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TECHNICAL QUARTERLY

An Exchange of Ideas
Editor:
Kathleen M. Jones

REUSABLE GUARDRAIL END TREATMENT

by Mohanan Achen and Kathleen Jones based on ***Development of New Guardrail End Treatments (FHWA/TX-89/404-1F)*** *by Dean L. Sicking, Asif B. Qureshy, Roger P. Bligh, Hayes Ross, Jr., and C. E. Buth*

BACKGROUND

Research Objectives

Designing a terminal end for strong post W-beams barriers that is safe for subcompact automobiles and still affordable is a complex task. Research Study 404, ***New Guardrail End Treatment***, undertaken by the Texas Transportation Institute (TTI) for the Texas State Department of Highways and Public Transportation (SDHPT) set out to develop a guardrail end terminal that would fulfill current safety criteria and yet be economical enough for routine use (Fig. 1). The primary objectives for the new design were: to meet nationally recognized safety standards; to be inexpensive to install and maintain; to perform safely when installed on a tangent section of guardrail; to provide attenuation of head-on collisions; and to be simple to construct.

Existing Guardrail Designs

One important consideration in the design of a suitable guardrail end treatment is softening the hard point associated with the end of a longitudinal guardrail, particularly to prevent spearing the vehicle with the barrier end. In the late 1960's to solve the spearing problem, SDHPT engineers decided to twist the guardrail end and slope it into the ground. This design was known as the Texas Twist. While it did solve the spearing problem, crash test data has shown that vaulting is a potential result when a vehicle hits a barrier end like this outside the normally expected impact conditions.

FIG. 1: First installation of Study 404 guardrail end, Austin, IH-35, 21 June 1990.

To try to prevent both spearing and vaulting at the barrier end, a new "floppy end" design was introduced. This was a sloped guardrail end treatment that would be pushed down by impacting vehicles. It worked well in crash tests, but was difficult to install and posed maintenance problems because roadside mowers knocked these "floppy ends" down frequently. Since no effective way of

INSIDE...

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FIG. 2a: Extruder and modified cable anchor (Dst. 14).

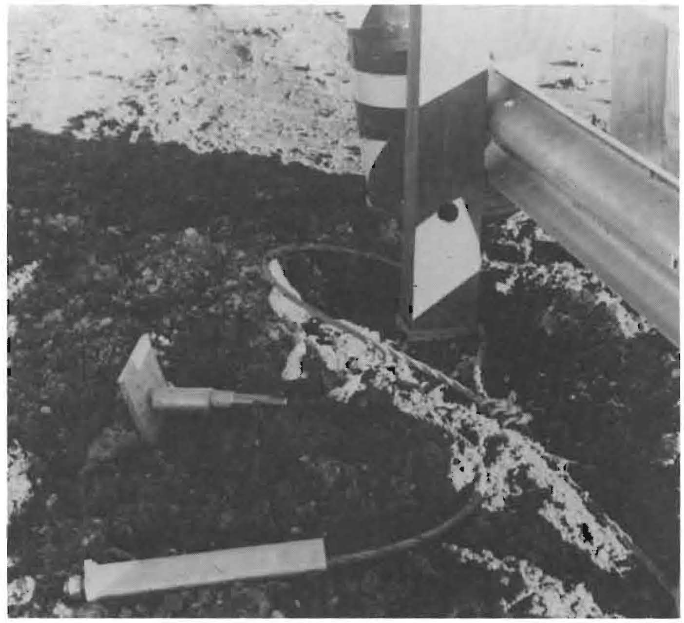

FIG. 2b: Detail of anchor installation (Dst. 8).

solving the maintenance problem was identified and since the potential for impacting this point under field conditions is low, the original turned down end design was kept.

The breakaway cable terminal (BCT) is another guardrail end treatment that has gained acceptance in other states. It relies on dynamic buckling of a flared section of guardrail to slow impacting vehicles. Unfortunately, even minor variation of the flare rate from the design standard greatly reduces this end treatment's effectiveness, making it a problem to install correctly. Another problem is that the BCT system decelerates subcompact cars with unacceptably high force. Eccentric loader breakaway cable terminals (ELBCT), a variation of the BCT design currently under examination, acceptably decelerate small cars; however, they are as sensitive to flare rate variation as standard BCTs and more expensive.

The Sentre and Vehicle Attenuator Terminal (VAT) end treatments are proprietary guardrail terminals that have been introduced recently. Even though they meet nationally recognized safety standards, the proprietary nature and complexity of the designs, along with future maintenance costs in time and materials, make these units too expensive for general use.

In short, designers have a limited choice of economical guardrail end treatment systems with adequate safety performance available for routine use. TTI, along with SDHPT, has been working for more than five years on this problem. The guardrail extruder terminal design is a positive step in that direction.

GUARDRAIL EXTRUDER TERMINAL (GET)

Design

The GET design softens the end hard point of a longitudinal guardrail element by placing a 258-pound extruder and a modified cable anchor at the end of a straight W-beam guardrail section (Fig. 2). The first post is set in concrete so it will shear quickly on impact. When a vehicle hits a GET head-on, the impact energy is absorbed as the W-beam is fed through the extruder which alters the rail shape from a W-section to a flattened plate section. The flattened rail is curled and exits the extruder in a semicircular arc away from the front of the vehicle and behind the guardrail. Enough energy is absorbed by this plastic deformation to decelerate a vehicle uniformly and safely.

Internally, the extruder consists of two sections: a "squeezer" and a

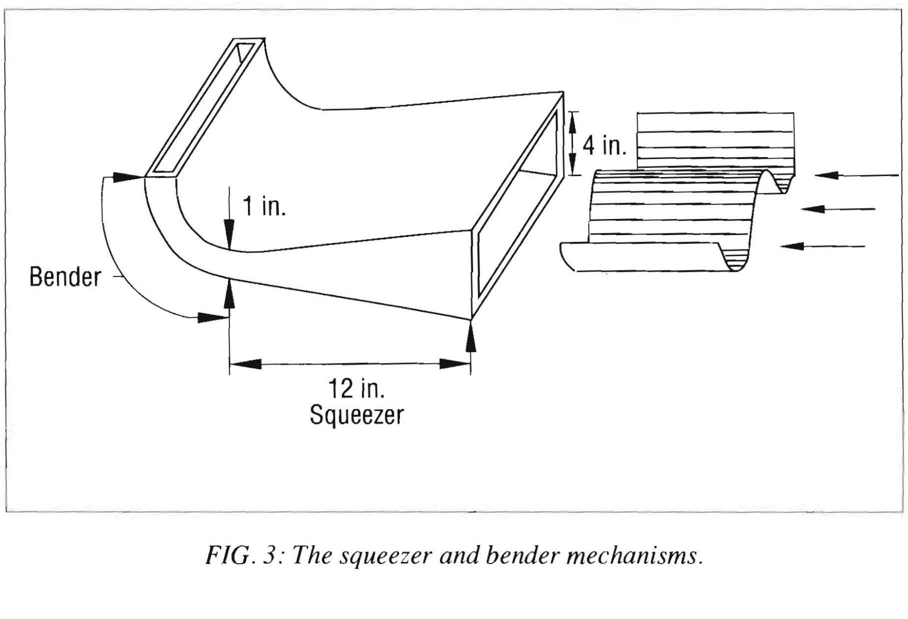

FIG. 3: The squeezer and bender mechanisms.

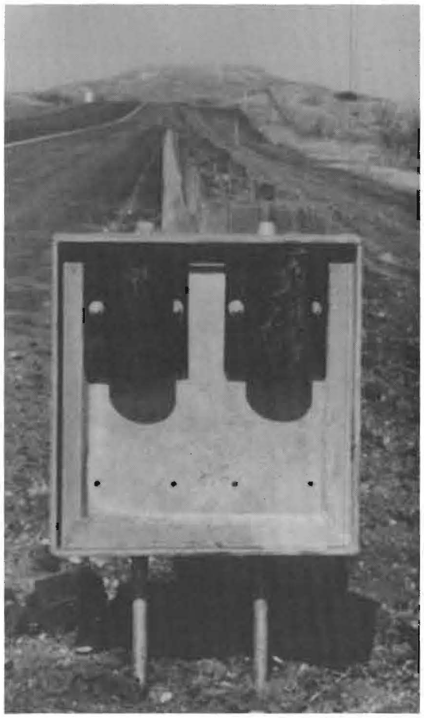

FIG. 4: Front bumpers.

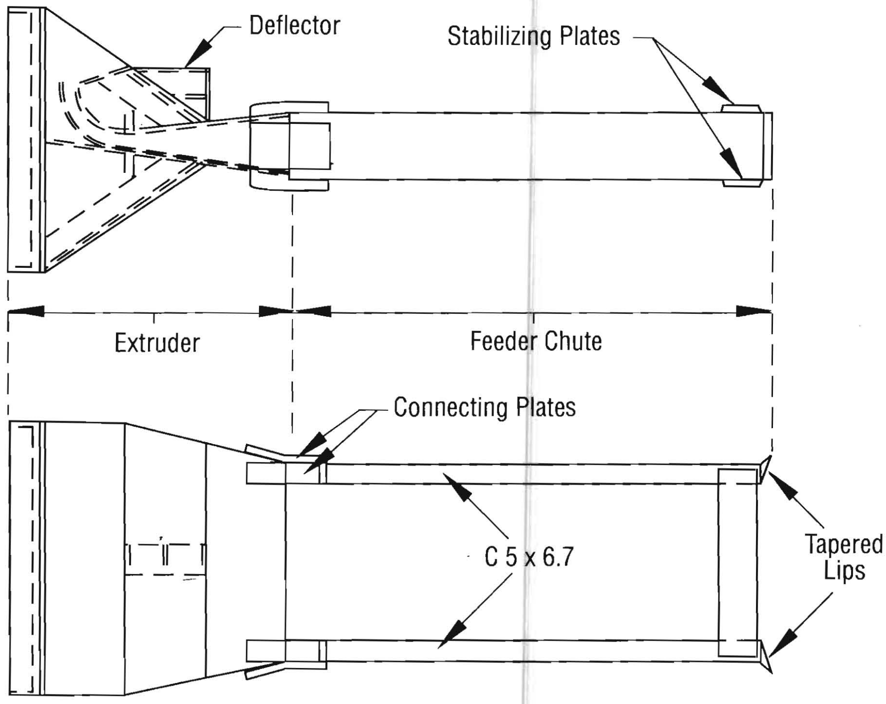

FIG. 5: Extended feeder chute attachment.

"bender" (Fig. 3). Static load-deflection testing showed a force of approximately 11,000 pounds is required to extrude 12 gauge W-beam from the 1 foot long squeezer section. Not only does flattening the W-beam dissipate energy, but also the W-beam's bending strength is reduced severely. The bender section bends the relatively flat W-beam around a small radius and directs it away from an impacting vehicle.

Externally, the extruder has two cylindrical rubber bumpers (Fig. 4) on the front that maintain the vehicle-bumper-to-extruder contact while reducing the eccentric pitch load. It also has a 3-foot feeder chute (Fig. 5) which consists of two longitudinal steel channels that are held together by two vertical steel stabilizer plates (Fig. 6). These steel channels are tapered at the ends. This feeder chute helps resist bending moments. A post deflector is located to the side, where the extruder head necks into the feed chute, to counter the lateral load placed on it by the first post shearing.

The GET system uses a quick releasing cable attachment to allow the W-beam to feed into the extruder during frontal impact. The releasing mechanism consists of a 2 x 2 x 1/4-inch square structural steel tube (Fig. 7) with six wedge-shaped lugs welded onto it.

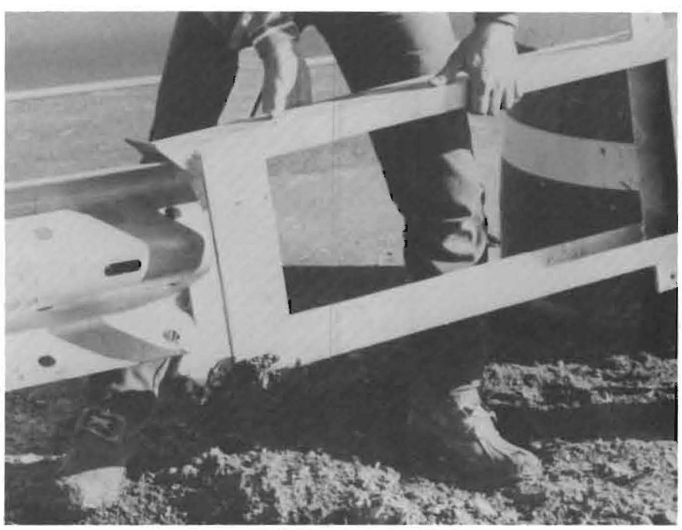

FIG. 6a: The chute feeder is slipped over the guardrail.

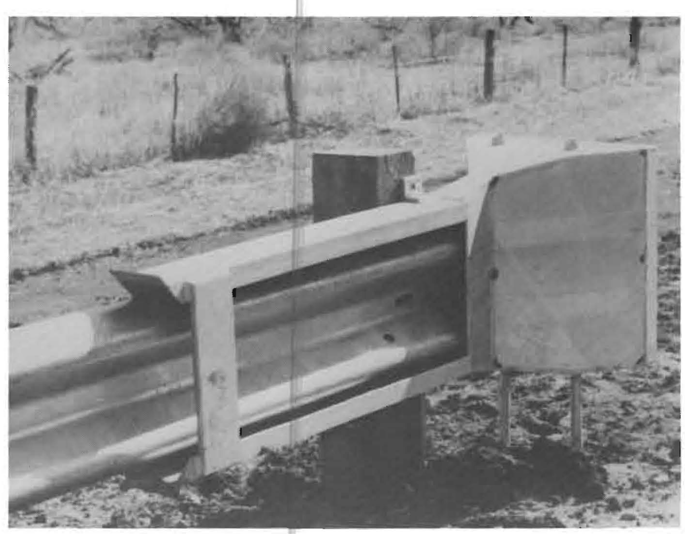

FIG. 6b: The chute feeder and extruder in place.

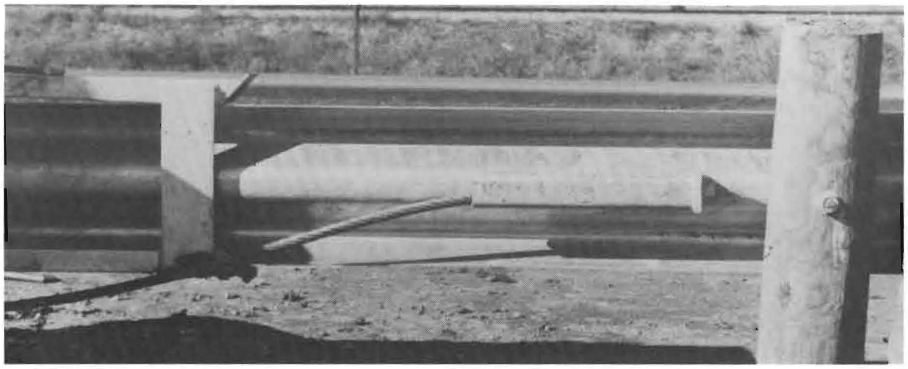

FIG. 7: Detail of release mechanism.

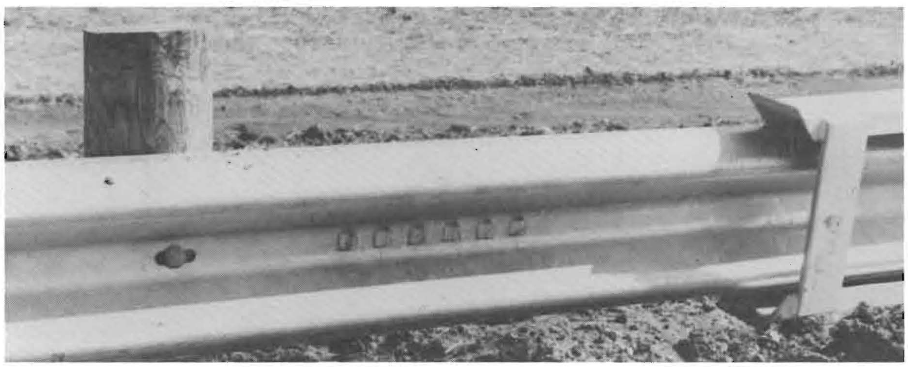

FIG. 8: Wedged-shaped lugs (traffic-side).

These wedge-shaped lugs fit into small square holes cut into the W-beam, and small protrusions on the front of the lugs lock the device onto the rail (Fig. 8). When the guardrail is impacted on the side, the lugs transfer tensile forces into the steel tube which is attached to a standard BCT cable assembly. During a head-on impact, the extruder breaks the first post and frees the upstream end of the cable assembly. When the extruder encounters the release mechanism, the wedge-shaped lugs force the mechanism out of the holes in the W-beam. The W-beam can then continue to feed without jamming on the release mechanism. Testing proved that the release mechanism can resist a peak static load of 38 kips (38,000 pound force) before the W-beam began to tear at the edges of the square holes, sufficient tensile capacity for redirection purposes.

The posts that support the GET system have a pair of 2 3/8-inch diameter holes to facilitate easy breakaway. The first wooden post has a concrete foundation to facilitate quick shearing at the groundline. The hole at the groundline weakens the post in stiff soils because the maximum bending moment during impact is near the ground. The other hole, which is 1.5 feet below the surface, is meant for soft soils where the maximum bending moment is at the same location as this hole. The holes also reduce longitudinal bending strength by 54 percent which helps soften a head-on impact.

FIG. 9: Snyder installation US84, 25 January 1991, Dst. 8.

Crash Testing

Five full-scale crash tests were made during the development of the prototype GET to see if design changes had eliminated problems of yawing, pitching and jamming. Once these problems had been worked out, a series of four compliance crash tests were run, two head-on and two side-impact tests, each with one 1800-pound car and one 4600-pound car. All were successful. No significant damage was sustained by the extruders or the release mechanisms during any of the full-scale crash testing.

Field Installations

Texas is the first state to install these innovative guardrail end treatments. Currently, in Austin District (Dst. 14), there are two projects on Interstate 35 between Austin and San Marcos which will have GETs. One will have two GETs, while the other one will have fourteen of the new terminals. Abilene District installed several GETs on new construction in early 1991 (Fig. 9). The first two of the fourteen Austin District's GETs were installed in June 1990 near Buda. Neither of these GETs have been impacted yet.

The wooden posts in the first 50 feet have two 2 3/8-inch diameter holes near the base for easy breakaway. The first post is square and set in concrete. The W-beam in this 50 foot section consists of two 25-foot lengths that are spliced together by bolts. No major problems were noted with erecting the GET as designed.

The installation method that was used is similar to the one pioneered by Lufkin District two years ago (see "Innovative Guardrail Placement," Technical Quarterly 4-3 [October 1988]:1-2.) where rails were aligned on hanger jigs and a truck-mounted drilling and piledriving rig was used to place the posts next to the aligned rail. This speedy method helped finish installation of all the necessary guardrail in the space of two days. If not for the heavy traffic, the job could have been done in a day. Actual bid prices received thus far for the GET average about $2,400. The steel was supplied by Syro Steel Company. The rest of the GETs are expected to be installed by next year. For further construction details, please refer to Special Specification Item 5652 and standard details which are available from the Highway Design Division.

SUMMARY

The primary objectives for the new barrier end terminal design were: to meet nationally recognized safety standards; to be inexpensive to install and maintain; to perform safely when installed on a tangent section of guardrail; to provide attenuation of head-on collisions; and to be simple to construct. The GET has already fulfilled all the objectives that can be quantified without long-term field performance data.

The GET is an economical strong post W-beam barrier end treatment that meets NCHRP 230 safety requirements. Crash tests indicate that it can attenuate head-on collisions by subcompact as well as full-sized cars without spearing or rollover problems. On tangent sections, it can safely redirect side-impacting vehicles. The first two field installations did not reveal construction difficulties. Data on field performance, durability and ease of maintenance will be collected and presented when it becomes available.

SPECIAL THANKS TO:
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Mr. Gary Humes, D-8
Mr. Rick Collins, D-18
Mr. Dean Sicking, TTI

SUPER LIGHTWEIGHT ROAD FILLS

INTRODUCTION

Bearing capacity and settlement problems usually plague road construction on soft soils. Ordinary fill material has a unit weight of approximately 2 tons/cubic meter which exerts a lot of pressure on soft soils. Lightweight fill materials are often used as a solution to the problem of constructing durable roads on soft soils like peat bog or soft clay deposits.

Norway has begun to use expanded polystyrene blocks as a super lightweight fill. For the past 30 years, the Norwegians have experimented with bark, cellular concrete waste and light expanded clay for lightweight fill materials. These traditional light fill materials possess half the unit weight of ordinary fill material. Expanded polystyrene unit density is about 100 times lighter than ordinary fill materials (Fig. 1).

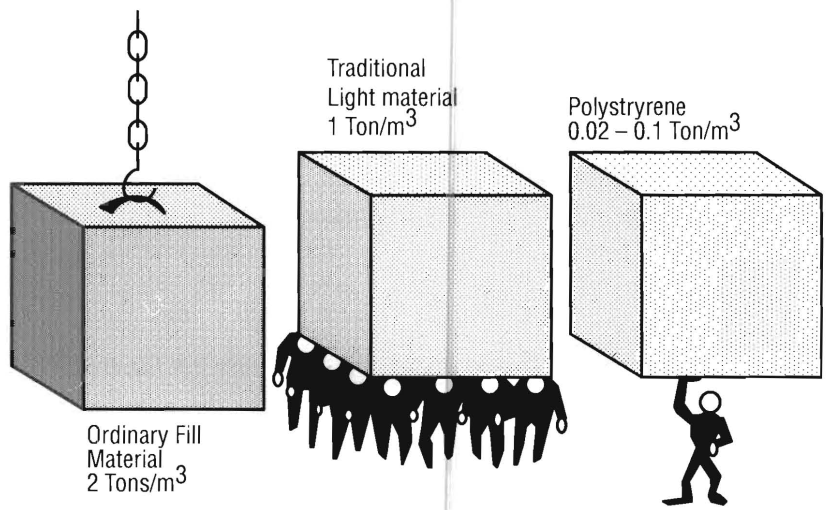


FIG. 1: Weight comparison of fill materials [Ref. 2].

EXPANDED POLYSTYRENE

Since 1972, the Norwegian Road Research Laboratory has been experimenting with expanded polystyrene (EPS) as a fill material [Ref. 2]. This research developed from tests in which polystyrene had been used as an insulation material for frost protection. Compressive strength under repeated loading and water absorption properties, in particular, indicated that significant increases in EPS panel thickness 2 to 20 inches (5 cm to 500 cm) did not cause strength problem [Ref. 2]. Therefore, EPS feasibly could be used as super lightweight fill material.

Material Properties

As mentioned earlier, EPS has a very low unit density. One EPS block which is 1.64 x 3.28 x 9.84 feet (0.5 x 1.0 x 3.0 m), only requires a lifting force of 68 lbf (300N)[Ref. 2].

Load cycling tests have proven that EPS can absorb an unlimited number of load cycles as long as the repetitive loads are kept below 80 percent of the compressive strength. For road construction, the unconfined compressive strength of 2 x 2 x 2 inch (5 x 5 x 5 cm) cubes should have a minimum mean value of 2089 psf (100 kN/m^2) with a maximum deformation of 5 percent [Ref. 2]. Single measurements should be at least 1671 psf (80 kN/m^2)[Ref. 2].

Polystyrene is a very stable compound chemically. Specimens from 4-year old and 7-year old fills do not exhibit any decay [Ref. 3]. However, it can be dissolved by gasoline. To prevent decay due to oil spills, a 4-inch (100 mm) slab of lean reinforced concrete (2100 psi at 28 days) is cast on top of the fill [Ref. 2].

EPS is also resistant to biological destruction from bacteria and enzymes. EPS, being nonfire resistant, could be ignited upon exposure to air but the chance of this occurring to an EPS road fill is rather slim. There is hardly

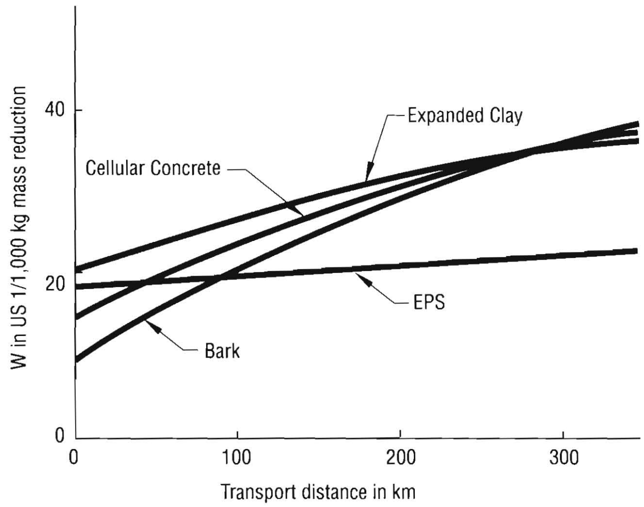


FIG. 2: Cost comparison of various light fill materials [Ref. 2].

enough oxygen under the concrete slab and soil to trigger a fire.

Thick EPS fills interrupt subsoil heat transfer to the surface which enhances the formation of ice on the pavement. A bituminous surface course can reduce that problem.

Figure 2 shows a cost comparison of lightweight fill materials.

APPLICATIONS

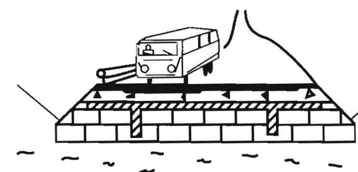
EPS fills vary in thickness from 1.6 to 19.7 feet (0.5 to 6 m) and 423,451 cubic feet (12,000m^3) fills have been used [Ref. 2]. At present, 1,235,064 cubic feet (35,000m^3) of EPS is used annually [Ref. 2]. Apart from Norway, at least six other countries (Sweden, France, the Netherlands, the UK, Canada and Japan) use or are planning to use EPS fills. The first application of a polystyrene fill in Norway was to solve a 2.7 feet (80 cm) differential settlement problem between the embankment and the bridge on the outskirts of Oslo [Ref. 3]. The embankment was subsiding 2.8 inches (7 cm) annually. A meter of EPS was introduced into the road which increased its elevation by 2.7 feet (80 cm). The load on the embankment was reduced by 105 psf (5 kN/m^2). In another application on the Lenken bridge outside Oslo, 10 feet (3 meters) of EPS was used over a length of 132 feet (40 meters) to solve settlement problems [Ref. 3]. The embankment height was increased by 10 to 16 feet (3 to 5 meters) at the bridge abutment. After the EPS was introduced, settlements were reduced to an inch per year and the stress on the subgrade was reduced by approximately 209 psf (10 kN/m^2).

EPS IN THE UNITED STATES

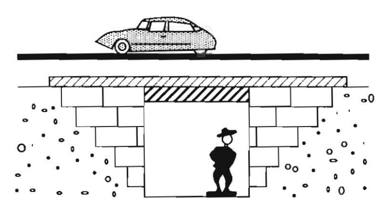
During the winter of 1988, EPS made its American debut on a slide-plagued embankment on Colorado Highway 160 [Ref. 1]. EPS was used to remedy the problem instead of the usual sawdust, because it was much lighter. A 104 foot long, 12 foot deep fill was constructed using 358.8 X 4 X 2 foot EPS blocks weighing 80 lbs each [Ref. 1]. An intricate French drain system was used to install the fill. The blocks were chainsawed for proper fitting and timber fasteners at 4-foot intervals prevented the blocks from shifting. A 4 inch thick layer of Class A concrete capped the fill to prevent damage from fuel spills. A bituminous surface course was laid over the concrete in spring to prevent icy roads. The performance through the spring of 1988 was good.

FUTURE

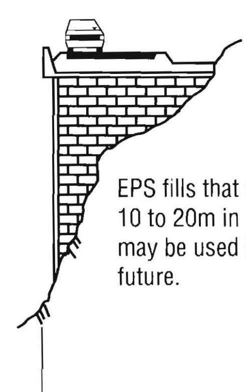
There is no technical limit to the height of an EPS fill. These fills may attain heights of 33 to 65 feet (10 to 20 meters) in the future [Ref. 2]. EPS blocks have been used as a formwork for concrete beams which are an integral part of slab on top of the fill. This reduces the problem of uneven settlements along the road. EPS has potential in the construction of temporary roads. EPS could also be used in the construction of sidewalls of pedestrian or culvert underpasses. If an EPS fill is used on top of the embankment with vertical



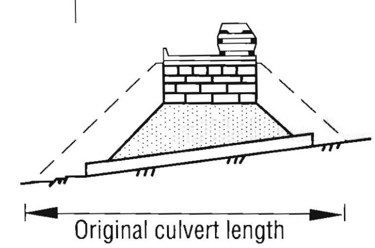
The bog bridge concept may be used where uneven settlements are expeted.



A pedestrian underpass may be a suitable place to use EPS.



EPS fills that reach 10 to 20m in height may be used in the future.



By topping an embankment with EPS fill, the length of a culvert can be reduced.

FIG. 3: Potential applications [Ref. 2].

walls on top of the fill, the cross-sectional width is reduced and a shorter culvert can be required. EPS could also be used to construct "floating" bog bridges. For more information contact TQ editor, (512) 465-7947, TexAn 241-7947.

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GRADATION AND THE USE OF 0.45 POWER PAPER (SHORT COURSE 1990)

by Nick Turnham
Laboratory Supervisor
District 17, Bryan, Texas

For years researchers and designers have been searching for a standard by which they can plot hot mix aggregate gradations and figure out the properties of the finished product. They have plotted gradations on arithmetic scales, logarithmic scales, double log scales, and combinations of each.

In the early 1900's, William Fuller and Sanford Thompson did a considerable amount of work using portland cement concrete aggregates. They plotted the gradations on a double log scale. That is, both the percent passing and sieve sizes were plotted on a logarithmic scale. They found that on those mixes that had achieved theoretical maximum density, the slope of the plot ranged from 0.38 to +0.5 percent. In other words, for every unit in a horizontal distance, the vertical distance of the plot was 0.38 to 0.5 percent of the horizontal distance. They found the size and shape, whether the rock was crushed or uncrushed, and other properties of the aggregates influenced the slope of the plot. Because of their findings and other research, the National Crushed Stone Association used a 0.5 power paper to plot theoretical maximum density in portland cement concrete designs. The results of Fuller and Thompson's work werepublished in the ***ASCE Journal***, April 17, 1907.

In 1919, Roy Green achieved, or thought he had achieved, the ideal gradation for hot mix. Green, a professor at the Agriculture and Mechanical College of Texas, studied some 36 different hot mixes throughout the state. These mixes were evaluated on performance standards established by Green. He selected the "best" mixes using his criteria. From his study, he developed an ideal gradation for a 3/4-inch and 1-inch maximum size aggregate mix. He plotted his ideal gradations on a straight line using an arithmetic scale for percent passing and no scale for sieve sizes (Fig. 1). He then compared "poor" performance mixes to his ideal mixes. He found some were finer and some were coarser. No particular pattern developed comparing his ideal gradations with poor performance gradations.

One method used in the past that is still being used today by some states is plotting gradations on log paper. The percent passing is an arithmetic scale and the sieve sizes are on a log scale. When using this method, the theoretical maximum density line plots as a smooth curve (Fig. 2). This plot is hard to use for several reasons. You are working with a curve instead of a straight line,

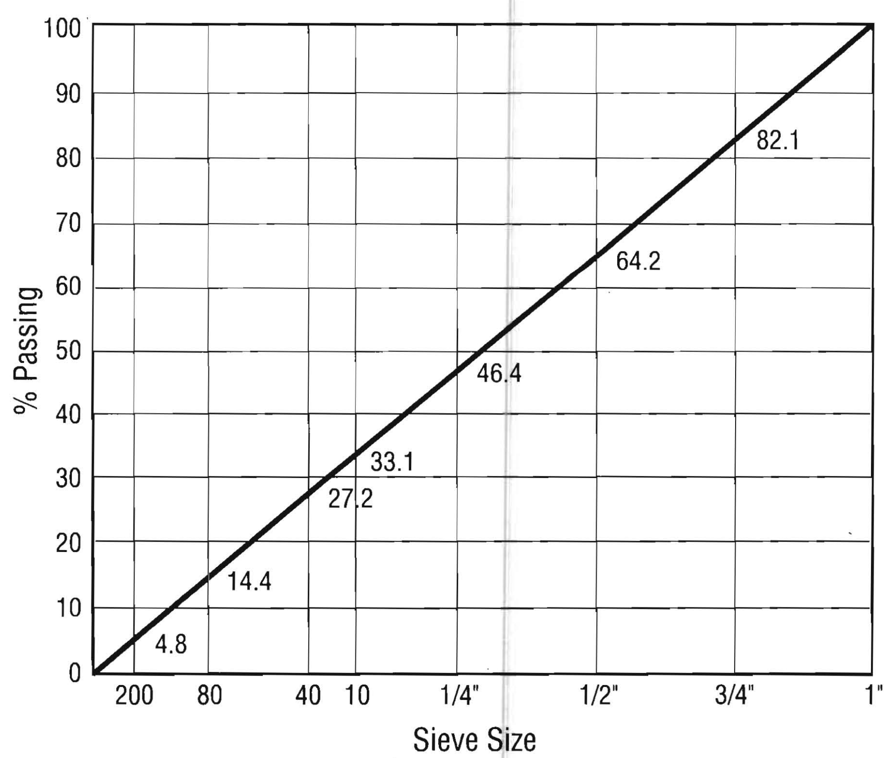


FIG.1: Roy Green's 1919 "ideal gradation" for hot mix.

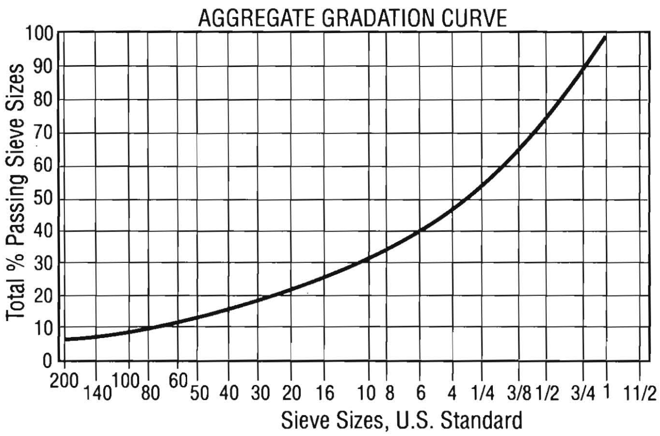


FIG. 2: An aggregate gradation curve.

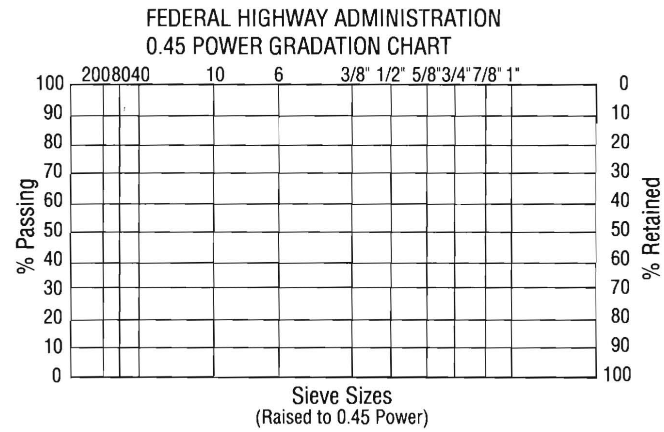


FIG. 3: Federal Highway Administration 0.45 power gradation chart; sieve sizes raised to 0.45 power.

and it is hard to evaluate the individual sieve sizes with regard to the specification requirements. Essentially it's a problem of: "Where are you in the specifications envelope?"

In the early 1960's, J. F. Goode and L. A. Lufsey of the BPR expanded on work previously done in 1948 by L. W. Nijboer of the Netherlands. Nijboer plotted theoretical maximum density gradations on double log paper. He found these slopes to be mostly 0.45 percent. There were some variations like Fuller had found, but usually a 0.45 percent was a good number. Minor variations were found but were considered as not being significant. Goode and Lufsey then developed the 0.45 power paper as we know it today (Fig. 3): the percent passing on an arithmetic scale and the horizontal or sieve size raised to the 0.45 power. They investigated mixes throughout the nation and found that mixes that were tender had a "hump" below the Nos. 8 or 10 sieve usually at the No. 30 sieve (Fig. 4). Mixes which were not tender generally stayed all on one side or the other, without crossing over the maximum density line. In the past, this tenderness was thought to be caused by the asphalt and not by the aggregate. This is not to say that all mixes that have humps in the gradation curve will be tender. Still, it is a good indication of tenderness. Goode and Lufsey's findings were presented at the AAPT meeting at New Orleans, January 30, 1962.

The typical Texas mix will usually have a hump in the gradation below the

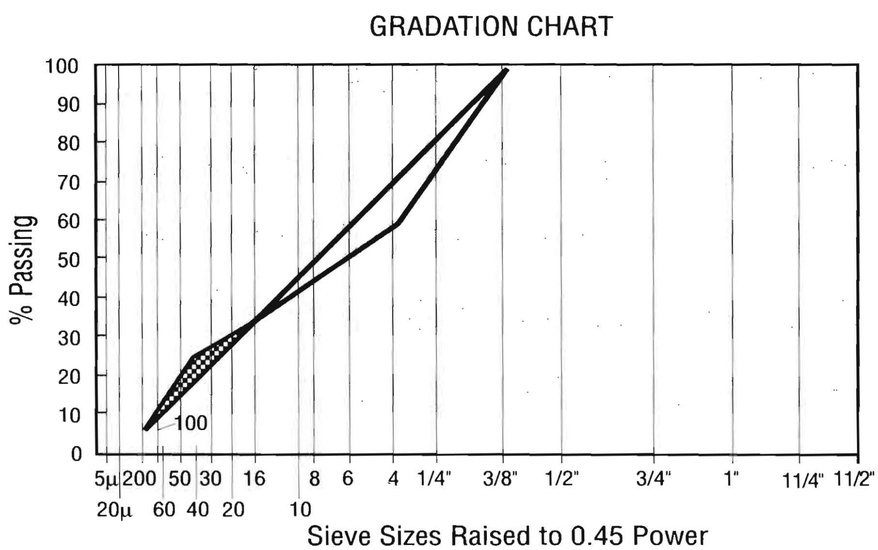


FIG. 4: The hump in the curve of a typical Texas mix.

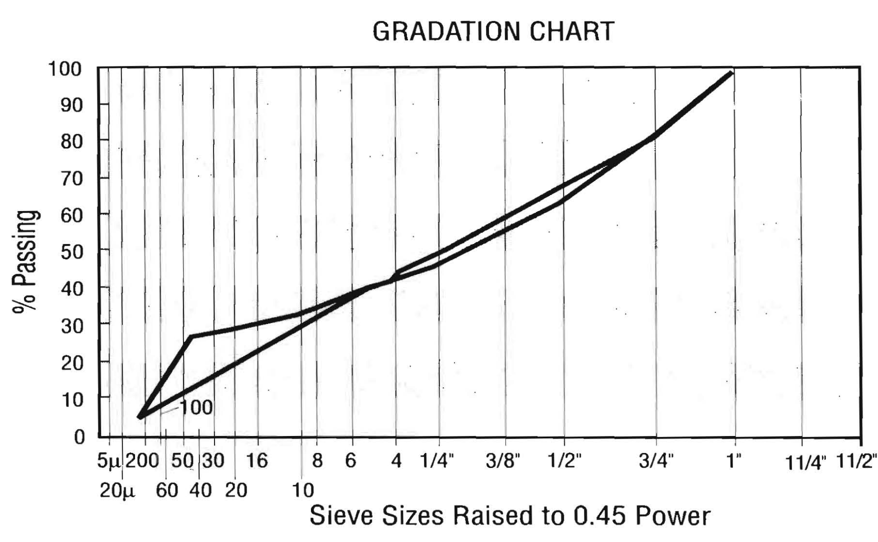


FIG. 5: Green's "ideal" mix plotted on 0.45 paper.

No. 10 sieve. If we plot Green's "ideal" mix using the 0.45 power paper, we find the typical hump in the gradation (Fig. 5). The 0.45 power paper should be used by the designer as a tool to acquire the best possible gradation for his mix. Remember, if your gradation is above the theoretical maximum density line you have a finer mix. If it is below, the mix is coarser. Figure 6 shows a "B" mix currently being used in District 17. You will notice the gradation is above the theoretical maximum density line; therefore, it is somewhat finer than normal. There is no hump. The mix was not tender and had a VMA of over 14.

Being a tougher mix, compaction to an air void content of 5 to 6 percent was somewhat difficult to achieve. It was accomplished by using a pneumatic roller in the breakdown position.

Researchers and designers have an ongoing discussion on where the theoretical maximum density line should be drawn. The National Center for Asphalt Technology is getting input even today — there is no consensus (Fig. 7). Some want it drawn from the maximum sieve size to the zero point (line A), others from the nominal maximum sieve size to the zero point (line B). Some use either the maximum sieve size or the nominal maximum sieve size and draw the line to the No. 200 mesh point.

To be consistent throughout the Texas highway department, I propose to draw the line from the point where material is first retained on the maximum sieve to the point on the No. 200 mesh sieve (Line C). This ideas has the approval of both the Executive Director of the Texas Hot Mix Asphalt Pavement Association and Paul Krugler of the Materials and Tests Division (D-9). If we, both contractor and highway department employees, will use these points, we will all be talking and using the same language in the use of the 0.45 power paper. Obviously, all the above lines cannot be theoretical maximum density lines. Also, other factors such as aggregate angularity affect what the densest gradation may be for a given set of materials. So, do not call the line from the point where aggregate is first retained to the No. 200 point line the maximum theoretical density line, call it the *Texas gradation reference line*.

For further information, call Mr. Paul Krugler, D-9, 465-7603, TexAn 241-7603.

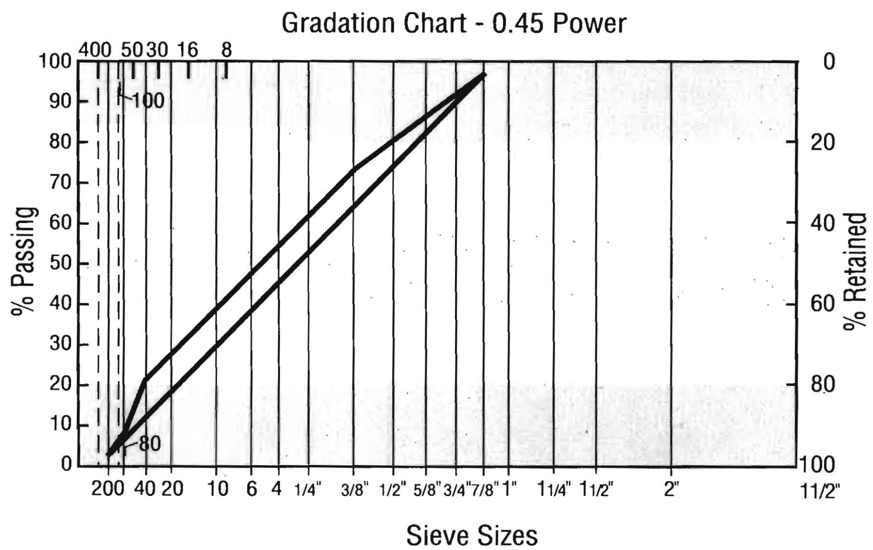


FIG. 6: District 17's Type B mix in current use.

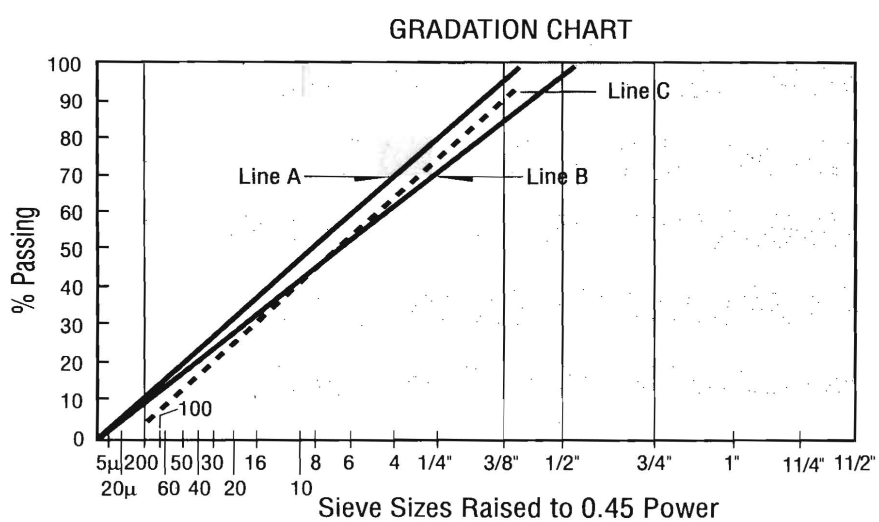


FIG. 7: Where to draw the line?

USING BARCODE READER

Sacramento County, California, has developed a special procedure to improve user efficiency for its traffic design data entry effort using a wand-type, commercially available barcode reader. The reader is connected in-line between the keyboard and the computer, a 10-minute job. The barcode wand is used to read custom codes representing commonly used data entry item combinations. The wand-read codes appear to the computer as keyed ASCII characters from the computer keyboard, with custom barcodes produced by the County on its dot matrix printer... .

The County finds that this procedure has reduced typing errors by approximately 80 percent and decreased data input time requirements by 20-40 percent. This procedure allows field personnel to load sign data as fast as a very fast and accurate typist. For information, contact Augie Bodhaine at Sacramento County, (916) 366-2227.

TOLL COLLECTION BASED ON AVI TECHNOLOGY

by Edmond C.-P. Chang, Ph.D., P.E.
Manager: Traffic Operations Program
Texas Transportation Institute,
Texas A & M University

INTRODUCTION

Many states have traditionally used toll collection as a basic means of financing transportation facilities. States such as Texas, Oklahoma, Kansas, Colorado, and California have established tollroad agencies and turnpike authorities to administer the planning, design, operation, management, and financing of additional freeway facilities. To enhance system efficiency, new system designs have been developed to improve inherently labor-intensive toll operations. One effective approach is to employ automatic vehicle identification (AVI) technology for effective traffic management.

The study, "Synthesis of Automatic Vehicular Identification (AVI) Technology for Efficient Traffic Operations, Freeway Corridor Control, and Traffic Monitoring Applications," is sponsored by the Texas Advanced Technology Program (ATP), Texas State Board of Higher Eduction. This study has investigated various issues and reviewed functional design of Automatic Vehicle Identification (AVI) for Electronic Toll Collection (ETC) and Automatic Traffic Management (ATM). This paper summarizes the application of AVI/TOLL technologies and operational efficiency of different toll collection designs for improved freeway AVI/ETC/ATM operations.

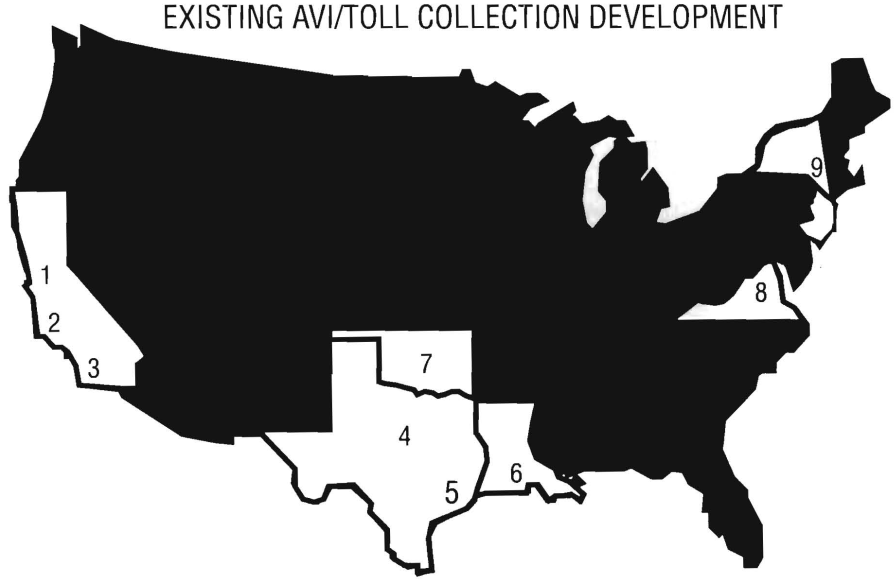
AVI TECHNOLOGY

Automatic vehicle identification (AVI) can be defined as "the technique which uniquely identifies different types of vehicles as they pass specific points on the highway, without requiring any actions by the driver or an observer." AVI is a rapidly developing technology with immense potential for automating transportation management activities typically performed manually. Several manufacturers have offered a range of automatic toll collection systems based on AVI technology. At present, four traffic operations areas have successfully adopted AVI technologies. These applications include intermodal container transportation, fleet management, vehicular monitoring, and automatic toll collections. AVI technology also provides a viable example for the future development of intelligent vehicle highway system (IVHS).

Development History

Figure 1 graphically illustrates the AVI/TOLL efforts in the United States. Early AVI development, originally supported by the United States Department of Agriculture (USDA) for livestock identification and inventory, has contributed to the success being achieved today. However, relatively few of the earlier systems related to transportation were developed through rigorous testing in an actual highway environment. The most promising developments are those technologies that have evolved most recently. Recent implementation efforts by operating agencies in Texas, California, and Virginia have drastically superseded the many trial studies completed in the early 1960s and 1970s. Overall, those successful systems implemented designs that can combine effective operating practices which address practical experience, sociological problems, and institutional issues during system development.

EXISTING AVI/TOLL COLLECTION DEVELOPMENT



1. Golden Gate Bridge (70–NOW)
2. Orange County HELP Program (84–NOW)
3. San Diego Bridge (86–NOW)
4. North Dallas Toll Road (89–NOW)
5. Houston Hardy Toll Road
6. New Orleans Bridge (88–NOW)
7. Oklahoma (90–NOW)
8. Dullas, VA. (89–NOW)
9. New York/New Jersey Bridge (63–NOW)

FIG. 1: Development of AVI/TOLL technology.

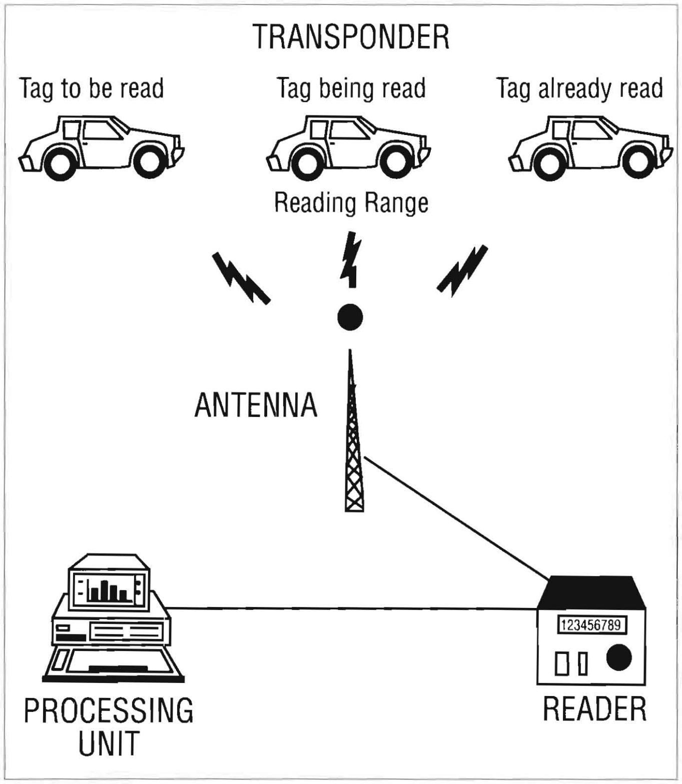


FIG. 2: Components of AVI/TOLL system.

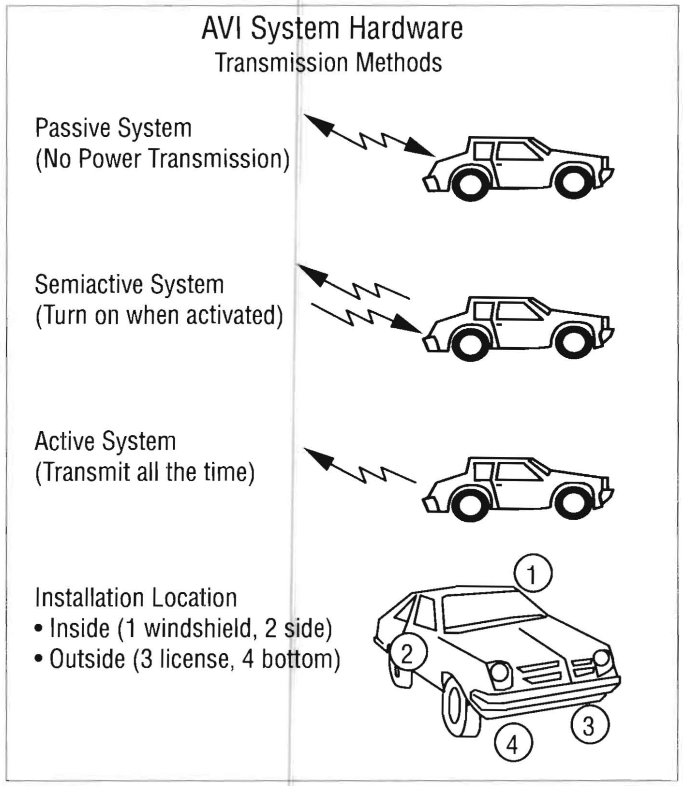


FIG. 3: Characteristics of AVI/TOLL design.

Functional Components

Most AVI systems consist of three basic elements (Fig. 2): a vehicle-mounted "transponder" or "tag," a roadside reader with associated antennas, and a computer system for processing various real-time information. As the vehicle passes the reader, the transponder will be triggered and will transmit coded data to the roadside reader unit via its built-in antenna. The system integration design depends on the type of messages to be transmitted and on how data processing can be effectively distributed among each subsystem. At the simplest level, the unique identification will be encoded into the transponder. This information may consist of an identification number and accompanying coded message such as prepaid tolls. The data will then be checked for account integrity before being transmitted for further processing. An even more complex AVI/TOLL system may be equipped with two-way communications to allow data to be written and transmitted from the roadside device back to the on-vehicle equipment without having to be checked through the central processing system.

Operational Principle

The AVI system (Fig. 3) automatically collects tolls whenever the reader, located at the toll booth area, reads signal messages sent from the transponder on the vehicle as it passes through the designated toll booth. The reader then sends the decoded information to the computer processing unit. In the past, five basic sensoring techniques have been used experimentally with the AVI system. These techniques include: optical systems (OS), inductive systems (IS), radio transmission system (RT), supersonic wave systems (SWV), and integrated systems (IS). The major differences in these techniques are in the allowed frequencies, wave lengths, and power used for signal transmission.

Three scanning techniques (Fig. 3) are commonly considered for AVI/TOLL implementation. Most AVI systems use either of these three basic forms: passive system (no power transmission), semiactive system (turn-on only when activated), and active system (transmit continually). The passive system will not transmit any messages, nor is it equipped with the power needed for data transmission. The transponder only transmits messages when it receives power from the roadside unit. The active system, on the other hand, transmits messages all the time. The semiactive system is equipped with transmission power and will transmit messages on its own whenever it receives the initial signal from the roadside unit. The passive system has a unique advantage over the others because its self-contained transponder is secure, requiring only periodic maintenance, and uses a relatively lower power transmission to energize the transponders. However, the reader antenna must constantly transmit a signal. The passive system remains the most popular because it uses a low power transmission, requires little maintenance, reduces the environmental concern, and has a lengthy operational range.

The transponder, or "tag," has been designed for installation at different positions on a vehicle. It can be located either outside or on the inside. When located on the outside, the tag can be placed on the front license plate, the side, or on top of the vehicle. When the tag is located inside the vehicle, it can be attached to the windshield or side window. Due to the nature of the current operations, most AVI/TOLL systems commonly require the users to install the tag at the designated location for a specific vehicle type.

TOLL COLLECTION METHODS

Three toll collection methods are commonly available for efficient operations and audit control. These methods are a combination of toll collection and payment methods. They include: (1) fully manual or conventional toll collection systems; (2) manual automatic or semiautomatic systems; and (3) attended automatic or fully automatic systems. The fully manual system requires collectors to accumulate funds in their own cash drawers and report to the main toll building at the end of every shift. Manual automatic systems differ from the attended automatic systems only in that tolls deposited into the coin machine can be routed into sub-vaults for different collectors, thereby improving audit control. An attended automatic system or full-automatic system offers toll booths requiring exact change or booths with only a coin machine. All tolls can be deposited into a common vault and vehicles automatically preclassified by requiring them to enter a designated traffic lane. The AVI/TOLL collection system can be considered a form of the attended automatic system.

System Elements

There are eight (8) basic system components involved in the design and operation of both semi-automatic and fully automatic toll collection systems. These design components include: preclassification subsystem, toll indicators subsystem, payment subsystem, AVI subsystem, vehicle audit subsystem, security and enforcement subsystem, lane control subsystem, and computer and communication subsystem. The first three subsystems are common to both toll collection systems. The other five subsystems are required for the fully automatic system, especially the subsystems that apply AVI technologies.

The computer and communications subsystem is the essential part of an automatic toll collection system. This subsystem will coordinate both data and/or voice communications among all the items that support overall AVI/TOLL activities. The system will consist of plaza computers and communications links between toll stations and center computers. The computer system controls and monitors other system elements; records all financial transactions conducted through either manual, attended, or AVI-based toll collection system elements; maintains financial and traffic data records; and provides real-time system status reports and statements to AVI/TOLL users, audit personnel, and toll road managers.

Operational Efficiency

There are two important considerations in selecting toll collection designs. First, any toll system improvement has to consider the voluntary nature of system usage, the relative proportion of potential AVI users, the likely use of the toll collection method, and the number of mixed users during system development. Secondly, it is important to recognize that any type of operation, even in the most efficient AVI/TOLL system, will still require some motorist action to complete the toll collection. Even in the "nearly nonstop" operations, these required human actions, such as observing the toll signal or slowing down to pass toll station, will eventually become the maximum achievable capacity of any AVI/TOLL system.

Figure 4 compares the operational characteristics and maximum throughput capacity of the three toll collection systems. This comparison addresses these systems as the "Manual System," "Machine System," and "AVI/TOLL System." Many existing freeway toll collection systems in the United States use a combined manual and machine system. The key to operational improvements is to reduce the required actions needed by the driver, acquaint drivers with the exact change function, and inform the public of the required operations through the mass media. Even though the machine system may not be as efficient as the manual system, the machine system will provide operating agencies with an added opportunity to illustrate system improvements using semiautomatic toll collection, and help users get accustomed to the unattended toll collection. This automatic operation helps prepare drivers and potential users for future automatic toll operations.

SUMMARY

AVI is a rapidly developing technology. Its implementation has largely been experimental to date. Yet, recent advancements in system integration havespurred substantial interest in utilizing AVI technology. A number of projects are currently underway to use AVI on an operational basis. The increasing AVI usage is a result of recent advances in electronics technology with improved technical and economical feasibility. This review confirms that the nonstop toll collection based on AVI is now considered a technically viable option. An AVI-based toll collection system provides motorists the opportunity to pay tolls automatically, without stopping at toll booths. It will also offer fleet managers an efficient method of administering toll payments and cost estimations without having to pay drivers in advance or reimburse them for tolls claimed.

When designing an AVI/TOLL system, engineers should avoid specifications for a single-source supplier, use video record verification for added enforcement, design a high-speed fiber optics communication system for video imaging and computer communications, and establish communication protocols for system expansion. However, user acceptance will be an extremely key factor to the system's success. A basic prerequisite of the AVI/TOLL operation is that participation be primarily

TOLL STATION THROUGHPUT CAPACITY
TRAFFIC OPERATION EVALUATION

	COLLECTION	METHOD	AVG. TIME	CAPACITY
A	MANUAL	NORMAL	6.00 SEC	600 VPH
B	MANUAL	NO CHANGE	4.24 SEC	850 VPH
C	MANUAL	TICKET	4.00 SEC	900 VPH
D	MACHINE	COIN	4.50 SEC	800 VPH
E	MACHINE	TOKEN	4.80 SEC	750 VPH
F	AVI/TOLL	LOW	3.00 SEC	1200 VPH
G	AVI/TOLL	HIGH	2.57 SEC	1400 VPH

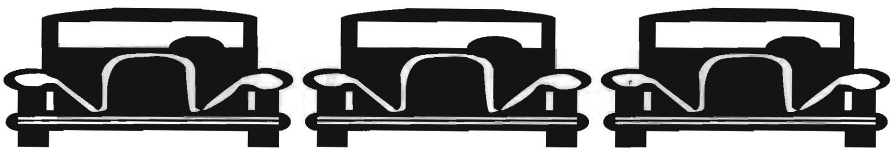


FIG. 4: Maximum station throughput capacity.

voluntary, with the need to retain existing manual facilities to accommodate nonsubscribers during the development process. Besides toll operations, AVI technology offers significant potential for improving driver information systems. With relatively little effort, AVI/TOLL can be extended to provide real-time traffic and travel information to-and-from drivers. This added system monitoring and operational evaluation capability makes the AVI/TOLL system a powerful highway system management tool for future freeway corridor operations.

FRENCH TOLL ROAD NETWORK GROWS: NOW FEATURES CREDIT CARD USE

Some 159 kilometers of French toll roads were opened to traffic during 1987, according to the International Bridge, Tunnel and Turnpike Association.

Major roads opened during 1987 included the 73 kilometer Clermont-Ferrand to Montmarault section of the Paris-Clermont Ferrand Motorway (A.71); and the 34 kilometer St. Quentin Sud-Loan link of the Calais-Rheims Motorway (A.26). The A.26 will provide a link between the North Sea and Germany. The A.71 and the A.26 are both scheduled for completion in 1989.

Also, the 22 kilometer Macron-Bourg section of the Macon-Geneva Motorway (A.40) was placed in service. By 1989 this facility will provide a link between France and Italy. The 30 kilometer Angers Durtal portion of the Paris Le Mans Angers Nantes Motorway (A.11) opened in 1987. The A.11 is scheduled for completion in the summer of 1989, providing a direct motorway link between Paris and Nantes.

Motorists can now use bank and credit cards to pay tolls on the 4870 kilometer French toll road network. The service has been gradually phased in, and is open to all French and foreign motorists carrying Carte Bleue, Eurocard, Mastercard, Visa, Credit Mutuel, Access and Eurocheque. There is no additional cost to the motorist for the service.

USAP, the union of French toll authorities, is working in collaboration with the French Department of Highways to develop a high-capacity toll collection system. With traffic growing at an annual rate of six percent, particularly in urban areas such as the Paris metropolitan region, a "fast toll payment" program is designed to enhance traffic capacity by allowing motorists to pay tolls without stopping.

Toll authorities are experimenting with an Automatic Vehicle Identification (AVI) system on the French North and East Motorway (SANEF). The subscribing motorist uses a micro-transmitter to send a code number to the receiver, paying the toll without coming to a stop. Tests are being carried to determine the maximum capacity of the system with or without toll gates, the effect of lane width, and the ability to process vehicles in close proximity to one another.

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MULTI-DEPTH DEFLECTOMETER

INTRODUCTION

Since 1988, the Texas Transportation Institute (TTI) has been evaluating the multi-depth deflectometer (MDD) for measuring pavement response under wheel loads and nondestructive testing equipment (NDT). The instrument was initially developed by the National Institute of Transport and Road Research (NITRR) in South Africa as part of their accelerated loading tests. It has been modified by TTI researchers for monitoring long-term performance on in-service pavements.

This instrument can measure variations in pavement deflections vertically through the pavement depth under the influence of a passing wheel load or some form of NDT device. It can also measure the permanent deformation of each layer in the pavement structure. Research Report 1123-2, ***Field Evaluation of the Multi-Depth Deflectometers*** is available documenting TTI's efforts to correlate MDD-measured deflections with those monitored under falling weight deflectometers (FWD). The device, retrofitted into the pavement layers, is relatively inexpensive, durable, and reusable. It shows great potential in assisting in several areas of pavement research including backcalculation analysis, tire pressure and rutting studies.

DESCRIPTION OF THE MDD UNIT

The MDD unit is composed of a maximum of six modules holding linear variable differential transformers (LVDTs). The total length of each module is 4 to 5 inches depending on the LVDT used. An adjustable center rod containing the LVDT cores runs through the modules and is attached to an anchor positioned approximately 7 feet below the pavement surface. The module length is the governing factor for the spacing of the module within the pavement layers (Fig. 1).

The MDD modules (Fig. 2) are held in position by turning a clamping nut which forces steel balls towards the sides of the hole. The MDDs are connected to the data acquisition system via a cable which is laid in a small groove cut into the pavement surface. The only part of the system visible from the surface is a small brass cap which is used to seal the hole.

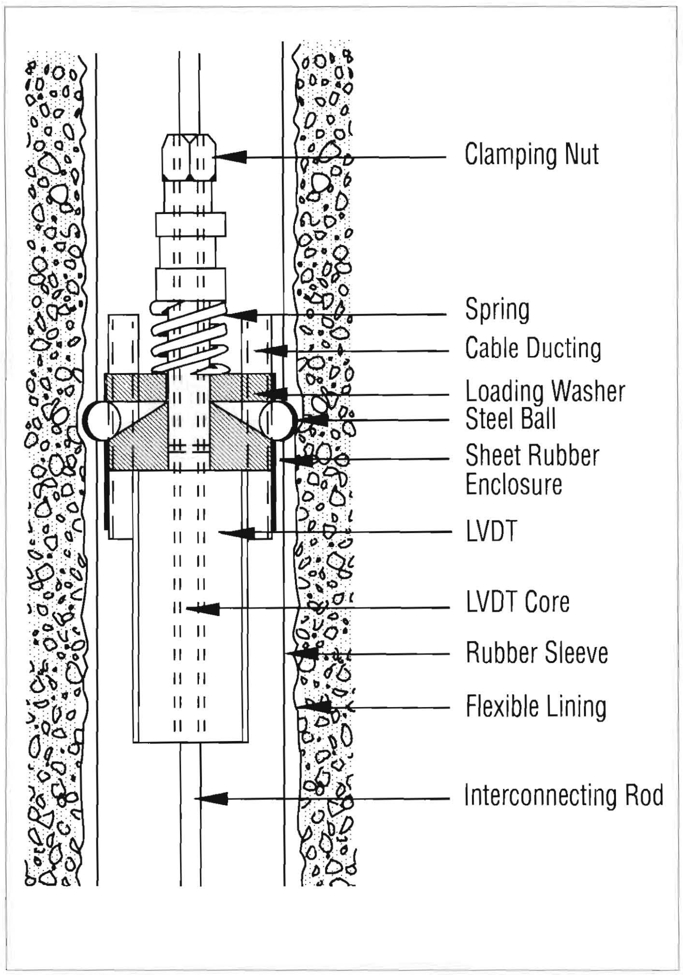

FIG. 1: Components of a MDD module.

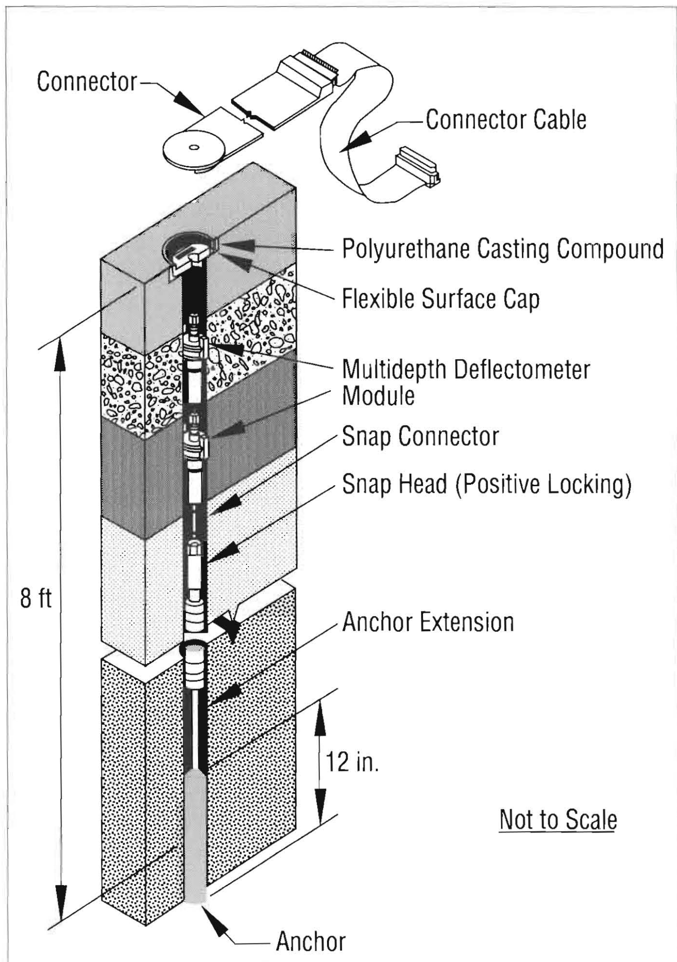

FIG. 2: Configuration.

LVDT Selection

Both alternating current (AC) and direct current (DC) LVDTs have been used successfully. For long-term monitoring, exceeding one year, hermetically sealed LVDTs are recommended. These cost between $250 and $350 each. Unsealed LVDT costing $35 to $40 can be used for short term testing.

Data Collection

A Compaq 386/20 microcomputer and a Metrabyte DAS-16F translation data acquisition board is used to log MDD pulses under FWD and truckloads (Fig. 3). At the highest sampling rate, the data acquisition board records 600 points in the 60 millisecond period at a sampling rate of 10,000 readings per second.

INSTALLATION PROCEDURES

The complete installation process consumes 1 1/2 days. A 1.5 inch (38mm) diameter hole is required. The hole is lined with a 0.1 inch (2.5 mm) flexible lining tube to provide both waterproofing and a smooth surface and to minimize "cave-ins." The voids between the tube and the wall are filled with rubber grout. The hole is drilled and lined during the first day. The anchor pin is also installed on the first day using a fast-setting cement/sand paste.

During the second day, the MDD modules are installed and calibrated. A pilot rod positions the modules at the correct depth; turning the clamping nut then locks them in place. The modules are numbered from the shallowest to the deepest in ascending order.

THE USES AND BENEFITS OF MDD

MDD is a valuable asset for pavement research since it monitors the response and performance of individual layers within the pavement structure. It can contribute to accelerated load testing, tire pressure studies, rutting studies and modulus backcalculation. MDD can track the deformation of each layer in the pavement structure since it is positioned at layer interfaces. MDD measures the relative displacement between the layer and the anchor. The difference between these two MDD readings gives an insight into the strain in each layer. The vertical strains in the base and subgrade can be measured by placing MDDs in each of these layers. A depth deflection profile is also generated.

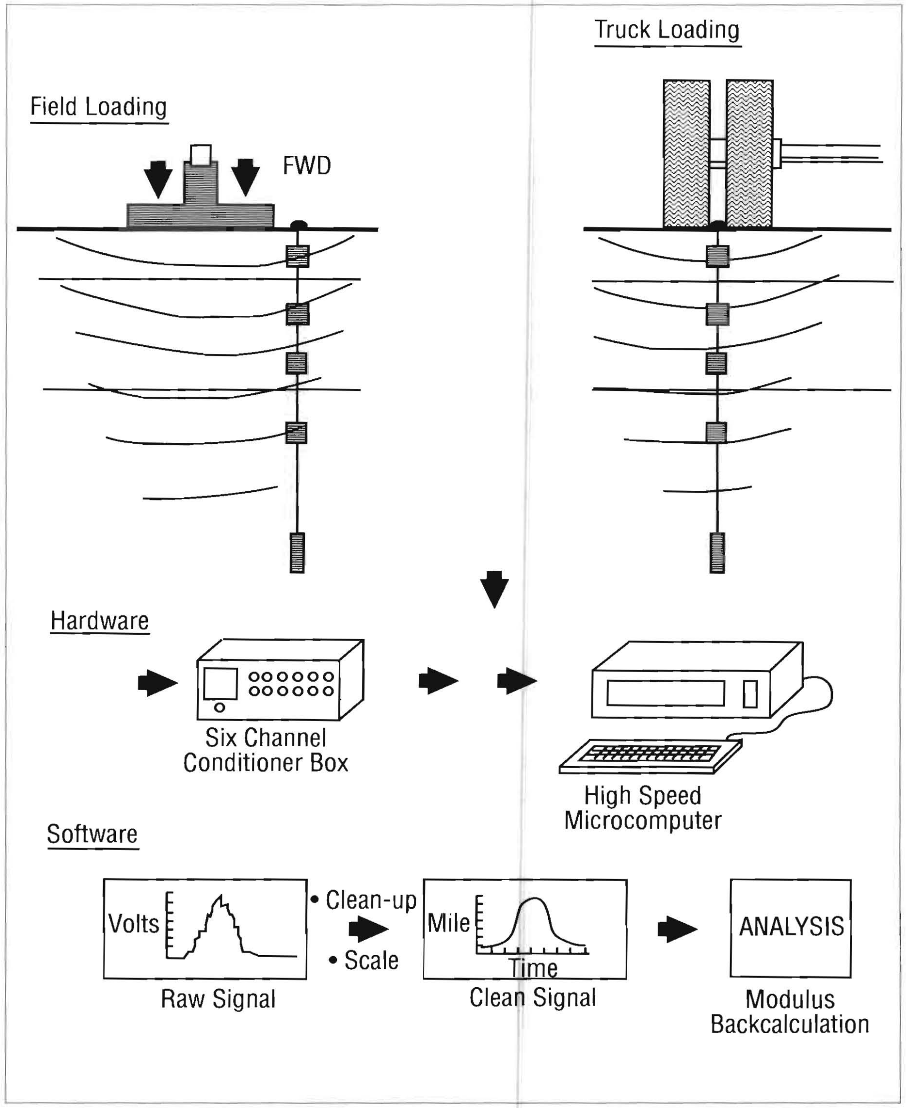

FIG. 3: MDD data-logging system.

An MDD located near the surface can be used to measure the surface curvature of the pavement. This curvature value provides an insight into the strains at the bottom of the asphalt layer. It can also be used to confirm the layer modulii values which are obtained through backcalculation procedures. Layer moduli values from MDD and FWD showed a good fit on a pavement with a 5-inch asphalt surface over a 24-inch granular layer on a natural subgrade. TTI researchers believe the MDD provides the best method of validating the adequacy of modulii backcalculation procedures.

The system is durable and gives repeatable responses. An instrumented site has been in operation at the Texas A&M Research Annex for over a year without any problems. The hardware for a typical installation costs approximately $2,000 depending on the LVDTs chosen.

One of the biggest advantages of using a multi-depth deflectometer is that it can be recovered for future use. The LVDT modules can be extracted from the hole once testing is complete. The center core, snap head connector and surface cap can be reused again.

Only the anchor and hole lining cannot be extracted for future use.

FINAL COMMENTS

MDD has shown great potential as a research tool. It is currently being used to monitor the impact of wide base single tires on in-service Texas pavements. In the near future, it will be used by the U.S. Army Corp of Engineers to study the benefits of fabric reinforcement under accelerated load testing conditions. It is anticipated that the MDD will be useful for monitoring the on-set of pavement rutting during accelerated testing with the Mobile Load Simulator which is currently under development at The University of Texas at Austin.

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TECHNOLOGY TRANSFER

Editor/Tech. Writer:
Kathleen Jones
(512) 465-7947

Librarian:
Dana Herring
(512) 465-7644

Our TEX-AN exchange # is 241.

FERTILIZER FOR THOUGHT

You're getting ready to fertilize your lawn. Like any responsible consumer, you read the directions for the recommended amount to use. To make sure you do a ***really*** good job, you might say to yourself, "I'll just put on a little extra. After all, everybody knows that if one pound is good, two pounds is better." Shucks, if you set your lawn spreader according to the directions, it just doesn't look like that much coming out. You want to see that stuff flyin' outta that spreader! You want to hear that satisfying "Whoosh" of millions of little pellets pelting the grass blades. You want RESULTS!

Using too much fertilizer, especially before a rain, can pollute local water supplies, and it won't make your lawn any prettier. When you add more nutrients to the soil than plants can absorb, the water which dissolves the nutrients can also carry them into the nearest street gutter or storm sewer, or percolates through the soil into underground water supplies. Keep in mind that neighborhood storm sewers do not always lead to water treatment facilities and can serve only as conveyances to the nearest creek or reservoir. Fertilizer in the water feeds excessive plant growth, particularly algae, increasing subsequent plant decay, thereby decreasing oxygen supplies for fish. Fish kills are often the end result of excessive fertilizer. Additionally, if you've ever noticed a "funny" taste or smell in your drinking water, it may have been caused by nutrient-fed algae blooms.

Fertilizer also occurs naturally as organic matter decays, and helps maintain a fragile balance in the eco-system that humans can disrupt by adding additional nutrients. Yard clippings casually tossed into the street gutter or storm sewer release nutrients through decay that can adversely affect the eco-system as much as manufactured fertilizers.

You can have a beautiful lawn without using too much fertilizer. With the proper amounts, you'll have to mow and water less because it won't grow abnormally fast. You can also augment, or even replace, your fertilizer use with leaves and grass from your yard. Cut grass left on the ground decays into nature's own fertilizer for live grass, and it aids in water retention. Also, your autumn leaves (a major landfill space eater) will decompose in about a year if piled in a small corner of your yard, leaving a fine humus for use as potting soil or in garden or shrub areas. With minimal effort, you can make FREE fertilizer in just several weeks by composting a moist mixture of grass and leaves.

The same faulty wisdom that teaches "if one is good, two is better" also wrongly teaches that one person's fertilizer habits are too insignificant to have any effect on the ecosystem. Talk to a neighbor about it. If only a few homeowners in each neighborhood merely read and followed the directions on fertilizer packages, it would decrease the potential for water pollution. And your yard will be as green and lovely as ever.

From the Pollution Abatement Unit, Texas Water Commission.