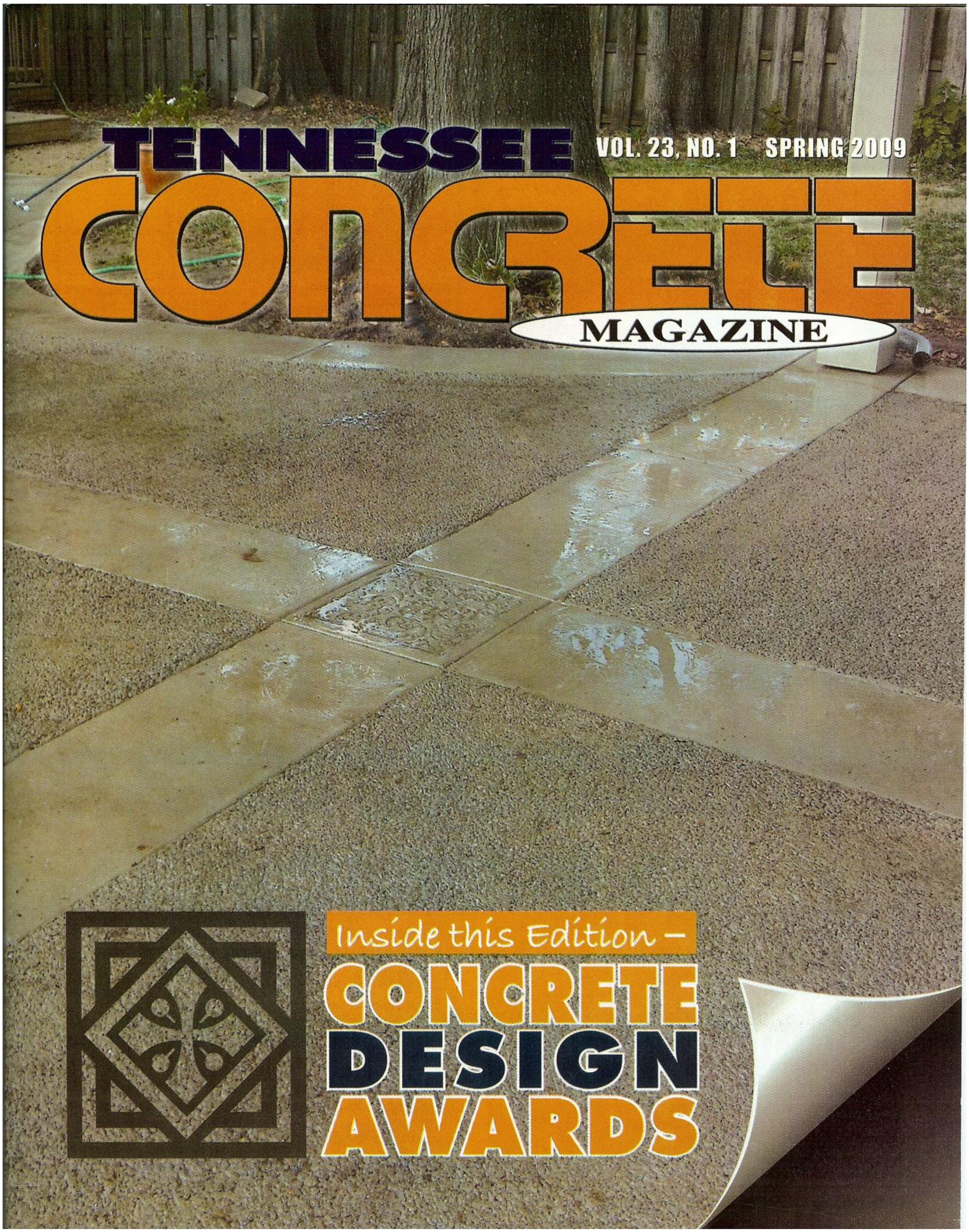
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Five Part Series on the—

New TDOT 204.06 CLSM Specification

Part 5: The Future of CLSM in Tennessee

L. K. Crouch, J. D. Self, Adam C. Walker, Jason Phillips and Alan Sparkman

INTRODUCTION

This paper is the fifth in a five part series of technology transfer articles on the new 2006 TDOT 204.06 CLSM Specification (1). We hope you find the information presented helpful in producing CLSM mixtures meeting the new specification. In the final article, the authors address the question, "What are the next steps in CLSM research and development in Tennessee?"

Table 1 shows performance-related property requirements of the 2006 TDOT 204.06 CLSM Specification. Through the first four articles in the series, the authors have attempted to show that the 2006 TDOT 204.06 CLSM Specification is an excellent specification for CLSM. The 2006 TDOT 204.06 CLSM Specification:

- Is versatile and flexible in recognizing the need for different types of CLSM mixtures for various applications;
- Encourages innovation on the part of ready mix producers and contractors through specifying performance-related properties rather than proportions;
- Is proven and practical by being based on years of research including numerous field demonstrations and tests;
- Is rigorous and safe by requiring demonstration test trenches for EFF and ESFF CLSM mixtures prior to use;
- Fosters cooperation between government and industry since the specification was developed from research co-sponsored by TCA and members of the Tennessee concrete industry;
- Encourages sustainability by allowing byproduct supplementary cementing materials;
- Encourages sustainability by allowing high-fines screenings as aggregate;
- Is progressive and practical by specifying a cylinder capping method superior to current ASTM methods for CLSM.

What are the next steps in CLSM research and development in Tennessee? Can we develop CLSM mixtures that surpass the performance criteria from the new 2006 TDOT 204.06 CLSM Specification? The following two questions explore that possibility:

1. Can air-entrained and non-air-entrained CLSM mixtures that use materials commonly available in Tennessee, develop compressive strength significantly faster than required by the 2006 TDOT 204.06 ESFF Specification?
2. Can a single CLSM mixture be developed that uses materials commonly available in Tennessee and meets the performance requirements for all three CLSM types in the 2006 TDOT 204.06 Specification?

See Table 1 below.

RECENT PROGRESS ON CLSM MIXTURE DEVELOPMENT IN TENNESSEE

Can air-entrained and non-air-entrained CLSM mixtures that use materials commonly available in Tennessee develop compressive strength significantly faster than required by the 2006 TDOT 204.06 ESFF Specification?

The 2006 TDOT 204.06 ESFF Specifications were developed to minimize traffic delays due to backfilling pavement repairs. More rapid compressive strength development might further reduce traffic delays due to backfilling. Therefore, the Federal Highway Administration (FHWA) sponsored a research project entitled "Rapid Repair of Highway and Airfield Pavement Subgrades with Controlled Low-strength Materials" at TTU. Four types of high-early strength, non-excavatable CLSM mixtures were developed in the laboratory. The first two types were air-entrained mixtures containing only Portland cement (Type I or

TABLE 1.
2006 TDOT 204.06 PROPERTY REQUIREMENTS

Performance-Related Property	General Use	Excavatable	Early Strength
Consistency	8″ min.	8″ min.	8″ min.
Load application (ASTM D 6024) (2)	24 hours max.	24 hours max.	6 hours max.
Air content, if air entrained (ASTM D 6023) (3)		30% max.	30% max.
Compressive Strength @ 24 hours (ASTM D 4832)* (4)			30-psi min.
Compressive Strength @ 28 days (ASTM D 4832)*		30-psi min.	
Compressive Strength @ 98 days (ASTM D 4832)*		140-psi max.	

*May use 4x8 inch cylinder molds; preferred capping method is wet-suit neoprene in rigid retainers.

III) as cementing material modified with chemical admixtures; the third type was a sustainable non-air-entrained mixture that contained only Class C fly ash as the cementing agent modified with chemical admixtures. The final type was identical to the third except that fifty percent of the fine aggregate volume was replaced by ASTM No. 67 coarse aggregate for increased stiffness. Each type was produced with a different primary repair purpose in mind using three different fine aggregates so that the vast majority of PCC producers could make use of the mixtures. The primary purpose of each mixture type is shown in Table 2.

TABLE 2.
FHWA LIGHTNING CLSM MIXTURE PRIMARY PURPOSES

FHWA CLSM Mixture Type	Primary Purpose
Lightning Versatile	Widely Available Rapid Subgrade Repair
Lightning T3	Cold Weather (Down to 40°F) Rapid Subgrade Repair
Lightning Sustainable	"Green" Rapid Subgrade Repair
Lightning Coarse Sustainable	"Green" Rapid Base Repair

The proportions for FHWA Lightning CLSM Mixtures are shown in Tables 3(a) through 3(d). Plastic properties of the FHWA Lightning CLSM Mixtures and a *ZOOM!* comparison mixture as well as TDOT 204.06 ESFF requirements are shown in Table 4. Compressive strength development of the FHWA Lightning CLSM Mixtures and a *ZOOM!* comparison mixture as well as TDOT 204.06 ESFF requirements are shown in Table 5. All FHWA Lightning CLSM Mixtures met 2006 TDOT 204.06 TDOT plastic property requirements and have at least triple the compressive strength of the *ZOOM!* CLSM Mixture at 6 hours. Lightning is a giant leap forward in CLSM technology.

TABLE 3(A).
FHWA LIGHTNING VERSATILE LABORATORY CLSM MIXTURES AND *ZOOM!* COMPARISON MIXTURE

Component	Lightning Versatile River Sand	Lightning Versatile High-fines Limestone Screenings	Lightning Versatile Limestone Manufactured Sand	TDOT River Sand ESFF (ZOOM!)
Type I PC (lbs/CY)	450	450	450	300
Water (lbs/CY)	315	383	315	317
Fine Aggregate (lbs/CY)	2097	2182	2170	2425
Air-entrainer (oz/CY)	3	3	3	70
HRWR (oz/CY)	7	7	7	30
WR Accelerator (oz/CY)	450	450	450	225

TABLE 3(B).
FHWA LIGHTNING T3 LABORATORY CLSM MIXTURES

Component	Lightning T3 River Sand	Lightning T3 High-fines Limestone Screenings	Lightning T3 Limestone Manufactured Sand
Type III PC (lbs/CY)	450	450	450
Water (lbs/CY)	315	383	315
Fine Aggregate (lbs/CY)	2097	2182	2170
Air-entrainer (oz/CY)	3	3	3
HRWR (oz/CY)	7	7	7
WR Accelerator (oz/CY)	450	450	450

TABLE 3(C).
FHWA LIGHTNING SUSTAINABLE LABORATORY CLSM MIXTURES

Component	Lightning Sustainable River Sand	Lightning Sustainable High-fines Limestone Screenings	Lightning Sustainable Limestone Manufactured Sand
Class C Fly Ash (lbs/CY)	1011	1137	1095
Water (lbs/CY)	364	387	383
Fine Aggregate (lbs/CY)	2411	2320	2360
HRWR (oz/CY)	30	34	33
WR Retarder (oz/CY)	20	23	22

TABLE 3(D).
FHWA LIGHTNING COARSE SUSTAINABLE LABORATORY CLSM MIXTURES

Component	Lightning Coarse Sustainable River Sand	Lightning Coarse Sustainable High-fines Limestone Screenings	Lightning Coarse Sustainable Limestone Manufactured Sand
Class C Fly Ash (lbs/CY)	910	1137	1095
Water (lbs/CY)	319	284	328
Fine Aggregate (lbs/CY)	1314	1300	1255
ASTM No. 67 (lbs/CY)	1373	1304	1266
HRWR (oz/CY)	0	34	16
WR Retarder (oz/CY)	18	23	22

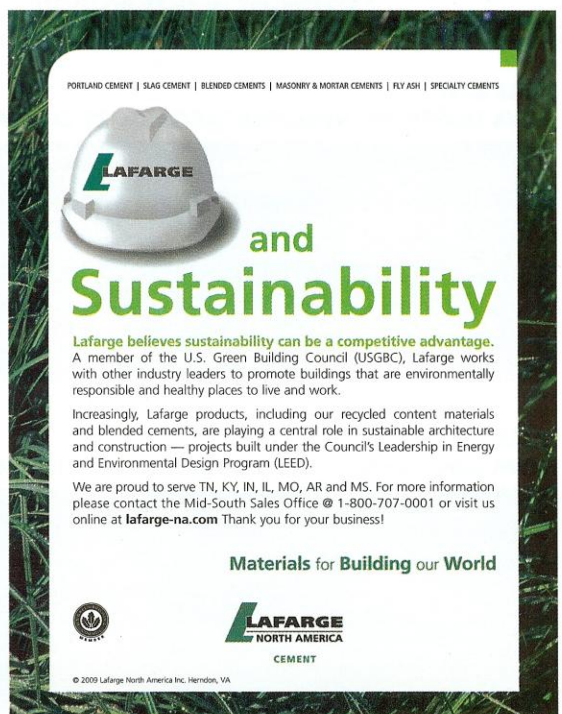

TABLE 4.
PLASTIC PROPERTIES OF LABORATORY FHWA LIGHTNING CLSM MIXTURES AND *ZOOM!* COMPARISON MIXTURE

Component	Flow (Inches)	Air Content (%)	Unit Weight (pcf)
Lightning Versatile River Sand	9.3	16	118
Lightning Versatile Limestone Screenings	13	20	113
Lightning Versatile Limestone Manufactured Sand	11.3	20	116
Lightning T3 River Sand	9	17	116
Lightning T3 Limestone Screenings	8.3	15	121
Lightning T3 Limestone Manufactured Sand	10.3	16	121
Lightning Sustainable River Sand	15.8	Non-AE	139
Lightning Sustainable Limestone Screenings	10.8	Non-AE	142
Lightning Sustainable Limestone Manufactured Sand	13.8	Non-AE	134
Lightning Coarse Sustainable River Sand	10	Non-AE	146
Lightning Coarse Sustainable Limestone Screenings	8.8	Non-AE	147
Lightning Coarse Sustainable LS Manufactured Sand	10.8	Non-AE	146
TDOT River Sand ESFF (ZOOM!)	8.5	26	105
TDOT 204.06 ESFF Requirements	≥8	≤30	

TABLE 5.
COMPRESSIVE STRENGTH DEVELOPMENT (IN PSI) OVER TIME OF LABORATORY FHWA LIGHTNING CLSM MIXTURES AND *ZOOM!* COMPARISON MIXTURE

Component	4 Hours	6 Hours	24 Hours	28 Days
Versatile River Sand	59	135	537	1145
Versatile Limestone Screenings	44	89	384	846
Versatile Limestone Manufactured Sand	68	129	497	1007
T3 River Sand	61	171	814	1186
T3 Limestone Screenings	66	201	687	1300
T3 Limestone Manufactured Sand	151	359	831	1436
Sustainable River Sand	28	30	293	1125
Sustainable Limestone Screenings	29	36	224	1284
Sustainable Limestone Manufactured Sand	28	31	301	1254
Coarse Sustainable River Sand	39	47	446	1694
Coarse Sustainable Limestone Screenings	50	61	646	3303
Coarse Sustainable LS Manufactured Sand	43	48	426	2310
TDOT River Sand ESFF (ZOOM!)	NA	10	71	299
TDOT 204.06 ESFF Requirements			≥30	

*Correlations show that compressive strengths greater than 6.1 PSI yields a good chance of passing the suitability for load application test

"Rapid Repair of Highway and Airfield Pavement Subgrades with Controlled Low-strength Materials" was an extensive two year project. Presentation of all the results from this study is beyond the scope of this article; however, listed below are a few of the project highlights. The authors recommend that for additional information the readers refer to "Very Early Strength, Non-excavatable CLSM" by J. D. Self (5). Project highlights include:

- Lightning Versatile CLSM was field tested in Cookeville, TN in August 2007 (with Irving Materials, Inc.'s assistance) and continues to perform well as a subgrade repair.
- Lightning T3 CLSM achieved a compressive strength of 6.2-psi in 4.5-hours at an ambient temperature between 37 and 40°F and a CLSM temperature of 45°F (with pre-cooled ingredients) in the laboratory.

- Lightning Sustainable CLSM showed that ligno-sulfate based retarders could stop flash set of Class C fly ash only binders and still allow high early compressive strengths. Further, CLSM binders could be extremely 'green" and need not contain Portland cement.
- Lightning Coarse Sustainable CLSM (see Figure 1) showed that a CLSM containing coarse aggregate could achieve adequate flow without segregation and provide substantially higher California Bearing Ratio and static modulus of elasticity values needed for rapid base repair applications.

FIGURE 1. FHWA LIGHTNING COARSE SUSTAINABLE LABORATORY FLOW TEST

CURRENT CLSM MIXTURE DEVELOPMENT FOR TENNESSEE

Can a Single CLSM Mixture Design be Developed Using Commonly Available Tennessee Materials that Meets the Performance Requirements for All Three 2006 TDOT 204.06 CLSM Types?

The 2006 TDOT 204.06 CLSM Specification correctly recognizes the need for different CLSM mixture types for different applications. However, some concrete industry personnel as well as Cookeville and Clarksville municipal officials have expressed a desire for a universal CLSM mixture, a mixture that meets the requirements for all three 2006 TDOT 204.06 CLSM types. Reviewing Table 1 shows that any CLSM meeting EFF or ESFF requirements also meets "General Use" requirements. Therefore, it is only necessary to develop an ESFF/EFF mixture to meet the requirements of all three CLSM types. An excavatable, rapid-set, early strength CLSM mixture might be ideal for backfilling utility cuts across pavements that may need to be re-excavated for repairs at a later time.

TTU researchers have approached the rapid-set, early strength, excavatable challenge from both directions by:

1. Attempting to increase the early compressive strength development of an EFF mixture;
2. Attempting to limit the later compressive strength of an ESFF mixture.

Walker (6) did the initial work on attempting to increase the early strength of Class C fly ash binder EFF. Subsequent TTU research assistants Ryan Hewitt and Ben Byard continued and refined Walker's work. Self and Phillips successfully produced a few Class C fly ash binder CLSM mixtures that met both 2006 TDOT 204.06 EFF and ESFF compressive strength and flow requirements in the lab. Self and Phillips also began work on limiting the later compressive strength of air-entrained PC binder ESFF mixture. The air-entrained PC binder CLSM mixture meets ESFF requirements and is close to meeting the 98-day EFF compressive strength requirement of 140-psi maximum. Plastic properties and compressive strength development, as well as 2006 TDOT 204.06 CLSM performance-related property requirements, are shown in Tables 6(a) and 6(b), respectively. Proportions for the two attempts at ESFF/EFF mixtures are not provided since these mixtures are still in development and unproven in the field.

TABLE 6(A). PLASTIC PROPERTIES OF THE BEST TTU LABORATORY ATTEMPTS TO PRODUCE A 2006 TDOT 204.06 ESFF/EFF MIXTURE

Component	Flow (Inches)	Load Application (Hours)	Gravimetric Air Content (%)
Non-air-entrained Class C Fly Ash / River Sand ESFF/EFF	10.5	Not Available	Not AE
Air-entrained PC / River Sand ESFF/EFF	8.8	Not Available	29.7
TDOT 2006 204.06 General Use Requirements	≥8	≤24	-
TDOT 2006 204.06 EFF Requirements	≥8	≤24	≤30 if AE
TDOT 2006 204.06 ESFF Requirements	≥8	≤6	≤30 if AE

TABLE 6(B).
COMPRESSIVE STRENGTH DEVELOPMENT (IN PSI) OVER TIME OF THE BEST TTU LABORATORY ATTEMPTS TO PRODUCE A 2006 TDOT 204.06 ESFF/EFF MIXTURE

Component	6 Hours*	24 Hours	28 Days	98 Days
Non-air-entrained Class C Fly Ash / River Sand ESFF/EFF	19	41	84	68
Air-entrained PC / River Sand ESFF/EFF	8	46	131	155
TDOT 204.06 General Use Requirements	-	-	-	-
TDOT 2006 204.06 ESFF Requirements	-	≥30	-	-
TDOT 2006 204.06 EFF Requirements	-	-	≥30	≤140

Fails to meet TDOT EFF 98-day compressive strength requirement of 140-psi maximum

*Correlations show that compressive strengths greater than 6.1-psi yield a good chance of passing the suitability for load application test;

FUTURE CLSM RESEARCH AT TTU

TTU researchers are also continuing to pursue ESFF/EFF CLSM mixture design research. In April 2008, further development and field testing were proposed to TDOT and TCA; both organizations are currently considering the merit of the proposed research.

SUMMARY

The 2006 TDOT 204.06 CLSM Specification is an excellent example of what can be done when government, industry and academia cooperate. Recent additional progress includes:

1. The development of non-air-entrained and air-entrained CLSM mixtures that use materials commonly available in Tennessee and develop compressive strength significantly faster than required by the 2006 TDOT 204.06 ESFF Specifications;
2. A single CLSM mixture design can be developed using commonly available Tennessee materials that meets the performance requirements for all three 2006 TDOT 204.06 CLSM types.

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NEW TDOT SPECS, Part 5

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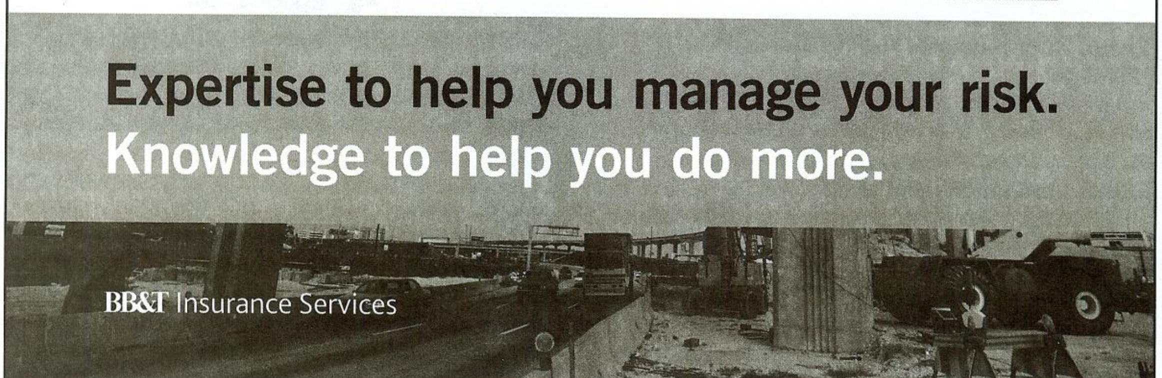

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