce the MTO problem,

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Published by the Texas State Department of Highways and Public Transportation
Transportation Planning Division, Research and Development Section
Technology Transfer Subsection
P.O. Box 5051, Austin, TX 78763-5051

and explore the potential for implementing these solutions in Texas.

ACCIDENT CONTROL MEASURES

The most popular mower for state highway departments is the rotary blade type, which gave the best results over a broad spectrum of roadside conditions, had the highest production rates, and had the least maintenance and down-time costs. However, the rotary blade also was the type with the highest MTO accident rate. To control this problem, states have taken several measures, including:

- Restricting the height of cut to 6 in.
- Using chain guards.
- Choosing proper equipment.
- Using herbicides and retarders.
- Enhancing operating training.
- Cleaning area prior to mowing.

SDHPT DATA ANALYSIS

Almost 150 accident reports for 1984 were obtained from SDHPT, entered into a data base, and analyzed to develop correlations between accidents and variables (such as time of day and mower-motorist orientation); these correlations were developed to provide insight into how and why MTO accidents occur.

Time of day

Time of day seemed to have some correlation with the number of accidents but its significance is questionable. It is not known if a reduction in the number of accidents was due to fewer motorists or fewer mowers being operated. As shown in Figure 2, few accidents occurred before 9 a.m., possibly because there were fewer motorists in the morning. The number of accidents also fell during the noon hour and after 4 p.m., probably because of a decrease in the number of mowers. The largest number of accidents occurred in the early afternoon, most likely due to large numbers of motorists and mowers.

Time of month

The summer and fall months experienced the largest number of accidents (Fig. 3) probably due to the increased number of motorists. Fewer accidents were reported in the winter and spring months, presumably due to a decrease in mowing activity.

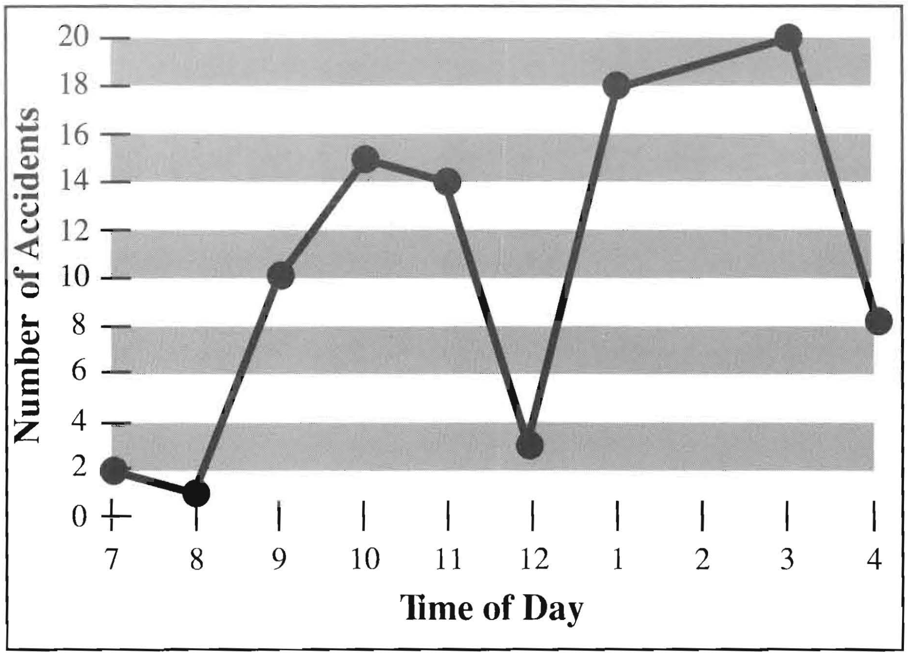

FIGURE 2: Number of accidents by time of day.

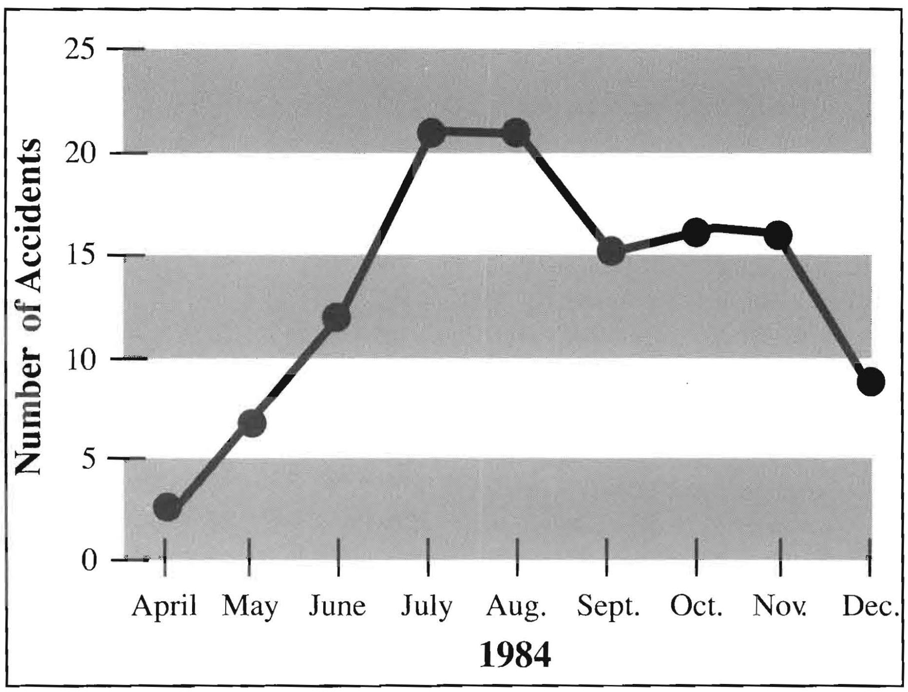

FIGURE 3: Number of accidents by month.

Type of mower

The most widely involved type of mower was the rotary bat-wing type. The second largest group consisted of 30 different flex-wing mowers. Figure 4 shows the types of mowers involved in MTO accidents in Texas.

Vehicle region struck

Windshields were hit in over 39 percent of the reported accidents; the second most vulnerable place was the right side of the vehicle, which had 33 hits. The left side was hit 19 times. There were a few incidents of personal injury. Although most of the damage was caused by rocks, other debris—including concrete, metal, wood and an armadillo—also was thrown (Fig. 5).

Direction of travel

Five directions were used to classify the positional relationships between the mowers and the cars, as shown in Figure 6. The largest number of accidents (39) occurred when the mower and the damaged vehicle were traveling in the same direction and the car was to the left of the mower. The second largest group also consisted of vehicles traveling in the same direction as the mowers but to the right of the mowers. Twelve vehicles were struck while traveling in the opposite direction of and to the right of the mower. Six accidents occurred when the mower and car were perpendicular to each other. The remaining records did not list vehicle position.

FIELD EXPERIMENTS

Experiments were conducted to determine the types of objects hit by bat-winged mowers and the effects of this hit on the objects. These variables were considered:

- Object size.
- Object mass.
- Location of object entry into mower.
- Direction of mowing (forward, backward).
- Chain and cable guards (with, without).

Preliminary testing indicated that two types of objects should be used: 4-inch pressure-treated wooden cubes and 3- to 5-inch limestone rip-rap. A bat-wing mower with pivoted lift blades and a 15-foot cutting span was used in the experiments. The effectiveness of three different safety devices was evaluated. They are:

1) Mowing with chains and cables.
2) Mowing with chains but without cables.
3) Mowing without chains and without cables.

A testing method was developed for a 400- by 600-foot testing site. Mowing was performed both forward and backward, and wooden blocks and limestone rip-rap were placed at predetermined locations. The tests were repeated under various conditions: with and without chains and cables; forward and backward; and over level and uneven terrain. Average distance of thrown objects was calculated for four trials and for each of the 15 stations.

All testing done with rocks and blocks showed that the operation of the mower without chains produced the longest object travel. However, the distinction between using cables during operation and not using them is not as clear. For block testing, the results from maximum distances and the distance distribution indicate that there was virtually no difference between using and not using cables; there was, however, a slight increase in average distance when the cables were not used. For rock testing, average distances and maximum distances were slightly greater in testing without cables. The distance distribution also supports the conclusion that rocks travel slightly farther without cables.

DISCUSSION OF RESULTS

Test results show that the safety devices on current mowers (chains,

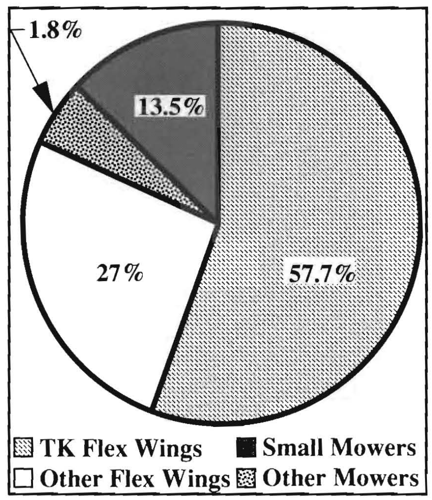

FIGURE 4: Mower types involved in MTO accidents.

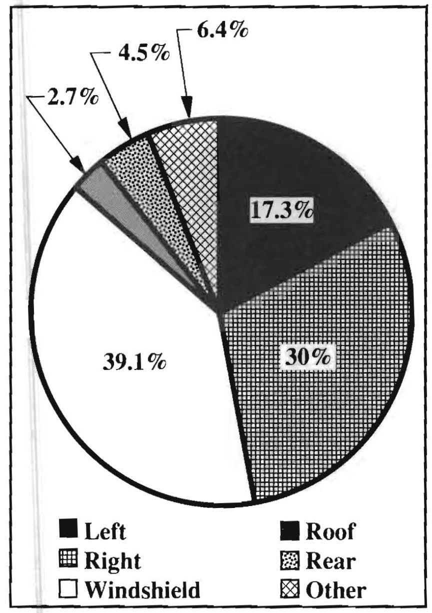

FIGURE 5: Vehicle regions of impact.

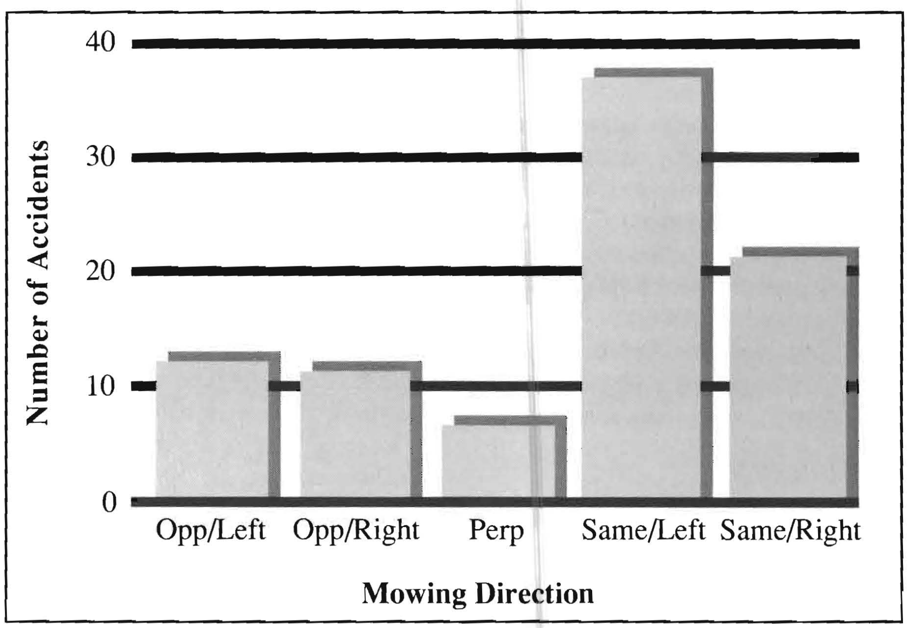

FIGURE 6: Number of accidents vs mowing direction.

cables, skirts, etc.) are effective in normal use: When used properly and with care, the mower is relatively safe. These safety devices, however, cannot stop every object from being thrown from the mower—under certain conditions, the mower is likely to throw an object.

When used in a forward direction, the mower tended to throw objects out to the back of the mower. This was mainly due to the way in which the cutting height was set for the mower. The height of the mower's rear was set 1 inch higher than the front. The resulting angle tended to force the objects that were hit forward, and down slightly so that the chains were more effective in deflecting them to the ground. Also, objects hit forward could be hit again and finally exit the back of the mower.

When objects were thrown forward by one of the blades, the chain guards tended to either deflect them down or backward into the mower. The chain guards were solid down to about the level of the blades; the chains were attached below this point. A comparison of the tests performed with and without chains shows that without both chains and chain guards, many objects were thrown forward. Also, the objects thrown in these tests were very large. Sometimes the entire rock or block was thrown. This shows the effectiveness of the front chain guards and chains in preventing objects from exiting this area.

One of the safety devices used on mowers involved cables through a lower link in the chains. The test results did not show a significant effect in reducing the distance a lighter weight object (e.g., wood) is thrown. The cables

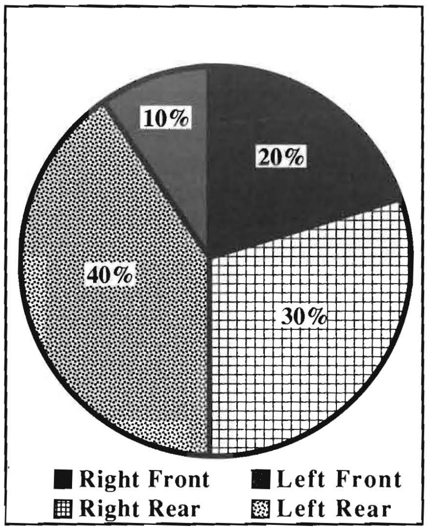

FIGURE 7: Percentage of rock exiting the mower in each direction for testing with safety devices and mowing in forward direction.

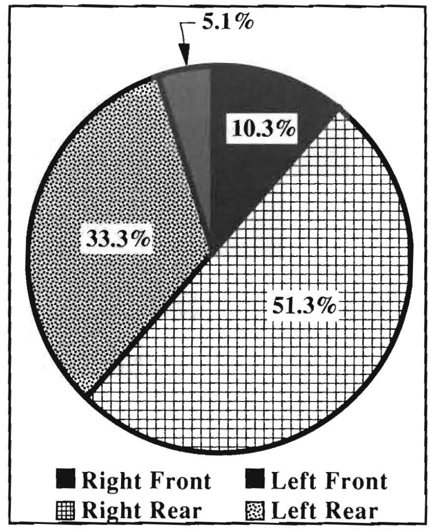

FIGURE 8: Percentage of blocks exiting the mower in each direction for testing with safety devices and mowing in forward direction.

did seem effective in reducing the distance a heavy object (e.g., rock) was thrown. The cables helped the chains act as a curtain. Finally, the tests showed that objects were thrown farther when the mower was used in a a backward direction than when it was pulled forward. Objects that entered the mower from the back tended to exit the mower immediately after being hit. This was because the back was higher than the front, and thus provided less resistance to the object's flight (Figs. 7 and 8).

CONCLUSION

Most of the States participating in this study regard the height of the cut as a major contributing factor to MTO accidents. Therefore, restricting the height of cut to 6 inches will reduce MTO accidents.

Since field experiments with a batwing rotary mower showed that most debris exited the right side rear of the mower, tractor/mower drivers should be made aware of this danger zone so they can avoid placing co-workers or others in this area. In addition, mowers should move against traffic since statistics show that this is the safest way to mow. In this configuration, the motorist and any MTO's are traveling in the same direction, and the impact velocity from the MTO is lessened.

Field experiments showed that mowing without safety chains was significantly more dangerous than mowing with them, and that mowing without the cables that were strung through safety chains was slightly more dangerous than mowing with the strung cables.

from ***Public Roads*** *52 (March 1989): 119.*

LEGISLATION AND ALTERNATIVE FUELS

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INTRODUCTION

This article, the third in a series of articles regarding issues pertaining to alternative fuels, deals with enforcement of alternative fuel programs. Since gasoline is still more convenient than the other alternative fuels to purchase, the federal or state government will have to intervene by offering incentives to persuade the public to convert to alternative fuels. During the course of this article, we will discuss the pertinent legislative efforts on federal and state level.

TRANSITION TO UNLEADED GASOLINE: A MODEL FOR ALTERNATIVE FUEL ENFORCEMENT

Lead had been used as a antiknock compound in gasoline since 1920 [Ref. 2]. When first introduced, leaded gasoline generated a lot of opposition because of the health hazards involved with the emission of lead. However, these warnings were largely ignored for fifty years.

The Clean Air Act of 1970 established emission standards for six pollutants [Ref. 2], one of which was lead. According to the Clean Air Act, the two conditions under which a fuel or fuel additive can be prohibited is when the fuel or additive is dangerous to health or interferes with the performance of emission control devices. Since installation of catalytic converters was considered to be the means for achieving emission standards and since lead reduces the effectiveness of catalytic converters by as much as 90 percent, as well as being a health hazard in its own right, the way was cleared for the elimination of leaded gasolines [Ref. 2].

The transition to unleaded gasoline was unique in the sense that it was orchestrated by the government and not by market forces. It is the most successful model of government involvement in the introduction of a new transportation fuel anywhere in the world. The transition was even more effective because there was a single agency in charge of administering the change, namely the then newly created Environmental Protection Agency (EPA). There was no problem of interagency bickering to delay the transition. The automobile industry had to meet a strict timetable to effect the transition. There was less uncertainty and risk involved to businesses and customers because of active government participation. Consumers knew that they had to purchase unleaded gasoline vehicles; unleaded gasoline was going to be widely available; and the automobile and parts industry was behind this transition due to regulations [Ref. 2].

As we approach the era of alternative fuels, government intervention in the promotion of alternative fuels is going to be crucial. The low price of gasoline will not encourage people to shift fuels. Car manufacturers will be deterred by huge capital costs in producing alternative fuel vehicles. While there is no substitute that can fully match the performance of gasoline now, there may be in the future. Government has to play an active role to prevent further pollution and global disaster due to the greenhouse effect [Ref. 2].

THE CLEAN AIR ACT

The amended 1970 act (42 USC, Sec. 7401 et seq.) required that the concentration of pollutants in exhaust gases from the nation's automobiles and heavy vehicles conform to certain limits [Ref. 1]. The EPA was authorized to establish maximum concentration levels called National Ambient Air Quality Standards (NAAQS) [Ref. 1]. Six NAAQS were established: three for major automotive exhaust pollutants, carbon monoxide, nitrogen oxides, and ozone or smog; two for pollutants emitted from burning of diesel fuel in trucks and buses, particulate matter and sulfur oxide; and the sixth for lead [Ref. 1]. State Implementation Plans (SIP) are required in areas where pollutant concentrations exceed the NAAQS [Ref. 1].

Noncooperative states possibly could face sanctions on new source construction and freezes in federal grants and highway trust funds. If the state fails to implement an adequate SIP, then EPA is empowered to develop a Federal Implementation Plan (FIP). FIP may take the form of downtown parking restrictions, staggered working hours, gasoline rationing, Stage-II gasoline vapor recovery and other requirements.

President Bush released his own clean air proposals in mid-1989. His plan asked auto makers to produce 500,000 alternative fuel units by 1995 and 1 million per year from 1997 [Ref. 3].

THE ALTERNATIVE MOTOR FUELS ACT

The major provision of this act (15 USC, Sec. 2001 et seq.) was to amend the existing Corporate Average Fuel Economy (CAFE) program to permit the production of less fuel-efficient gasoline cars and to exempt auto makers from fines for noncompliance with CAFE requirements. The CAFE standards were introduced in 1978 to set a minimum standard for fuel efficiency for auto car makers [Ref. 1]. The 1990 standard for model passenger cars has been increased by 1 mpg to 27.5 mpg [Ref. 1]. The penalty for noncompliance is $5 per car for each one-tenth mile below the standard [Ref. 1]. Under the new law, CAFE fuel economy calculations will be based solely on the gasoline content in the fuel used [Ref.1]. A M85 vehicle (85 percent methanol and 15 percent gasoline) which is actually achieving 25 mpg, will be credited with 167 mpg because of the new law above. CNG/LNG vehicles are assumed to burn 15 percent gasoline for CAFE calculations. Multiple-fuel vehicles receive half the CAFE credit awarded to pure alternative fuel vehicles. The law provides a limit of 1.2 mpg on the overall CAFE credit that can be awarded to any manufacturer of alternative fuel vehicles [Ref. 1].

The second key provision of the Alternative Motor Fuels Act was to expand the alternative fuels research, development and commercialization program run by the Department of Energy (DOE) [Ref. 1]. DOE was authorized to spend $12 million over a four-year period to fund alternative fuel demonstration projects using federally owned passenger vehicles over a four year period. Six million was spent on a truck and bus demonstration program; $4 million was spent on heavy-duty truck engines, while $2 million was spent on alternative fuel use in buses [Ref.1]. An Alternative Fuels Advisory Council, which consists of representatives from Congress, state governments, industry and the general public, was created [Ref. 1]. This council is to report to another newly created entity, an Interagency Commission on Alternative Motor Fuels which includes representatives from at least seven federal government organizations [Ref. 1].

Fuel Volatility Standards

Average national gasoline volatility has been steadily increasing due to the phaseout of tetraethyl lead. Fuel volatility is measured by the Reid vapor pressure test (RVP). For colder weather, gasoline volatility is increased to help cold starts. During the summer months, RVP standards were based on ASTM specifications. Several states have limited their gasoline volatility to 9.0 psi from May 1 to September 15

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NEW PASSER II-90 SYSTEM

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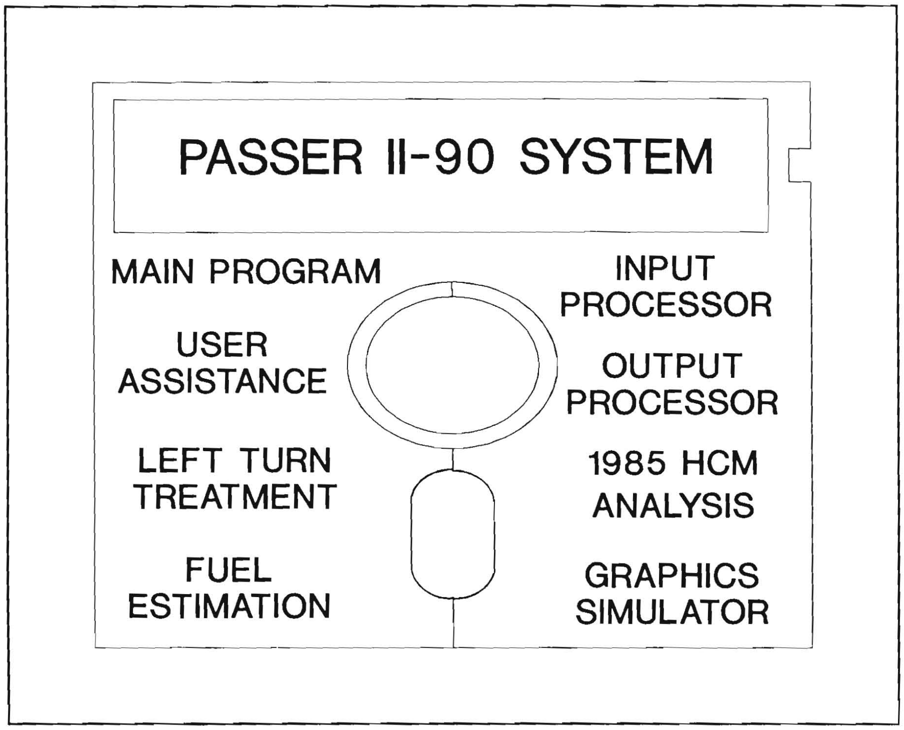


FIGURE 1: The PASSER II-90 system.

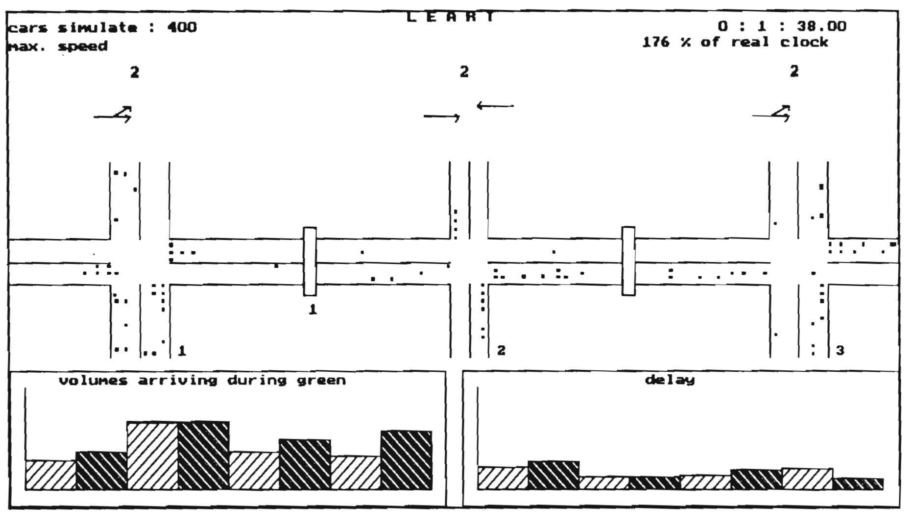


FIGURE 2: The PASSER II-90 dynamic arterial graphics simulator.

Over the years, Texas Transportation Institute (TTI) has developed the ***PASSER*** (***P****rogression* ***A****nalysis and* ***S****ignal* ***S****ystem* ***E****valuation* ***R****outine*). Constantly being improved to meet the analysis needs to upgrade the signal intersection operations and arterial progression for the Texas State Department of Highways and Public Transportation (SDHPT), several versions of PASSER II, including PASSER II-80, PASSER II-84, and PASSER II-87 programs, have been developed, enhanced and implemented since 1970's. PASSER II system has been recognized by the transportation professions as one of the two most widely used computerized signal timing software in the free world. At present, PASSER II is supporting the statewide signal retiming efforts under the Traffic Light Synchronization (TLS) and Traffic Management (TM) projects through the Governor's Office on Energy Management Center (GEMC) and Texas SDHPT of more than 2,500 traffic signals in Texas.

Being recently completed under Texas HPR Study 2-18-86-467, ***PASSER II-90*** system is the most recent development from TTI research. As illustrated in Figure 1, PASSER II-90 system contains the updated analysis of the signalized left turn treatments, arterial progression optimization, existing timing evaluation, advanced highway capacity evaluation, improved fuel consumption estimation, interactive input/output assistance, user help information, dynamic graphics simulator and complete program documentation. In additions to review the regular time-space diagrams, the user can also examine the traffic operational effects through the dynamic arterial graphics simulator and visualize interactions of the arterial signal coordination and random traffic variations as shown in (Fig. 2). The PASSER II-90 has been enhanced to interface with FHWA's new Arterial Analysis Package (AAP) to allow convenient data exchange with TRANSYT-7F Release 6 program. The new PASSER II-90 computerized traffic engineering package can significantly improve arterial progression, signal designs, and progression analysis.

FLY ASH AND THE SULFATE RESISTANCE OF CONCRETE

*Excerpted by Mohanan Achen and Kathleen Jones from Research Report 481-1, **Effect of Fly Ash on the Sulfate Resistance of Concrete Containing Fly Ash,** FHWA/TX-88+481-1, and 481-5 (preliminary review draft), "The Effect of Fly Ash on the Sulfate Resistance of Concrete," by P. J. Tikalsky and R. L. Carrasquillo.*

INTRODUCTION

Fly ash is becoming a standard part of concrete for highways and structures throughout Texas and the southern United States. Problems of durability cropped up when certain types of fly ash were used with Type II (sulfate-resistant) portland cement in sulfate-rich environments. Certain combinations behaved as though they were made from nonsulfate resistant materials.

Nonsulfate-resistant concretes exposed to sulfate suffer a series of reactions. The products of the reactions try to expand within the hardened cement paste. This expansion causes tensile stresses which fracture the concrete. This mechanism is known as 'sulfate attack.' Besides loss of durability, other characteristics of sulfate attack are loss of strength and reduced stiffness.

The Center for Transportation Research Study 481, ***Durability and Performance of Concrete Containing Fly Ash Including Its Use in Hot Weather Concreting and Prestressed Concrete Girders,*** examines the effect of fly ash on the long term durability of concrete. Reports 481-1 and 481-5 deal with fly ash concrete exposed to sulfate environments. This research indicates that a specific kind of fly ash can be used to improve the sulfate resistance of concrete, while a different kind will decrease the sulfate resistance of concrete.

The calcium oxide content of the fly ash provides the best indication of sulfate resistance. Concrete containing low calcium oxide fly ash was found to have a sulfate resistance greater than or equal to that of concrete containing only Type II portland cement. Concrete containing high calcium oxide fly ash was found to have a lower sulfate resistance than similar concrete containing no fly ash. Extended moist curing, the addition of entrained air or a reduction in water content did not improve the sulfate resistance of concrete containing high calcium oxide fly ash to the sulfate resistance level of similar concrete without fly ash.

Results from this research caused a change in standard specifications disallowing the use of high calcium oxide Texas Type B fly ash when sulfate-resistant Type II portland cement is specified. The durability problem which caused Type B fly ash to be disallowed for use when Type II portland cement is specified is not because the fly ash reacts badly with the cement, but because of the nature of the Type B fly ash itself. This article will summarize the research that lead to that conclusion.

TEST PROCEDURES

Very little information was available on the long term performance and durability of high calcium oxide fly ash in sulfate-rich soils and groundwater or in marine environments. The sulfate resistance portion of the 481 research effort was initiated in 1987. It mainly involves the monitoring of expansions, mass changes and cracking of 900 specimens soaking in 10 percent sodium sulfate (Na_2SO_4) and the performance of a series of quantitative tests. The sulfate exposure test procedure was based on guidelines published by the U.S. Bureau of Reclamation and approved by the SDHPT's Material and Test Division (D-9) for use in this research. The quantitative tests include chemical and physical analysis of the fly ashes and other concrete materials, diffraction analysis of fly ash, petrographic analysis of the concrete specimens to determine the extent of deterioration, ion permeability of concrete and periodic physical inspection of the specimens. These testing procedures and material standards are those described in the SDHPT ***Manual of Testing Procedures,*** "Physical Section 400-A Series"; ***ASTM Standards (1988),*** Volume 04.01, "Cement," "Lime," "Gypsum" and Volume 04.02, "Concrete and Aggregates"; and the ***AASHTO Manual of Standardized Testing.***

Eighteen different fly ashes and five different types of portland cements at four levels of volumetric replacement are being evaluated during the course of this study. The fly ash content varied from 25 to 45 percent replacement to investigate the effect of fly ash content on sulfate resistance. Other variables studied were workability, air content, curing conditions and permeability.

MATERIALS

The materials used in this study are those typically used in the commercial production of portland cement concrete. Except where specifically noted, these materials are approved for use in the state of Texas by D-9. The materials include portland cement, fly ash, crushed lime stone coarse aggregate, natural sand, air entraining admixture, water reducing/retarding admixture, and water. Other materials included silica fume and blast furnace slag.

Fly Ash

The present use of fly ash in concrete to prevent sulfate attack is a result of the excellent performance of most pozzolans in sulfate resistant concrete. Physically fine fly ash reacts more thoroughly than coarser cement particles and reduces the permeability of the mortar matrix within the concrete. However, each combination of fly ash and portland cement performs differently according to the hydration compounds in the hardened paste.

Fly ash consists of finely divided particles which are formed at furnace temperatures of nearly 2500° F and carried out of the furnace by flue gases. The ash particles solidify into spherical particles and are collected by electrostatic or mechanical precipitators. The burning of finely pulverized coal is the primary source of fly ash. The type of coal, in addition to the furnace conditions, influences the chemical composition of the fly ash. Low calcium oxide ASTM Class F fly ashes are mainly from bituminous coals. High calcium oxide ASTM Class C fly ashes are from subbituminous coals. The typical high calcium oxide Texas Type B fly ashes originate from the burning of subbituminous coals from Wyoming or Montana. The low calcium oxide Type A fly ashes in Texas are obtained from lignite coals. Fly ashes from high calcium coal sources have more complex mineralogy and are more heterogeneous than fly ashes from low calcium coal.

Two phases of fly ash, glassy and crystalline, account for most of its composition. Glassy phases form between 70 to 90 percent of the fly ash, while crystalline phases account for between 11 and 17 percent of the fly ash. These two phases are not entirely separate and independent of each other: the crystalline phase may be present within a glass matrix or attached to the outside of a glass sphere. This makes fly ash a complicated material to characterize.

There are several chemical subdivisions of both the glassy and crystalline phases. The presence or absence of certain compounds in stable or unstable (or in soluble or insoluble) forms, affects how the fly ash reacts in a given environment. For instance, pozzolanic activity is a measure of the material's ability to react with calcium hydroxide to form compounds with cementing properties. Fly ash is a pozzolan because of the high content of soluble aluminosilicate or calcium aluminosilicate glasses. The amount of soluble calcium-bearing glasses in a fly ash appears to be the key to its durability in a sulfate environment.

Portland Cement

Five portland cements are being used in this study; an ASTM Type I, Type II, Type V and two 0 percent tricalcium aluminate cements. Both of the 0 percent tricalcium aluminate cements meet the ASTM C 150-86 standard specification for Type II portland cement. The chemical and physical properties of the five cements are given in Table 1. For design purposes, the specific gravity of all five portland cements was assumed to be 3.10. The control concrete in this study contained 5.5 sacks per cubic yard of an ASTM Type II portland cement.

Tricalcium aluminate ($Ca_3Al_20_6$) has been shown to be harmful to sulfate resistance. ASTM Type III portland cement cannot be used in areas of slight sulfate exposure because of its extremely high $Ca_3Al_20_6$ content (15 percent). ASTM Type I portland cement will perform at an unacceptable level in moderate to severe sulfate environments. ASTM Type II cements are designated for moderate exposure and are the most commonly used sulfate resistant concretes. Type V is the most sulfate resistant of the ASTM classifications and is recommended for severe exposure. The 0 percent $Ca_3Al_20_6$ cements are also good performers in severe sulfate environments, but like Type V, they are expensive.

Coarse Aggregate

A 5/8 inch, Grade 5 crushed limestone from Georgetown, Texas, was used as coarse aggregate. This aggregate was chosen because it is nonreactive to alkali and is locally available. The aggregate has a specific gravity of 2.50, an absorption of 3.5 percent and a 54.7 percent of solids.

Fine Aggregate

The fine aggregate is a natural siliceous sand from the Colorado River Basin, and was obtained from a local source in Austin. The sand has a specific gravity of 2.64 and an absorption of 1.19 percent. The sieve analysis resulted in a fineness modulus of 2.58.

SULFATES AND SULFATE ATTACK

Presence of Sulfates

Sulfates can always be found in saline lakes and seawater. Frequently, high concentrations of sulfates occur in the soils and groundwater of small localized geographic zones, as well. These local zones are formed from ions leaching from the pore water of alkali soils and from groundwater movement over rocks and sediments containing gypsum. The sulfate-rich areas in Texas are west Texas and the coastal region from the Louisiana border to Mexico.

TABLE 1: Mill test analysis for Project 481.

ASTM Type	I	II	V	01	02
Si Oxide	20.6	21.8	22.0	21.3	21.8
Al Oxide	5.3	4.2	3.4	2.8	2.5
Fe Oxide	3.3	3.2	3.2	4.8	3.8
Ca Oxide	64.2	64.7	64.9	64.4	64.8
Mg Oxide	0.9	0.6	3.3	3.9	1.3
SO_3	3.5	2.9	2.5	3.0	2.3
LOI	0.5	0.9	0.6	0.7	1.3
Insol. Res.	0.4	0.3	0.2	0.2	0.4
C_3S	51.5	54.0	62.2	66.2	70.0
C_2S	20.1	21.8	16.2	11.3	9.6
$Ca_3Al_2O_6$	9.9	6.0	3.6	0.0	0.0
$C_4AF + C_2F$ [sic]	10.0	14.3	3.8	14.6	11.6
Total Alk.	0.7	0.6	0.5	0.3	0.5
Physical Data					
Specific Surface					
Blaine (cm^2/g)	3283	3350	—	—	3625
Comp. Str. (psi)					
1 Day	—	2030	—	—	1850
3 Day	—	3670	—	—	3960
7 Day	—	4670	—	—	5069
Set Time					
Vicat Test					
Initial Set	—	132 min.	—	—	140 min.
Final Set	—	244 min.	—	—	305 min.

The dissolution by pore water or by groundwater of salts such as sodium sulfate, potassium sulfate, magnesium sulfate and calcium sulfate into sulfate ions makes them available to combine with aluminates in the hydrated cement to form expansive compounds.

Seawater contains high concentrations of soluble sulfates, especially large amounts of magnesium and calcium sulfates; however, seawater also contains many other salts which are not sulfate based. The presence of ions from other salts, for reasons not clearly understood, slows the formation of expansive sulfate compounds. The combined effects of these salts lessen the severity of the sulfate attack.

Attack Environments

The most commonly observed sulfate attack environments fall into two categories:

(1) Wet-Dry-Wet category — Concrete is occasionally dried but spends most of the time submerged in a sulfate-rich environment. Drying allows sulfate crystals to form under the surface of the concrete as water is slowly evaporated from the concrete pore structure. The crystal formation may cause surface flaking, and, as the concrete is rewetted with sulfate water, the sulfate ion concentration increases as the crystals dissolve into the solution again.

(2) Submerged category — There is a continual source of sulfate ions and a constant concentration of sulfates in the concrete. Sulfate expansion occurs over a long period of time until the concrete is no longer serviceable.

The relative degree of sulfate attack on concrete depends on the sulfate ion concentration in the water or soil. Table 2 relates the degree of sulfate attack to the different sulfate concentrations.

Sulfate attack will not occur in areas of low humidity and dry concrete conditions. The sulfates in the soils of continually dry areas do not migrate into the concrete and therefore are not available to cause sulfate deterioration. A harmless layer of white powdered sulfates in anhydrous form can be found on the surface of concretes exposed occasionally to sulfates in an environment with low relative humidity. As far as sulfates in seawater are concerned, it was discovered that the greatest damage was found in the zones between low tide and high tide.

TABLE 2: Attack on concrete by soils and water containing sulfates.

Severity of Attack	Water Soluble Sulfate in Soil (%)	Sulfate in Water (ppm)
Negligible	0.00 to 0.10	0 to 150
Positive	0.10 to 0.20	150 to 1500
Severe	0.20 to 2.00	1500 to 10,000
Very Severe	2.00 to More	> 10,000

(From ACI ***Guide to Durable Concrete***, 201.2R-82)

Sulfate Attack Mechanism

Sulfate attack occurs in two stages: (1) slow diffusion of sulfate ions into the paste structure; (2) rapid chemical attack of the hydration compounds. The time to apparent sulfate attack is long, but the deterioration is rapid once the attack commences.

There are a number of soluble sulfates that can attack concrete. Most of these sulfates attack by forming ettringite. Calcium hydroxide, which has no cementitious value, is a by-product of portland cement hydration reaction. Exposure to sulfates in solution converts the available calcium hydroxide in the mortar to gypsum. The gypsum will react with monosulfoaluminate to form ettringite.

Ettringite consists of small rod-like crystals which are 1-2 microns long and 0.1 microns thick in high pH environments such as portland cement. In low pH environments, such as supersulfated and rapid-setting cements, ettringite crystals assume lath-like or long needle-shaped structures which are 10-100 microns in length and 1-4 microns thick. The total solid volume expansion during the sulfate attack mechanism has been conservatively estimated as 2.5 times and may be as high as 7 times the volume of the original hydrates in hardened concrete.

The formation of ettringite early in the hydration reaction causes no damage because the cement is still plastic, and volumetric changes will not cause internal stress. Ettringite formed in the later stages of hydration or in already hardened paste causes internal strains that cannot be totally absorbed by the internal voids, and subsequently, damage occurs.

Magnesium sulfate is unique among the soluble sulfates. Magnesium reacts with the calcium hydroxide in the pore water solution to form crystalline magnesium hydroxide or brucite. As the hydroxide ions are depleted, the corresponding reduction in pH destabilizes the calcium silicate hydrate binder. The binder is weakened further by the formation of expansive sulfate compounds. However, extensive exposure to sulfates results in the formation of an impermeable layer by the magnesium hydroxide, which prevents further sulfate intrusion. This protective coating may or may not form before the concrete is deemed inserviceable.

SULFATE RESISTANCE

Physical Factors

Permeability is an important consideration as far as sulfate attacks are concerned. Permeability governs the flow of fluids, gases, and ions through hardened concrete. Sulfate ions are transported into the concrete by a mecha-

FIGURE 1: PICTORIAL SUMMARY OF RESULTS

↓ **CONTROLS** ↓ ↓ **TYPE B FLY ASH, VARIOUS PERCENTAGES** ↓

→ TYPE II PORTLAND CEMENT →

1a: Type II PC, 5.5 sack 300 days immersion in 10% sodium sulfate.

1b: Type II PC, 5.5 sack , 25% Type B fly ash, 270 days immersion .

1c: Type II PC, 5.5 sack, 45% Type B fly ash, 180 days immersion.

→ TYPE I PORTLAND CEMENT →

1e: Type I PC, 5.5 sack, 270 days immersion in 10% sodium sulfate.

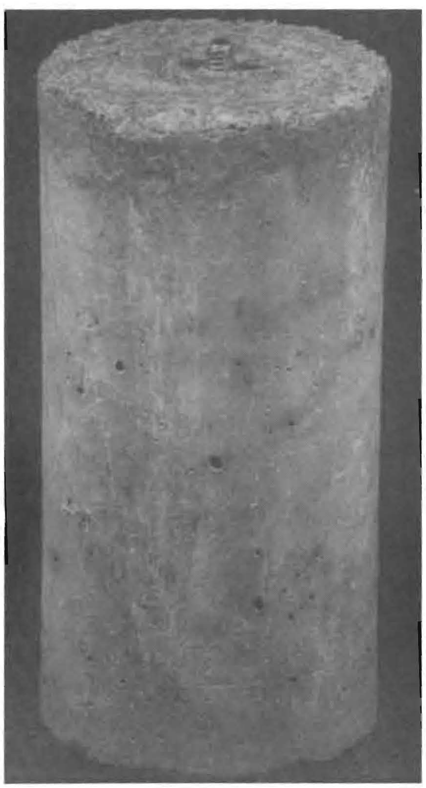
1f: Type I PC, 5.5 sack, 25% Type B fly ash, 210 days immersion.

1g: Type I PC, 5.5 sack, 35% Type B fly ash, 270 days immersion.

Photographs by Wayne Clampitt, D-10.

↓ TYPE A FLY ASH ↓

1d: Type II PC, 5.5 sack, 35% Type A fly ash, 180 immersion.



1h: Type I PC, 5.5 sack, 25% Type A fly ash, 270 immersion.

nism known as ionic diffusion which allows ions to move from areas of high concentration to areas of low concentration. Impermeable concrete can withstand sulfate attacks better because it can resist the intrusion of sulfate ions. Permeability is the least complicated approach and the most beneficial one to combat sulfate attack.

The four factors which are related to the permeability of concrete play a major role in the sulfate resistance of concrete. These factors are water/cement ratio, cementitious content, air content, and maturity of the concrete. Lower water/cement ratios, high cement content, a good air-entrained structure and properly cured concrete provide the concrete with a compact matrix of disconnected voids and reduce the presence of bleed water channels. The chloride ion permeability of concrete is reduced by low water/cement and fly ash ratios, longer moist curing times and through the use of heat curing.

Chemical Factors

The key to controlling sulfate attack in concrete is preventing the formation of ettringite. The components needed for this reaction are calcium hydroxide, reactive alumina, sulfate and water. From the results of Project 481, the most reliable indicator of the effect of fly ash on sulfate resistance of concrete containing a given cement was found to be the calcium oxide content of the fly ash. The effects, good or bad, of a particular fly ash on the sulfate resistance of concrete increase as the amount of fly ash increases in volumetric replacement from 25 to 45 percent.

Fly ash containing less than 10 percent calcium oxide (glassy phases) improved sulfate resistance in all concrete combinations tested. These low calcium oxide fly ashes, represented by Texas Type A, reduce the amount of calcium hydroxide available for expansive reactions in the hardened concrete. This is accomplished by binding the calcium in calcium silicate hydrate form. The long term formation of calcium silicate hydrate structure produces a cement paste with a more refined pore structure, thus preventing the diffusion of chloride ions. The consumption of calcium hydroxide during pozzolanic reactions also reduces the amount of leaching which may occur during wetting and drying cycles and reduces the damage associated with carbonation.

The use of high calcium oxide (greater than 20 percent) Type B fly ash eliminates or reduces the sulfate resistance of concrete. High calcium oxide fly ashes possess a higher dissolution rate than low calcium oxide ones and a higher alumina conversion rate. Rapid dissolution leads to the addition of calcium aluminates which leads to the formation of monosulfoaluminate and subsequently ettringite. Slow dissolution leads to the formation of calcium silicate hydrate. Proper air entrainment, extensive moist curing and reduced water content helped, but did not bring the performance up to the same level as similar cement without Type B fly ash.

Results from Study 481 showed that fly ashes containing more than 40 percent silica increased sulfate resistance. Also, fly ashes containing more than 70 percent bulk sum of metallic oxides ($SiO_2 + Fe_2O_3 + Al_2O_3$) were sulfate resistant.

CONCLUSIONS

1. The chemical and mineralogical composition of fly ash strongly influences the sulfate resistance of concrete. The calcium oxide content of the fly ash is the best indicator of the effect of fly ash on the sulfate resistance of concrete.
2. Texas SDHPT Type A or ASTM Class F low calcium oxide content fly ashes improve the sulfate resistance of concrete when used as a 25 to 45 percent replacement for Type I, II and 0 percent $Ca_3Al_20_6$ portland cement.
3. Texas SDHPT Type B or ASTM Class C high calcium oxide content fly ashes decrease the sulfate resistance of concrete when used as a 25 to 45 percent replacement for Type I, II, V and 0 percent $Ca_3Al_20_6$ portland cement.
4. Extended moist curing is not a reliable means for producing sul-

fate resistance in high calcium oxide fly ash concrete.

5. The addition of entrained air is not a reliable means for producing sulfate resistance in high calcium oxide fly ash concrete.
6. Minor changes in the water content of concrete do not significantly affect the sulfate resistant of fly ash concrete.
7. The effects of a particular fly ash on the sulfate resistance of concrete are amplified by increasing the amount of fly ash from 25 to 45 percent as a volumetric replacement for portland cement.
8. Conventional concrete exposed to low concentrations of sulfates may become susceptible to sulfate attack if high calcium oxide fly ash is introduced.
9. Fly ash reduces the permeability of concrete to chloride ions. Low calcium oxide fly ashes provide a greater reduction in chlorine ion permeability than high calcium oxide fly ashes.
10. At early ages, silica fume and blast furnace slag substantially reduce the permeability of concrete to chloride ions as compared to similar concrete with or without fly ash.
11. At later ages, low calcium oxide fly ash, silica fume and blast furnace slag are effective means of producing low permeability in concrete.

RECOMMENDATIONS

Based on the findings of Study 481, the researchers have offered several recommendations to improve the quality of concrete exposed to a sulfate environment.

1. Wherever a specific type portland cement is specified for the express purpose of providing sulfate resistant concrete, fly ashes conforming to Texas SDHPT Type A or ASTM Class F standards with a total calcium oxide content less than 10 percent can be used as a partial portland cement replacement to increase the sulfate resistance of the concrete.
2. Fly ashes containing greater than 10 percent calcium oxide conforming to the Texas SDHPT D-9-8900 (Type B) or ASTM C618-87 (Class C) standard specifications should not be used in concrete exposed to sulfate environments.
3. A new standard should be added to the existing fly ash specifications which specifies sulfate exposure testing of fly ashes with greater than 10 percent calcium oxide if the fly ash is to be used in concrete exposed to sulfates.

SOUNDS LIKE A SMOOT POINT TO US

"The Harvard Bridge, which links the Massachusetts Institute of Technology (MIT) with Boston, is 364.4 Smoots plus one ear long. A Smoot is 5 feet, 7 inches, the height of Oliver Reed Smoot Jr., whose body was used in place of a more conventional measuring unit when Lambda Chi Alpha pledges at MIT were ordered to determine the length of the bridge in 1958," reported a recent issue of the Los Angeles Times. As the pledges manhandled Smoot end-to-end like a ruler, they marked each length with chalk.

But the markings, which are maintained by pledges who twice a year have denoted 10-Smoot lengths with paint on the sidewalk, were threatened by a reconstruction project. Refusing to thumb its nose at tradition, however, the Metropolitan District Commission and the Department of Public Works decided the Smoot had "become part of the folklore" of the bridge. So the new sidewalk is scored at 5-foot, 7-inch intervals instead of the usual 6 feet to facilitate Smoot Mark painting.

A Smoot length was chosen, you may be wondering, because in 1958 he was the shortest of the 14 pledges, a fact recently revealed by Smoot at a ceremony for the new sidewalk.

from ***Public Works*** *120(Sept. 1989):11.*

THE 1990 4R CONFERENCE & ROAD SHOW™

Highway, road and bridge owners/managers, contractors and designers will find the money-saving tips they need to make highway dollars go farther at the Fourth Annual 4R CONFERENCE & ROAD SHOW, December 5 - 7 in San Antonio.

America's contractors, consulting engineers, designers and governmental/public works professionals have learned that reconstruction and maintenance of existing highways, roads and bridges has become the nation's <u>number one</u> transportation priority.

More than 120 speakers will provide over 62 hours of helpful and practical information and instruction on pavement maintenance, management, construction, drainage, surface treatments, work zone safety and more. "Technology Transfer" is the focal point of the Conference and ROAD SHOW - which will emphasize the "4Rs" of pavements: resurfacing, rehabilitation, reconstruction and restoration.

The 4R CONFERENCE & ROAD SHOW is specifically designed to met the need to transfer road and bridge reconstruction and maintenance technology to individuals in all segments of the market who are responsible for making it happen.

This conference is sponsored by the Gillette Exposition Group. For more information, including a complete list of the conference speakers, write: Janet Curry, 4R CONFERENCE & ROAD SHOW, 380 Northwest Highway, Des Plaines, IL 60016.

SPECIALLY STRESSED PAVEMENTS NEED SPECIAL ATTENTION, PART II

by M. Ameri-Gaznon, D. N. Little, and J. W. Button
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INTRODUCTION

The findings of Research Report 1172-1F, ***Avoiding Early Failure of Intersection Pavements*** [Ref. 1], indicate that existing technology can be used to design and construct pavements of adequate strength and stability to withstand the special stresses associated with intersection approaches. The full report recommends changes in existing materials specifications, laboratory test procedures, and asphalt mixture design methods in order to decrease the probability of premature failure of intersection pavements. It suggests that alternatives other than standard dense-graded asphalt mixtures should be considered for construction of intersection approach pavements because these standard mixtures are neither designed to withstand the special stresses applied at intersections, nor have they proved to be successful in intersection applications. Initial costs of implementing improved intersection designs will be significantly more than those encountered in normal practice. However, use of the improved designs and/or paving materials may show a significant cost savings during the designed service-life resulting from reduced spot maintenance and user costs associated with maintenance activities. This will be particularly true for high volume roadways.

The ***AASHTO Guide*** [Ref. 2] states, "The designer will need to concentrate on some aspects of design which are not always covered in detail in the ***Guide***." There is a need to analyze the horizontal shear forces unique to certain portions of pavement systems and develop design procedures, specifications and materials acceptance criteria which can be used to prolong pavement service life and reduce maintenance/rehabilitation activities in these specially stressed portions of pavement.

This article presents a rational approach for intersection mixture design to increase the probability of success. Results of this work may be implemented to provide adequate structures in other specially stressed segments of pavements such as bus terminals, steep vertical and horizontal curves and even airport runways and taxiways.

MOHR-COULOMB FAILURE THEORY

The application of the Mohr-Coulomb failure criterion is well documented in its application to soil mechanics. A simple way to approximate the envelope is to draw a straight line tangent to at least two Mohr's circles.

A failure envelope is defined by the Mohr-Coulomb equation:

$$\tau = C + \sigma_f \tan \phi \qquad (1)$$

where:

τ = shear strength, psi,
σ_f = normal stress at failure, psi
ϕ = angle of internal friction, and
C = inherent cohesive strength, psi.

The Mohr-Coulomb failure envelope is a simple and direct method of evaluating stability of ACP overlays and their potential to resist rapid deformation. For a particular mixture, conditions causing failure under any vertical principal (compressive) stress from the wheel load can be calculated from the geometry of the failure envelope. The equation representing the relationship between major and minor principal stresses at failure is as follows [Ref. 3]:

$$\sigma_1 = \sigma_3\left[\frac{1+\sin\phi}{1-\sin\phi}\right] + 2C\left[\frac{1+\sin\phi}{1-\sin\phi}\right]^{1/2} \qquad (2)$$

where:

σ_1, σ_3 = major and minor principal stresses,
ϕ = angle of internal friction, and
C = cohesion.

Equation (2) demonstrates that the maximum vertical stress that can be supported by an given material is influenced directly by lateral support, σ_3, cohesion, C, and angle of internal friction, ϕ.

OCTAHEDRAL STRESSES

Ameri-Gaznon and Little [Ref. 4] have performed a complete stress analysis of the surface course with and without the influence of horizontal surface shearing forces in combination with vertical load. They concluded that when shearing forces are applied in combination with the vertical load, the stress state is far more critical than that which has been assumed in conventional pavement design procedures. This demonstrates the importance of considering horizontal stresses in pavement design where intersections are concerned. Their findings indicate that shearing stress has a more logical meaning in the study of stress state in a pavement than a vertical compressive surface load. This is true because, unlike vertical compressive stress, which is practically independent of the surface thickness, shearing stress distribution varies significantly with variation in the surface thickness. Moreover, plastic deformation is a shear failure and is a direct function of the triaxial stress field induced under applied loads. The critical normal and shear stresses on the octahedral plane will depict the complete stress field and can be simply expressed in terms of stress invariants as follows:

$$\sigma_{oct} = 1/3 \; I_1 \qquad (3)$$

$$\tau_{oct} = 1/3 \; (2I_1^2 - 6I_2)^{1/2} \qquad (4)$$

where:

$$I_1 = \sigma_x + \sigma_y + \sigma_z$$

$$I_2 = \sigma_x\sigma_y + \sigma_y\sigma_z + \sigma_z\sigma_x - (\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)$$

Quantities I_1 and I_2 are stress invariants because they are independent of how the coordinate axes are oriented in a given stress state. Furthermore, expressing octahedral normal and shearing stresses in terms of invariants does not require computation of principal stresses in order to determine normal and shear stresses on the octahedral plane.

DESIGN CONSIDERATIONS

In contrast to the current empirical pavement design procedures where one is unable to determine if a paving mixture of specific strength parameters is capable of sustaining vertical and horizontal loads of varying magnitude, implementation of the mechanistic design methods provide a rational approach to design of pavement sections capable of withstanding high tire pressures in addition to horizontal forces produced at the surface. Furthermore, application of these methods, due to their sound theoretical background warrants that detrimental shear stresses induced in the surface layer under any pavement boundary and environmental conditions will not exceed the bearing capacity of the mix.

The octahedral shear stress ratio concept can be used to evaluate the potential of an asphalt concrete overlay, over either existing asphalt concrete or portland cement concrete, to rut or deform under traffic. This ratio is based on the principle of octahedral shear stress which is a scaler or numerical representation of the stress state at any point within the pavement cross section. This scaler quantity is calculated from the three normal and six shearing stresses acting at a given point within the pavement. Since materials fail in different modes based on the conditions of loading and temperature, and since a number of failure criteria exist, selecting the proper failure mode and criterion by which to judge failure potential is of great importance. It makes sense that the potential to deform, shove or rut in an asphalt concrete pavement at an intersection should be evaluated based on a shearing failure criterion. The authors believe that the octahedral shear stress is the most appropriate way to evaluate the asphalt concrete deformation potential.

When the octahedral shear stress ratio (OSR) is high, the potential to deform excessively is high. When the OSR is low, the potential to deform is low. Theoretically, an OSR equal to unity represents incipient failure. However, research has shown that conditions favoring excessive deformation can result at OSR's of 0.65 in highways subjected to normal loading conditions. Although it is not possible, at present, to identify on OSR which represents a selected quantification of deformation, the OSR is an excellent way to compare various mixtures of asphalt concrete as to their relative potential to resist permanent deformation in specific structural and climatic categories.

CALCULATION OF OCTAHEDRAL SHEAR STRESS RATIO

The following example is presented strictly as a guide to assist the user of this method with stepwise calculation of the octahedral shear stress ratio (OSR).

Stress analysis of a pavement section is performed using Modified ILLIPAVE finite element computer program. However, researchers at Texas Transportation Institute (TTI) have recently developed an interactive finite element computer program (TTI-PAVE) which includes a provision to accommodate horizontal surface force in combination with the vertical load at the surface.

Any appropriate computer program may be used to perform stress analysis of pavement structure to obtain required information needed for calculation of octahedral shear stress ratio (OSR). After obtaining the stresses induced in the pavement due to application of loads at the surface, equations (3) and (4) can be used to calculate octahedral normal stress and octahedral shear stress, respectively. Since the level and position of octahedral shear stress varies, depending upon pavement geometry, loading, and boundary conditions, it is advisable to calculate these values at several points within the pavement under and away from the wheel load centerline at different pavement depths.

Once the above task is performed, the octahedral shear strength of the paving mixture is obtained using the methodology outlined in this report.

The steps follow:

1. Determine C (cohesion) and the ϕ (angle of internal friction) from at least two triaxial shear tests or (1) an unconfined compression test and (2) a confined compression test with confining pressure that best simulates field conditions. These parameters should be obtained at the temperature and the loading rate that best simulate field conditions.
2. Determine σ_1 values concomitant with assumed σ_3 values using equation (2) or construct Mohr-Coulomb failure envelop using the C and the ϕ parameters determined in step 1.
3. Compute octahedral normal and shear stresses corresponding to failure condition of Mohr-Coulomb envelope obtained in step 2 as follows:

$$\sigma_{octi} = 1/3\ (\sigma_{1i} + 2\sigma_{3i})$$

$$\tau_{octi} = 0.471\ (\sigma_{1i} + \sigma_{3i})$$

4. Construct octahedral failure envelope from σ_{octi} and τ_{octi} values computed in step 3 (Fig. 1).
5. Measure C ' and ϕ ' (octahedral cohesion and octahedral frictional angle parameters), respectively (Fig. 1).
6. Using these parameters (from step 5) and the normal octahedral stress value obtained from computer output (results) corresponding to the maximum octahedral shear stress induced, the octahedral shear strength of the mixture is then calculated using equation (5) as follows:

$$(\tau_{oct})_{critical} = C' + \sigma_{oct} \tan\phi' \qquad (5)$$

7. The octahedral shear stress ratio (OSR) is thus, $\tau_{oct}/(\tau_{oct})_{critical}$, where τ_{oct} is the induced maximum octahedral shear stress within the pavement, and $(\tau_{oct})_{critical}$ is the maximum octahedral shear strength as computed in step 6.

SAMPLE CALCULATION

Assume a paving mixture of asphalt concrete surface layer that is extruded from the pavement will yield a cohesive strength of 90 psi and an angle of internal friction of 35° in a triaxial shear test 3.

1. Construct Mohr-Coulomb failure envelope for the C and the σ values assumed above.
2. For any Mohr's circle tangent to the Mohr-Coulomb failure envelope, the octahedral normal stress and the corresponding octahedral shear stress at failure is calculated as follows (Fig. 1):

$$(\sigma_{octi})_{failure} = 1/3\,(\sigma_{1i} + 2\sigma_{3i})$$

$$(\tau_{octi})_{failure} = 0.471\,(\sigma_1 - \sigma_3)$$

3. Connect the locus of all points representing octahedral normal and shear stresses at failure (from step 2) to obtain octahedral failure envelope (Fig. 1).
4. From the octahedral failure envelope (step 3), measure C ' and ϕ '. (In this example, C ' = 85 psi and ϕ ' = 33.) Using equation (5), octahedral shear strength is calculated as follows:

$$(\tau_{oct}) = 85 + \sigma_{oct}\tan(33°)$$

In the above expression, σ_{oct} corresponds to the induced $(\tau_{oct})_{max}$ obtained from the analytical stress analysis of the pavement, using Modified ILLIPAVE computer program.

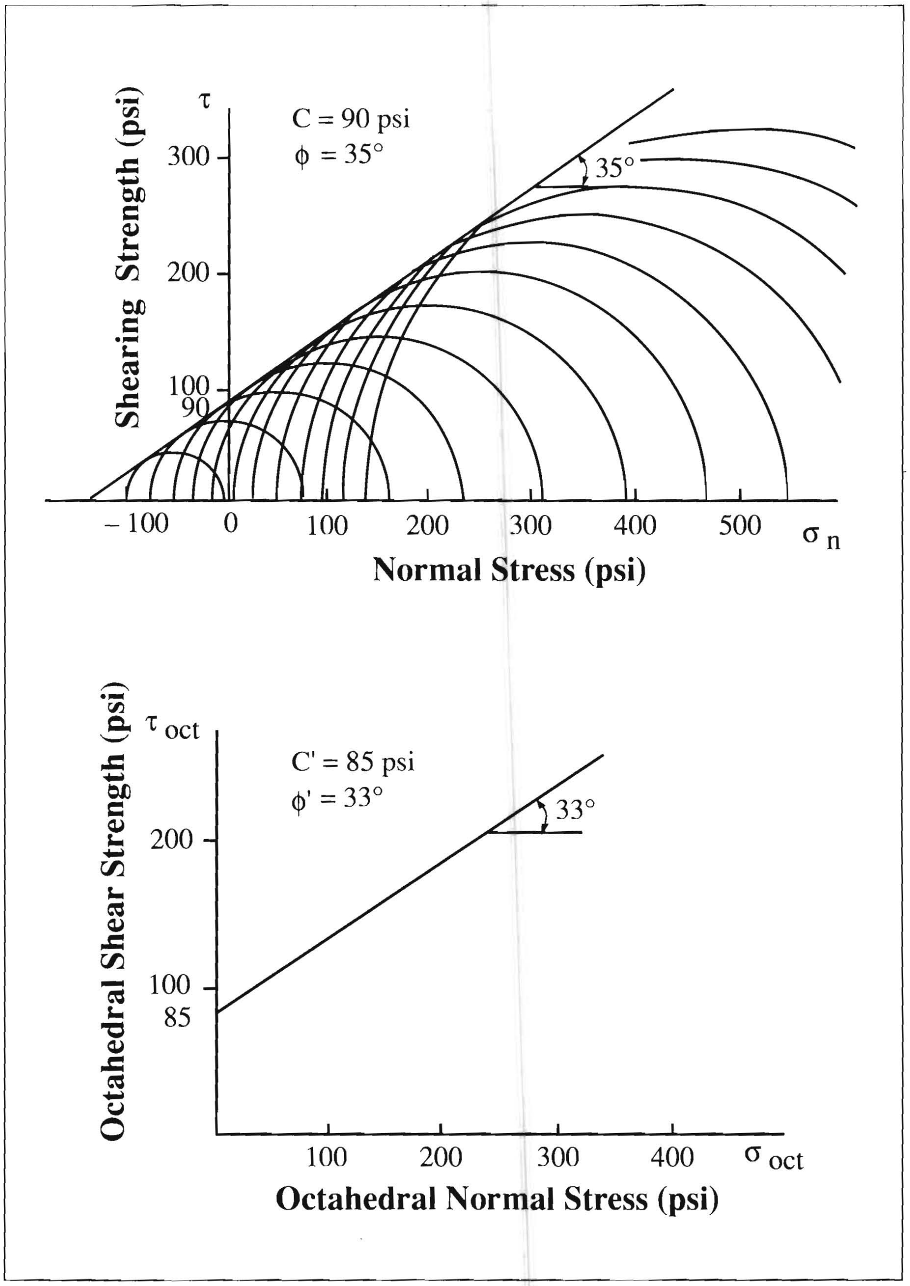

FIGURE 1: Typical octahedral failure envelope developed from Mohr-Coulomb failure envelope (After Reference 4).

TABLE 1: Sample calculations for a given 4-inch asphalt concrete pavement surface layer having a modulus of 100 ksi or 500 ksi.

Modulus of Asphalt Concrete Surface, ksi	Complete slippage between the surface layer and the base layer				Full friction between the surface layer and the base layer			
	No surface shear		*With surface shear*		*No surface shear*		*With surface shear*	
	σ_{oct}	τ_{oct}	σ_{oct}	τ_{oct}	σ_{oct}	τ_{oct}	σ_{oct}	τ_{oct}
100	37	49	69	100	58	29	115	68
500	29	54	47	104	62	24	71	63

For a 4-inch overlay with resilient modulus of 100 ksi and 500 ksi, respectively, over an 8-inch portland cement concrete (PCC) base layer with modulus of 3000 ksi resting on a clay subgrade with reactive modulus of 7500 psi, the induced critical octahedral normal and shear stresses are found for two pavement boundary conditions and are tabulated in Table 1.

5. Using equation (5) (step 4) with σ_{oct} from Table 1 for complete slippage without surface shear,

$$(\tau_{oct})_{critical} = 85 + (37)\tan(33) = 109$$

6. The octahedral shear stress ratio is then calculated as follows:

$$OSR = \frac{49}{109} = 0.449$$

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1. Ameri-Gaznon, M., Joe W. Button, D. Perdomo, D. N. Little, D. G. Zollinger. ***Avoiding Early Failure of Intersection Pavements***, Research Report 1172-1F. College Station: Texas Transportation Institute, Texas A&M University, November 1989.
2. American Association of State Highway and Transportation Officials. ***AASHTO Guide for Design for Pavement Structures.*** Washington, D.C.: AASHTO, 1986.
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4. Ameri-Gaznon, M., and D. N. Little. "Permanent Deformation Potential in Asphalt Concrete Overlays Over Portland Cement Concrete Pavements," FHWA/TX-88/452-3F. College Station: TTI, Texas A&M University, November 1988.

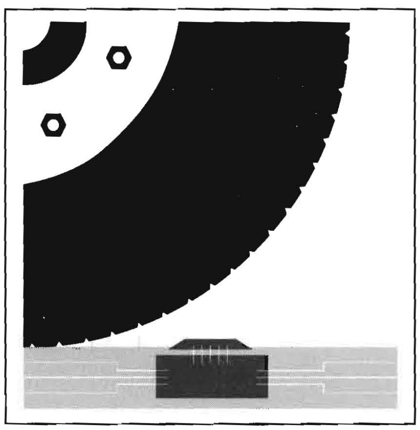
TRAFFIC DATA ACQUISTIONS TECHNOLOGIES CONFERENCE A GREAT SUCCESS

During the National Traffic Data Acquisition Technologies Conference (NTDATC) held in Austin, Texas, on August 26-30, more than 275 participants viewed 18 demonstration installations of international state-of-the-art data collection equipment making this two-mile loop on the Texas highway system the most comprehensive working display of traffic and truckweight data collection equipment in the world.

The participants, wearing Day-Glo caps and safety vests, were shuttled from each installation site by bus to view the latest in weigh-in-motion (WIM) piezoelectric, capacitance, bending plate and infrared technologies, as well as various traffic classifiers, under actual working conditions. Some specialized systems with law enforcement applications were also shown.

"The coordination with two district offices allowed us to provide sufficient safety measures for letting this many people out on the roadway at one time. Of course, the travelling public would have had a hard time missing those 275 orange caps," said Mr. Rick Norwood, Field Trip Conference Coordinator, Texas State Department of Highways and Public Transportation (TSDHPT).

The field trip demonstration consisted of the following installations in the order of their location.



Toledo Scale of Worthington, Ohio, featured the BridgeMATE, a portable, battery-operated strain transducer WIM system, that is mounted to the underside of a bridge and uses the bridge itself as a scale. It is virtually undetectable from the bridge deck, can weigh accurately at highway speeds and can collect data without an operator.

Golden River Instruments of Bethesda, Maryland, demonstrated their Marksman 600 with a new type of aluminum alloy capacitance WIM strip for semiportable and permanent systems. The capacitance strip has a design life of 10 years, is flush to the road, is not affected by lateral forces, and was installed at the site location in under four hours. Golden River also displayed their WIM portable capacitive pad.

PAT Equipment Corporation of Chambersburg, Pennsylvania, had onsite a PAT DAW200 portable electronic WIM and permanent bending plate WIM sensors, along with a piezo film C100S Permanent Classifier. The PAT DAW300, a portable low-speed WIM system, was also demonstrated, as well as two types of low-profile, lightweight wheel-load weighers with digital readouts.

AVIAR, Inc., of Austin, Texas, installed a Truvelo Traffic Data Logger-500 which is a portable or permanent, self-contained, battery-powered capacitance mat WIM system. They also demonstrated their M4 MPC, a permanent or portable traffic law enforcement camera system for speed and/or red light violations. This system, based on piezoelectric coaxial cables for traffic sensing, has been used successfully in West Germany for 10 years.

An existing TSDHPT permanent WIM site which contains a load-cell plate WIM built by Radian Corporation was demonstrated.

Also at this site, Dr. Clyde Lee of the Center for Transportation Research at the University of Texas displayed his current WIM project, sponsored by the TSDHPT, which uses an application of modulated infrared light sensors for counting, classifying and measuring the speed of the vehicle.

Saratec of Mundelein, Illinois, had demonstrations of four items on the roadway: the Saratec 241 StreeterAmet Classifier, the Saratec GK Piezoelectric WIM, the Saratec Weighwrite Piezoelectric WIM and the Saratec 5150 XT, a van-supported, portable mat WIM. The 5150 XT is a high-speed WIM system fully compatible with IBM PCs.

International Road Dynamics (IRD) of Marlboro, Massachusetts, and Saskatoon, Canada, presented an IRD DD200 low-profile, bending plate WIM scale suitable for all speed applications, a piezoelectric WIM system for continuous unmanned data collection, a Dynax[tm] permanent dynamic axle sensor and an IRD TC/C 500 series traffic counter and classifier. All of the foregoing IRD equipment is compatible and integrative.

Motorola of Cupertino, California, was tied into the IRD units demonstrating their MultiPersonal computers' interfacing and networking abilities, capabilities in communications with mainframes and skill in manipulating raw data to produce meaningful information.

Trevor Deakin Consultants, LTD, Trowbridge, Wiltshire, England, had planned to demonstrate a portable, low-profile static vehicle-weighing system based on infrared and radio signals; however, the equipment was damaged during transport from England.

The field trip, along with the lectures from people around the world involved in traffic data acquisition technologies, and the products displayed made this an exciting technology transfer opportunity.

The conference was sponsored by the American Society for Testing and Materials, Texas A & M University, University of Texas and the Federal Highway Administration and hosted by the TSDHPT.

To obtain a copy of the proceedings or additional information, please contact Ms. Cindy King, Technology Transfer Manager, Transportation Planning Division, D-10 Research, TSDHPT, P.O. Box 5051, Austin TX 78763-5051. Photographs are available on request.

LEGISLATION AND ALTERNATIVE FUELS

(Continued from page 5)

[Ref. 1]. These states are Connecticut, Maine, Massachusetts, New Jersey, New York, Rhode Island and Vermont [Ref. 1]. Gasohol will be permitted to have a RVP which is 1 psi higher than gasoline or gasoline blended with other fuel substitutes on condition that retail outlets and wholesale purchaser-consumer facilities must indicate that ethanol is being sold, and its percentage of concentration must be specified [Ref. 1].

ENVIRONMENTAL PROTECTION AGENCY (EPA) REGULATIONS

Fuel Waivers

EPA has issued a substantial number of fuel waivers for oxygenated fuels, especially before 1988 [Ref. 1]. The gasohol waiver was issued in 1979. In 1981, gasoline was permitted to contain the following oxygenated fuels: methanol, propyl alcohol, butyl alcohol, MTBE, tertiary amyl methyl ether and isopropyl ether [Ref. 1]. These oxygenated fuels have prescribed limits by volume to qualify for the waiver. Grade tertiary butyl alcohol (GTBA) was allowed in gasoline in 1981, too. The 1985 DuPont Waiver allowed the use of corrosion inhibitors along with oxygenated fuels. MTBE was allowed in gasohol in September 1988 [Ref. 1].

Methanol Emission Regulations

On 23 February 1989, EPA announced emission certification standards for methanol-fueled vehicles which include passenger cars, light trucks, heavy duty vehicles and motorcycles in 1991 [Ref. 1]. These regulations took effect on 12 June 1989 [Ref. 1]. The difference between methanol emission standards and regular emission standards concerns organic emissions which are the unburned and partially burned fuel in vehicle exhaust and evaporative emissions. Information on these standards are as follows [Ref. 1]: for cars and light duty trucks using spark plugs, carbon monoxide emission limits — 3.4 grams/mile and nitrogen oxide emission limits — 1.0 gram/mile; for spark-plug-ignited heavy duty vehicles weighing 14,000 pounds or less, hydrocarbon emission limit of 1.1 grams per break horsepower-hour; for spark-plug-ignited heavy duty vehicles weighing more than 14,000 pounds, hydrocarbon emission limit of 1.9 grams per break horsepower-hour.

INTERNAL REVENUE SERVICE TAX CREDITS

The IRS allows a federal tax credit (26 USC, Sec. 40) for gasohol. The value of this tax credit is 60 cents per gallon [Ref. 1]. The IRS is planning to extend this tax credit to the ethanol-derived octane additive known as ETBE [Ref. 1]. Only "qualified" mixtures are allowed this tax credit. President Bush and the Energy Secretary have stated their support for this move, but there is significant opposition. The gasohol exemption itself has caused a significant drop in revenue for the Highway Trust Fund to the tune of $500 million annually [Ref. 4]. The current tax credit will expire in September 1993. If a proposed law to extend this exemption to the year 2000 is passed, the losses would be much higher.

TEXAS LEGISLATION

There are two important bills which directly relate to alternative fuels in Texas, Senate Bill 740 (71st Leg., Ch. 1189, effective 28 August 1989) and Senate Bill 769 (71st Leg., Ch. 1190, effective 28 August 1989). Other legislation, already in place, also applies to alternative fuel use.

Senate Bill 740 (Alternative Fuels Program)

This bill was signed on 16 June 1989. It was created to promote the use of natural gas and other alternative fuels in Texas. The key provisions (*Education Code,* Sec. 21.174) of this bill are:

(a) School districts with more than 50 buses, state agencies with more than 15 vehicles and metropolitan transit authorities may not purchase or lease after 1 September 1991 any vehicle that is not capable of using compressed natural gas or other alternative fuel that reduces harmful emissions.

(b) The affected entities should have replaced at least 30 percent of their fleet with alternative-fueled vehicles by 1 September 1994, and at least 50 percent by 1 September 1996. If the Texas Air Control Board determines that the program has been effective in reducing total annual emissions, a 90 percent replacement target will be set by 1 September 1998.

(c) The affected entities may acquire the necessary equipment or refueling facilities for alternative fuels use by purchase or lease; by gift or loan; or by gift or loan pursuant to a service contract for the supply of fuel.

(d) The State Purchasing and General Services Commission (SPAGS) is permitted to encourage and facilitate the conversion and use of state vehicles that are capable of using alternative fuels, especially compressed natural gas. SPAGS is permitted to establish centralized refueling stations throughout the state, operate regional conversion and repair facilities and provide all services and support to expedite the use of compressed natural gas or other alternative fuels by state agencies and school districts. SPAGS has the authority to grant waivers.

Senate Bill 769 (Clean Air Act Amendments)

This bill strengthens the ability of the Texas Air Control Board to improve the quality of Texas air by enforcing the use of natural gas or other alternative fuels. The key provisions (*Health and Safety Code,* Sec. 382.019) are:

(a) Rapid transit authorities in metropolitan statistical areas with a minimum population of 350,000 or not in compliance with federal ambient air quality standards should have replaced at least 30 percent of their fleet with alternative-fueled vehicles by 1 September 1994, and at least 50 percent by 1 September 1996. If the Texas Air Control Board determines by 31 December 1996 that the program has been effective in reducing total annual emissions, a 90 percent replacement target will be set by 1 September 1998.

(b) If the above program is successful by 1996, then local government fleets of more than 15 vehicles (excluding law enforcement and emergency vehicles) and private fleets with more than 25 vehicles (excluding emergency vehicles) in nonattainment areas must ensure that at least 30 percent of their vehicles are capable of running on compressed natural gas or other alternative fuels by 1 September 1998; at least 50 percent by 1 September 2000; and at least 90 percent by 1 September 2002.

Liquefied Gas Tax Decal

Liquefied gas is taxed at the same rate as gasoline and diesel fuel: 15 cents a gallon, but this tax is not collected at the pump. Users buy a tax decal based on vehicle weight and mileage traveled. These decals will cost less beginning 1 September 1989. The current high-mileage category will be 15,000 miles and higher, instead of the present 10,000 miles and more; and the current rates will be lowered.

TAXING FUEL CONSUMPTION

Taxes on fuel consumption, especially fossil fuels, have been suggested as away to encourage the use of alternative fuels. It has been predicted that within the next half century, many industrial nations would derive one-fifth of their revenues from such taxes and pollution charges [Ref. 1]. An EEC proposal suggests a "carbon" tax on the carbon dioxide emitted when fossil fuels are burned [Ref. 1]. The revenues from this tax would be used to substitute timber revenue in third-world countries in attempt to prevent the destruction of their natural forests.

A precedent of sorts has been set in the United States. Starting on 1 January 1990 American companies will pay as much as $1.37 for each pound of chlorofluorocarbons (CFCs) they use in a bid to discourage the use of CFCs by making them more expensive [Ref. 1]. This "user fee" will also be an additional source of revenue for the government at the expense of the particular company's profits. This tax is assumed to be a forerunner for future taxes on carbon dioxide emissions.

THE KEY FACTOR: CONSUMER ACCEPTANCE

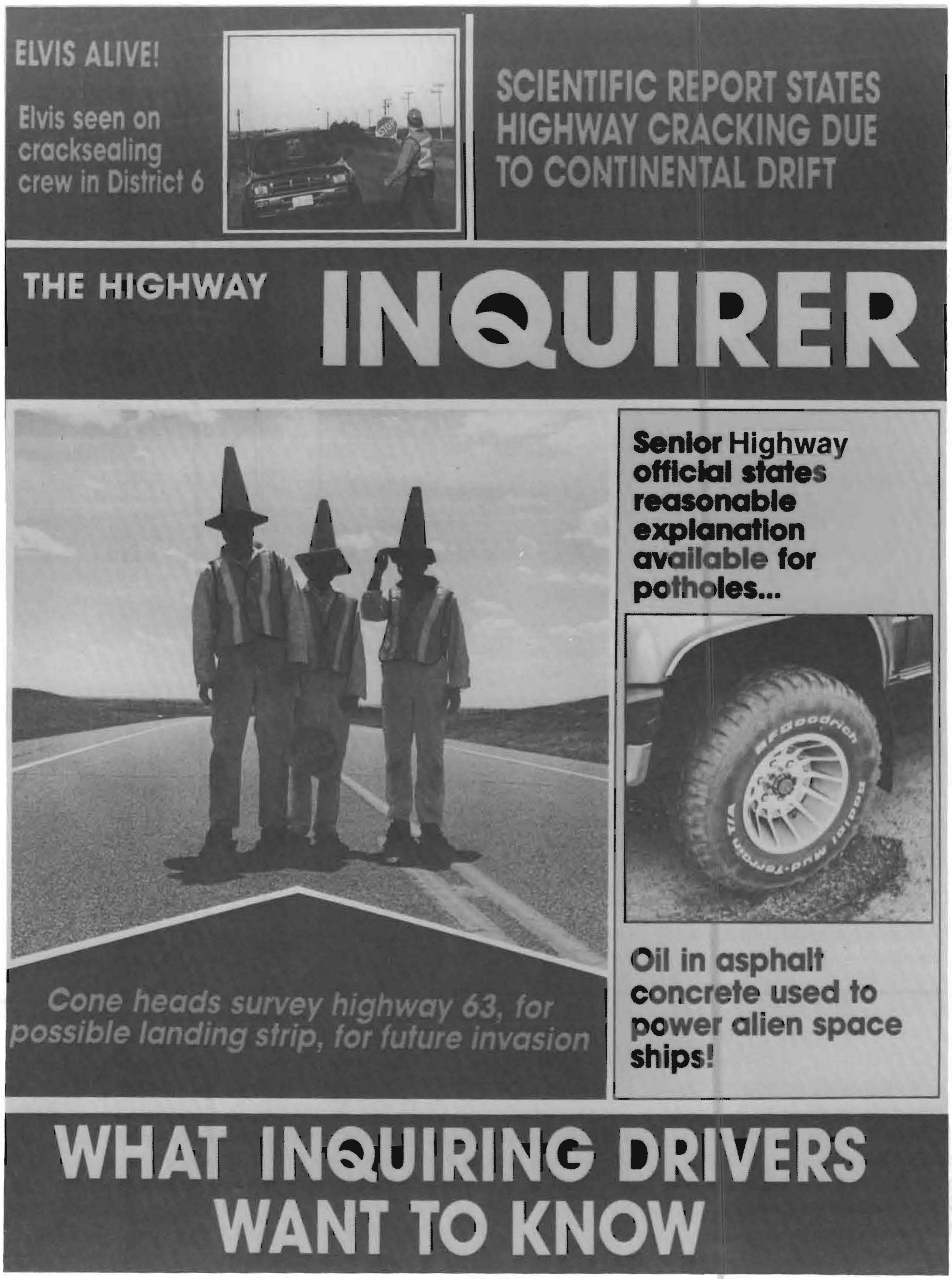
Although much can be said about government enforcement, the final and, possibly, the key link in the chain is the consumer. Consumer acceptance will be important for the success of the alternative fuels program. The government and industry has to place a lot of emphasis on consumer satisfaction in propagating the use of alternative fuels. Some of the factors that will influence the consumer acceptance of alternative fuel vehicles are model availability, vehicle performance, vehicle range, vehicle costs, fuel costs and fuel availability. As stated earlier, government legislation will force each consumer to switch, but consumer acceptance of the product will accelerate the process and cause less problems in the long run. No consumer would like to be coerced into changing vehicles at substantial expense. The livelihood of car manufacturers and automobile dealers, especially small ones, depend upon the success of this alternative fuels program. The unpopularity of alternative fuel vehicles will force automobile dealers to bear the costs of idle inventory and financing expenses.

The best possible approach to the problem would be a joint cooperative effort between the government and the private sector. Market forces provide the consumer with the best products and have a better idea what the consumer wants. A total government effort without any input from the private sector would not be advisable.

CONCLUSION

The primary motivation behind the alternative fuels program is environ-

A SHORT COURSE SPECIAL FEATURE?



*from Alberta Transportation and Utilities' **TRANSEARCH** 2(August 1990):7.*

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mental concerns. Alternative fuels are not the only method to combat the problem. We could find ways to reduce traffic congestion on the roads or, in other words, the reduction of mobile sources of pollution. Carpooling and vanpooling are good methods in that respect. Increased use of public transportation and better maintenance of vehicles are also effective methods. That is the argument used by a number of opponents to the enforcement of alternative fuel programs. Another important point here is that automobiles maybe a significant source of pollution, but they are not the only one. The industrial sector also has to share the burden of the clean air task. The use of alternative fuels does help reduce pollution, but it cannot be expected to solve the problem by itself.

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NHI ADMIXTURES SEMINARS OFFERED

The Materials and Tests Division (D-9), in conjunction with the Research Section of the Transportation Planning Division (D-10R), and FHWA Region 6 are sponsoring 2 one-day concrete admixture seminars (Demonstration Project No. 75, "Field Management of Concrete Mixes — Admixture Seminars") in Texas. The subjects for discussion are: 1) Superplasticizers [High Range Water Reducers]; 2) Accelerators and Retarders; 3) Fly Ash; and 4) Air Entraining Agents.

The seminars will be of interest to materials, construction and bridge engineers from Region 6 State and Federal Highways Administration offices. Space permitting, consultants providing services to the SDHPT are also encouraged to attend.

The seminars are scheduled as follows:

LOCATION	***DATE***	***TIME***
Arlington, Texas	Tuesday, 29 January 1991	8:00 a.m. to 5:00 p.m.
San Antonio, Texas	Thursday, 31 January 1991	1:00 p.m. to 5:00 p.m.
	Friday, 1 February 1991	8:00 a.m. to 12:00 noon

For more information, contact the local coordinator, Mr. Gerald Lankes, Concrete Engineer, (D-9), (512) 465-7331, TEX-AN 241-7331.

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FRENCH MAINTENANCE STRATEGY

French maintenance strategy is largely built around the chip seal surface treatment. In the 1970's, the French government began a major research program to investigate the adhesion and permeability qualities of this very thin layer technique.

They hoped that the technique could be extended to the maintenance of pavements carrying heavy traffic and to the application of new and upgraded wearing courses.

Today, more than 300 million sq. meters of chip seal surface treatments are applied every year in France, and about 1/4 of the nation's road system has been treated. The binders used are modified asphalts, or rubber asphalts containing little solvent, and the quantity applied may be double that which is used in the traditional technique.

An important social and economic benefit has been the reduction in the number and severity of accidents. On wet pavements, the number of accidents has been reduced by 78 percent after surface treatment, and the severity, expressed in financial cost, has decreased 62 percent.

Slurry seals are used also. A new design using completely crushed aggregate almost 1/2" in size is being used and almost one-third of the nation's rural roads surfaced this way.

*As seen in **Update** 32(1989):30, excerpted from **Roads & Bridges** (March 1989).*