TECHNICAL QUARTERLY

"AN EXCHANGE OF IDEAS"

TQ10-3/10-4, August 1996 *EDITOR: Kathleen M. Jones*

REPAIRING DAMAGED PRESTRESSED GIRDERS

From Research Project 0-1370,
Repair of Impact-Damaged Prestressed Concrete Girders,
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BACKGROUND

On average, one Texas prestressed bridge girder a week gets hit, usually by an overheight vehicle. Minor damage accounts for two-thirds of all reported impact damage. District personnel report one-fifth of all damage as moderate and about one-eighth as severe. Much of the minor damage needs no repair. Some of the most severely damaged girders must be replaced. What about the moderate to severely damaged girders that you can repair? What are the best methods? How do you figure out which method to use?

In Research Project 0-1370, ***Repair of Impact-Damaged Prestressed Concrete Girders,*** the project team, headed by Robert Zobel, reviewed current girder repair practices in the United States and Canada looking for repair procedures that result in durable, easily maintained structures. They evaluated the most promising repair techniques and verified several, such as preloading a damaged beam before patching. They also developed a very promising way of injecting epoxy. This article will discuss useful field repair techniques verified by 0-1370.

WHEN A PRESTRESSED BRIDGE IS HIT

The first order of business when a bridge girder is hit is to protect the traveling public (Figs. 1 & 2). Remove loose debris from the roadway and the damaged beam. Shield (diaper) the damaged area with tarps or chicken wire. Call the Bridge Construction and Maintenance Section of the Construction and Maintenance

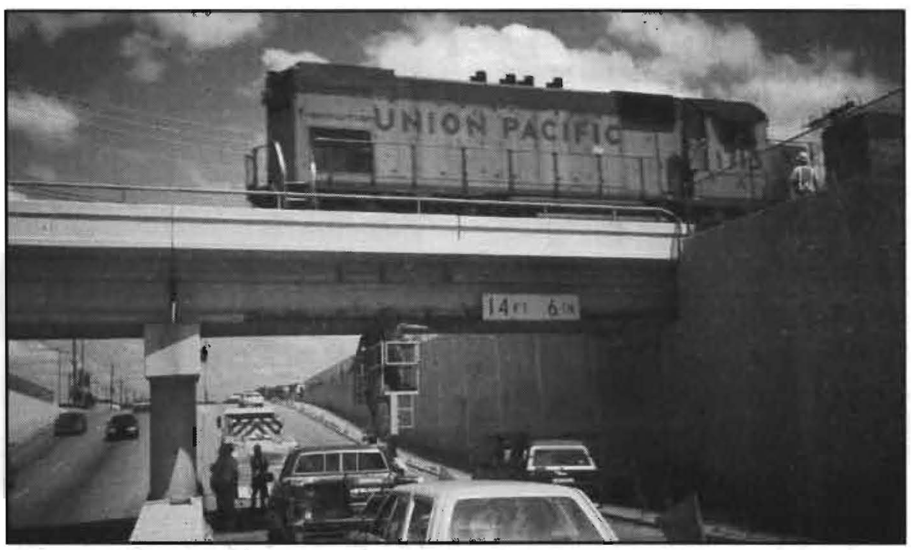

FIG. 1: The 0-1370 research team examines impact damage at the Steck Ave. RR bridge in Austin, TX.

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FIG. 2: Close-up of the damage to the Steck Ave. RR bridge. The traveling public must be protected from falling debris.

Division. (Randy Cox, P.E., is the Section Head. His number is [512] 416-2189.) If a bridge construction engineer can't get there during the removal of debris, the shield might have to be taken down for a thorough structural inspection. After the inspection, the engineer will recommend one of four options:

★ Do nothing

★ Replace the beam or beams. (Plans to be done by the Design Division, usually.)

★ Make repairs

★ Replace some beams and repair others

As Randy Cox, Bridge Construction and Maintenance Engineer, says, "Some girders can't be repaired." [Fig. 3] Those are usually easy to determine. It's the borderline of "replace" or "repair" that is difficult to determine. It's almost always cheaper to repair a beam than to replace it — but is it safe? How much prestressing has the beam lost? Will the repaired beam still bear the required operational load? Answering those sorts of questions is where the newly developed strand tension indicator is useful. (See *Prototype Estimates Remaining Strand Tension,* page 7.)

VERIFIED FIELD REPAIR METHODS

If the engineer decides that repairs should be made, what are the best methods and materials to use? 0-1370's Project Director Alan Kowalik says the project verified and refined several methods already current in TxDOT — cleaning, preloading, and epoxy injection. Also, the Project 0-1370 team was able to incorporate information from another project to give some guidance regarding what are the best patching materials in what situations.

Cleaning

Before making any repair, clean the repair area thoroughly. Saw or chip the area to remove feather edges. Make the saw cuts shallow and perpendicular to the feather edge. Roughen the surface to partially expose coarse aggregate in the base concrete (Fig. 4). Exposing the aggregate will enhance the bond between the new patch and the existing material.

If the patch is going to be fairly deep, use some supplemental steel. Epoxy small reinforcing bars or bolts into drilled holes.

Make sure the repair surface is dry and free of dust and debris before any patching starts.

Preloading

Moderate damage to a girder can expose many prestressing strands without apparent damage to the strands themselves. However, these undamaged strands may still have lost much of their prestressing force through camber of the damaged girder. In the past, this concern has often made engineers hesitant to repair girders with exposed strands or with extensive concrete damage. Preloading is a way to return pre-

FIG. 3: Sometimes replacement is the only option.

FIG. 4: The impact-damaged beam from the Steck Ave. RR bridge cleaned, sawed, and ready for patching material. This beam was removed to Ferguson Lab and instrumented for testing during Project 0-1370. Note plastic tubes shoved into cracks for future epoxy injection.

stressing force to the strands in a damaged girder so it can be repaired successfully (Fig. 5).

Load the damaged girder with deadweight by means of trucks or sandbags until enough downward deflection occurs to restore the girder to its original shape. Preloading allows the patched concrete to be in compression under deadload. An added advantage of preloading is that you can use it to open up cracks in the tension zone of the beam so you can inject epoxy where it's needed.

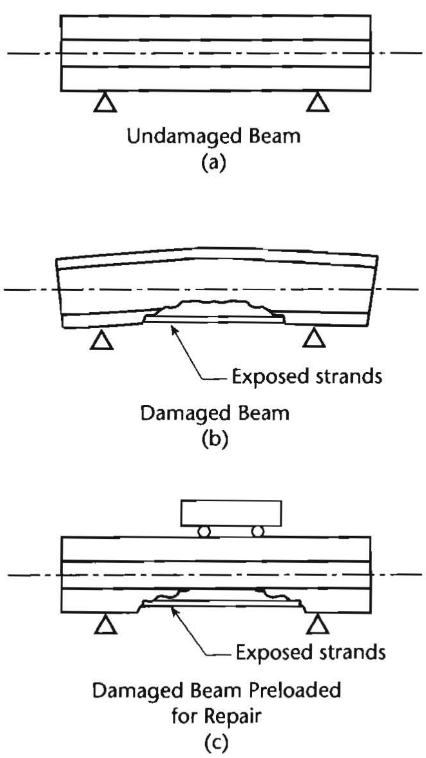


FIG. 5: A schematic of preloading.

Epoxy Injection

Cracks in damaged concrete girders reduce long-term durability by allowing salt and oxygen to get to the reinforcing steel, causing it to corrode. Epoxy injection is a common method of sealing such cracks. The 0-1370 team came up with a new way to make sure the epoxy gets in deep. After chipping and sawing back to clean concrete, the researchers preloaded an overheight-load-damaged girder section and attached tubing to opened cracks. They made the tube lengths long enough to be outside the finished patch area (Fig. 6). They then patched the area with several different types of commercial patching materials, cut the tubes nearly flush with the patch, and attached epoxy injection ports to the tubes. Using relatively inexpensive, off-the shelf, low-pressure equipment (essentially caulking guns), the researchers successfully injected epoxy into areas that might not have been accessible even with high-pressure equipment (Fig. 7).

This method worked so well in the lab that in November 1995, the Austin District used it in a field trial repairing the 11th Street bridge. District personnel report that the repair went very well and the technique was not difficult. They had added confidence in the job because they knew that epoxy would fill any voids, even deep in the patch (Figs. 8 & 9).

FIG. 6: Steck Ave. RR bridge beam showing epoxy injection tubes in place.

FIG. 7: Project 0-1370 graduate student uses hand-held, low-pressure caulking-type gun to inject epoxy into the Steck bridge beam.

FIG. 8: Cross section of repaired Steck bridge beam. Different shades of gray denote different types of patching materials.

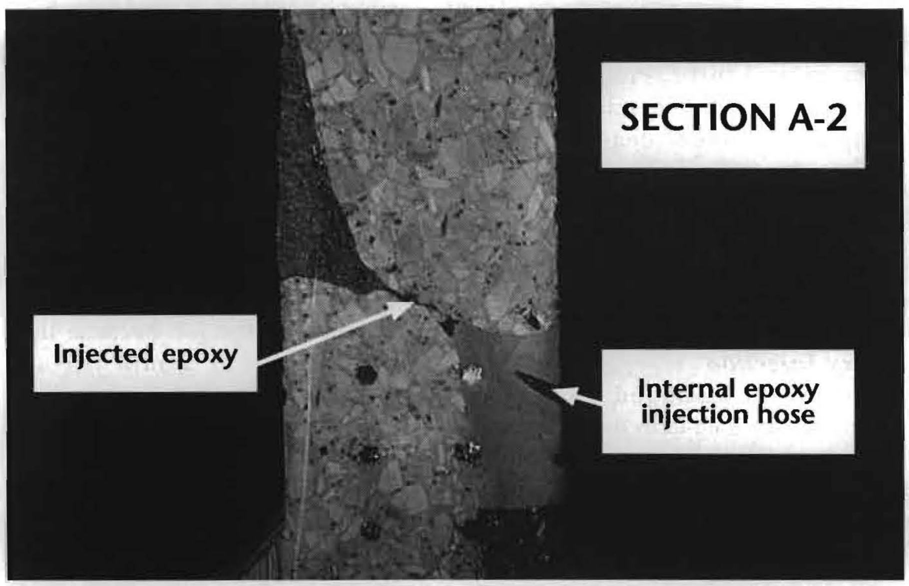


FIG. 9: Close-up of cross section showing how internal tubes carried epoxy deep into the beam.

Using the research and Austin District's experience, Brian Merrill, P.E., of the Bridge Construction and Maintenance Section, has drafted a permanent repair specification for statewide use. The name of the draft is "Special Maintenance Specification for Repairing Impact-Damaged Prestressed Concrete Bridge Beams." One strategy the draft specification recommends is a prebid conference. It is helpful to take prospective contractors to the site to examine the bridge. That way, the contractors will be better able to estimate the quantity of epoxy required. They will also have a much better idea of the placement and number of tubes. If prospective contractors know both these items before bidding starts, bids will be more accurate, and the job will probably go more smoothly.

Although the draft specification references pertinent requirements from Standard Specification Item 420, "Concrete Structures"; Item 412, "Portland Cement Concrete"; Item 431, "Pneumatically Placed Concrete"; Item 440, "Reinforcing Steel"; and Item 575, "Epoxy," districts can use it as a stand-alone specification.

Strand Splicing

Numerous strand splicing systems exist. The problem with most of them is that they congest the patching area, making it difficult to place the patching material correctly. Also, it is difficult to know how much tension has been developed in the repaired strand. For these reasons, the Construction and Maintenance Bridge Section usually does not usually recommend strand splicing as a repair method.

Materials

The 0-1370 team made use of information being generated from Research Project 0-1412, ***Repair of Structural Concrete.*** The materials considered for repair of damaged girders were:

★ latex-modified concrete

★ epoxy mortars
★ polymer-modified mortars
★ cementitious patching materials
★ expansive patching materials
★ portland cement
★ epoxy for injection or sealing of cracks

Using the right material for the patch is as important as determining the type of patch. The patching material must have:

★ a thermal expansion/contraction rate similar to that of the existing concrete so the patch doesn't pop out when the ambient temperature rises or drops
★ a compressive strength as high as or higher than that of the surrounding concrete
★ a low slump
★ a low shrinkage rate
★ low permeability
★ the ability to be placed vertically if the patch is an overhead or vertical one. Several proprietary items, such as Set 45, can be used for vertical patching. Project 0-1412 research is looking at engineering properties that define what makes good vertical patching material so that TxDOT can write end-result specifications.

Shallow patches can often be made with latex-modified concretes or latex adhesive grouts. Use coarse aggregate in more extensive patches to help minimize thermal changes.

If there are significant voids, consider a repair technique used on the US 87 bridge over the Neches River in Beaumont District. The repair crew sealed the sides of the cracks with a paste-like epoxy mortar. Using a sandblasting rig, the repair crew then preplaced a special aggregate (that looked rather like aquarium gravel) in the voids (Fig. 10). They blew aggregate into the voids until the aggregate started flowing out of the crack in the haunch. After the paste epoxy cured, they used a high-pressure epoxy injection system to force epoxy into the voids and cracks through holes drilled in the deck along the length of the crack. When the injected epoxy had set, they cored to see if epoxy had filled all the voids. They repumped any that weren't.

A number of materials that the researchers found to be most satisfactory are proprietary. Shelf life of these materials is very important. Never use a material that is out of date, and always use proprietary material according to the manufacturer's recommendations.

OTHER CONSIDERATIONS

Repaired girders never have quite as much capacity as they did before they were damaged. Report all bridges with repaired girders in BRINSAP. Note which girders were damaged, and indicate what types of repair procedures were used. This information becomes critical if the bridge is selected for widening in the future. Exterior beams become interior beams during widening. A structurally repaired beam may have sufficient capacity to serve as an exterior beam but may not be adequate as an interior beam of a widened bridge. If the extent and nature of the repairs are shown in BRINSAP, designers can take into account whether or not repaired beams need to be replaced before the contract is let. This kind of planning saves the taxpayers' money and saves the district and contractors from a lot of frustration and delay. BRINSAP inspectors will want to check repairs during routine inspections as a means of long-term monitoring.

As best practice, the research team recommends writing a detailed report for each case of impact. Include in this report:

★ repair materials used
★ the contractor performing the repair
★ before-and-after photos of the damaged girder and repair
★ equipment used for the repair
★ techniques used for the repair
★ cost of the repair
★ any limitation of use for the repaired bridge
★ results of long-term monitoring if applicable.

Detailed reports like this should be shared among the districts so we can gain a better understanding of what types of repairs work best under what conditions.

SUMMARY

Every week in Texas, at least one prestressed girder bridge is hit and sustains moderate to severe damage. Research Project 0-1370, through lab and field studies, has verified and refined current repair strategies. From the research and from field experience, a draft special maintenance specification for repairing impact-damaged prestressed beams has been written. Table 1 is an overview of the sequence of events that should take place after a prestressed bridge is hit. Table 2 is an overview of the repair process. For further information, call Alan Kowalik, P.E., at (512) 416-2569, Randy Cox, P.E., at (512) 416-2189, or Brian Merrill, P.E., at (512) 416-2232.

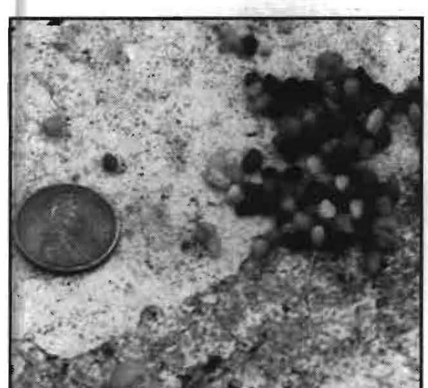


FIG. 10: Special small aggregate can be used to fill big voids before injecting epoxy.

TABLE 1: WHAT HAPPENS AFTER A PRESTRESSED BRIDGE IS HIT

Stage	Who Does It	What Happens
1	Someone reports a bridge hit to the district.	The district calls the Bridge Construction and Maintenance Section of Construction and Maintenance Division and sends out a maintenance crew.
2	The maintenance crew —	removes debris from the roadway and loose concrete about to fall from the girder. If necessary they put up tarpaulins or chicken wire around the girder to shield the traveling public from further falling debris. Traffic control may be required to limit traffic access to the damaged structure.
3	A Bridge Construction and Maintenance Engineer or other qualified structural engineer —	makes a structural inspection of the damage.
4	The inspecting engineer —	makes recommendations:

IF THE ENGINEER RECOMMENDS	*THEN*
No action is needed.	The district does nothing further.
The beams be replaced.	The district contacts the Design Division, and DES begin to draw up plans for replacement.
Repairs should be made.	The district bridge engineer or CMD Bridge Section usually decides what repairs to make.
Some beams should be replaced and some repaired.	The district, DES, and CMD work out replacement and repair strategies.

Stage	Who Does It	What Happens
5	The district —	lets a contract or makes the repairs with in-house maintenance forces.

TABLE 2: OVERVIEW OF REPAIR PROCESS

Stage	Who Does It	What Happens
1	District maintenance or contractor's crew —	removes loose concrete, saw cuts feather edges, places supplemental steel, and provides a clean, dry, roughened surface for patching.
2	District maintenance or contractor's crew —	preloads the beam to be repaired.
3	District maintenance or contractor's crew —	splices strands and/or places epoxy injection tubes as called for in the repair plan
4	District maintenance or contractor's crew —	places patching material in accordance with specifications and manufacturer's recommendations.
5	BRINSAP inspector —	should note in the bridge's file which girder(s) were repaired so they can be replaced if/when the bridge is widened.

PROTOTYPE ESTIMATES REMAINING STRAND TENSION

The research team of Project 0-1370, headed by Scott Civjan for this phase, developed a prototype device to estimate stress level in the remaining strands of a damaged girder. Team members also calibrated and field-tested this device and compared it to existing other types. The objective was to develop an easy-to-use, inexpensive field instrument. The device (Fig. 1), called a strand tension indicator, measures the deflection of the strand when an incremental force is applied transversely. The researchers considered the simplicity of this "lateral force-deflection approach" particularly attractive.

The researchers constructed two prototypes, one with a strand or gage length between the bearing pegs of 609.6 mm (2 feet) and a second with a 304.8 mm (1-foot) gage length. They assumed that the larger gage length would give more accurate results because, under a given load, the longer strand length would allow for more lateral displacement at the center of the loaded strand. Although the results might not be as accurate, the researchers felt that the smaller prototype would be a more practical field instrument, since exposed strand length in a damaged girder may be quite short. In initial laboratory testing, the results of the smaller prototype appeared to be within 10 percent of the actual strand tension. The researchers considered this sufficient and continued testing using the smaller prototype exclusively. They think that by standardizing testing procedures and improving the device design, the tension indicator should estimate tension within a given strand consistently within 10 percent of the strand force.

Improvements recommended by the researchers to turn the prototype into a working model include:

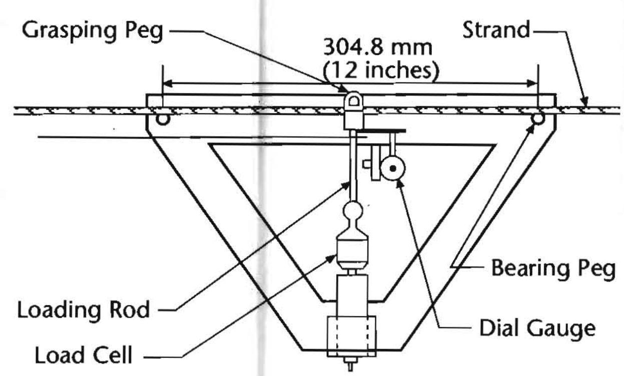
★ adding a deflection indicator that is directly in line with the load applied

★ machining all parts for extra stability and precision

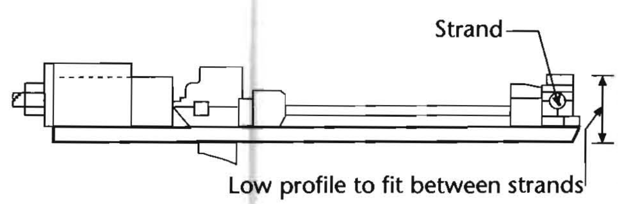
★ miniaturizing the instrument to allow testing of interior strands

★ enabling the instrument to output the corrected slope of the load-deflection plot on site so engineers could determine the strand tension within minutes

★ conducting more tests on various strands sizes to provide a larger database on which to base standardized plots for estimating strand loads



Prototype



Typical cross section

FIG. 1: Strand tension indicator.

FIRST IN-CYLINDER DIRECT INJECTION GASOLINE ENGINE ANNOUNCED

BACKGROUND

Mitsubishi Motors Corporation has announced the successful development and practical application of the first ever in-cylinder direct injection gasoline engine — a high-efficiency power unit that has been the dream of development engineers for over half a century. By reducing carbon dioxide emissions, among other things, this new-generation technology will make a major contribution to conservation of the global environment and its resources.

Fuel supply response and combustion control hamper current gasoline-powered engines because gasoline is fed into the cylinders after being mixed with air. The in-cylinder direct injection engine, however, injects gasoline directly into the cylinders, as in a diesel engine. Direct injection enables more precision in fuel control and, therefore, more complete combustion of much leaner air-to-fuel mixtures.

The Mitsubishi engine employs new combustion control technology to create stable ultralean combustion. Mitsubishi reports better fuel economy than a diesel engine, together with higher power output.

PRINCIPLE FEATURES

Low Fuel Consumption

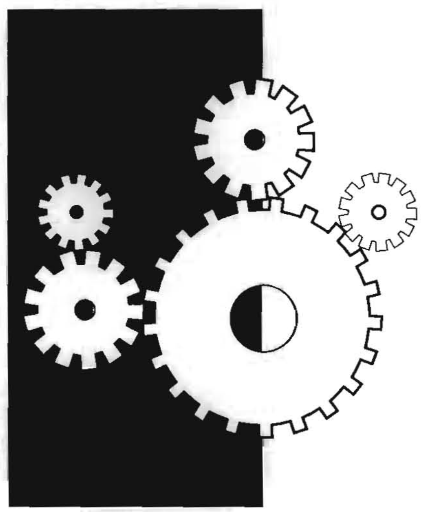
Achieving low fuel consumption requires the stable combustion of ultralean mixtures. The in-cylinder direct injection gasoline engine combusts ultralean mixtures with air-to-fuel ratios of up to 40:1 using original Mitsubishi technology. A new type of airflow in the cylinder stratifies the fuel charge. A new configuration sprays gasoline in directly into the cylinder during the final stages of the compression stroke. While the air-to-fuel mixture in the combustion chamber as a whole is very weak, its stratified and mixed state near the spark plug makes it very rich so that it ignites readily.

This stratification enables stable combustion with an ultralean mixture at idling speeds where combustion is normally least stable. The result is a reduction in idling fuel consumption of about 40 percent over conventional engines. In addition, consumption under normal driving conditions is reduced by about 25 percent at 40 km/h.

Higher Power Output

The new engine achieves higher power output (10 percent increase in torque and power output at all engine speeds over conventional engines) by increased volumetric efficiency and by higher compression ratios.

High-load volumetric efficiency is improved by a smoother intake flow in the redesigned intake port and by injection of the fuel during the intake stroke. The injected fuel cools the intake air as it vaporizes, subsequently increasing the air's density. As a result, the new engine achieves a significant increase over conventional engines in volumetric efficiency and the amount of air drawn in at all engine speeds.



The injection of fuel directly into the cylinder produces less detonation, while cooling of the intake air suppresses detonation further. These two factors make significantly higher compression ratio possible. With a combustion ratio of 12:1, the new engine realizes very high-efficiency combustion.

BENEFIT REALIZED

Operation of the new engine is split into economy and power zones, giving low consumption under normal driving conditions and high power output under high engine loads. In the ultralean burn economy zone, the engine operates with air-to-fuel ratios of between 30:1 and 40:1. This zone covers practical operation of speeds up to 120 km/h. The power zone fills the demands of high-load operation, such as hard acceleration.

Source: *In-Cylinder Direct Injection Gasoline Engine* [Mitsubishi Motors Corp. SHIBA, MINATO-KU, TOKYO, 108, JAPAN; phone (03) 5232-7165, (May 17, 1995)]. Abstracted from an article in *Document Review (June 1996): 23-24,* a digest of transportation-related issues published monthly by the Arizona Transportation Research Center. *Document Review* is available on the Internet at: http://www.azfms.com. Once there, select "full graphics," then "Document Reviews."

AASHTO METRICATION CLEARINGHOUSE

The AASHTO Metrication Clearinghouse often receives queries from local governments and consulting engineers. The theme of these questions is invariably the same. Customers want to know what is happening in their state and how to prepare to do business in a metric environment.

If you need to incorporate metric information into your strategic plans, the Clearinghouse can provide you with a list of metric publications, relate any new metric specification, or simply provide a brief statement on the metrication status of your state. The Clearinghouse works closely with the 50 state departments of transportation and serves as a good starting point for highway and transportation engineers seeking to understand the merits of the metrication effort.

WHY A CLEARINGHOUSE?

Due to federal legislation, an executive order, and a Federal Highway Administration (FHWA) mandate, all state departments of transportation (DOTs) must convert their standards, specifications, publications, equipment, and software to metric (SI) units. In undertaking this massive transition, the DOTs expressed an early desire to share information.

The American Association of State Highway and Transportation Officials (AASHTO) recognized this need and in June of 1994, the Texas Transportation Institute (TTI) was selected by the National Cooperative Highway Research Program to design and operate the AASHTO Metrication Clearinghouse. TTI brings to the project an unique combination of proven transportation and information experts.

Staff members have created databases which contain information about transportation-related metric issues, metrication publications, metric standards, metric conferences, and metric contacts. This information is communicated back to the transportation community through a customer support desk, the AASHTO Metrication Clearinghouse Newsletter, and files posted on the World Wide Web.

Customers of the Clearinghouse include state DOT metric coordinators, private firms contracted with the state DOTs to conduct metrication activities, FHWA metric coordinators, public or private entities conducting metrication for AASHTO under agreement with MCHRP, AASHTO staff members and committees, transportation industry-related associations, local government units, FHWA LTAP/T[2] Centers, and suppliers of highway-related products.

The Clearinghouse staff looks forward to sharing information with your state, cities or counties and hopes to be able to work together on our common goal of facilitating the adoption of the metric system. Comments, suggestions, and information requests are welcome and should be addressed to:

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SHRP CORNER

TEXAS HIGH PERFORMANCE CONCRETE BRIDGES

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INTRODUCTION

Two high performance concrete (HPC) bridge projects are currently under construction in Texas, with scheduled completion in mid-1996. The design and construction of these bridges are sponsored by the Federal Highway Administration (FHWA) and the Texas Department of Transportation (TxDOT), in cooperation with the Center for Transportation Research at The University of Texas at Austin. The Louetta Road Overpass in Houston, Texas, was placed under construction contract in February 1994, and the eastbound mainlanes of the North Concho River, U.S. 87 & S.O. Railroad Overpass (called the "San Angelo Overpass" in this paper) in San Angelo, Texas, were placed under contract in June 1995.

The need to consider the potential benefits of HPC in bridges is critical due to the deteriorating condition of the nation's infrastructure [Ref. 1]. The advantages of the increased durability that can be attained with HPC should result in longer-lasting bridges that have reduced maintenance requirements throughout their service lives [Ref. 2]. In addition, longer spans and/or fewer beams are possible with the higher strengths that can be attained with HPC [Ref. 3]. This should result in more economical bridge construction, either immediately or after the HPC technology has become a standard for bridge design.

[Editor's note: Mary Lou Ralls first presented this paper at Fourth International Symposium on Utilization of High-Strength/High-Performance Concrete, Paris, 1996. HPC has been a major thrust of the Strategic Highway Research Program (SHRP).]

STRUCTURAL DETAILS

The beams for both projects were designed according to the American Association of State Highway and Transportation Officials (AASHTO) shear requirements and prestress losses, and the AASHTO HS20 truck live load was assumed [Ref. 4]. Using psi units as defined in current AASHTO, an allowable concrete tensile stress of $10(f'_{ci})^{1/2}$ was used rather than the standard $7.5(f'_{ci})^{1/2}$ for release, and $8(f'_c)^{1/2}$ rather than the standard $6(f'_c)^{1/2}$ at 56 days. The 33 percent increase in allowable tensile stresses was based on test results for the laboratory trial mixes developed for the bridge beams in these projects. The standard allowable concrete compressive stresses of $0.6(f'_{ci})$ for release and $0.4(f'_c)$ for service state were used in the design of the beams. The design modulus of elasticity was a constant 41 GPa, to ensure adequate stiffness to resist the deflections resulting from the prestress force at release and the applied loads at service state.

Louetta Road Overpass

The Louetta Road Overpass, 119 m in length, consists of two adjacent three-span bridges of variable road-

FIG. 1: Interior of U-beam at precast plant.

way width with skewed supports [Refs. 5, 6]. The width of each structure accommodates three traffic lanes, two shoulders, and a ramp transition. The 37.0 m – 41.3 m – 40.4 m span configuration was required due to underneath roadway constraints. The maximum Louetta beam spacing of 4.8 m would have limited the span length of normal strength concrete U-beams to approximately 35 m, thus showing the need for HPC's high strength characteristic in congested urban environments.

The recently developed Texas U-beams [Ref. 7] are 1372 mm deep, open-top trapezoidal-shaped beams with a total top flange width of 2440 mm (Fig. 1). The U-beams are topped with composite precast prestressed concrete subdeck panels and cast-in-place concrete, for a total deck thickness of 184 mm. The six U-beams per span in the southbound mainlanes and the five U-beams per span in the northbound mainlanes are simply supported at the ends.

The U-beams are supported between abutments by piers (Fig. 2). The piers, designed by TxDOT to complement the aesthetic U-beam superstructure, are unique in several areas. Unlike conventional substructures with continuous caps supporting the beams, individual piers support the U-beams. Also, rather than the cast-in-place reinforced concrete substructures typically constructed in Texas, the precast hollow-core segments for the piers are match-cast and post-tensioned together prior to beam erection. A single-column drilled shaft foundation supports each pier.

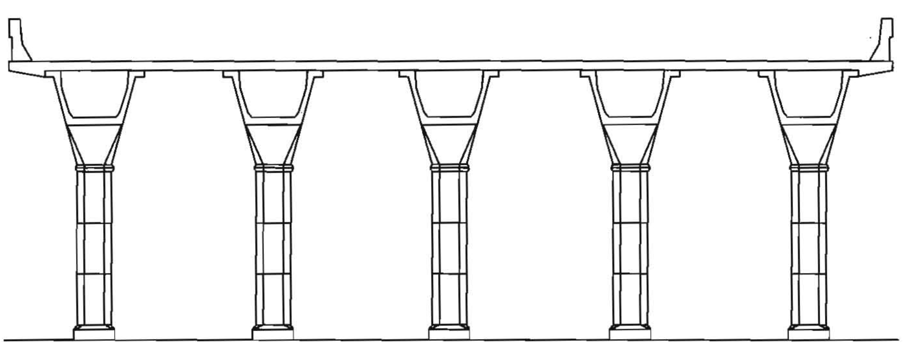

FIG. 2: Cross section of Louetta northbound mainlanes.

San Angelo Overpass

The San Angelo Overpass is a 290 m long, 8-span bridge. The 12.2 m width accommodates two traffic lanes and two shoulders, and gradually widens for an exit ramp beginning in Span 5 [Ref. 8]. A length of 47.9 m allowed Span 2 in the bridge to clear the North Concho River, thus easing construction of the substructure and also giving a more pleasing aesthetic appearance in the urban park along the banks of the river.

The beams in this bridge are the 1372 mm deep, I-shaped AASHTO Type IV beams (Fig. 3). The Type IV beam is the most common bridge beam used in Texas. A comparison of Span 1 in this HPC bridge with an identical Span 1 in an adjacent normal strength concrete bridge shows a reduction in number of beams from 7 to 4, made possible by the use of HPC. The simply supported beams in the five longest spans have beam spacings that range from 3.4 m in the 39.9-m Span 1, to 2.0 m in the 47.9-m Span 2. The 190 mm thick deck consists of precast prestressed concrete subdeck panels and cast-in-place concrete.

The AASHTO Type IV beams are supported on a cast-in-place concrete single-column bent with continuous cap. The substructure departs from conventional design with the use of windows bordered by fractured fin formliners in the columns. This treatment lightens the substructure for improved aesthetic appearance. A footing with two drilled shafts provides the foundation for each column.

Concrete Strength

The concrete compressive strengths required for the design of the Louetta and San Angelo bridge components are shown in Table 1. The most apparent benefit of HPC for beams is its higher strength capacity. The maximum required design strength is 90 MPa in the Louetta beams and 101 MPa in the San Angelo beams. These higher strengths allow the design of longer spans with fewer sup-

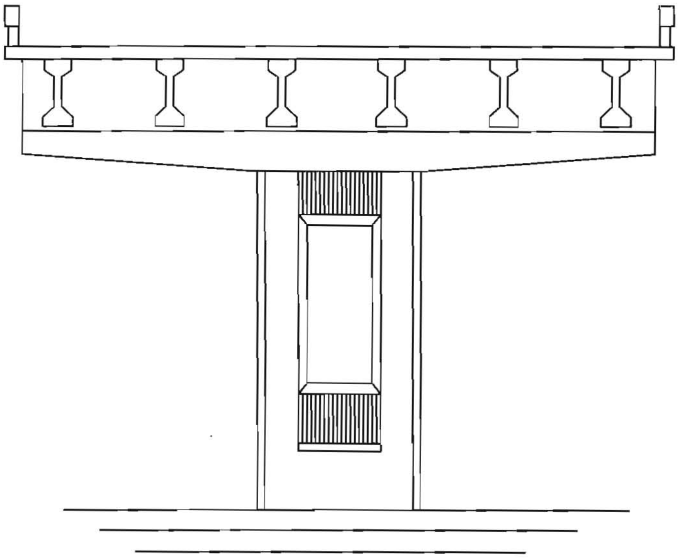

FIG. 3: Cross section of San Angelo span 2.

TABLE 1: DESIGN COMPRESSIVE STRENGTHS

Bridge Component	Design Concrete Strength (MPa)	
	Louetta	San Angelo
Beams	**69 – 90**	**75 – 101**
Substructure	**69**	**41 – 55**
Deck	**28 – 55**	**41**

ports, and/or wider beam spacings with fewer beams.

The precast, post-tensioned Louetta substructure requires 69 MPa strength. This compares to a required strength of 55 MPa in the cast-in-place caps and 41 MPa in the cast-in-place columns of the San Angelo substructure. The primary benefit of HPC in cast-in-place substructures is its increased durability. The San Angelo substructure could have, in fact, been designed with 28 to 34 MPa concrete strength.

The 89 mm thick precast prestressed subdeck panels in the Louetta project require 55 MPa compressive strength, compared to the 102 mm thick panels with 41 MPa strength in the San Angelo project. These design strengths are consistent with the cast-in-place portion of the decks, which require 55 MPa and 41 MPa in the southbound Louetta and the San Angelo panels, respectively.

The benefit gained from increasing compressive strength is not significant in the design of bridge decks. The cast-in-place portion of the northbound Louetta deck is, therefore, designed for 28 MPa, the strength typically required for bridge decks in Texas. The mix design components for the 28 MPa concrete are being apportioned to enhance the durability, with long-term monitoring planned to evaluate the performance.

Prestressing Steel

In order to fully utilize the 69 to 101 MPa concrete compressive strengths in the HPC beams in these projects, the larger 15 mm diameter prestressing strands at 50 mm spacing were required. This is consistent with previous research results that demonstrated the need for the larger strand [Ref. 3]. However, FHWA currently has a moratorium on the use of 15 mm diameter strand in pretensioned concrete applications [Ref. 9]. The moratorium was ordered because of concerns related to the transfer and development of this larger strand with its 40 percent greater prestress force.

In addition, AASHTO design code requires a minimum clear spacing between prestressing strands at beam ends equal to three times the diameter of the strand [Ref. 4]. Use of the 15 mm diameter strand would require a minimum clear spacing between strands of 45 mm rather than the 35 mm clear spacing that results from a strand spacing of 50 mm. Standard 13 mm diameter strands have a clear spacing of 37 mm with the 50 mm strand spacing.

Research was needed, therefore, to demonstrate that the 15 mm diameter strand at 50 mm spacing would

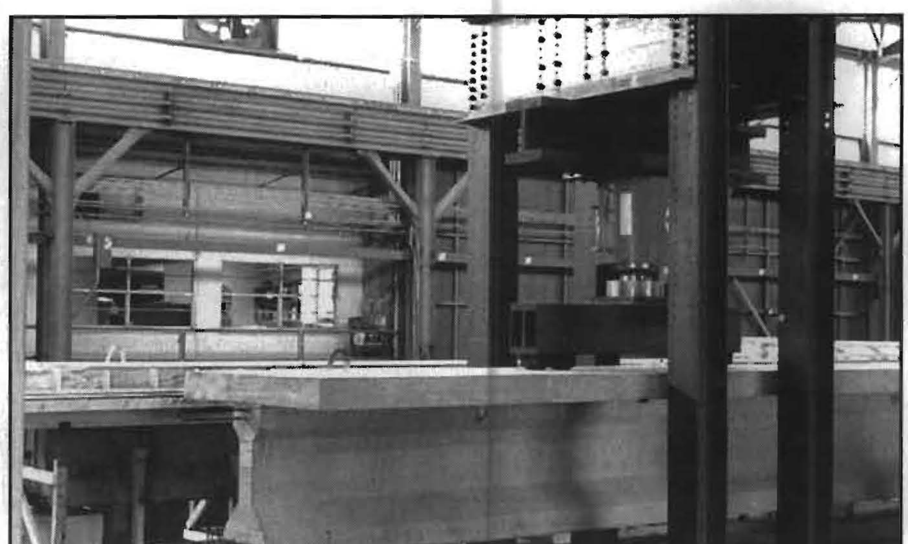

FIG. 4: Louetta U-beam steel placement.

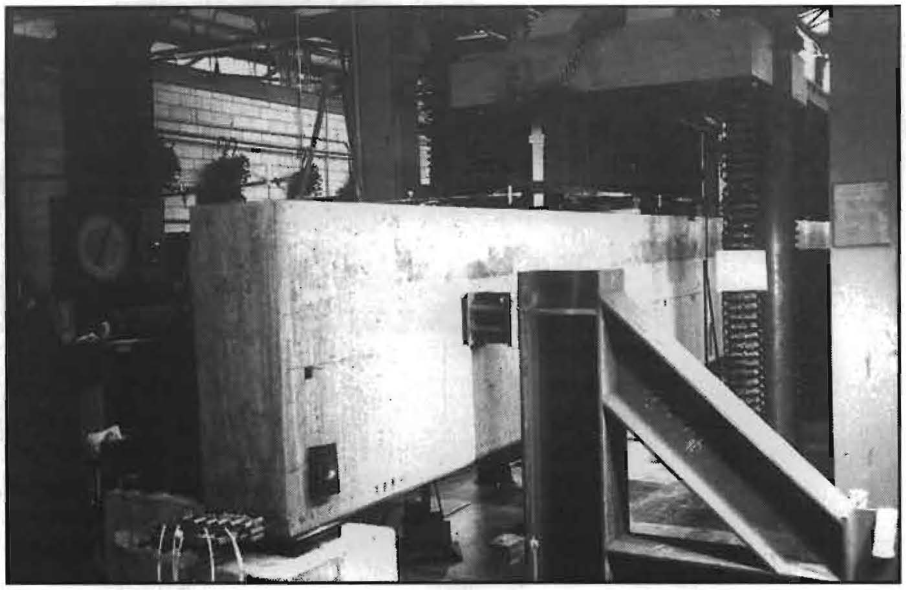

FIG. 5: Hoblitzell-Buckner beam testing.

provide adequate transfer and development lengths in the 69 to 101 MPa pretensioned concrete beams, with no concrete cracking at the ends of the beams. To obtain FHWA approval to use the strand, research beams were cast and tested in each project.

Hoblitzell-Buckner Beams

The 1400 mm bottom flange width of the Louetta U-beams allows 27 prestressing strands at 50 mm spacing to be placed in each of three layers, as well as additional strands in the stems (Fig. 4). The maximum number of 15 mm diameter strands required in the Louetta U-beams was 87. The use of this larger strand creates a very large prestressing force and, therefore, very large bond stresses in the concrete at the ends of the beams as the concrete grips the strands at release and at ultimate load.

To evaluate the transfer and development length of the 15 mm diameter strands in the high strength concrete, two 356 mm wide, 1067 mm deep rectangular beams, named the "Hoblitzell-Buckner" beams after their developers, were cast with six 15 mm diameter strands having a rusty surface condition and a spacing of 50 mm (35 mm clear spacing). Transfer of prestress was obtained by flame cutting the strands. The concrete compressive strength was 49 MPa at transfer.

The two beams were then transported to the Phil M. Ferguson Structural Engineering Laboratory at The University of Texas at Austin, and each end was tested to failure (Fig. 5). The concrete compressive strength was 91 MPa at the time of testing. Flexural failures in all four tests were obtained at concrete strains in the top fiber in excess of 0.0023, and calculated strains in the prestressing steel in excess of 0.034.

Average transfer length for the four ends was 363 mm. Development length was less than 1980 mm. No significant end slip occurred. For the parameters of this project, AASHTO code equations are conservative by a factor of 2.76. FHWA approval was received to use 15 mm diameter strand at 50 mm spacing in the Louetta project.

Texas Type C-Beams with Composite Decks

The 660 mm width of the bottom flange of the 1372 mm deep I-shaped AASHTO Type IV beams can accommodate 12 prestressing strands at 50 mm spacing placed in each of the first three layers, with a reduction of 2 strands per layer in the fourth layer and up into the 2-strand-per-layer web. The maximum number of 15 mm diameter strands required in the San Angelo I-shaped AASHTO Type IV beams was 84 with a 50-mm grid spacing.

Because FHWA approval for the use of 15 mm diameter strand in a pretensioned concrete application must be requested on a project-by-project basis, and this approval is based on test results showing satisfactory performance, a series of tests on I-shaped beams with composite

Figure 6: I-shaped beam with composite deck testing.

decks was initiated.

Two 1016 mm deep I-shaped HPC Texas Type C beams were cast with 10 strands in the bottom layer and 6 strands in the second layer of the 560 mm wide bottom flange. In addition, 2 strands in each of the top two layers of the top flange were added to control the concrete stresses at release. The strands, with bright surface condition, were spaced at 50 mm. Transfer of prestress was achieved by gradual multistrand release, which is the standard method used in Texas for pretensioned concrete beam fabrication. The beam concrete compressive strength was 69 MPa at transfer.

The two HPC beams were transported to Ferguson Lab, where a 190 mm thick, 1830 mm wide composite deck was cast on each beam. Each end of the beam was then tested to failure for each of the beams (Fig. 6). The concrete compressive strengths were 93 MPa in the beams and 35 to 40 MPa in the decks at the time of testing. Flexural failures in all four tests were obtained at concrete strains in the top fiber of the deck in excess of 0.0024, and calculated strains in the prestressing steel in excess of 0.031.

Average transfer length for the four ends was 508 mm. Development length was less than 1830 mm. Although a couple of the strands had end slips approaching 1 mm, overall performance was not affected. For the parameters of this project, AASHTO code equations were again conservative. FHWA approval was received to use the larger strand in the San Angelo project.

CONCRETE

Mix Design

Beams

The basic concrete mix design developed for the Louetta U-beams will also be used for the San Angelo beams. Texas Concrete Company in Victoria, Texas, the precast beam subcontractor for both projects, was guided by the project researchers in the development of this mix design. Table 2 gives typical mix components.

Decks and Substructures

Laboratory trial mixes for use in the precast and cast-in-place components of both projects have been completed by the project researchers. Final mix adjustments are being done at the precast plants and the batch plants based on field trial mixes, with guidance from the project researchers. Testing and evaluation of these mixes by the producers and the researchers are ongoing.

Heat of Hydration

The high heat gain in the concrete from hydration of the cement is an important part of the performance of HPC for both the U-beams and the I-shaped beams in these two bridge projects. The Louetta U-beams have solid end blocks with 460 mm minimum thickness at each end, creating a large volume of concrete in these regions of the beam. Temperatures reached a maximum value of slightly over 93°C in these areas overnight in the initial 12 hours after casting the concrete at Texas Concrete Company in Victoria, Texas. Thermocouples that were installed in the end block regions gave these temperature measurements of heat gain during initial curing under a wet cure blanket which completely covered the forms after the beams were cast.

The bottom flange of the U-beams is only 208 mm thick and, therefore, experienced smaller heat rise in the concrete. The thin web areas (126 mm thickness — see Fig. 2) had a smaller maximum temperature than either the end block or bottom flange areas. No steam curing was required but the heat of hydration was held under the curing blankets over the first 12 hours. While some shrinkage cracking developed, none of the cracks were structurally significant.

Some cylinders were cast in molds which had the instrumentation to maintain the same temperature in the cylinders during curing as was experienced for heat gain in the U-beam as described above. Figure 7 shows the cylinder molds which matched the beam temperature. Tests showed that these match-cured cylinders had slightly higher initial strength than the companion cylinders which were simply placed under the curing blanket beside the form. In general, it has been found that early heat generation resulting in concrete temperatures in excess of about 70°C results in negligible strength gain or strength loss. Thus, from the standpoint of concrete strength efficiency, temperatures in excess of about 70°C do not result in any additional benefit in strength gain, and may, in fact, result in a loss.

TABLE 2: MIX DESIGN FOR HPC BEAMS [REF. 6]

Component	Quantity	Type
Coarse Aggregate	1138 kg/m^3	Crushed dolomitic limestone, 13 mm max., ASTM GR 7
Fine Aggregate	610 kg/m^3	Sand
Water	147 kg/m^3	Potable
Cement	398 kg/m^3	Type III
Fly Ash	187 kg/m^3	ASTM Class C
Retarder	1045 kg/m^3	ASTM Type B
Superplasticizer	6885 – 8780 mL/m^3	ASTM Type F

Similar data will be taken with the I-shaped beams for the San Angelo bridge and the heat gains will be compared. Since the I-shaped beams are less massive than the 460 mm thick end blocks of the U-beams, the heat rise is expected to be smaller.

Beam Strength

Control cylinder strengths for the Louetta U-beams cast to date have exceeded design compressive strength requirements. Measured concrete compressive strengths average 61 MPa in 16 to 21 hours, 96 MPa in 28 days, and 105 MPa in 56 days [Ref. 6]. This indicates an average increase of 9 percent in strength gain from 28 days to 56 days.

The beam fabricator has decided to use the mix design shown in Table 2 for all HPC beams on both projects. This simplifies concrete batching operations and gives confidence that the required characteristics will be attained.

Testing and evaluation of the deck and substructure concrete continues.

Beam Modulus of Elasticity

Test results for the beam concrete to date show a typical modulus of elasticity of 45 GPa at 24 hours and 48 GPa at 28 days. Both values exceed the required design value of 41 GPa.

Beam Creep and Shrinkage

The ongoing test program consists of 28 creep and shrinkage specimens of the HPC beam mix. Of these 28 specimens, 9 creep specimens are being monitored for each of the two curing temperatures, with 4 companion shrinkage specimens for the low-temperature-cured HPC mix and 6 companion shrinkage specimens for the high-temperature-cured HPC mix. Results to date indicate that the total creep will be substantially lower than the total creep of normal strength concrete, with a significant percentage of the creep occurring at an early age. Measured shrinkage to date also indicates that the total value will be lower than shrinkage in normal strength concrete, with a large percentage occurring at an early age.

FIG. 7: Match-cured cylinder mold system.

Permeability

Permeability testing is ongoing, with the emphasis placed on the cast-in-place deck concrete and the substructure concrete since the durability of these components is most critical. A series of laboratory trial mixes has been evaluated for the decks, the substructures, and the beams. Variables include size and type of aggregate, and type and proportion of cementitious materials and admixtures. Results from these tests are being used in the development of the field trial mixes. Testing and evaluation of the field trial mixes and the actual mix designs used in the bridges are also planned.

Permeability values for the high strength beams are typically very low. Values for the deck and substructure trial mixes have typically varied from moderate to low to very low, as the project researchers continue their adjustments to obtain their target of less than 1500 coulombs.

INSTRUMENTATION

Both the Louetta and the San Angelo bridge projects involve a detailed instrumentation plan for monitoring HPC bridge performance. These instrumentation plans were developed by the research team at The University of Texas at Austin and approved by both TxDOT and FHWA before any beams were cast. The design of the instrumentation was aimed at obtaining long-term measurements to record the actual performance of these HPC bridges over the first three years of their life. The installation of the instrumentation in the prestress plant allows these measurements to be made over the full life history of the beams.

The selected beams are instrumented with three basic types of electronic gauges: electric resistance strain gauges, vibrating wire strain gauges and thermocouples. In addition to electronic gauges, some concrete surface strains are measured with mechanical gauges. The mechanical gauges record the response of the concrete to transfer of the prestress force and these data allow the transfer length for the 15-mm diameter strand to be determined. Camber and deflections of these beams are measured with a stretched-wire system. The electronic gauges are used to measure strain and temperature from a period shortly after casting to a period well after the bridge has been completed. The vibrating wire gauges were selected because of their known long-term dependability for obtaining concrete strain data.

The electronic gauges are hooked up to a very compact data acquisition system that stays with the beams as they move from the plant to the bridge. The battery-powered system has proven to be very reliable, allowing readings to be scanned at preselected time intervals.

The stretched-wire system allows the deflections to be monitored at all stages of construction. A ruler is attached to the beam at midspan and small retrofit bolts are installed at each end of the beam after removal of the forms but prior to release of the prestressing strands. A stretched wire between the bolts provides a reference for camber and deflection readings from the ruler. The ability of the stretched-wire deflection system to move with the beam as the bridge is constructed is an important consideration. The long-term deflection performance is very important to obtain along with the strains measured with electronic gauges.

Thermocouples are mounted in selected beams to allow measurement of temperature over the depth of the section during the day or night. It is known that deflections occur due to thermal changes in the concrete, and these measurements of the thermal strain gradient are important to capture. Little data is available to support currently used thermal gradients in design of bridges. Data on deflections from load changes, temperature changes and applied live load will be measured.

SUMMARY

Two high performance concrete bridges are under construction in Texas. Research results to date include the following.

★ High performance concrete, with its improved durability and higher strength, as needed, promises to be a cost-effective material for use in bridge construction. Reduced maintenance over a longer service life is anticipated to result from the use of HPC.

★ Concrete properties (strength, modulus of elasticity, permeability, etc.) continue to be tested in the laboratory trial mixes, field trial batches, and actual bridge concrete. Performance requirements continue to be evaluated.

★ Research beam test results show that 15 mm diameter strands at 50 mm spacing in beams with concrete compressive strengths in excess of 69 MPa have excellent bond characteristics. Measured transfer and development lengths are less than AASHTO code requirements.

★ Long-term monitoring of bridge behavior under service load is critical for evaluating the long-term improvement in durability of high performance concrete bridges.

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The Local Technical Assistance Program (LTAP) has served Texas since 1984, when the Federal Highway Administration (FHWA) officially made it a Technology Transfer Center. The Texas Department of Transportation (TxDOT) and the FHWA fund the program. The Texas LTAP is a cooperative effort between TxDOT and the Texas Engineering Extension Service (TEEX). TEEX is a part of the Texas A&M University System.

The Transportation Training Division of TEEX manages the Texas LTAP project. TEEX provides training and technical assistance, based on the level of need, to cities, counties, state agencies, and private consultants. Such training reduces the time lag between development and implementation of technologies, upgrading the skills of transportation workers at all levels. LTAP's goal is to improve roads and bridges through technical assistance and training mainly geared to local government workers.

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Many Texas counties and road personnel have received training and technical assistance through the program. TxDOT Division and District personnel can direct local transportation officials to LTAP for help. TxDOT Area Engineers may wish to partner with local county engineers on LTAP traffic control courses or other training for roadworkers. TxDOT training coordinators in areas where Spanish is widely spoken may want to make use of the LTAP Spanish Language Subcenter. LTAP provides a variety of information and services to any interested party. Some of the services are:

★ **Lone Star Roads Newsletter:** LTAP's quarterly newsletter, *Lone Star Roads,* tr¡anslates into understandable terms the best available technologies in the areas of roads, bridges, and public transportation. It outlines new highway technologies, announces upcoming workshops and training programs, and summarizes technical reports and publications.

★ **Workshops:** Training is scheduled on selected topics at convenient locations throughout the state.

★ **Roadshow:** The LTAP "Roadshow" is a low-cost, traveling training program that is available on request. Cities and counties across the state supply the location and audience. LTAP provides the latest videotapes, films, and slide/tape shows on roadway-related topics.

★ **Roads Scholar Program:** LTAP offers training for city and county employees by civil engineers in the latest technologies and innovations. This program is a series of special training sessions conducted throughout the state. People who complete the specified number of training sessions become "Roads Scholars."

★ **Technical Assistance:** TEEX training specialists field questions received through the mail or phoned in to the LTAP toll-free number. Over 3,000 publications and nearly 400 videotapes are available through the center's library collections. Upon request, LTAP can locate a book, article or research report on almost any topic and provide a copy.

★ **Special Projects:** An ongoing project of LTAP is The University of Texas at El Paso Spanish Language Subcenter. The subcenter produces Spanish-language technical manuals, training courses, and videotapes. Subjects include traffic control in construction zones, pavement maintenance, and heavy equipment operation.

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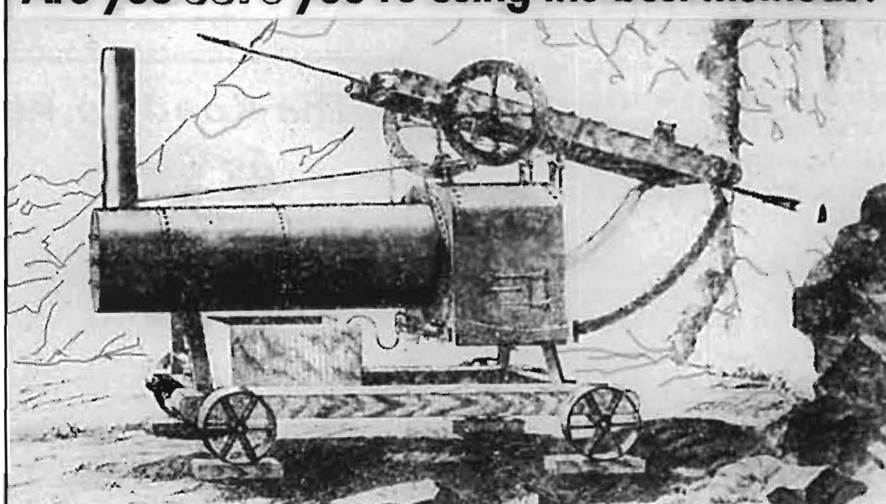

Rock drill invented by J. J. Crouch 1849

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CAN PLASTICS BE USED IN GUARDRAIL SYSTEMS?

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INTRODUCTION

The use of plastic in the construction industry is growing exponentially since the mid-1970s. Because of their unique and wide range of material properties, plastics offer advantages in many applications, enhancing both design and performance. However, to ensure optimum value, engineers need to consider these unique properties carefully before using plastics in a design.

This article explores the possible use of plastic in metal beam guardrail systems or in innovative guardrail system designs. It presents the background and required performance of guardrail system posts and explores some potential advantages of using plastic.

PLASTIC AS A CONSTRUCTION MATERIAL

In many ways, plastics are very similar to other construction materials. No construction material is superior to all others in every way. Each has its strengths and limitations. In construction, plastics are beginning to take their place among the more traditional materials: steel, concrete, and wood. Selecting the best material for a particular job is a decision based on many factors. Plastics are not suitable for every application, but they may provide the best value in specific cases.

Types of Plastics

There are two broad classes of plastics: thermoplastics and thermosets. Thermoplastics are plastics that soften when heated and harden when cooled. They may be reheated and cooled, and thereby reformed, repeatedly. Thermosets are plastics that may be formed only once. These plastics "set" by chemical reaction or by heating and cannot be reheated and reformed.

Plastics may also be divided into two other simple, broad categories: reinforced and unreinforced. The addition of reinforcing such as glass fibers to a plastic may greatly enhance the properties of the material, but they also make the plastic more expensive.

Material Properties

A wide variety of material properties may be achieved from plastic (Table 1); but the more the properties are enhanced, such as by the addition of reinforcing, the more sophisticated and expensive the plastic becomes.

TABLE 1: GENERAL MATERIAL PROPERTIES OF PLASTIC

Usually Positive	Usually Negative
Is light weight	Deteriorates under UV
Has good specific strength	Has high thermal expansion
Is flexible	Is not ductile
Is corrosion resistant	Is very susceptible to creep
Is formable	Has low modulus of elasticity

Tensile and compressive strengths for unreinforced plastic can vary from 21 MPa [3000 psi] to over 69 MPa [10,000 psi]. With reinforcing, strengths can reach well over 690 MPa [100,000 psi], though such materials are somewhat exotic. Plastics are light materials. Therefore, they tend to have good specific strengths. However, they also have relatively low modulus of elasticity values, typically 730 kPa [1.0 x 106 in./in^2]. It is important to understand that, while plastics tend to be very flexible, they generally are not ductile. Further, plastics are very susceptible to creep, also known as viscoelastic behavior: time-dependent strains that increase under uniform application of stress [Ref. 1].

Plastics have relatively low specific gravities. Typical values run from 0.9 to 1.3 and above. They are lighter than aluminum or glass, but heavier than wood [Ref. 1].

One of plastic's most attractive features is corrosion resistance. Though plastics are susceptible to deterioration under sustained ultraviolet (UV) exposure, they are easily protected from this phenomenon with pigmentation. Plastics are nonconductive and therefore make good electrical and heat insulators. However, they also have high coefficients of thermal expansion, exhibiting relatively high expansions when they are subjected to temperature gradients.

For more in-depth material property descriptions, the ASCE Structural Plastics Design Manual [Ref. 1] is an excellent resource.

Fabrication

There are many ways to fabricate plastic components. The process used can greatly affect the cost of the material and the material properties. Plastic components that are not too large may be molded. Longer plastic components of uniform section, such as sheeting, shapes, and conduit, may be extruded or pultruded. These processes tend to be very economical. Large, sophisticated parts requiring a great deal of reinforcing are usually made one at a time and therefore can be very expensive.

POTENTIAL PLASTIC APPLICATIONS IN GUARDRAIL SYSTEMS

Current Systems

Two types of longitudinal traffic barriers exist on highways in Texas: "rigid" and "flexible." They both serve the same purpose: to contain and redirect errant vehicles. Rigid barriers — concrete safety shapes — are needed where deflections are high, such as on bridge decks [Ref. 6]. Flexible systems, such as metal beam guardrail systems, are generally used to protect vehicles from steep slopes and from fixed objects . (Fig. 1).

Guardrail system comes in two basic varieties, depending upon the type of post used: wooden (timber) posts or steel posts (Figs. 2 and 3). Both pass current performance testing, so the choice between the two is primarily economic. Up front, timber posts cost less than metal posts. Timber posts run $11.00 to $15.00 each, where metal posts cost about $20.00 each. In construction contracts where a linear-foot-per-installed-system cost is used, the cost differences are less.

FIG. 1: This guardrail system protects vehicle from concrete columns and, further afield, from an overhead sign structure.

FIG. 2: Not-so-typical steel post. This variety is no longer in use, but when rails become obsolete, they remain in place until they need to be repaired. On this post, the grains from galvanizing are visible.

The biggest factor effecting the life-cycle cost of the posts is durability. Timber posts must be chemically treated to withstand decay, but the effectiveness of this protection varies greatly with the environment. In arid west Texas, timber posts may last indefinitely. On the Texas coast, however, the expected life of timber posts may be as short as seven years. Steel posts, which are always galvanized, perform much better in coastal environments [Ref. 6].

Guardrail systems contain and redirect errant vehicles. Though their operation is obvious for the most part, guardrail system details help minimize crash severity. First, the system is designed so that the post will often rotate out of the soil before it fractures, with a hinge forming at the soil line to about 457 mm [18 in]. below. This rotation absorbs more energy than fracture and provides a less severe deceleration than an impact with a tree or column [Ref. 2].

The front end of metal beam guardrail — the end being approached by traffic — requires special treatment. In the past, untreated, stand-up rails, when struck head-on, have speared vehicles, passing through passenger compartments when the impact speeds were great enough. A popular way of avoiding spearing is to turn the beam down at the end — the "Texas Twist" — but this treatment occasionally can cause subcompact cars to ride up onto the rail. In newer treatments like the guardrail-extruding terminal, the first several posts break away when the treatment is struck end-on. To ensure fracture, holes are drilled into the

FIG. 3: Typical wooden post. The cracks seen here are not a structural problem. However, cracks expose untreated areas of wood and speed deterioration.

posts at the base. Metal tubes are used to make the poles easier to replace, but they are only marginally effective as the posts tend to swell and get stuck in the tubes [Ref. 2].

A feature becoming more common in Texas is the block found on some guardrail systems between the rail and the post (Figs. 4). The block is provided for two reasons: first, to move the rail out past the face of an existing curb and second, to minimize snagging of a vehicle's wheels on the posts. Most other states use square wooden posts in their guardrail systems, and the square geometry results in sharp corners that can snag a vehicle during impact. Snagging subjects the vehicle's occupants to severe deceleration forces [Ref. 2]. In Texas, the block has been used to move the rail away from curbs, but round posts have precluded the need for blocks to prevent snagging. Where block-outs are needed on round posts, a molded plastic block curved on the back to match the round post might be an attractive alternative to a flat-backed wooden block.

Performance Criteria

The National Cooperative Highway Research Program (NCHRP) has provided performance criteria for guardrail systems and other highway safety details since 1962. ***NCHRP Report 350, Recommended Practice for the Safety Performance Evaluation of Highway Features*** [Ref. 5], published in 1993, now governs guardrail system performance criteria.

There are no specific design criteria for guardrails; rather, NCHRP Report 350 establishes performance criteria. Report 350 outlines a required test matrix that includes six basic test levels. The description of the tests is very comprehensive, including details about the testing facility, the soil, propulsion, braking, and surrogate occupants. The report also details requirements for documentation, evaluation, and implementation. Of special interest when considering a new material or design, "Appendix D: Analytical and Experimental Tools" describes the general method for designing new safety features. The introduction to this appendix reads:

> Design, synthesis, and development of a new safety feature is not a straightforward procedure but is an iterative process requiring trade-offs among sometimes conflicting safety performance requirements, environmental consideration, and costs. In this appendix, analytical and experimental tools (excluding full-scale crash tests) that are typically used in developing and evaluating new safety features are presented and discussed. Also, application and limitations of these techniques are presented.

For any serious consideration of new materials in guardrail system assemblies, such as plastics, Report 350 is an excellent design guide and a necessary means of evaluating their performance.

Useful Properties of Plastic

Plastic has a number of properties and construction aspects that may prove beneficial when considering use of the material in guardrail systems:

Durability

Plastic performs well in adverse environments. In west Texas, timber posts last indefinitely, but closer to the coast, decay becomes a big problem. Galvanized steel posts have good life spans, but can also become susceptible to corrosion in the long term. Unpigmented plastic is susceptible to UV deterioration. Adding the correct pigment to a plastic prevents UV deterioration.

Flexibility

A very important feature for a guardrail system is that it has the right amount of give. Vehicles must not break through it, nor must they bounce back into traffic. Present metal beam guardrail system achieves sufficient flexibility when posts rotate through the soil or yield. Most plastics do not have sufficient ductility to yield like a steel post, and designing a plastic post stiff enough to rotate through clay would probably not be cost effective. However, if taken advantage of properly,

FIG. 4: Here a timber block carries the rail out over an unseen curb.

plastic's flexibility might result in a system with performance superior to present designs.

Traditional designs minimize the severity of accidents by containing and redirecting vehicles, but the impact is still very violent, often causing severe damage to both the vehicle and the barrier. Damage can be minimized by using a flexible plastic net to decelerate an errant vehicle, much in the same way that nets are used to catch trapeze artists. Such a system has been developed and is being marketed. Though this idea might have seemed farfetched a few years ago, it is the type of thought process that should be used when considering plastics for construction applications: how can the unique properties of the material be best put to use?

Formability

Because of its formability, it is often easy to do with plastic what is impossible to do with other materials. This trait could provide some advantages. For example, instead of having to make blockouts and posts as separate items, the post and block could be molded as one piece, or if a weak plane is needed at ground level, a smaller section could be molded. Formability could provide a benefit if posts were designed of an extrudable shape and material. For example, if plastic pipes were used, they could be extruded or pultruded, potentially resulting in a very economical product.

Combining elasticity and formability, plastics could be used only for the blocks. They would be cheap to manufacture, and they might improve the design of the rail by providing a softer material immediately behind the beam, cushioning vehicle impact. Further, the interaction of the square blocks with the round poles is less than ideal. Plastic blocks could be molded with a convex surface just as easily as with a square surface. With the change in performance criteria and the subsequent need for blocks with all posts, plastic blocks could be an economical solution that enhances the performance of the rail as well.

Absorption

Guardrail systems are now being designed with safety end treatments to prevent spearing and ramping. To work correctly, the first 5 or 6 posts in this type of system must fracture on contact. Holes drilled into these posts at ground-level provide a plane of weakness and ensure the fracture. Tubes make the fractured posts easier to replace, but timber posts swell and become stuck in the tubes. Plastic posts would not be susceptible to this absorption, and so their use may prove to be a benefit in this application.

Though plastics tend to have high coefficients of thermal expansion, this can be managed by design of the material if necessary. Expansion varies between types of plastic, and reinforcing can minimize expansion.

Recycling Potential

Transportation officials are making a strong effort to use recycled materials. Many states now provide a bonus if the contractor uses recycled materials. Because thermoplastics may be melted and reformed an indefinite number of time, they have a strong potential for being recycled. However, manufacturers of recycled plastics typically use a wide variety of materials in the mix, making it difficult to ensure uniform performance of the materials in construction applications.

Unforeseen Benefits

Sometimes when a new material is used for one reason, it turns out to provide additional, unanticipated benefits. For example, Florida DOT wrote a specification for recycled fence posts (not guardrail posts). They anticipated and achieved longer life in the plastic posts over wooden ones, but they also found that the plastic performed a better job of keeping the fencing up. As wooden posts swell and shrink, staples eventually loosen and fall out. The staples attaching fence to plastic posts were ten times harder to get out and stayed in place much longer. [Ref. 3]

DESIGN CONSIDERATIONS

Plastics have a number of properties that can lead to a superior product. However, to make the use of plastics successful, a number of important considerations must be kept in mind:

Reinforced Versus Unreinforced Materials

Performance can be greatly enhanced by adding reinforcing to the base material. However, the more reinforcing that is added, the more difficult it is to fabricate components properly and, consequently, the more expensive the products become. Therefore, design engineers should consider using unreinforced plastic or moldable reinforced plastics to best utilize the flexibility of plastics.

Viscoelasticity

Plastic has many unique properties, but engineers may find creep, or time-dependent deformations under constant load, challenging to work with at first. All plastics exhibit viscoelastic behavior, and this trait must be considered in any design.

Commitment to the Product

Guardrail systems must meet Report 350 criteria before they can be used. Plastic may prove to be very beneficial as a guardrail system material, but the material developer must be prepared to stand behind the product and take it through all the necessary stages of evaluation to ensure conformance with Report 350. Evaluations can be costly and time-consuming. To achieve success, the developer or manufacturer needs a strong commitment to the product.

Cost

To be given serious consideration, the use of plastic products, whether for some components or for the entire structure, must be economically viable. If plastic posts are to be substituted, their cost must be commensurate with timber and steel post prices — or they must provide an extraordinary benefit. Cost analysis should include consideration of life-cycle costs and not just up-front cost. However, cost should not be seen as the bottom line. If plastics can be used to develop a better, safer, longer lasting guardrail system, cost may be outweighed.

CONCLUSIONS

Plastics are finding their way into all industries, including construction. As relatively new materials, plastics have a great potential to provide significant, positive impacts on many types of structures. One is guardrail systems.

Points to consider in the use of plastic for guardrail systems are:

- ★ **Performance Criteria** — NCHRP Report 350 governs performance of guardrail systems. Developmental work and ultimate performance of any new material and/or detail must conform to this report.
- ★ **Material Properties** — Because of their unique properties, plastics may improve the shock-absorbing performance of safety barriers. Plastic's durability, flexibility, formability, and absorption all suggest possibilities for guardrail system innovation.
- ★ **Design Innovations** — Use of plastics should not be limited to replacing parts with plastic imitations; use of plastics should focus on their key properties and optimize a design entirely.
- ★ **Recycling Potential** — The potential for use of recycled materials is also attractive. Thermoplastics are easily remelted and reused.
- ★ **Cost** — To be viable, the cost of using plastic should be commensurate. However, new applications should not be avoided simply because they are more expensive.
- ★ **Product Commitment** — Efforts to implement the use of plastic need to be pursued. Manufacturers or innovators who have proven their parts or designs under NCHRP Report 350 testing should be given positive consideration.

Achieving the highest values in structures is a common goal among all transportation officials and engineers. Plastics present an opportunity to enhance the safety, reliability, and performance of transportation features, and guardrail systems are an excellent candidate for such improvement.

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HANDS-ON COMMUTING

By May of this year, 700 commuters in Houston had real-time traffic and transit information put in the palms of their hands. Those 700 volunteers are part of the ***Houston Smart Commuter IVHS Operational Test*** (TTI 7-1985)— a joint project that's using advanced technologies to give commuters current traffic and transit information so they will be less likely to drive alone and more likely to carpool on the HOV lane and take the bus.

Participants are provided with a Sony MagicLink handheld computer that graphically presents current travel speeds on the IH-45 Freeway general-purpose and HOV lanes and on the Hardy Toll Road. With the device, participants can access bus schedules, fares, and maps to park-and-ride lots and bus stops. They will also be able to access similar information by touch-tone phones.

"We are monitoring how frequently people access the systems, the types of information they request, and ultimately if they change their travel behavior," says Katie Turnbull, head of Texas Transportation Institute's (TTI) Systems Planning Division. "Commuters may choose to take the bus or carpool when traffic is especially bad on the freeways, or they may take a different travel route, alter their departure time, or even telecommute," Turnbull said.

Project 7-985 represents the joint efforts of federal, state and local agencies and the private sector. The Metropolitan Transit Authority of Harris County (METRO), the Texas Department of Transportation (TxDOT), the Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) are funding the project. TRW is heading the private sector consortium that includes CUE Networks Corporation, Fastline Traffic, Celebration Computer Systems, S&B I, and Software Decisions, Inc. The consortium is providing various components of the information delivery system, including the Sony MagicLinks, for the program volunteers.

"This effort is an excellent example of the public/private partnership needed to help advance the deployment of ITS," said Andy Schafer, TRW project manager. "We are pleased to be participating with METRO, TxDOT, and TTI in this exciting project."

Sholeh Karimi, project manager for METRO says, "The results from this project will benefit not only commuters in Houston, but travelers throughout the country."

As the first of its kind, the test will be watched carefully by other transportation agencies as they look for indications of whether or not these strategies will work, if the technology will be accurate, and if the public will even bother to use it.

Hand-held computers are putting real-time traffic information into the hands of commuters, allowing them to check traffic conditions before leaving home. Photo credit: James Lewis.

Using funding through the Texas A&M Intelligent Transportation Systems (ITS) Research Center of Excellence, researchers at TTI are also exploring other communications techniques to make it easier for commuters to obtain traffic and transit information. They are also investigating the use of the Internet, interactive cable television and other technologies as media to carry traffic and transit information.

People want to travel efficiently and safely, and in many cases they simply need to know what route or mode is best," says Turnbull. "That's what ***Smart Commuter*** is all about — getting them the right information at the right time. And we're using ITS to do it!"

For more information on study TTI 7-1985, ***Houston Smart Commuter IVHS Operational Test,*** contact TTI's Katie Turnbull at (409) 845-1535 or Darryl Puckett, (713) 686-2971; TxDOT's John Gaynor at (713) 881-3060; or METRO's Sholeh Karimi at (713) 613-0315.

*Reprinted with minor editing from TTI's **Researcher** 32 (Spring 1996): 12.*

Research Management Committee (RMC) Meeting
December 2-6 in Corpus Christi as follows:

December 2 (1:00 pm) — December 3 (5:00 pm)

RMC 1 "Management and Policy"
RMC 6 "Pavements"
RMC 9 "Traffic Operations"

December 4 (8:00 am) — December 5 (12:00 pm)

RMC 2 "Multimodal Transportation"
RMC 3 "ROW, Hydraulics, & Environmental Conservation"
RMC 7 "Materials"

December 5 (1:00 pm) — December 6 (5:00 pm)

RMC 4 "Roadway Planning & Design"
RMC 5 "Structures"
RMC 8 "Construction & Maintenance"

Contact RTT's Debbie Hall at (512) 465-7684 or Tom Yarbrough, P.E., at (512) 465-7685.

PIECING IT TOGETHER: A STATE ITS PLAN FOR TEXAS

With dozens of intelligent transportation system (ITS) projects in numerous cities, Texas Department of Transportation (TxDOT) is more than a little busy improving highway transportation in Texas. With all of the ITS plans and projects and new technologies, things could easily become overwhelming.

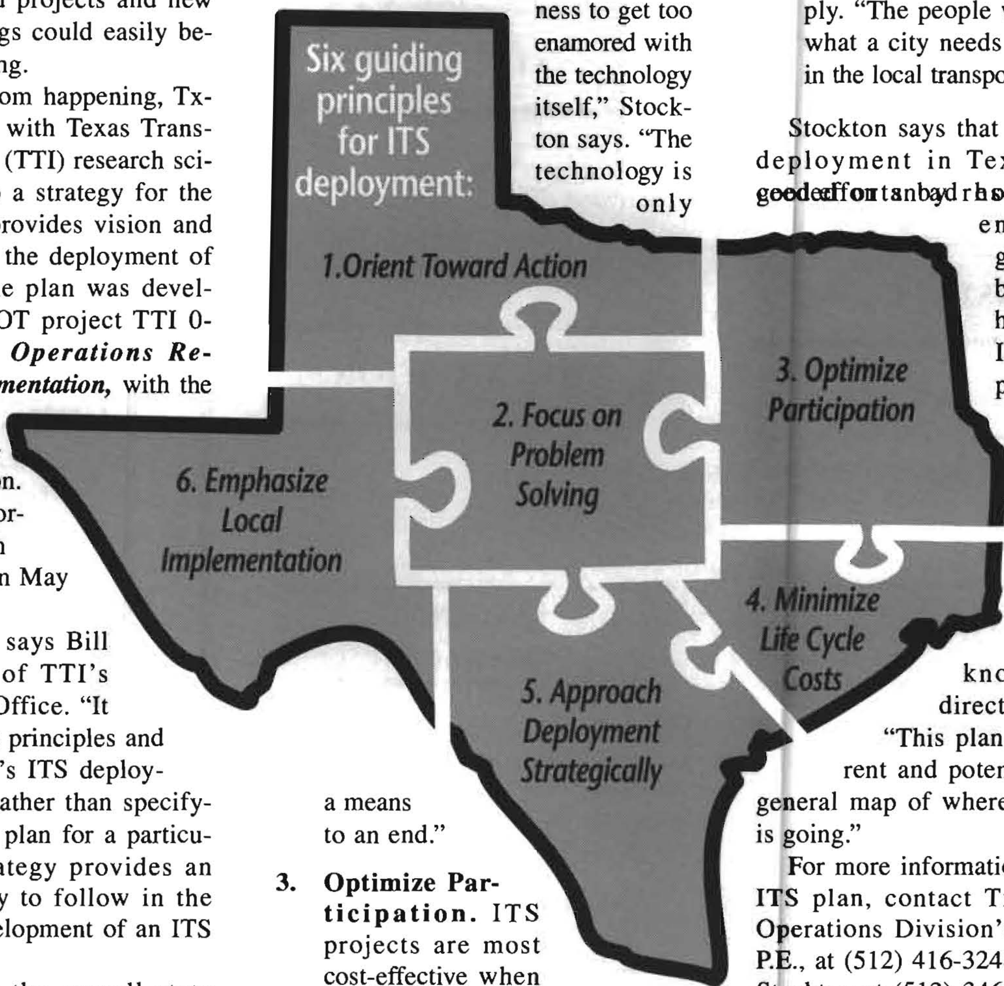
To keep this from happening, TxDOT has worked with Texas Transportation Institute (TTI) research scientists to develop a strategy for the entire state that provides vision and sets priorities for the deployment of ITS in Texas. The plan was developed under TxDOT project TTI 0-1467, ***Highway Operations Research and Implementation,*** with the cooperation of the Federal Highway Administration. The Texas Transportation Commission adopted the plan in May 1996.

"It's a guide," says Bill Stockton, head of TTI's Agency Liaison Office. "It highlights guiding principles and identifies TxDOT's ITS deployment priorities. Rather than specifying a deployment plan for a particular city, this strategy provides an overall philosophy to follow in the course of the development of an ITS project or plan."

Stockton says the overall state plan simply can't map out the deployment of every ITS project in the state, because everyone's needs are different and because of the rate at which ITS technology is changing.

"It's like computers," he says. "If you were to write a five-year plan for implementing a new computer system, the system would be outdated by the third year, and your plan would be useless."

The state plan, instead, outlines the following six guiding principles for ITS deployment:



1. **Orient Toward Action.** An emphasis on rapid deployment of "building blocks" while long-range planning is under way.
2. **Focus on Problem Solving.** "There's a tendency in this business to get too enamored with the technology itself," Stockton says. "The technology is only a means to an end."
3. **Optimize Participation.** ITS projects are most cost-effective when many entities — public and private — are involved. Stockton says that the potential for including the private sector is the most underdeveloped part of ITS.
4. **Minimize Life-Cycle Costs.** Agencies should avoid systems that they cannot afford to support fully for the life of the system.
5. **Approach Deployment Strategically.** ITS projects should fit with other transportation planning in the area, and the components of the technology used should be modular and upgradeable to allow for replacement of components without replacing the entire system.
6. **Emphasize Local Implementation.** "The Austin headquarters of TxDOT can't know what's best for every city," says Stockton simply. "The people who know best what a city needs are the people in the local transportation offices."

Stockton says that until now ITS deployment in Texas has proceeded on an ad hoc basis with good efforts and researchers engineers and good technology being used. But he hopes the state ITS plan will provide a clearer context and direction for future ITS deployment success.

"It's important that others know TxDOT's direction," he says. "This plan will give current and potential partners a general map of where ITS in Texas is going."

For more information on the state ITS plan, contact TxDOT Traffic Operations Division's Randy Keir, P.E., at (512) 416-3248 or TTI's Bill Stockton at (512) 346-9875 (E-mail: bill-stockton@tamu.edu).

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