August 2011
UCPRC-TM-2011-03

Evaluation of CT 371 Field Data

Authors:
B.-W. Tsai, M. Khan, J.T. Harvey, and C.L. Monismith

Part of Partnered Pavement Research Program (PPRC) Strategic Plan Element 4.21:
Subtask 1B: Evaluation of Alternatives in Terms of Specimen Preparation, Conditioning, and Performance Testing of CT 371 to Characterize HMA Moisture Sensitivity

PREPARED FOR:	**PREPARED BY:**
California Department of Transportation Division of Research and Innovation Office of Roadway Research	University of California Pavement Research Center UC Davis, UC Berkeley

<table>
<tr><td colspan="2">DOCUMENT RETRIEVAL PAGE</td><td colspan="2" align="right">Technical Memorandum:
UCPRC-TM-2011-03</td></tr>
<tr><td colspan="4">Title: Evaluation of CT 371 Field Data</td></tr>
<tr><td colspan="4">Author: B.-W. Tsai, M. Khan, J.T. Harvey, and C.L. Monismith</td></tr>
<tr><td>Prepared for:
California Department of Transportation
Division of Research and Innovation Office of Roadway Research</td><td>FHWA No.:
CA121874A</td><td>Date Work Submitted:
August 10, 2011</td><td>Date:
August 2011</td></tr>
<tr><td>Strategic Plan No:
4.21</td><td colspan="2">Status:
Stage 6, final version</td><td>Version No:
1</td></tr>
<tr><td colspan="4">Abstract: This study presents efforts to further inspect the variability of California Test Method CT 371—“Method of Test for Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage”—through the collection of field data. The purposes of this study are (1) to inspect the factors that affect the wet and dry indirect tensile strengths and their ratio (CT 371-TSR); (2) to identify the between- and within-variations of CT 371-TSR; and (3) to evaluate the factors that affect the stabilometer value (S-value). Trellis graphs and tree-based models were used to qualitatively and quantitatively characterize the data structure. Analyses revealed that (1) there is considerable within-variation and noticeable between-variation among CT 371-TSR values, (2) the effect of lime treatment on the CT 371-TSR value is prominent while the effect of liquid anti-strip (LAS) on the CT 371-TSR is far more limited, and (3) the ratio of percent passing at #200 sieve to percent asphalt content (#200/AC) is the most critical factor that affects S-value.</td></tr>
<tr><td colspan="4">Keywords:
CT 371, TSR, Moisture damage, stabilometer, lime treatment, LAS</td></tr>
<tr><td colspan="4">Proposals for implementation:</td></tr>
<tr><td colspan="4">Related documents:</td></tr>
<tr><td colspan="4">Signatures</td></tr>
</table>

B.-W. Tsai	J. T.Harvey	D. Spinner	J. T. Harvey	H. Zhou	T. J. Holland
First Author	**Technical Review**	**Editor**	**Principal Investigator**	**Caltrans Technical Advisory Panel Tech Lead**	**Caltrans Contract Manager**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 Background

California Test Method 371 (CT 371), titled “Method of Test for Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage,” has been in use since 2003 for evaluating the moisture sensitivity of hot-mix asphalt (HMA) compacted with a kneading compactor. This test method is a variation of the AASHTO Standard Method of Test T283, “Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage.” Round robin studies conducted in Caltrans and Industry laboratories during that time using laboratory-mixed, laboratory-compacted (LMLC) mixes have shown a large variability in CT 371 tensile strength ratio (CT 371-TSR) test results.

As part of the issuance of the revised Section 39 (hot-mix asphalt) specifications in 2007, Caltrans initiated a pilot study to investigate the use of CT 371 on field projects. This pilot study included Quality Control/Quality Assurance (QC/QA) projects for Hot Mix Asphalt (HMA) Type A, Type B, and Rubberized HMA Gap-graded (RHMA-G). Samples from the production were obtained and tested for CT 371, and the test results were submitted to the email address *Moisture_Tests@dot.ca.gov*. As of January 20, 2011, data from over 160 tests were available for review. Most of the test data sheets received included information about project expenditure accounts (EA), mix types, mix sizes, and treatments, but the types and amounts of binder used in mixes were generally not reported *(1)*.

To further inspect the factors that affect CT 371-TSR test variability in laboratory comparisons and among laboratory-prepared and plant-produced samples, the joint Caltrans–Industry Moisture Sensitivity Hot Mix Asphalt Subtask Group requested that the University of California Pavement Research Center (UCPRC) collect additional information for the QC/QA projects listed in Table 1.1 since these projects have provided CT 371 test results from the plant-produced samples.

To allow for a sound engineering analysis of the test data, the following information on each project was collected:

- Form CEM-3511 (Contractor Job Mix Formula [JMF] Proposal), Form CEM-3512 (Contractor Mix Asphalt Design Data), and Form CEM-3513 (Caltrans Hot Mix Asphalt Verification).
- HMA Pay (QC/QA) or HMA Evaluation (Standard) (Form LT-0302: Test Result [Production Start-Up Eval.]) with data populated.
- Any additional CT 371 test results that differed from those submitted via email to *Moisture_Tests@dot.ca.gov*.

1.2 Objectives

The CT 371 field data collection had the following objectives:

- To inspect the factors that affect the CT 371-TSR dry/wet strength and thus the CT 371-TSR value (Note: the CT 371-TSR value [in percent] is defined as the division of CT 371-TSR wet strength over CT 371-TSR dry strength.);
- To identify the variability of CT 371 by comparing data from forms CEM-3512 and CEM-3513 with data from a production start-up evaluation; and
- To evaluate the factors that affect the stabilometer "S" value (S-value).

Table 1.1: List of QC/QA Projects Including CT 371 Data

EA	Mix Type	Mix Size (mm)	Plant
02-0E6204	HMA-A	19	Sierra Nevada Construction—Mustang
02-1E0704	HMA-A	19	
02-2C5804	HMA-A	19	Tullis—Cottonwood Creek Sand & Gravel
02-371004	HMA-A	19	Tullis—Cottonwood Creek Sand & Gravel
03-0A7104	HMA-A	19	Teichert—Halwood
03-367824	HMA-A	19	Teichert—Perkins
04-1E5504	HMA-A	19	Granite Construction—Bay Area Branch
04-1E5504	RHMA-G	12.5	Granite Construction—Bay Area Branch
04-253794	HMA-A	19	Hanson Aggregates—Sunol
04-444214	HMA-A	19	BoDean Batch Plant—Santa Rosa
04-4A5204	HMA-A	19	Hanson Aggregate
06-0G6104	RHMA-G	12.5	Jaxon Baker—Deer Creek
06-0H8804	RHMA-G	12.5	Granite—Coalinga
06-0H9004	RHMA-G	12.5	Security Paving—Wheeler Ridge
06-0J3804	RHMA-G	12.5	
06-0J4704	RHMA-G	12.5	Jaxon Baker—Avenal
06-0K6504	RHMA-G	12.5	Jaxon Baker—Avenal
06-322104	HMA-A	19	
06-416104	HMA-A	19	
07-0P7904	HMA-A	19	Vulcan—Irwindale
07-0P7904	RHMA-G	19	Vulcan—Sun Valley
07-117074	HMA-A	19	AAA—Corona
07-2Y6304	RHMA-G	12.5	Security Paving—Wheeler Ridge
07-3Y3404	RHMA-G	12.5	All American Asphalt—Irwindale
07-3Y7504	RHMA-G	12.5	All American Asphalt—Irwindale
07-3Y8103	RHMA-G	12.5	All American Asphalt—Corona
07-3Y8104	RHMA-G	12.5	All American Asphalt—Irwindale
08-0071V8L	HMA-A	19	All American Asphalt—Corona
08-472304	HMA-A	19	Vulcan—Corona
08-472304	RHMA-G	19	Vulcan—Corona
09-214614	HMA-A	19	Skanska Independence
09-258014	HMA-A	19	
09-269014	HMA-A	19	Bishop—Gencor Plant
09-269014	RHMA-G	19	
10-0G7504	RHMA-G	12.5	George Reed—Table Mountain
10-0S4104	RHMA-G	12.5	George Reed—Clements Batch Plant
10-3A7404	RHMA-G	12.5	George Reed—Escalon Plant
11-2T0104	HMA-A	19	Vulcan—San Diego
12-0J0904	RHMA-G	12.5	Vulcan—Corona

Note: This table has been provided by Caltrans.

2 DATA EXPLORATION USING TRELLIS GRAPHS

2.1 Summary of CT 371 Field Data Collection

Table 2.1 summarizes the CT 371 test results, which were based on the collective effort resulting from the Caltrans QC/QA projects listed in Table 1.1. The CT 371 test results have been grouped by Caltrans district (district locations are shown in Figure 2.1), mix type (including maximum aggregate size and percent reclaimed asphalt pavement), treatment type, and binder type. The total sample size evaluated was 78. Analyses using the mix properties summarized in Appendix A include the use of Trellis graphs discussed in this chapter and tree-based modeling discussed in Chapter 3. Appendix A contains all of the available data for each of the samples tested. The data includes the following:

- project expenditure account (ea),
- district (dist),
- mix type with mix size (mix.type),
- binder type (binder),
- source of data (form.type),
- percent reclaimed asphalt pavement (rap),
- dosage of liquid anti-strip (xlas),
- dosage of lime (xlime),
- untreated TSR value in percentage (tsr),
- treatment type for CT 371-TSR (tsr.type)
- lime-treated TSR value in percentage (tsr.lime),
- LAS-treated TSR value in percentage (tsr.las),
- stabilometer value (s.value),
- percent air-void content (av),
- percent asphalt content (ac),
- percent aggregate passing at #200 sieve (no200),
- specific gravity of asphalt binder (gbinder),
- maximum specific gravity (rice),
- bulk specific gravity (oven dry) of coarse aggregate (cgmb),
- bulk specific gravity (oven dry) of fine aggregate (fgmb),
- bulk specific gravity of the aggregate blend (gave),
- documented surface area of aggregate blend in ft^2/lb (sa),
- calculated surface area of aggregate blend in ft^2/lb (sa.calc),
- calculated asphalt film thickness in μm (film.calc.um), and
- the ratio of percent passing at #200 sieve to percent asphalt content (n200oac).

Table 2.1: Summary of CT 371-TSR Field Data Collected

District	Mix Type	Treatment	Binder Type	Sample Size	Untreated Dry Strength (kPa)		Untreated Wet Strength (kPa)		Treated Dry Strength (kPa)		Treated Wet Strength (kPa)		TSR (%)	
					Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
D2	HMA-A_12.5mm	Untreated	PG 64-28 PM	1									78	
		Lime_1.0	PG 64-28 PM	2					743.5	166.3	717.4	13.0	89	0.7
		Lime_1.2	PG 64-28 PM	3					724.1	115.2	651.1	124.2	90	4.0
	HMA-A_19mm	Untreated	PG 64-28 PM	4	503.3	34.3	357.2	38.7					70	3.5
			PG 70-10	1	1,124.0	32.0	930.8	75.4					83	
		Lime_1.0	PG 64-28 PM	4					604.2	54.5	559.5	47.3	93	1.5
			PG 70-10	1					1,220.4	44.3	1,131.0	21.3	93	
		Lime_1.2	PG 64-28 PM	2					729.7	17.3	509.0	35.5	78	9.9
			PG 70-10	1					980.0	33.6	879.0	35.9	90	
	HMA-A_19mm R15	Untreated	PG 64-28	1	630.2	17.8	518.0	5.5					81	
			PG 64-28 PM	2	513.0	53.3	352.1	14.4					67	2.8
		Lime_1.0	PG 64-28	1					724.4	6.5	664.6	18.0	92	
		Lime_1.4	PG 64-28 PM	3					747.9	180.2	594.9	105.8	81	6.5
D3	HMA-A_19mm	Untreated	PG 64-10	1	119.5	27.6	514.8	41.4					46	
		Untreated	PG 64-16	1									75	
D4	HMA-A_19mm	Untreated	PG 64-10	1									50	
		Untreated	PG 64-16	1									84	
	HMA-A_19mm R15	Untreated	PG 64-10	1	1,064.5	35.5	605.4	36.9					57	
		LAS_0.75	PG 64-10	1					1,197.1	35.9	898.9	56.2	75	
	RHMA-G_12.5mm	Untreated	PG 64-16 R*	1									36	
		LAS_0.5	PG 64-16 R	1									40	
D6	HMA-A_19mm	Untreated	PG 70-10	1									56	
		LAS_1.0	PG 70-10	2									65	12.7
	HMA-A_19mm R15	Untreated	PG 64-10	2									69	17.7
	RHMA-G_12.5mm	Untreated	PG 64-16 R	1									28	
		LAS_0.5	PG 64-16 R	2					1,034.8	46.5	680.1	38.0	53	18.4
	RHMA-G_19mm	Untreated	PG 64-16 R	2									46	0
		LAS_0.5	PG 64-16 R	2									54	0

*: R indicates asphalt rubber binder having a base stock asphalt with PG XX-XX.

Table 2.1: Summary of CT 371-TSR Field Data Collected *(cont.)*

District	Mix Type	Treatment	Binder Type	Sample Size	Untreated Dry Strength (kPa)		Untreated Wet Strength (kPa)		Treated Dry Strength (kPa)		Treated Wet Strength (kPa)		TSR (%)	
					Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
D7	HMA-A_09.5mm	Untreated	PG 64-10	1	1,533.1	52.2	779.9	62.3					51	
	HMA-A_19mm	Untreated	PG 64-10	2	1,098.3	44.2	426.2	145.8					55	22.6
		LAS_1.0	PG 64-10	1									75	
	HMA-A_19mm R15	Untreated	PG 64-10	1	1,173.2	78.9	541.3	22.0					46	
	RHMA-G_12.5mm	Untreated	PG 64-16 R*	4	1,139.9	47.9	832.5	52.9					73	1.5
	RHMA-G_19mm	Untreated	PG 64-16 R	4	985.1	195.6	316.8	133.9					32	9.8
		LAS_0.5	PG 64-16 R	1					737.3	46.5	358.5	82.7	49	
		LAS_1.0	PG 64-16 R	2					948.0	128.9	603.1	286.8	62	30.4
D8	HMA-A_19mm R10	Untreated	PG 64-28 PM	1	317.8	11.6	228.0	13.7					72	
	RHMA-G_19mm	Untreated	PG 64-16 R	1	846.3	26.4	427.0	27.8					50	
		LAS_0.5	PG 64-16 R	1					770.5	65.6	397.5	45.4	52	
D9	HMA-A_19mm	Untreated	PG 64-28	2	719.6	29.6	399.3	6.7					55	0
		LAS_0.5	PG 64-28	2					712.5	32.7	506.7	7.6	71	0
	HMA-A_19mm R15	Untreated	PG 64-28 PM	2	550.7	11.8	426.6	9.0					77	0
	RHMA-G_19mm	Untreated	PG 58-22 R	2	1,185.8	2.5	730.6	6.3					62	0
		LAS_0.5	PG 58-22 R	2					1,243.9	11.0	866.9	11.6	70	0
D10	RHMA-G_12.5mm	Untreated	PG 64-16 R	1	515.8	11.8	152.8	NA					30	
		Lime_1.0	PG 64-16 R	1					741.8	27.9	354.2	52.7	48	
D12	RHMA-G_12.5mm	Untreated	PG 64-16 R	1	1,026.6	87.8	418.1	41.1					41	

*: R indicates asphalt rubber binder having a base stock asphalt with PG XX-XX.

Figure 2.1 schematically illustrates the Caltrans districts.

Figure 2.1: Map of Caltrans Districts.
(Courtesy of the California Department of Transportation).

It should be noted that many of the entries in Table 2.1 have a standard deviation of zero because the same values were documented for both the CEM-3512 and CEM-3513 forms of the project. The values listed under the headings for both treated and untreated dry and wet strengths in Table 2.1 have been calculated from the available CT 371-TSR strength data of the projects that have been categorized by district, mix type, treatment, and binder type. The TSR (%) values listed in Table 2.1 were computed from the values reported on the CEM-3512 or CEM-3513 forms. It should be noted that both detailed CT 371-TSR strength data and a reported TSR value were available for some but not all of the projects. Thus, a direct comparison of the TSR values may not be appropriate.

The following points should be noted regarding the collected CT 371 field data:

- Lime proportions included 1.0, 1.2, and 1.4 percent by weight of dry aggregate. *(Note:* According to Caltrans specifications, the combined lime ratio must be between 0.8 and 1.5 by weight of dry aggregate.)
- Liquid anti-strip (LAS) proportions included 0.5, 0.75, and 1.0 percent by weight of asphalt binder. *(Note:* According to Caltrans specifications, liquid anti-strip must be between 0.5 and 1.0 percent by weight of asphalt binder.)
- Air-void contents (expressed in percent) obtained from forms CEM-3512 and CEM-3513 were mostly from specimens prepared for stabilometer testing.

- Only a few QC/QA projects provided HMA Pay or HMA Evaluation data.
- The majority of the lime-treated mix data were provided by District 2, while one set of lime-treated mix data was from District 10. LAS mix–treated data were provided by the other districts.
- In addition to the QC/QA projects listed in Table 1.1, several QC/QA projects from Redding in District 2 were added during the analysis. These additional projects provided the test results for production start-up evaluation not available from the other QC/QA projects.

2.2 Boxplot and Trellis Graph

A boxplot, shown schematically in Figure 2.2, illustrates a measure of location (the median [solid black dot]), a measure of dispersion (the interquartile range, IQR [lower quartile: left or bottom-edge of box; upper quartile: right or top-edge of box]), and possible outliers (data points shown with a circle outside the 1.5 IQR distance from the edges of box; the most extreme data points within the 1.5 IQR distance are marked with square brackets), and also gives an indication of the symmetry or skewness of the distribution.

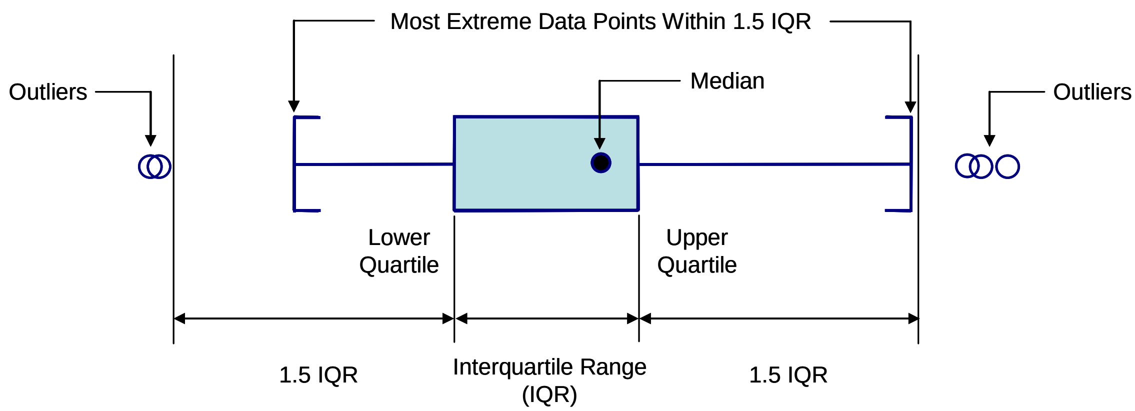


Figure 2.2: Schematic illustration of a boxplot.

The Trellis graph, which incorporates boxplots and was introduced by Cleveland in 1993 *(2)*, is a graphical way of examining a high-dimensional data structure by means of conditional one-, two-, and three-dimensional graphs. Figure 2.3 illustrates an example of a CT 371 test data distribution with information on treatment type (untreated, treated with lime, or treated with liquid anti-strip [LAS] agent), Caltrans district, and mix type. The Trellis graph of boxplots is arranged in such a way that each panel consists of treatment types (i.e., three boxplots in each panel representing LAS-treated, lime-treated, and untreated from top to bottom), each row contains nine districts (i.e., districts with data) with the same mix type, and each column five panels (i.e., five mix types) for the same Caltrans district. Thus, for each individual Caltrans district, the effects of mix type and treatment type can be examined vertically for each mix type, and the effects of treatment type for individual Caltrans districts can be inspected horizontally. Figure 2.3 also shows that mix types HMA-A_19mm, RHMA-G_12.5mm, and RHMA-G_19mm have been used most frequently.

The Trellis-graphs of CT 371-TSR value, CT 371-TSR dry/wet strength, and S-value, grouped as follows by factors and their corresponding levels, are discussed in detail in Sections 2.3, 2.4, and 2.5:

- Factor **tsr.type** for CT 371-TSR value, i.e., TSR with/without treatment, with three levels: 1.tsr, 2.tsr.lime, and 3.tsr.las.
- Factor **tsr.type** for CT 371-TSR dry/wet strength, i.e., dry/wet strength with/without treatment, with six levels: 1.tsr.dry, 1.tsr.wet, 2.tsr.lime.dry, 2.tsr.lime.wet, 3.tsr.las.dry, 3.tsr.las.wet.
- Factor **mix.type**, i.e., mix type with nominal maximum aggregate size (NMAS), with five levels: HMA-A_09.5mm, HMA-A_12.5mm, HMA-A_19mm, RHMA-G_12.5mm, and RHMA-G_19mm.
- Factor **dist**, i.e., Caltrans district, with nine levels (based on the data): Dist02, Dist03, Dist04, Dist06, Dist07, Dist08, Dist09, Dist10, and Dist12.
- Factor **binder**, with seven levels: PG 58-22 R (rubberized), PG 64-10, PG 64-16 (not included for CT 371-TSR Strength), PG 64-16 R (rubberized), PG 64-28, PG 64-28 PM, and PG 70-10.
- Factor **form.type**, i.e., source of data, with three levels: Prod.Start.Up.Eval, CEM-3512, and CEM-3513.

2.3 CT 371-TSR Value

In this section, the Trellis graph is used to qualitatively summarize observations on the effect of treatment, as shown in Figure 2.3 through Figure 2.8.

The factor **tsr.type** used in the Trellis graph has three levels: **`1.tsr`**, **`2.tsr.lime`**, and **`3.tsr.las`**.

Figure 2.3: The Trellis graph: **`tsr.type~tsr|dist*mix.type`**:

1. The majority of the data collected are for mix types of HMA-A_19mm, RHMA-G_19mm, and RHMA-G_12.5mm.
2. District 2 data indicate that CT 371-TSRs from the mixes treated with lime are greater than 80 percent. There is another lime-treated RHMA-G_12.5mm mix in District 10 for which the TSR was 48 percent. Note that several District 2 mixes included 15 percent RAP. The variation of TSRs, either treated or untreated, seems to be well controlled in that the IQR is smaller than 10 percent.
3. For RHMA-G_19mm and RHMA-G_12.5mm mixes, LAS has only a marginal effect on improving CT 371-TSR. Most of the treated and untreated CT 371-TSRs are less than 60 percent.
4. The variation of CT 371-TSR with treated or untreated mixes from District 7 data is noticeable.

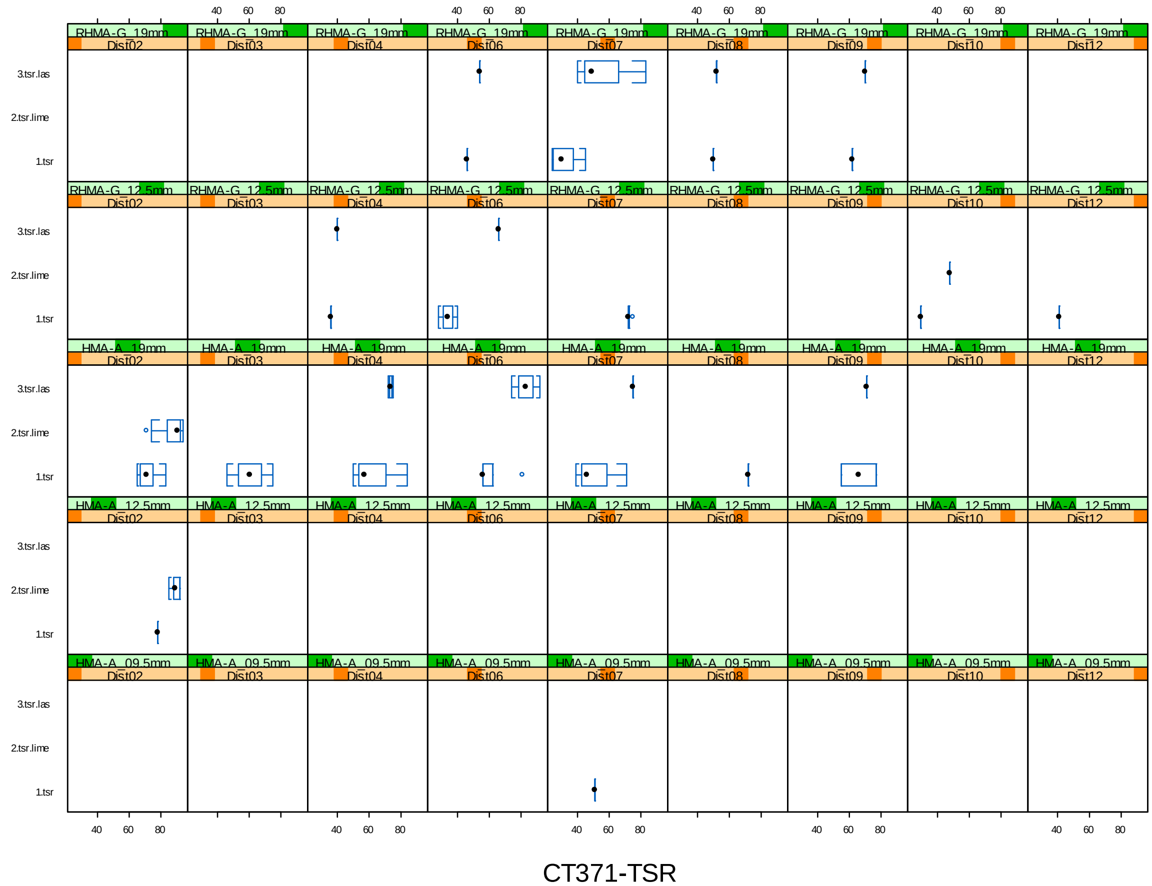


Figure 2.3: An example of Trellis graph: `tsr.type~tsr | dist*mix.type`.

Figure 2.4: The Trellis graph: **`tsr.type~tsr|dist`**

1. Generally speaking, LAS treatment improves mixes' CT 371-TSR values marginally as can be seen in test data from District 4, District 7, District 8, and District 9.
2. The lime-treated and untreated CT 371-TSRs of District 2 are higher than the other districts.
3. Variation of CT 371-TSR in District 7 seems to be larger than that of the other districts.

Figure 2.5: The Trellis graph: **`tsr.type~tsr|dist*binder`**

1. Judging from this figure, LAS treatment does not seem to have an effect on RHMA-G mixes with PG 64-16 R or PG 58-22 R binder.

Figure 2.6: The Trellis graph: **`tsr.type~tsr|binder`**

1. As in the case of Figure 2.5, it can be concluded that LAS or lime treatment does not seem to have an effect on RHMA-G mixes with PG 64-16 R or PG 58-22 R binder.
2. For mixes with PG 64-28 and PG 70-10 binders, lime treatment always appears to have a higher TSR than LAS treatment.

3. For mixes with PG 64-28, PG 64-28 PM, and PG 70-10 binders, the CT 371-TSR values of lime-treated mixes are greater than 80 percent.

Figure 2.7: The Trellis graph: **`tsr.type~tsr|mix.type`**

1. The LAS treatment effect is apparent for RHMA-G_19mm and HMA-A_19mm mixes but not for RHMA-G_12.5mm mixes.
2. For HMA-A_19mm mixes, the TSR value of lime treatment is better than that of LAS treatment.

Figure 2.8: The Trellis graph: **`tsr.type~tsr|dist*form.type`**

1. For treated or untreated mixes at District 2, District 6, and District 7, the CT 371-TSR values from Form CEM-3512 (Contractor Mix Asphalt Design Data) are generally greater than those values from Form CEM-3513 (Caltrans Hot Mix Asphalt Verification).
2. For lime-treated mixes used in District 2, the CT 371-TSR of CEM-3512 approximates the Production Start-Up Evaluation value and is greater than CEM-3513.

2.4 CT 371-TSR Dry and Wet Strength

In this section, the Trellis graph is used to qualitatively summarize observations on the effect of treatment in terms of strength, as shown in Figure 2.9 through Figure 2.13. The detailed information used to develop the Trellis graphs for CT 371-TSR dry and wet strengths is listed in Table A.2 of Appendix A. It should be noted that some of the reported CT 371-TSRs did not contain detailed CT 371-TSR test results, i.e., dry and wet strengths. The factor **tsr.type** used in the Trellis graph has six levels: **`1.tsr.dry`**, **`1.tsr.wet`**, **`2.tsr.lime.dry`**, **`2.tsr.lime.wet`**, **`3.tsr.las.dry`**, and **`3.tsr.las.wet`**.

Figure 2.9: The Trellis graph: **`tsr.type~strength|dist*binder`**

1. Regardless of the source of the data, LAS treatment does not seem to improve either dry or wet strengths for RHMA-G mixes with PG 64-16 R or PG 58-22 R binder.
2. Lime treatment improves not only dry strength but also wet strength.

Figure 2.10: The Trellis graph: **`tsr.type~strength|dist*mix.type`**

1. LAS treatment does not seem to improve the dry and wet strengths of RHMA-G_19mm and HMA-A_19mm mixes.
2. Lime treatment improves both dry and wet strengths for RHMA-G_12.5mm and HMA-A_19mm mixes.

Figure 2.11: The Trellis graph: **`tsr.type~strength|binder`**

1. Viewing the average strength for each binder type regardless of treatment effect, mixes with PG 64-28 and PG 64-28 PM binders seem to have a lower average strength compared with other types.

Figure 2.12: The Trellis graph: **`tsr.type~strength|mix.type`**

1. Since the TSR ratio is defined as the wet strength divided by the dry strength, it should be recognized that higher treated CT 371-TSR values are to be expected when treated wet and dry strengths are close, even if the untreated/treated strengths are relatively small; this can be seen in the comparison of treated HMA-A_19mm mixes (Figure 2.7).

Figure 2.13: The Trellis graph: **`tsr.type~strength|dist*form.type`**

1. The strength reported from District 2 appears to indicate that treated or untreated mixes for either dry or wet strengths are greater than those reported from Form CEM-3512. However, the variation between Form CEM-3512 and Form CEM-3513 is not seen from District 7 data.

2.5 S-Value

In this section, the Trellis graph is used to qualitatively summarize observations on the effect of treatment in terms of S-value, as shown in Figure 2.14 through Figure 2.16.

Figure 2.14: The Trellis graph: **`mix.type~s.value|dist`**

1. It appears that the stabilometer values are generally less than 40 for RHMA-G mixes and 40 or greater for HMA-A mixes.

Figure 2.15: The Trellis graph: **`binder~s.value|mix.type`**

1. Judging by this figure, binder type does not seem to have an effect on S-value for HMA-A_19mm and RHMA-G_19mm mixes.

Figure 2.16: The Trellis graph: **`form.type~s.value|mix.type`**

1. For both RHMA-G and HMA-A mixes, the S-values reported on Form CEM-3513 are always greater than those reported on Form CEM-3512.

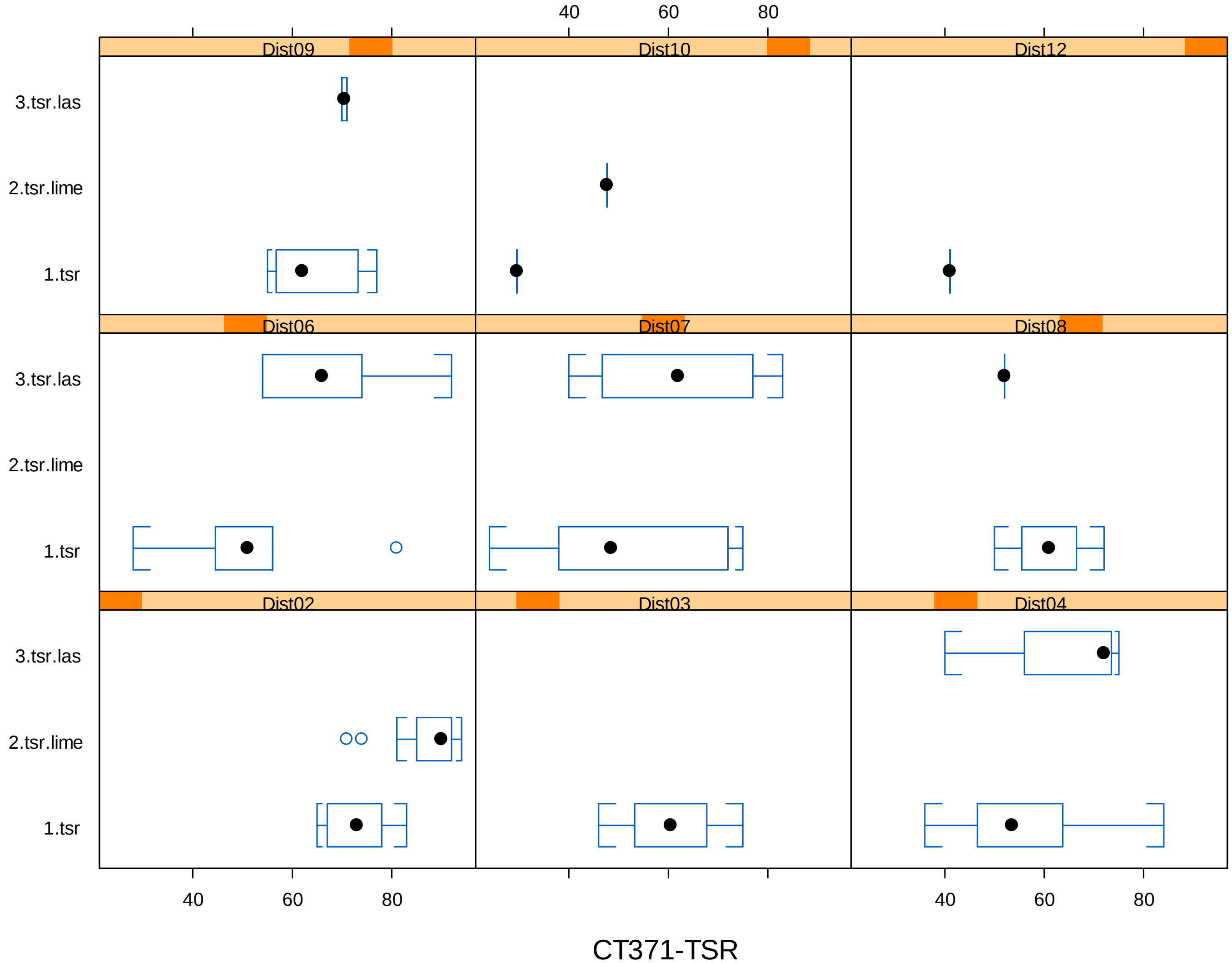


Figure 2.4: Trellis graph of CT 371-TSR value: `tsr.type~tsr | dist`.

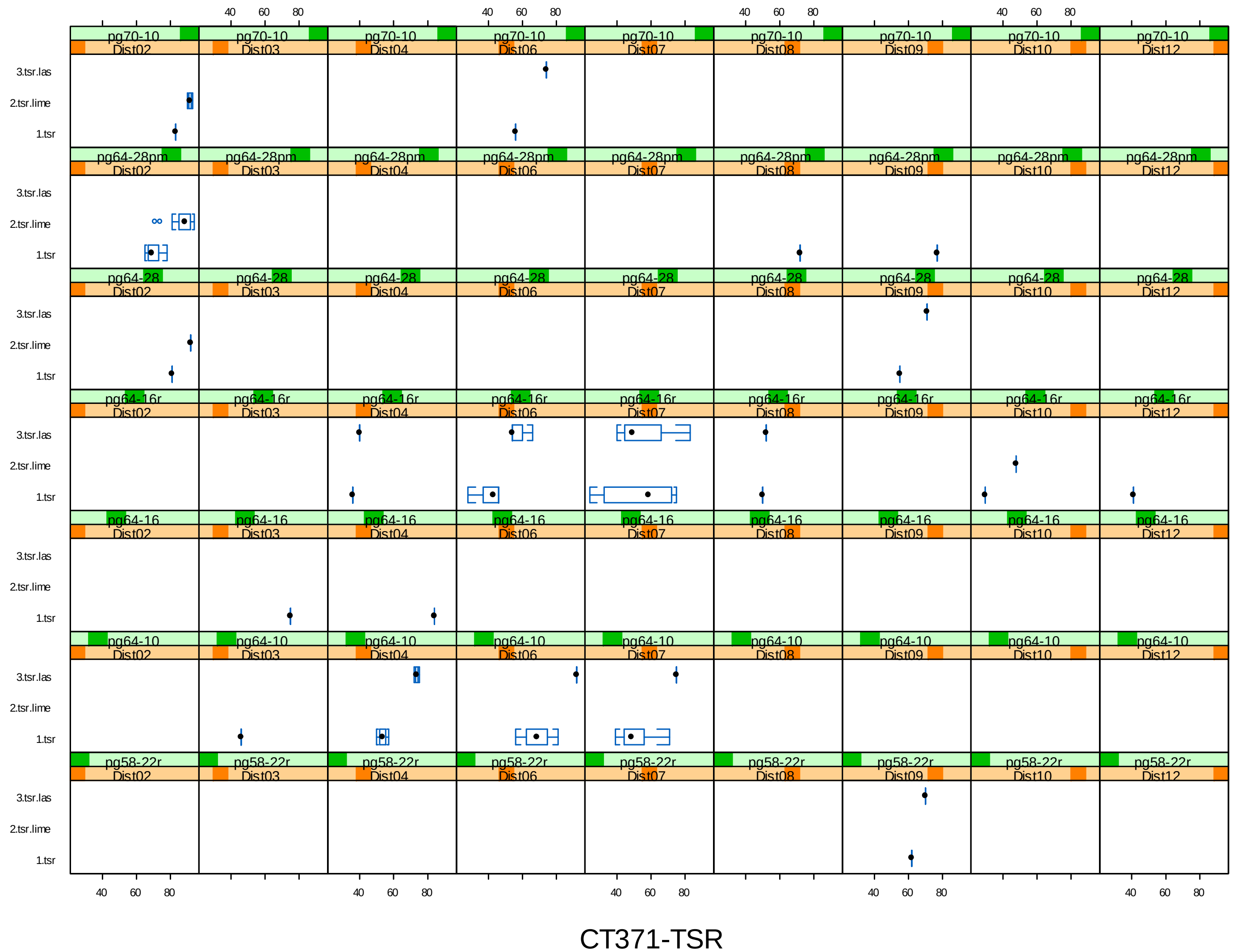


Figure 2.5: Trellis graph of CT 371-TSR value: `tsr.type~tsr | dist * binder`.

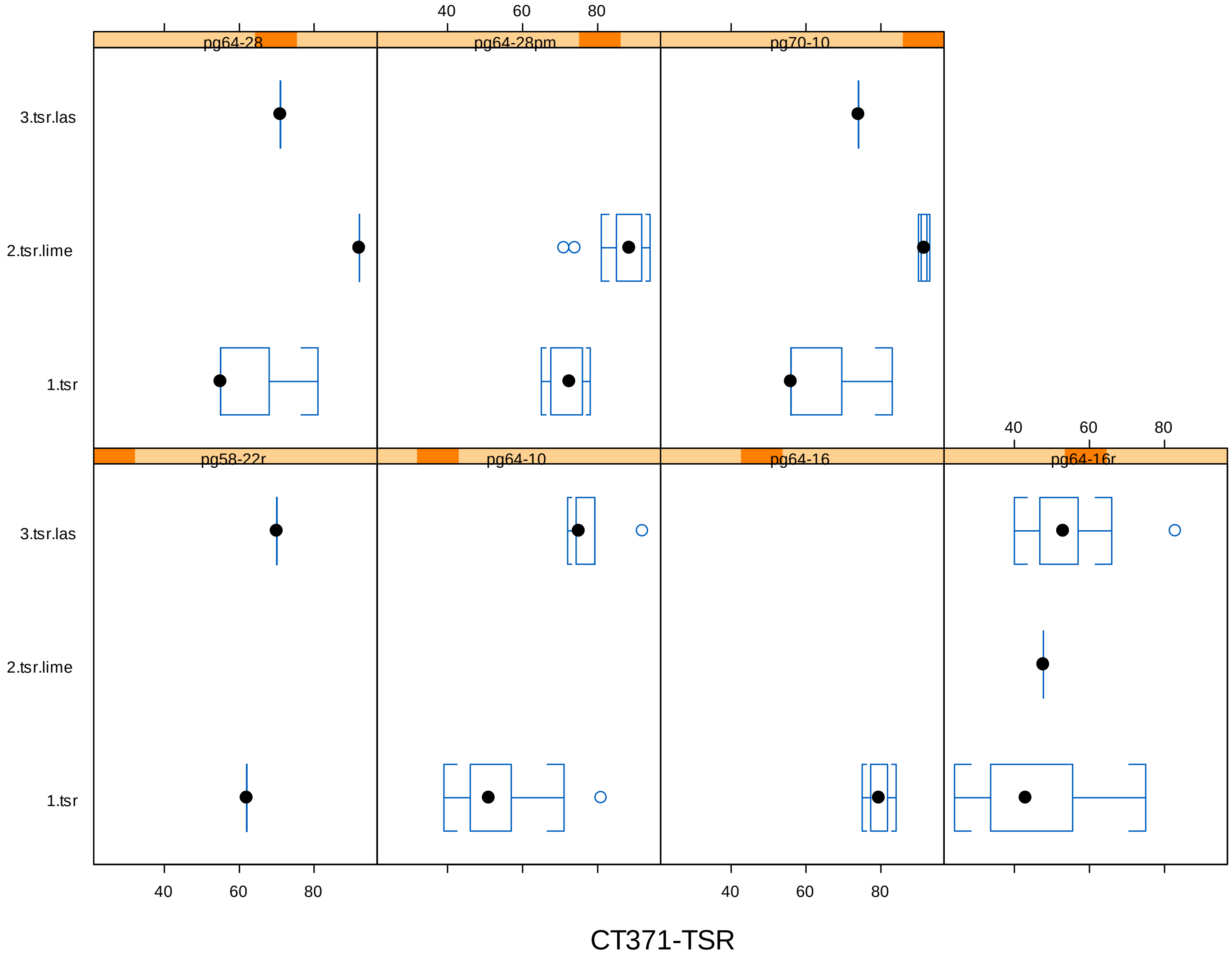


Figure 2.6: Trellis graph of CT 371-TSR value: `tsr.type~tsr | binder`.

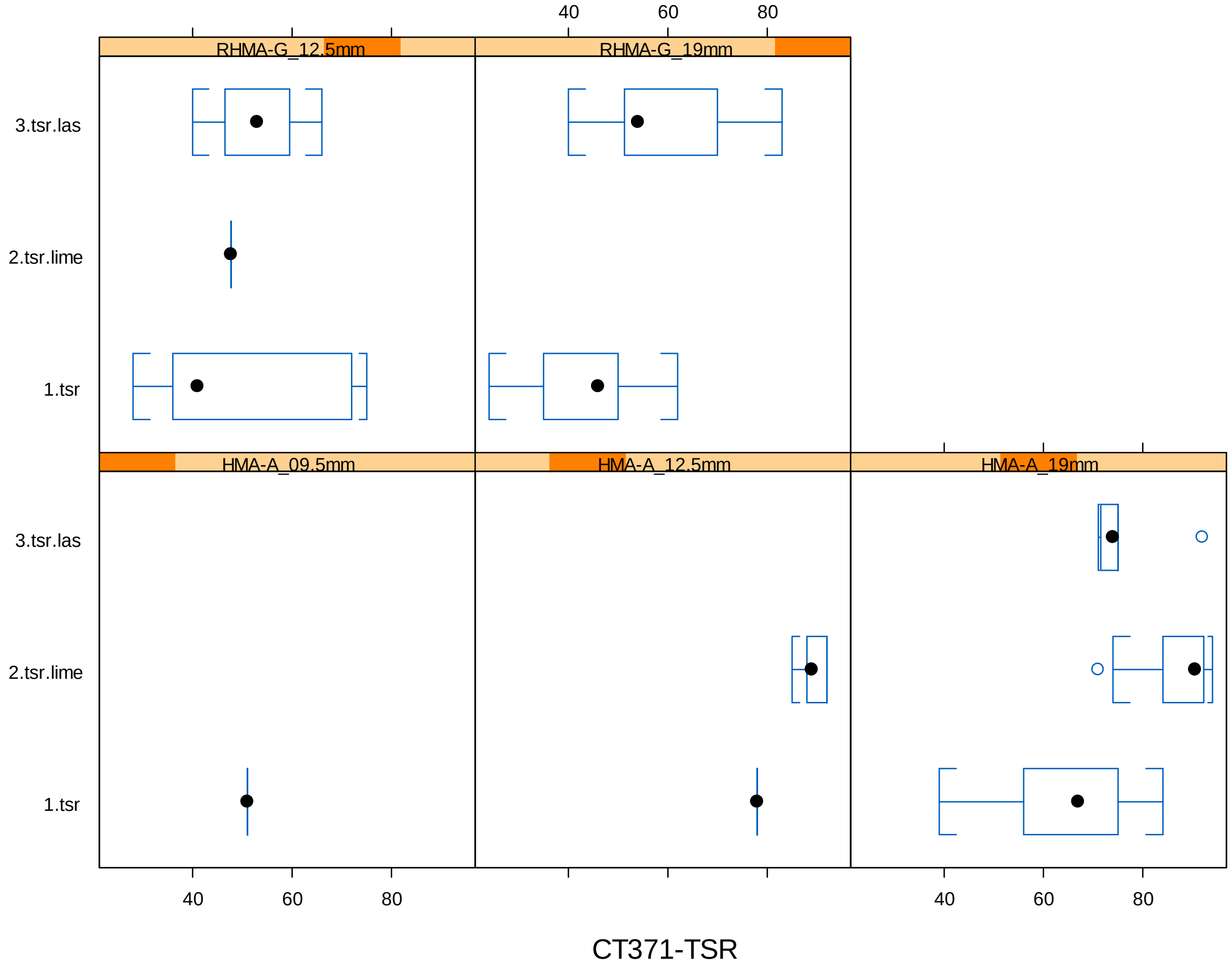


Figure 2.7: Trellis graph of CT 371-TSR value: `tsr.type~tsr | mix.type`.

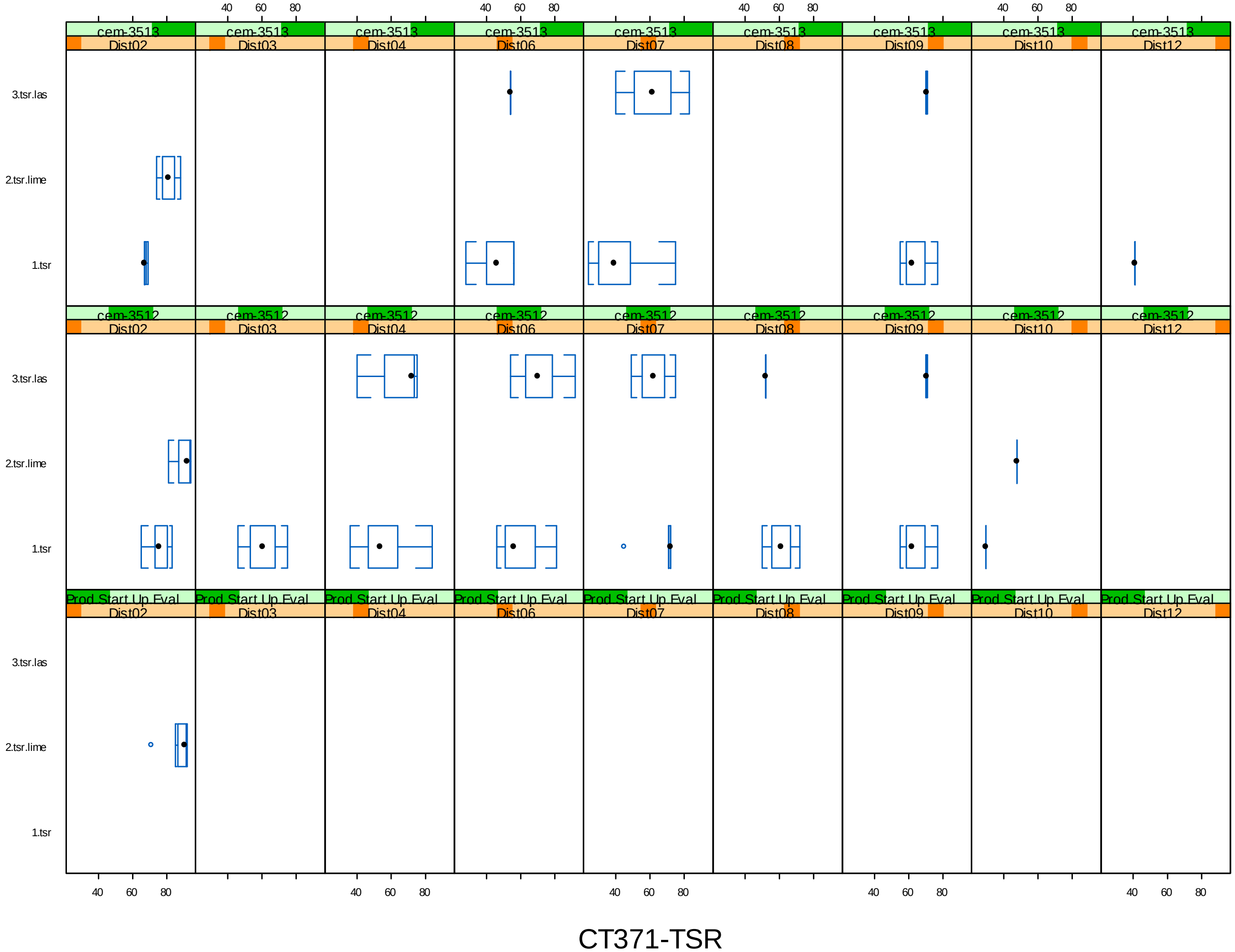


Figure 2.8: Trellis graph of CT 371-TSR value: `tsr.type~tsr | dist*form.type`.

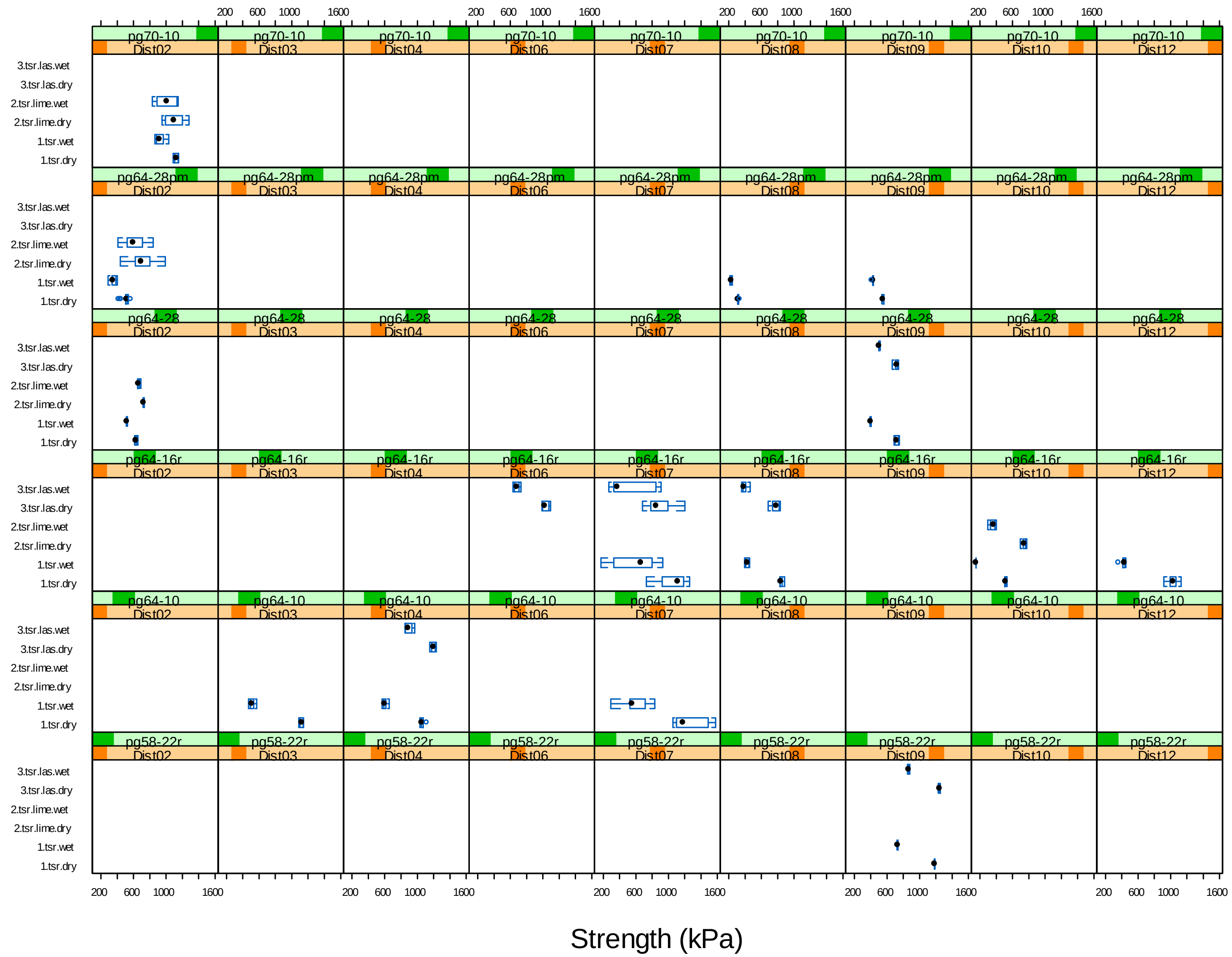


Figure 2.9: Trellis graph of CT 371-TSR dry/wet strength: `tsr.type~strength | dist*binder`.

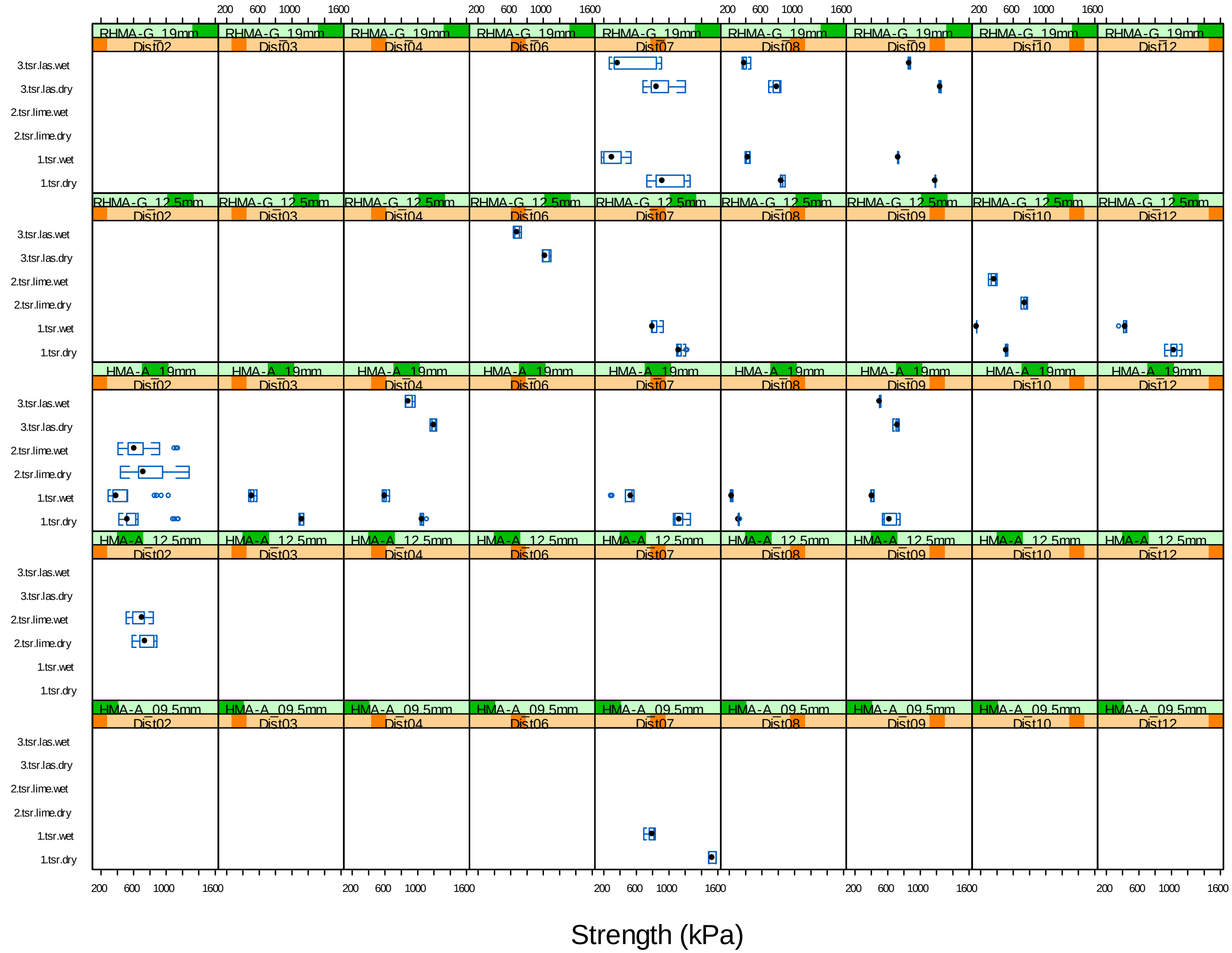


Figure 2.10: Trellis graph of CT 371-TSR dry/wet strength: `tsr.type~strength | dist*mix.type`.

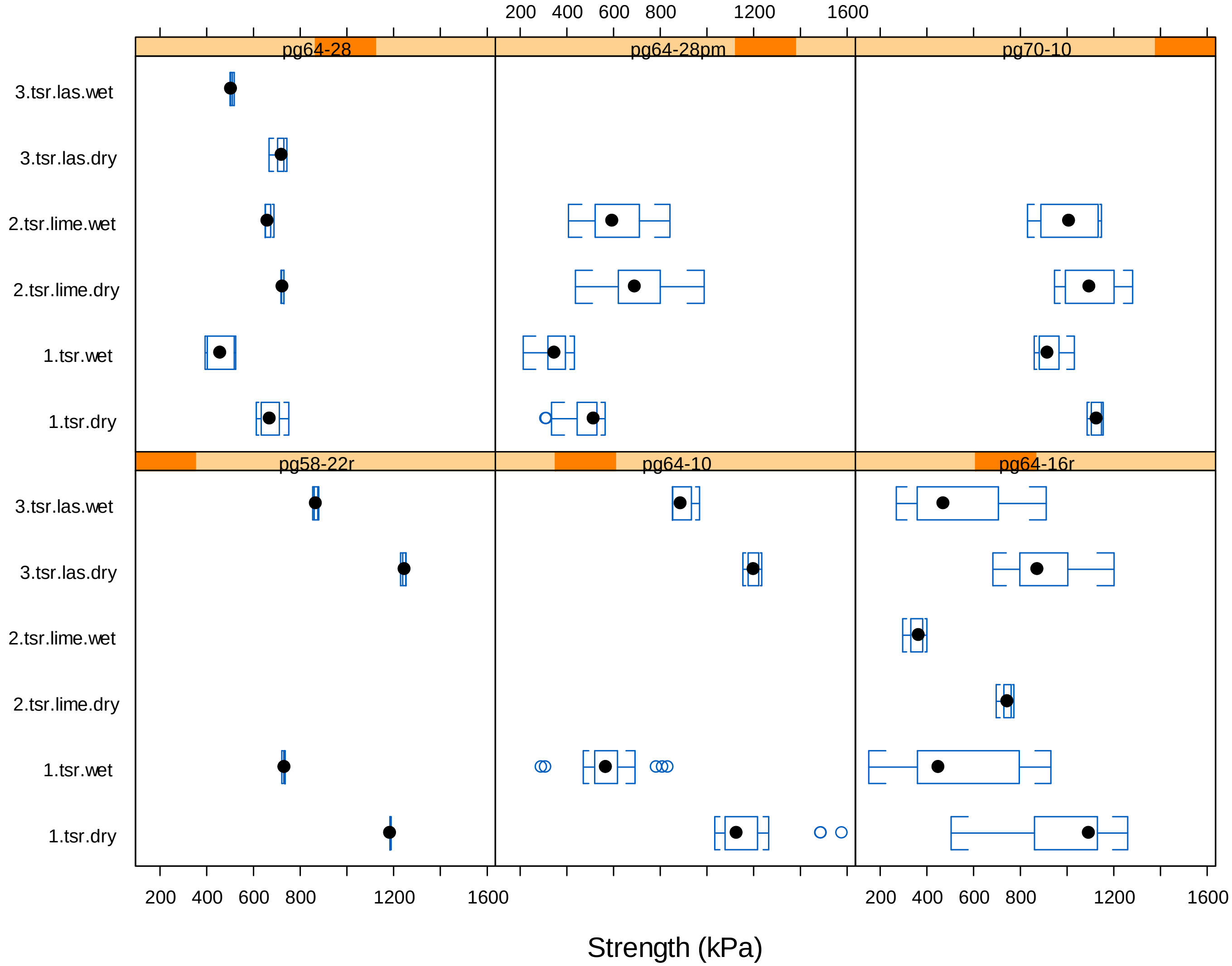


Figure 2.11: Trellis graph of CT 371-TSR dry/wet strength: `tsr.type~strength | binder`.

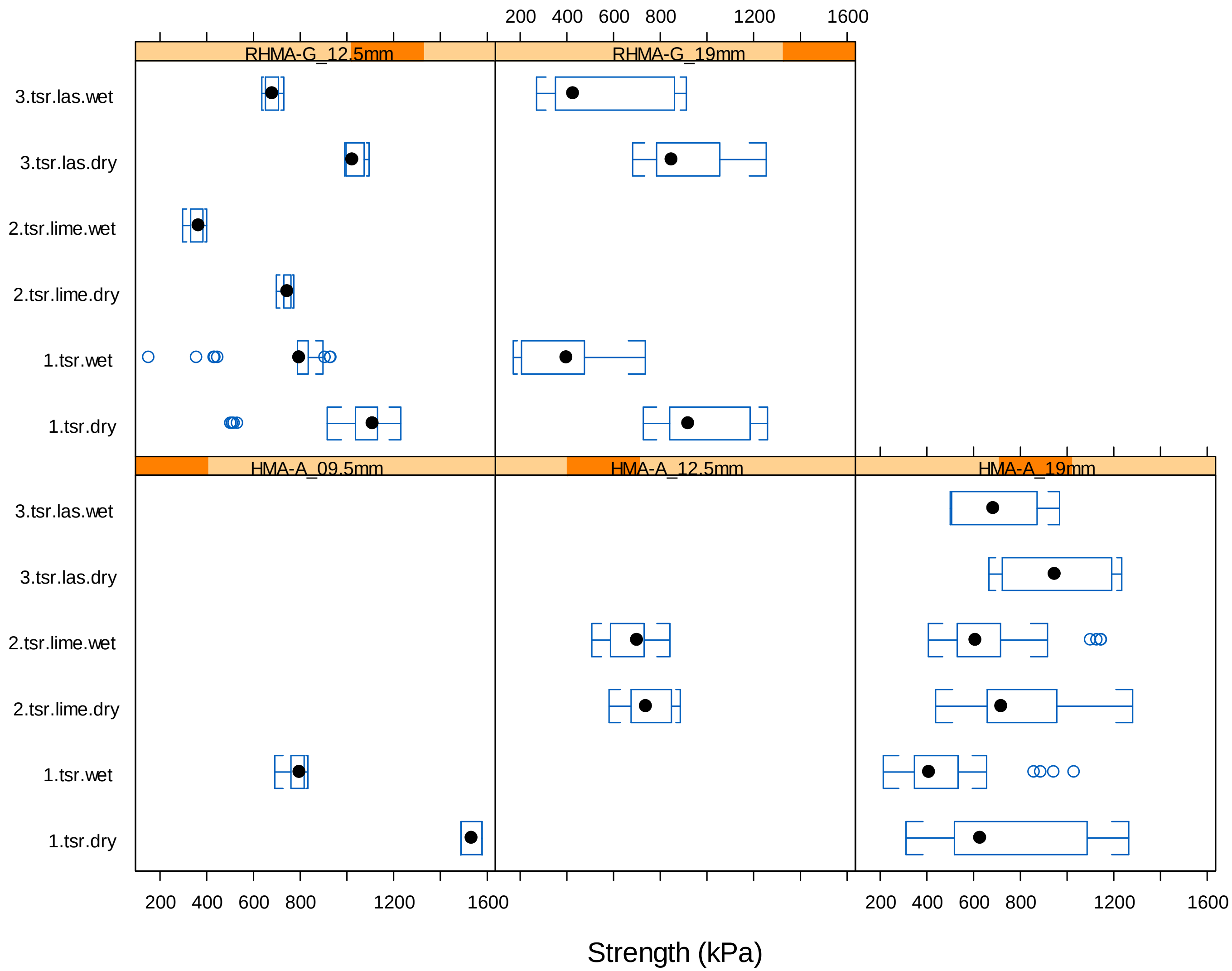


Figure 2.12: Trellis graph of CT 371-TSR dry/wet strength: `tsr.type~strength | mix.type`.

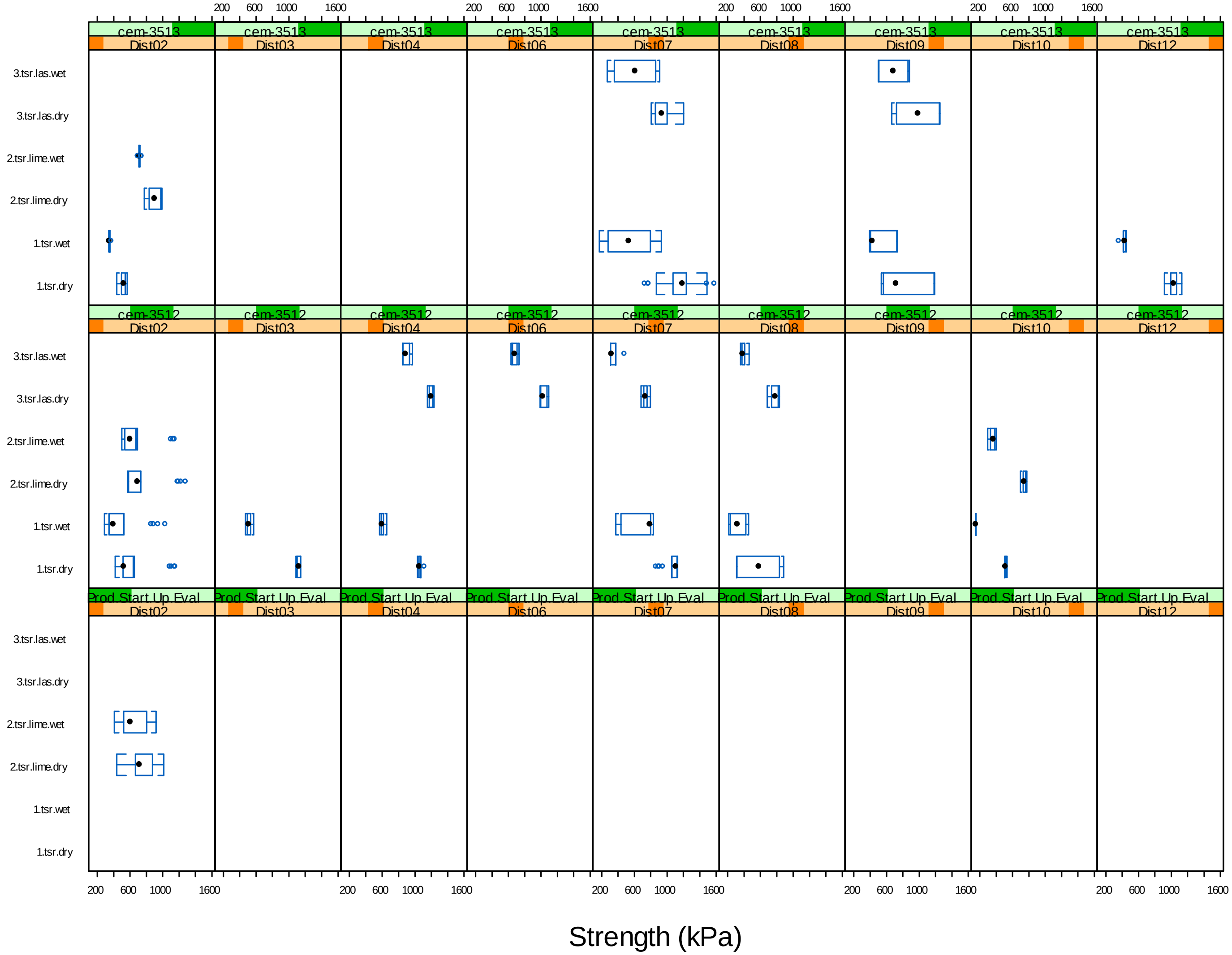


Figure 2.13: Trellis graph of CT 371-TSR dry/wet strength: `tsr.type~strength | dist*form.type`.

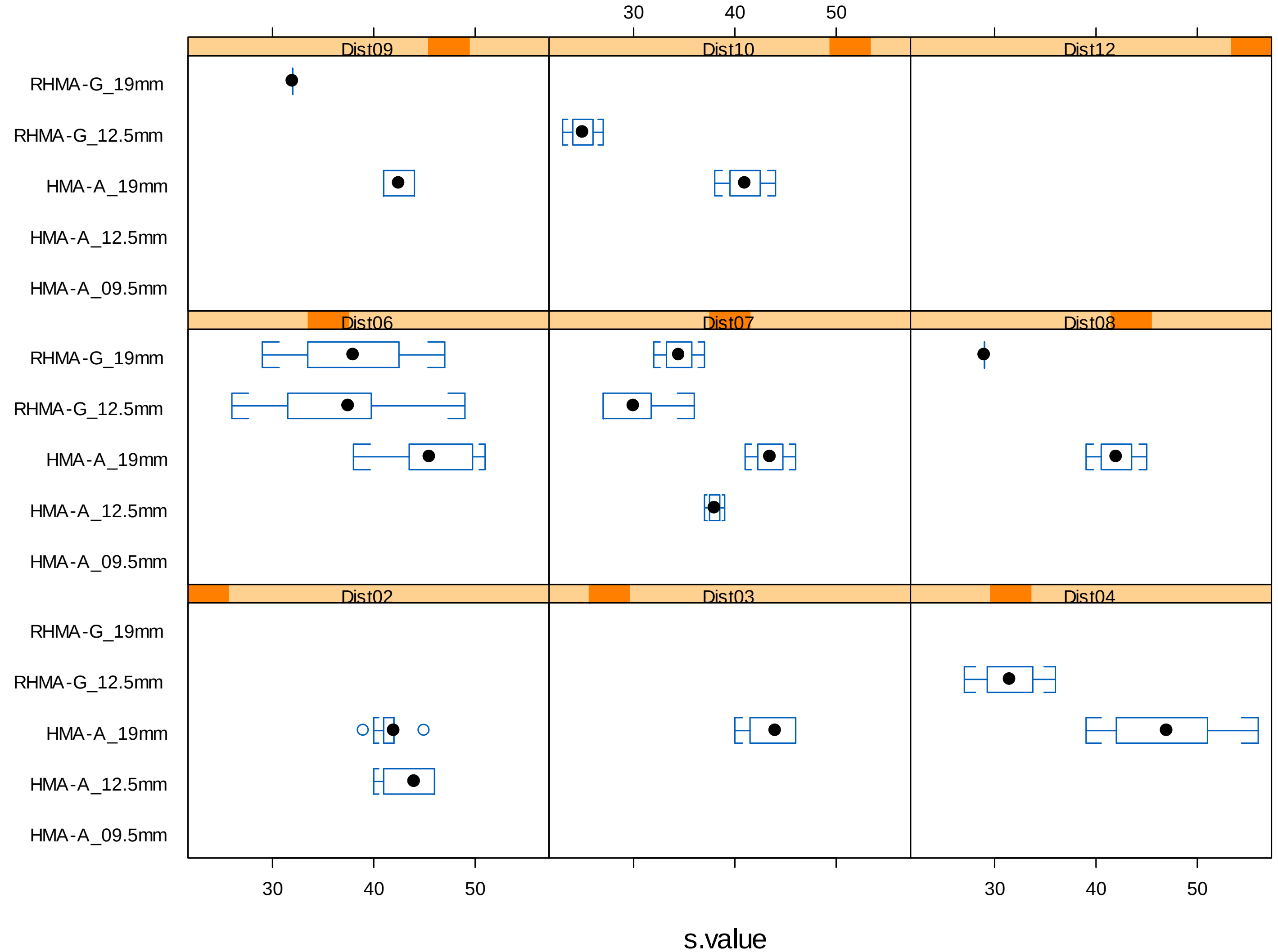


Figure 2.14: Trellis graph of S-value: `mix.type~s.value | dist`.

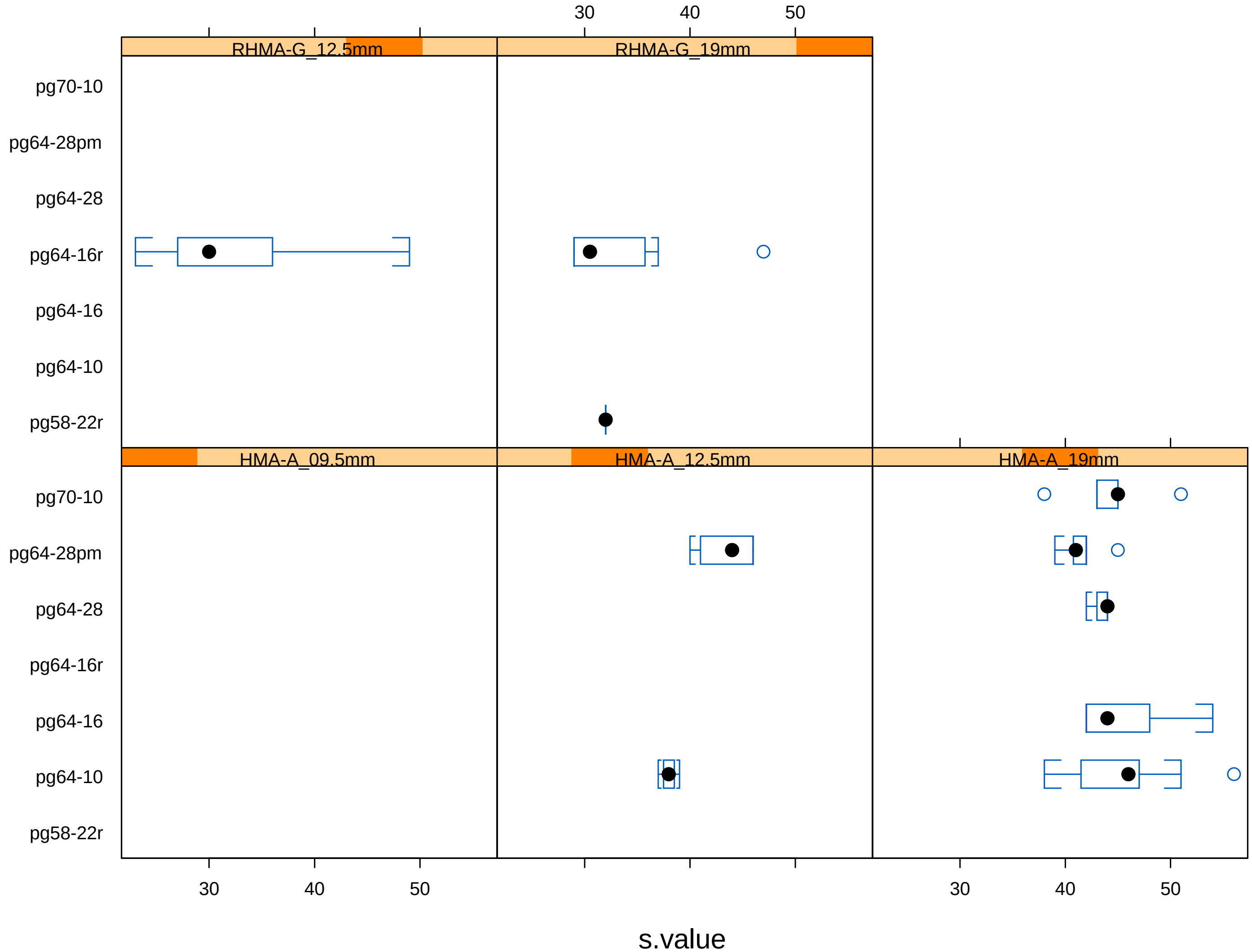


Figure 2.15: Trellis graph of S-value: `binder~s.value | mix.type`.

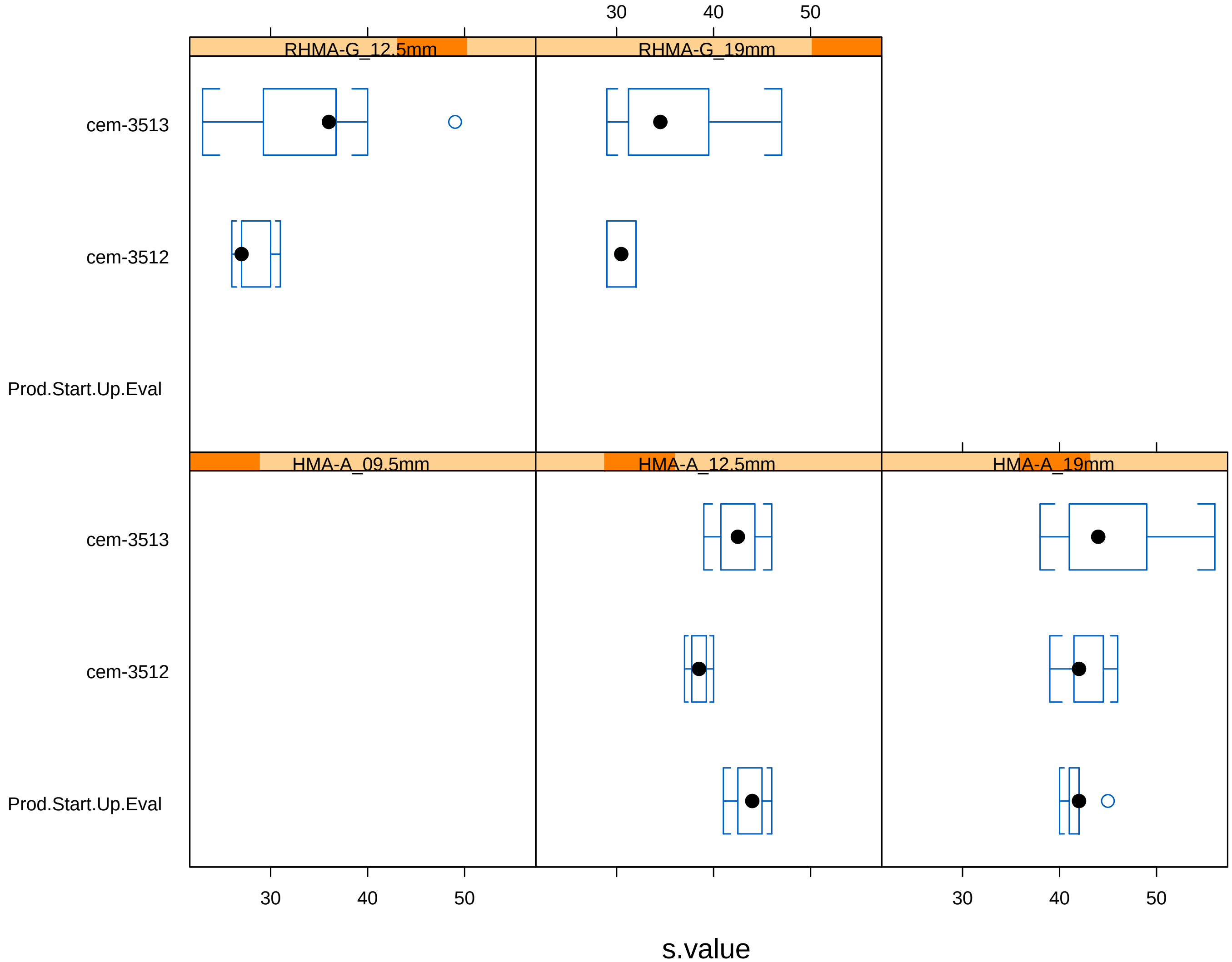


Figure 2.16: Trellis graph of S-value: `form.type~s.value | mix.type`.

3 TREE-BASED REGRESSION/CATEGORIZATION MODEL

3.1 Tree-Based Modeling

Tree-based modeling, which was developed by Breiman et al. in the early 1980s, is an exploratory technique for uncovering structures within data *(3)*. Tree-based models provide an alternative not only to the linear and additive models for regression problems but also to the linear logistic and additive logistic models for classification problems.

Tree-based models are fit based on the application of a binary recursive partitioning algorithm to a data set until it is successively split into increasingly homogeneous subsets. The response variable can be either a factor or a numeric, and the result is named either a *classification tree* or a *regression tree*, respectively. The tree-based model is the only means for analyzing factor response variables at more than two levels. A covariate in a tree-based model can either be a factor or a numeric.

The detailed data listed in Appendix A have been used to develop the tree-based models for CT 371-TSR value, CT 371-TSR dry/wet strength, and S-value.

3.2 Tree-Based Models for S-Value

Figure 3.1 shows the dendrogram of a tree-based model that relates S-value to the associated category covariates, **`form.type`**, **`dist`**, **`binder`**, and numerical covariate, **`n200oac`** (#200/AC). (It should be noted that the covariates, **`mix.type`**, **`film.calc.um`**, **`rice`**, and **`ac`**, are not significant enough to be included in the model.) To predict the S-value from the aforementioned covariates, one can follow the path from the top node of the tree (the *root)* to a terminal node (or *leaf)* according to the rules (called *split rules)* at the interior nodes. Note that the value enclosed by parentheses at the leaf represents the sample size.

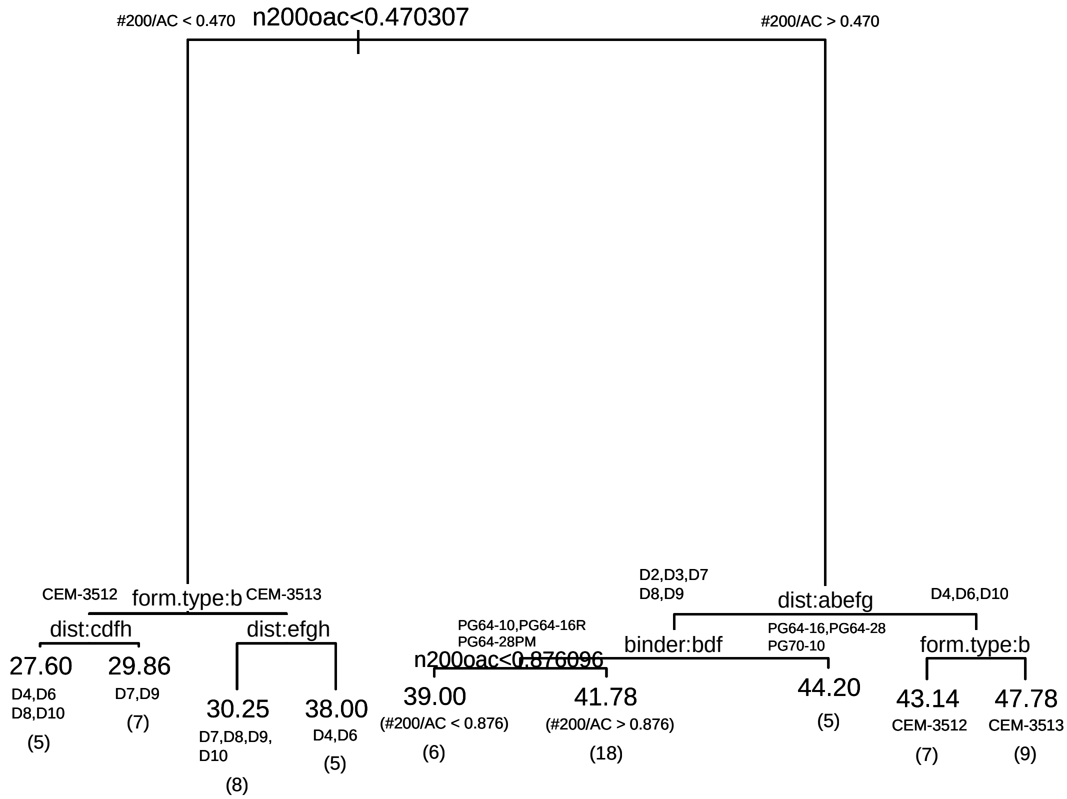


Figure 3.1: Dendrogram with split rules of S-value.
(Note: The value enclosed by parentheses at leaf represents sample size.)

As Figure 3.1 also shows, split rules have formats such as **`n200oac<0.470307`** (numeric) or **`dist:abefg`** (category). The category covariates, **`form.type`**, **`dist`** and **`binder`** have levels listed in alphabetical order as shown in the following. These levels have been labeled alphabetically starting with the letter "a."

```
> levels(ct371$form.type)
[1] "Prod.Start.Up.Eval"  "cem-3512"  "cem-3513"
           (a)                (b)         (c)
> levels(ct371$dist)
[1] "Dist02" "Dist03" "Dist04" "Dist06" "Dist07" "Dist08" "Dist09" "Dist10"
       (a)      (b)      (c)      (d)      (e)      (f)      (g)      (h)
[9] "Dist12"
       (i)
> levels(ct371$binder)
[1] "pg58-22r"  "pg64-10"  "pg64-16"  "pg64-16r"  "pg64-28"  "pg64-28pm"
        (a)        (b)        (c)        (d)         (e)        (f)
[7] "pg70-10"
        (g)
```

Therefore, the split rule, **`dist:abefg`**, standing for the Dist02 (a), Dist03 (b), Dist07 (e), Dist08 (f), and Dist09 (g) 5 levels will take the left path. The whole tree structure to predict the S-value can be written as follows *(4):*

```
> print(z.svalue)
node), split, n, deviance, yval
      * denotes terminal node

  1) root 70 3736.000 38.83
    2) n200oac<0.470307 25  691.400 31.16
      4) form.type:cem-3512 12   48.920 28.92
        8) dist:Dist04,Dist06,Dist08,Dist10 5    7.200 27.60 *
        9) dist:Dist07,Dist09 7   26.860 29.86 *
      5) form.type:cem-3513 13  526.300 33.23
       10) dist:Dist07,Dist08,Dist09,Dist10 8  147.500 30.25 *
       11) dist:Dist04,Dist06 5  194.000 38.00 *
    3) n200oac>0.470307 45  757.600 43.09
      6) dist:Dist02,Dist03,Dist07,Dist08,Dist09 29  168.800 41.62
       12) binder:pg64-10,pg64-16r,pg64-28pm 24  119.800 41.08
         24) n200oac<0.876096 6   16.000 39.00 *
         25) n200oac>0.876096 18   69.110 41.78 *
       13) binder:pg64-16,pg64-28,pg70-10 5    8.800 44.20 *
      7) dist:Dist04,Dist06,Dist10 16  413.000 45.75
       14) form.type:cem-3512 7   36.860 43.14 *
       15) form.type:cem-3513 9  291.600 47.78 *
```

Using “`2) n200oac<0.470307 25 691.400 31.16`” as an example to further explain the data structure, the first number, 25, after the split rule, `n200oac<0.470307`, is the number of observations. The second number, 691.400, is the deviance, which is a measure of the node heterogeneity used in the tree-growing algorithm. A zero deviance represents a perfectly homogeneous node.

Tree-based modeling can be diagnosed through residual plots as shown in Figure 3.2, an approach similar to that used for linear modeling. Figure 3.2a presents a histogram with one mode (peak value) and an approximately symmetrical shape of residuals distribution. Figure 3.2b is a normal probability plot of residuals that shows a very apparent pattern of long tails, a curve which starts below the normal line, bends to follow, and ends above it; that is to say, more variance of the residuals would be expected. Figure 3.2c plots the residuals-versus-fitted values and shows no strong pattern. However, there are possible outliers when the fitted values are approximately 38 and 47.78. With the exception of those possible outliers, the model appears to be adequate and acceptable.

To better explore the data structure of the S-value, Table 3.1, which is grouped by mix type, provides a quantitative summary of average S-values as well as average values for percent passing at #200 sieve, percent asphalt content, ratio of percent passing at #200 sieve to percent asphalt content (#200/AC), and asphalt film thickness.

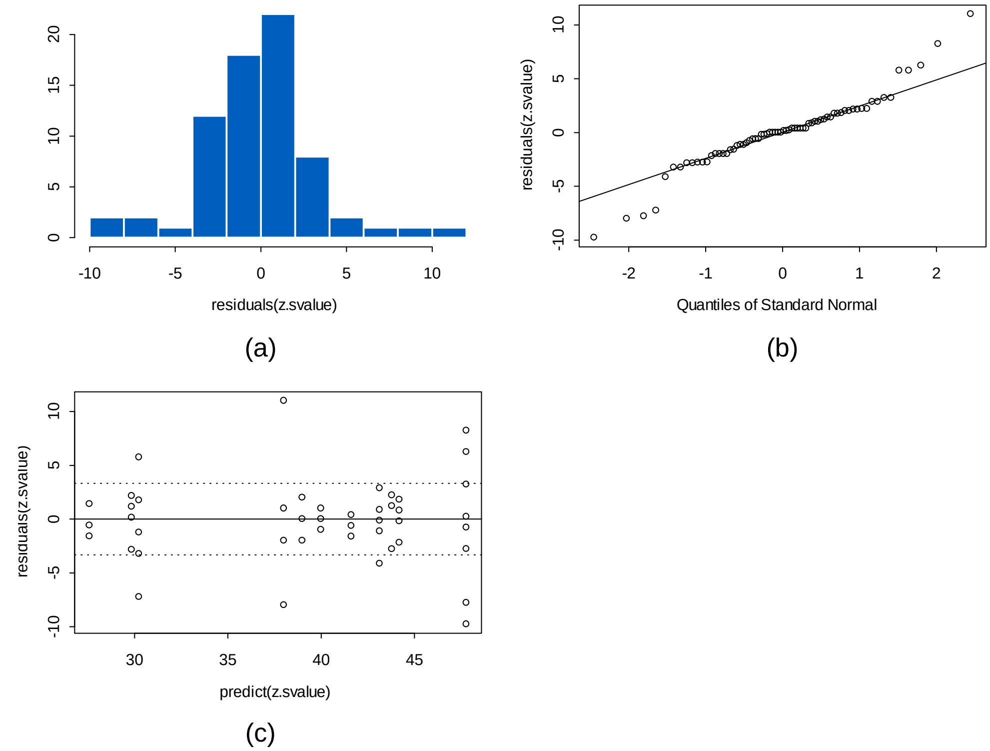


Figure 3.2: The residual analysis of the S-value tree model: (a) histogram, (b) normal probability plot, and (c) residuals versus fitted values.

Table 3.1: Quantitative Summary of Mix Properties Relating Stabilometer Value

Mix Types	Binder Types	Average S-Value	Average Percent Passing #200 (no200)	Average AC	Average #200/AC (n200oac)	Average Asphalt Film Thickness (film.calc.um) (μm)
RHMA-G_19mm	PG 64-16 R PG 58-22 R	33.4	3.05	7.1	0.425	21.81
RHMA-G_12.5mm	PG 64-16 R	31.8	2.60	7.6	0.347	28.14
HMA-A_19mm	PG 64-10 PG 64-16 PG 64-28 PG 64-28 PM PG 70-10	43.6	4.90	5.2	0.954	10.38
HMA-A_12.5mm	PG 64-10 PG 64-28 PM	41.9	6.15	5.6	1.096	8.95
HMA-A_09.5mm	PG 64-10	NA	NA	7.0	NA	NA

The tree-based modeling for S-value shown in Figure 3.1 suggests the following:

1. Viewed from the vertical distance between nodes, the covariate **`n200oac`** is far more significant than the other covariates. The value of **`n200oac`**, 0.47 based on the split rule at the root, separates the S-values into two groups ranging from 27.6 ~ 38.0 and 39.0 ~ 47.78 and actually separates the mix types into HMA-A (greater than 0.47) and RHMA-G (less than 0.47) according to Table 3.1. Figure 3.1 also shows that the S-values of HMA-A mixes are always greater than those of RHMA-G mixes. For #200/AC greater than 0.47, the mix with the higher PG grade issues a higher S-value; the mix with rubberized/polymer-modified binder or lower PG grade has a lower S-value. For #200/AC smaller than 0.47, the binder effect on S-value does not seem to be significant.
2. It is notable that the covariate **`mix.type`** is not significant enough to include in the modeling of S-value. The reason attributed to this insignificance may be the high correlation of covariate **`n200oac`** with the covariates **`mix.type`** and **`film.calc.um`** as indicated in Table 3.1. The covariate **`n200oac`** may also be more sensitive than the **`mix.type`** and **`film.calc.um`**.
3. Other than the primary covariate **`n200oac`**, the S-value relates secondarily to the geography-associated covariate **`dist`** and the covariate of **`form.type`** (CEM-3512 or CEM-3513). The S-values obtained from CEM-3513 are always greater than those from CE-3512, especially in Districts 4 and 6, regardless of mix type.
4. The geography-associated covariate **`dist`** might be the equivalent of aggregate source.

3.3 Tree-Based Models for CT 371-TSR Dry and Wet Strength

In this part of the discussion, tree-based modeling will be used to develop a data structure for the CT 371-TSR dry/wet strength. The covariates used to develop the data structure of CT 371-TSR dry/wet strength include five category variables: district (**`dist`**), mix type (**`mix.type`**), binder type (**`binder`**), form type (**`form.type`**), and treatment type (**`tsr.type`**). The factor levels for the five category covariates are listed below.

```
> levels(strength1$dist)
[1] "Dist02" "Dist03" "Dist04" "Dist06" "Dist07" "Dist08" "Dist09" "Dist10"  "Dist12"
       (a)      (b)      (c)      (d)      (e)      (f)      (g)      (h)       (i)
> levels(strength1$mix.type)
[1] "HMA-A_09.5mm"  "HMA-A_12.5mm"  "HMA-A_19mm"  "RHMA-G_12.5mm"  "RHMA-G_19mm"
         (a)             (b)             (c)            (d)              (e)
> levels(strength1$binder)
[1] "pg58-22r"  "pg64-10"  "pg64-16r"  "pg64-28"  "pg64-28pm"  "pg70-10"
        (a)        (b)        (c)         (d)        (e)          (f)
> levels(strength1$form.type)
[1] "Prod.Start.Up.Eval" "cem-3512"  "cem-3513"
           (a)              (b)         (c)
> levels(strength1$tsr.type)
[1] "1.tsr.dry"  "1.tsr.wet"  "2.tsr.lime.dry"  "2.tsr.lime.wet"
        (a)         (b)             (c)              (d)
[5] "3.tsr.las.dry"  "3.tsr.las.wet"
          (e)              (f)
```

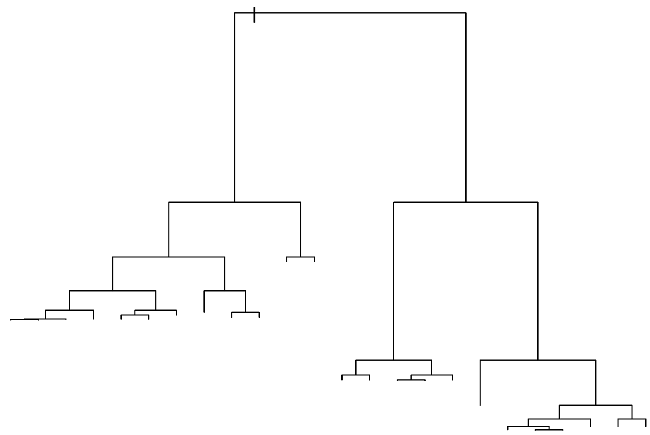
The letters of the alphabet associated with the factor levels will be used in the split rules of a dendrogram. (The entire tree structure for predicting CT 371-TSR dry/wet strength can be written as shown in Appendix A [Figure A.1]).

In a dendrogram, the vertical position of a node pair is a function of the importance of the parent split. In certain cases, a long-distance dendrogram makes it very difficult to clearly display the split rules on the nodes. Hence, if a complicated tree is developed, the dendrogram can be presented in two ways: (a) the original dendrogram without split rules (as in Figure 3.3[a]) and/or (b) the dendrogram with split rules but at a uniform distance among nodes (as in Figure 3.3[b]). It is necessary to prune the tree (as in Figure 3.4) if the data structure is to be addressed briefly. However, simplification of the tree must not sacrifice goodness-of-fit.

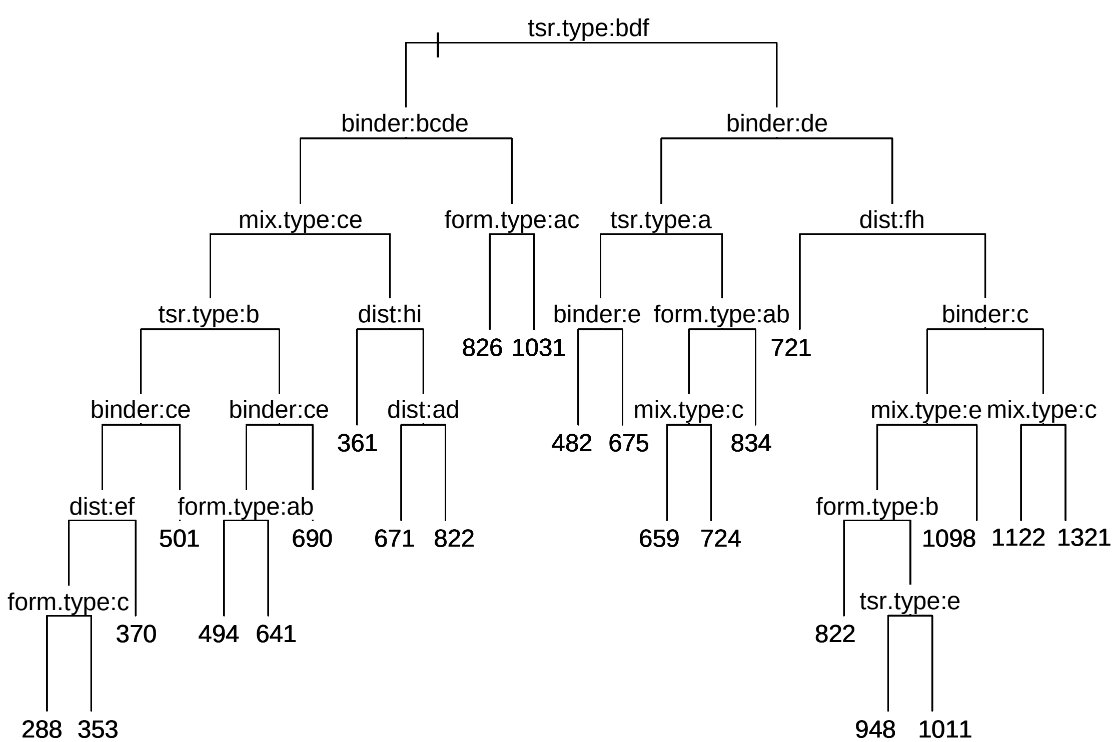
Figure 3.3a and Figure 3.3b display the dendrograms of CT 371-TSR dry/wet strength. Figure 3.4 illustrates a pruned tree that is four-nodes deep for each branch from the root. Based on the dendrogram in Figure 3.4, the following points are concluded:

1. The root node shows that the data are categorized into treated and untreated wet and dry strength groups. The **`binder`** is the next important covariate that affects dry/wet strength. Viewed from the vertical distance between nodes, the binder effect is far more important to dry strength than to wet strength.
2. For dry strength, the mixes with PG 64-28 or PG 64-28 PM binders show no obvious treatment difference. The treatments, LAS and lime, increase the dry strength from 530.1 kPa to 717.7 kPa.
3. For wet strength with treatment, strength increases from 398.6 kPa to 571.5 kPa. This can be seen for mixes with PG 64-10, PG 64-16 R, PG 64-28, and PG 64-28 PM binders in addition to mix types with larger nominal maximum aggregate sizes, i.e., HMA-A_19mm and RHMA-G_19mm mixes; a prominent difference between the wet strengths of District 10 and District 12 and those of Districts 2, 6, and 7 is observed for mix types with smaller NMAS, i.e., the HMA-A_09.5mm, HMA-A_12.5mm, and RHMA-G_12.5mm mixes.
4. For wet strength, the mixes with PG 58-22 R and PG 70-10 show a pronounced strength difference, based on the data collected in the project start-up evaluation and CEM-3512, and the data collected with form CEM-3513.

From the residual plots in Figure 3.5a and Figure 3.5b, the histogram and the normal probability plot indicate that the residuals of CT 371-TSR dry/wet strength tree-modeling exhibit the standard normal “bell curve” or Gaussian distribution with no strong pattern, as shown in Figure 3.5c. Thus, the residual analysis concludes that the tree-based model for CT 371-TSR dry/wet strength is statistically adequate and reliable to comply with the Gauss-Markov assumptions regarding regression fitting.



(a)



(b)

Figure 3.3: Dendrograms of CT 371-TSR dry/wet strength (a) without split rules and (b) with split rules and without vertical distance reference.

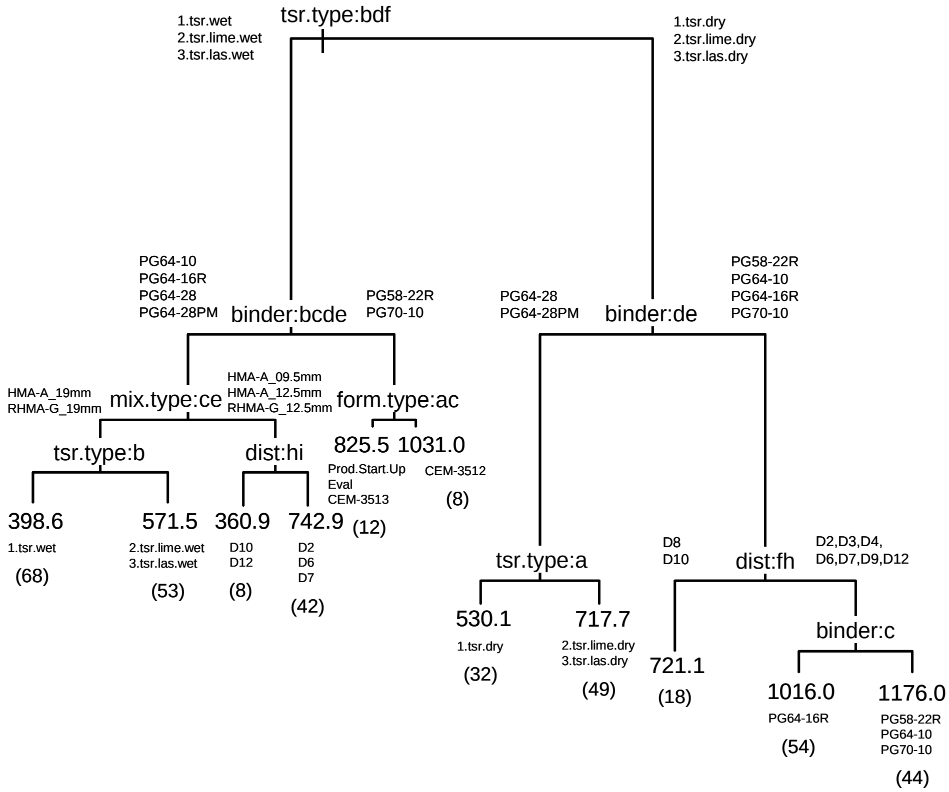


Figure 3.4: Pruned dendrogram with split rules of CT 371-TSR dry/wet strength. (Note: The value enclosed by parentheses at the leaf represents sample size.)

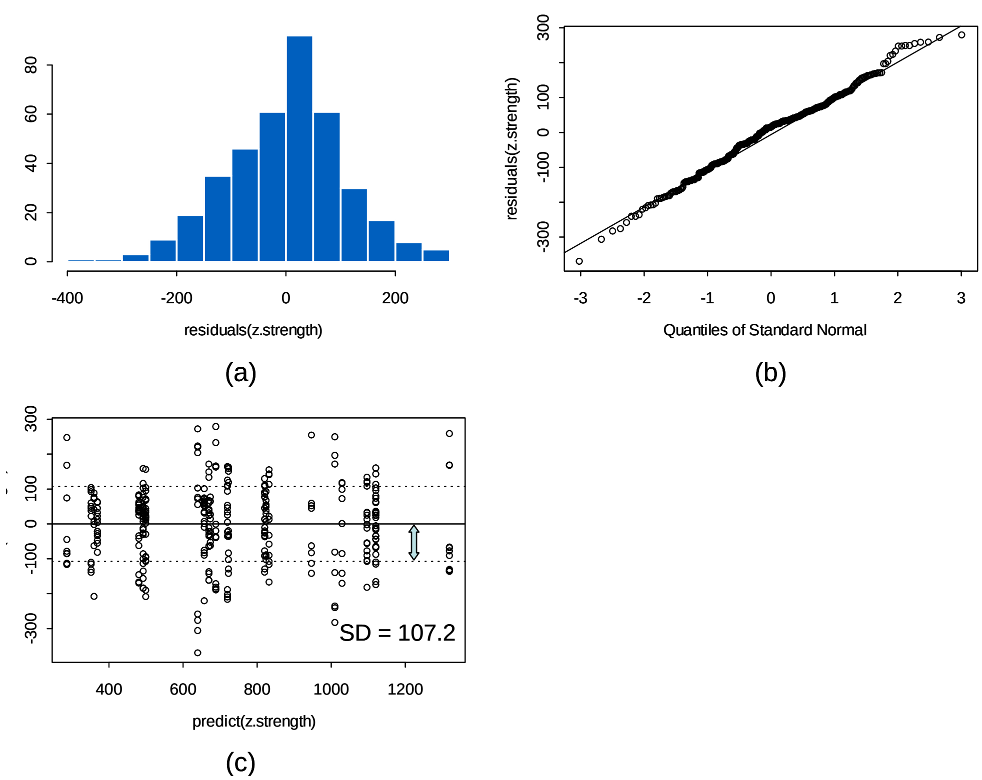


Figure 3.5: The tree model of CT 371-TSR strength: (a) histogram of residuals, (b) normal probability plot of residuals, and (c) residuals-versus-fitted values.

3.4 Tree-Based Models for CT 371-TSR Value

The covariates used to develop the data structure of CT 371-TSR value include four category variables—district (**`dist`**), mix type (**`mix.type`**), binder type (**`binder`**), and form type (**`form.type`**)—and nine numerical covariates—percent reclaimed asphalt pavement (**`rap`**), dosage of liquid anti-strip (**`xlas`**), dosage of lime (**`xlime`**), stabilometer value (**`s.value`**), percent asphalt content (**`ac`**), percent aggregate passing at #200 sieve (**`no200`**), maximum specific gravity (**`rice`**), calculated asphalt film thickness (**`film.calc.um`**), and the ratio of percent passing at #200 sieve to percent asphalt content (**`n200oac`**). The factor levels for the two category covariates included in the final tree-based model are listed below.

```
> levels(xtsr$dist)
[1] "Dist02" "Dist03" "Dist04" "Dist06" "Dist07" "Dist08" "Dist09" "Dist10"  "Dist12"
       (a)      (b)      (c)      (d)      (e)      (f)      (g)      (h)       (i)
> levels(xtsr$binder)
[1] "pg58-22r"  "pg64-10"   "pg64-16"   "pg64-16r"  "pg64-28"   "pg64-28pm"  "pg70-10"
        (a)         (b)         (c)         (d)         (e)         (f)          (g)
>
```

The letters associated with the factor levels have been used in the split rules of a dendrogram. The tree structure for predicting CT 371-TSR value is shown in Appendix A (Figure A.2).

Note that the available sample size of the TSR value is 65 records. For the CT 371-TSR value, the tree-based modeling, as shown in Figure 3.6, suggests the following results:

1. Based on this dendrogram, the **`dist`** covariate is the most important factor. It splits the data into two groups because District 2 primarily uses lime treatment, while the others use LAS treatment.
2. Based on District 2 data, it appears that the peak TSR value occurs when lime dosage is around 1.1 percent. The TSR value is reduced when lime dosage is greater than 1.1 percent. The reduction of the TSR value with a higher dosage of lime may be attributed to the agglomeration of lime that reduces the adhesion between asphalt and aggregate.
3. Generally speaking, for most binder types, LAS takes effect only when the asphalt film thickness is greater than 8.9 μm, i.e., RHMA-G_19mm, RHMA-G_12.5mm, and HMA-A_19mm mixes (according to Table 3.1), with asphalt content greater than 5.2 percent. The dosage of LAS is generally determined by the weight of binder; therefore, the thicker the asphalt film the higher the dosage. When heat is applied to LAS-treated asphalt, the treatment's effectiveness is reduced since the additive's heat endurance property is prone to volatility as temperature increases. Use of a thicker film, therefore, not only retards binder aging, but it also reduces volatility.
4. For the most of the binder types used in districts other than District 2, the average TSR was 53.8 if asphalt film thickness was less than 8.87 μm and 68.1 if it was equal to or greater than that.

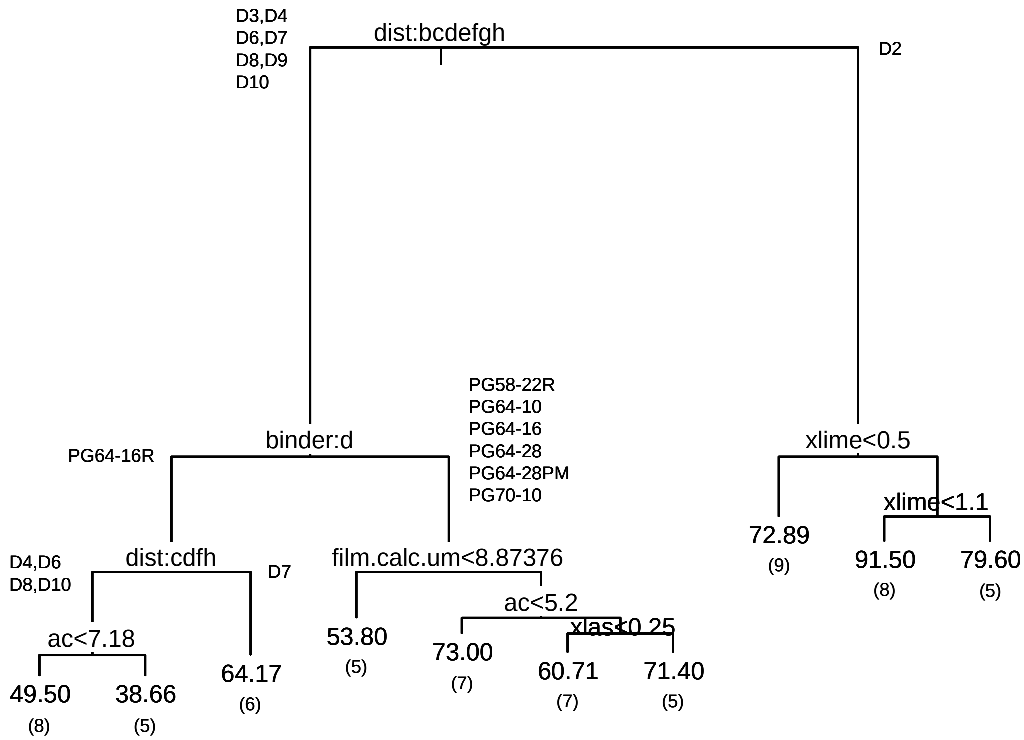


Figure 3.6: Dendrogram with split rules of CT 371-TSR value.
(Note: The value enclosed by parentheses at the leaf represents sample size.)

From the perspective of the residual analysis in Figure 3.7, Figure 3.7a presents a histogram with one mode (peak value) and an approximately symmetrical shape of residual distribution. A very pronounced pattern of long tails is shown in the normal probability plot, Figure 3.7b; it is a curve that starts below the normal line, bends to follow, and ends above it, which might indicate that more variance of the residuals would be expected. From the residual plot in Figure 3.7c, there are possible outliers when the fitted values of the TSR are about 50 and 60. Other than these possible outliers, the modeling seems to be adequate and acceptable.

Table 3.2 summarizes the first and second levels of the most significant covariates that affect the CT 371-TSR, CT 371-TSR strength, and S-value parameters. It is interesting to recognize that **`mix.type`** is not significant enough to include in the first- and second-level covariates for all three parameters; however, it should be noted that the **`mix.type`** is highly correlated with the covariates **`n200oac`** and **`film.calc.um`** according to Table 3.1. Also, note that District 2 is the primary district that uses lime treatment; the rest of the districts mostly use LAS treatment.

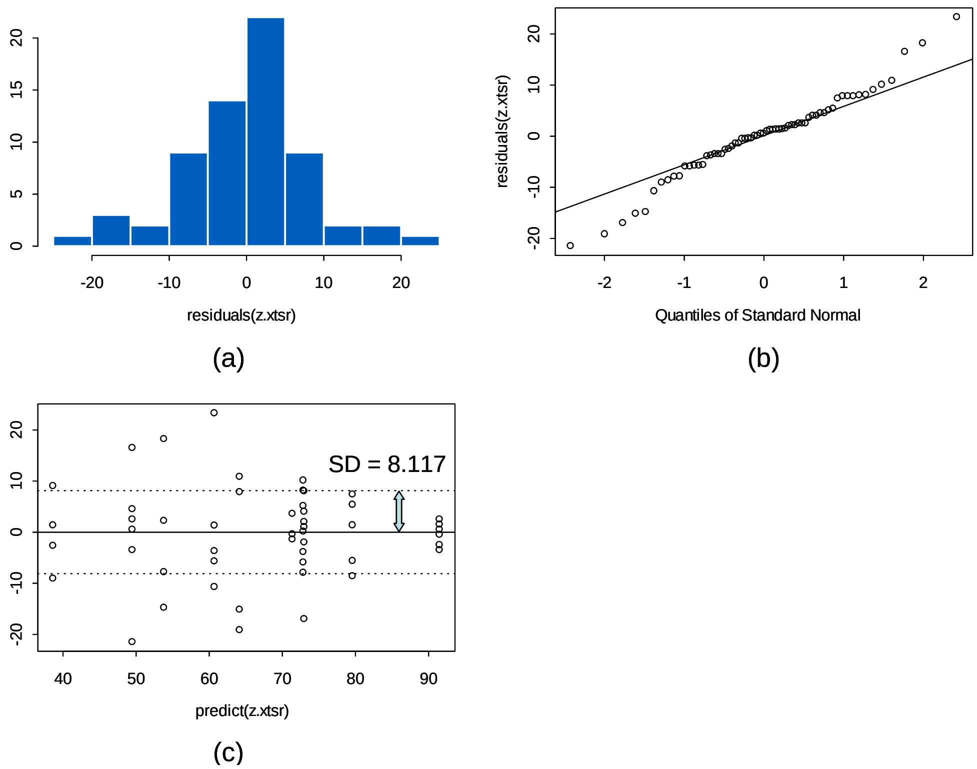


Figure 3.7: The residual analysis of the CT 371-TSR value tree model: (a) histogram, (b) normal probability plot, and (c) residuals-versus-fitted values.

Table 3.2: Summary of the First- and Second-Level Covariates

Parameter	**First Level**	**Second Level**	**Others**
CT 371-TSR	`dist`	`binder`, `xlime`	`film.calc.um`, `ac`, `xlas`
CT 371-TSR Dry/Wet Strength	`tsr.type`	`binder`	`mix.type`, `form.type`, `dist`
S-value	`n200oac`	`dist`, `form.type`	`binder`

4 FINDINGS AND DISCUSSION

From the discussion of Trellis graphs and the tree-based modeling of CT 371-TSR value, CT 371-TSR dry/wet strength, and stabilometer value (S-value), the following observations and suggestions can be made:

- *Data Incompleteness*: Even though the TSR values were documented in either the CEM-3512 or CEM-3513 forms, the detailed CT 371-TSR test results could not be located; the hot-mix asphalt pay QC/QA [HMA Pay (QC/QA)] information was collected from only a few QC/QA projects and provided little help in establishing a correlation with the CT 371-TSR value. It would make more sense to incorporate condition survey data of moisture damage into the evaluation of CT 371-TSR effectiveness as a QC/QA test.
- *Within and Between Variations*: Generally speaking, the within-variation is quite considerable for the CT 371-TSR value; for example, the interquartile range (IQR) of CT 371-TSR value can be as large as 35 percent for RHMA-G_12.5mm mixes with PG 64-16 R binder. The between-variation is rendered by the Trellis graphs for both S-value and CT 371-TSR value. The S-value reported on Form CEM-3513 is always greater than that on Form CEM-3512 when grouped by mix type, whereas for treated or untreated mixes the CT 371-TSR values reported on Form CEM-3513 are always smaller than those on Form CEM-3512 when categorized by district and form type. However, according to the tree-based modeling of CT 371-TSR dry/wet strength, the between-variation of the data from Form CEM-3512 (with an average of 1,031 kPa) and the data from Form CEM-3513 (with an average of 826 kPa) is noticeable only when the strength is wet strength and the binders are PG 58-22 R and PG 70-10.
- *Treatment Effect of CT 371-TSR Value*: LAS treatment does not seem to have an effect on PG 64-16 R mixes. LAS takes effect only when the asphalt film thickness is greater than 8.9 μm, i.e., RHMA-G_19mm, RHMA-G_12.5mm, and HMA-A_19mm mixes (according to Table 3.1), with AC greater than 5.2 percent. According to the tree-based model shown in Figure 3.6, the optimum dosage of lime treatment seems to be around 1.1 percent.
- *S-Value and #200/AC*: Tree-based modeling of the stabilometer value, which was found to be the most comprehensively recorded mix parameter, indicates that the #200/AC is the most critical factor and the value 0.47 of #200/AC separates the stabilometer values into two major groups. For #200/AC greater than 0.47 (i.e., HMA-A mixes [Table 3.1]) with S-values ranging from 39 to 48 (the right branch of the dendrogram in Figure 3.1), the mix with a higher PG grade results in a higher S-value; the mix with rubberized/polymer-modified binder or a lower PG grade has a lower S-value. For #200/AC smaller than 0.47 (i.e., RHMA-G mixes [Table 3.1]) with S-values ranging from 28 to 38 (the left branch of the dendrogram in Figure 3.1), the binder effect seems not to be significant.

- *CT 371-TSR Testing and Performance Specifications*: Within- and between-variations of test results are a generally unavoidable part of any testing process. The question then is, Can the degree of the variation be reduced to an acceptable level of error? For use of CT 371 testing as a QC/QA test method, therefore, the immediate concern becomes whether or not the testing variation can be reduced by improvements to specimen preparation, specimen conditioning, and testing. More importantly, a high priority should be given to the development of a rational QC/QA performance specification to statistically ensure that construction quality complies with design requirements.

REFERENCES

1. Moisture Sensitivity Hot Mix Asphalt Subtask Group. "Review of Moisture Sensitivity Test (CT 371) Data from the 2007 Pilot Study," Moisture Sensitivity Hot Mix Asphalt Subtask Group, HMA Task Group. Rock Products Committee, Sacramento, CA, Sept. 2, 2011.
2. Cleveland, W. S. *Visualizing Data*. Hobart Press, Summit, NJ, 1993.
3. Breiman, L., J. H. Friedman, R. A. Olshen, and C. J. Stone. *Classification and Regression Trees*. Wadsworth International Group, Belmont, CA, 1984.
4. Chambers, J. M., and T. J. Hastie. *Statistical Models in S*. Chapman and Hall Computer Science series, New York, NY, 1993.

APPENDIX A

1. Table A.1: Detailed Information of Mix Properties Listed by Project Expenditure Account, District, Mix Type, Binder and Form Type
2. Table A.2: CT 371-TSR Dry/Wet strength Listed by Project Expenditure Account, District, Mix Type, Binder, Form Type, and Tsr.type
3. Figure A.1: The Tree Structure of CT 371-TSR Strength
4. Figure A.2: The Tree Structure of CT 371-TSR

Table A.1: Detailed Information of Mix Properties Listed by Project Expenditure Account, District, Mix Type, Binder and Form Type

ea	dist	mix.type	binder	form.type	rap	xlas	xlime	tsr	tsr.lime	tsr.las	s.value	av	ac	no200	gbinder	rice	cgmb	fgmb	gave	sa	sa.calc	film.calc.um	n200oac
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	15	0	1	81	92	NA	42	4	5.2	6.1	1.023	2.577	2.825	2.661	2.748	NA	27.4456	9.0466	1.1731
02-3846U4	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	0	0	0	NA	92	NA	44	5.2	5.92	7.2	NA	2.483	NA	NA	NA	NA	NA	NA	1.2162
02-0E3103	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	0	0	0	NA	85	NA	46	5	5.56	NA	NA	2.47	NA	NA	NA	NA	NA	NA	NA
02-0E1203	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	0	0	0	NA	92	NA	41	4.8	5.49	6.1	NA	2.492	2.639	2.539	NA	NA	NA	NA	1.1111
02-0E3103	Dist02	HMA-A_19mm	pg70-10	Prod.Start.Up.Eval	0	0	0	NA	90	NA	45	5.8	4.99	5.8	NA	2.487	NA	NA	NA	NA	NA	NA	1.1623
02-0E0604	Dist02	HMA-A_12.5mm	pg64-28pm	cem-3513	0	0	1	NA	88	NA	46	5.1	5.57	6.5	NA	2.475	2.639	2.46	2.538	NA	29.4414	8.4614	1.1670
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	0	0	1	83	93	NA	45	4	5.3	5.5	1.0302	2.471	2.669	2.539	2.602	NA	25.2018	9.9713	1.0377
02-X25202	Dist02	HMA-A_12.5mm	pg64-28pm	cem-3512	0	0	1	78	89	NA	40	4.1	5.5	5.8	1.0094	2.451	2.669	2.539	2.595	NA	27.2243	9.7763	1.0545
02-0E6204	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	0	0	1.2	NA	85	NA	40	4.2	4.9	6.6	1.015	2.519	2.695	2.675	2.685	28	28.9604	8.1425	1.3469
02-0E6204	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	0	0	1.2	NA	NA	NA	39	3.9	5.32	4.5	1.015	2.519	2.704	2.482	2.592	NA	25.1191	10.1923	0.8459
02-0E6204	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	0	0	1.2	NA	71	NA	40	4.2	4.9	6.6	1.015	2.519	2.695	2.675	2.685	28	28.9604	8.1425	1.3469
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	0	0	1	73	94	NA	42	4	5.1	5.5	1.012	2.484	2.693	2.584	2.62	22	24.9554	9.8640	1.0784
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	0	0	1	67	NA	NA	42	5.1	5.3	5.5	1.012	2.494	2.689	2.489	2.584	NA	26.0419	9.8232	1.0377
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	0	0	1	NA	91	NA	42	5.1	5.3	5.5	1.012	2.494	2.689	2.489	2.584	NA	26.0419	9.8232	1.0377
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	0	0	1	73	94	NA	42	4	5.1	5.5	1.012	2.484	2.693	2.584	2.62	22	24.9554	9.8640	1.0784
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	0	0	1	67	NA	NA	42	4	5.1	5.5	1.012	2.484	2.693	2.584	2.62	22	24.9554	9.8640	1.0784
02-371004	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	0	0	1	NA	91	NA	42	4	5.1	5.5	1.012	2.484	2.693	2.584	2.62	22	24.9554	9.8640	1.0784
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	15	0	1.4	65	81	NA	41	3.7	5.7	5	1.0222	2.41	2.556	2.514	2.558	24.01	24.4115	11.1577	0.8772
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	15	0	1.4	69	74	NA	41	4.9	5.88	5	1.0222	2.445	2.561	2.431	2.535	24.01	19.4290	14.4617	0.8503
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	15	0	1.4	NA	87	NA	41	4.9	5.88	5	1.0222	2.445	2.561	2.431	2.535	24.01	19.4290	14.4617	0.8503
03-0A7104	Dist03	HMA-A_19mm	pg64-16	cem-3512	0	0	0	75	NA	NA	42	4	5.1	5.3	NA	NA	NA	NA	NA	NA	NA	NA	1.0392
03-0A7104	Dist03	HMA-A_19mm	pg64-16	cem-3513	0	0	0	NA	NA	NA	46	4.5	5.2	5.6	MA	2.581	2.77	2.67	2.73	NA	26.8256	9.4686	1.0769
03-367824	Dist03	HMA-A_19mm	pg64-10	cem-3512	0	0	0	46	NA	NA	40	3.9	5	6	1.03	2.496	2.757	2.668	2.767	NA	30.2093	7.8491	1.2000
03-367824	Dist03	HMA-A_19mm	pg64-10	cem-3513	0	0	0	NA	NA	NA	46	3.2	5.1	5.3	NA	2.53	2.72	NA	2.75	NA	NA	NA	1.0392
04-1E5504	Dist04	HMA-A_19mm	pg64-10	cem-3512	15	0	0	NA	NA	NA	42	3.7	4.9	4	1.02	2.588	2.776	2.711	2.745	25.8	22.9596	10.2203	0.8163
04-1E5504	Dist04	HMA-A_19mm	pg64-10	cem-3513	15	0	0	NA	NA	NA	50	5.8	4.48	4.3	1.02	NA	2.782	2.585	2.682	NA	26.1121	8.2161	0.9598
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	15	0.75	0	57	NA	75	46	4	5.3	3.3	1.025	2.501	2.681	2.589	2.644	18.5	19.2794	13.1005	0.6226
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3513	15	0.75	0	NA	NA	NA	48	3.7	5.37	4	1.025	2.521	2.682	2.573	2.627	NA	21.4192	11.9475	0.7449
04-253794	Dist04	HMA-A_19mm	pg64-10	cem-3512	0	0	0	50	NA	72	39	4.4	5.3	4.6	1.015	2.479	2.699	2.518	2.593	23	23.6255	10.7959	0.8679
04-253794	Dist04	HMA-A_19mm	pg64-10	cem-3513	0	0	0	NA	NA	NA	56	5.4	5.4	4.6	1.015	2.497	2.63	2.502	2.567	NA	23.7918	10.9227	0.8519
04-1E5504	Dist04	RHMA-G_12.5mm	pg64-16r	cem-3512	0	0.5	0	36	NA	40	27	3.4	8	1.8	1.023	2.494	2.788	2.726	2.766	25.8	12.6541	30.1866	0.2250
04-1E5504	Dist04	RHMA-G_12.5mm	pg64-16r	cem-3513	0	0.5	0	NA	NA	NA	36	2.2	8.11	2	1.023	2.498	2.737	2.616	2.693	NA	12.0267	32.1980	0.2466
04-444214	Dist04	HMA-A_19mm	pg64-16	cem-3512	0	0	0	84	NA	NA	42	3.83	5.3	3.7	1.02	2.475	2.66	2.544	2.602	NA	21.1672	11.9906	0.6981
04-444214	Dist04	HMA-A_19mm	pg64-16	cem-3513	0	0	0	NA	NA	NA	54	6.2	5.58	4.7	1.02	2.511	2.686	2.535	2.602	NA	24.5815	10.8707	0.8423
06-0G6104	Dist06	HMA-A_19mm	pg64-10	cem-3513	15	0	0	NA	NA	NA	45	5.2	4.9	4.2	NA	2.664	2.92	2.626	2.806	NA	25.3584	9.4385	0.8571
06-0G6104	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3513	0	0	0	NA	NA	NA	40	4.55	6.8	4.4	NA	2.596	2.913	2.746	2.86	NA	17.3519	19.1422	0.6471
06-0H8804	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3513	0	0	0	28	NA	NA	39	6.92	6.7	2.3	NA	2.403	2.59	2.464	2.565	11.72	12.1184	27.0059	0.3433
06-0H9004	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3513	0	0	0	NA	NA	NA	30	5.1	7.7	2.1	NA	2.403	2.624	2.44	2.593	NA	17.2604	21.7906	0.2727
06-0J3804	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3512	0	0.5	0	NA	NA	66	26	5	7	2.4	1.03	2.422	2.669	2.617	2.654	2.124	13.6626	24.2973	0.3429
06-0J3804	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3513	0	0.5	0	40	NA	NA	36	5.2	7.2	2.4	1.03	2.449	2.649	2.622	2.649	NA	9.4156	36.2642	0.3333
06-0J4704	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3513	0	0	0	NA	NA	NA	49	6.3	7	2.9	NA	2.389	2.58	2.461	2.565	NA	14.9449	22.8790	0.4143
06-0K6504	Dist06	HMA-A_19mm	pg70-10	cem-3513	0	0	0	NA	NA	NA	38	1.8	6.1	5	NA	2.436	2.601	2.459	2.508	NA	25.4175	11.7227	0.8197
06-322104	Dist06	HMA-A_19mm	pg70-10	cem-3512	0	1	0	56	NA	74	43	3.4	4.8	5.1	1.0246	2.57	2.75	2.69	2.72	NA	25.4183	9.0027	1.0625
06-322104	Dist06	HMA-A_19mm	pg70-10	cem-3513	0	1	0	56	NA	NA	51	5	4.9	5.7	1.0246	2.6	2.763	2.682	2.706	NA	27.7685	8.4124	1.1633
06-322104	Dist06	RHMA-G_19mm	pg64-16r	cem-3512	0	0.5	0	46	NA	54	29	5.1	7	2.6	1.028	2.52	2.75	2.64	2.72	NA	15.0024	22.1704	0.3714
06-322104	Dist06	RHMA-G_19mm	pg64-16r	cem-3513	0	0.5	0	46	NA	54	47	4.3	7.16	3.4	1.028	2.505	2.733	2.679	2.73	NA	15.2067	22.3725	0.4749
06-416104	Dist06	HMA-A_19mm	pg64-10	cem-3512	15	0	0	81	NA	92	46	4	5.1	4.3	1.0269	2.556	2.742	2.634	2.694	NA	23.0897	10.5064	0.8431
06-416104	Dist06	HMA-A_19mm	pg64-10	cem-3513	15	0	0	56	NA	NA	51	4.6	4.8	3.5	NA	2.545	2.733	2.598	2.698	NA	25.7607	8.8631	0.7292

Table A.1: Detailed Information of Mix Properties Listed by Project Expenditure Account, District, Mix Type, Binder and Form Type *(cont.)*

ea	dist	mix.type	binder	form.type	rap	xlas	xlime	tsr	tsr.lime	tsr.las	s.value	av	ac	no200	gbinder	rice	cgmb	fgmb	gave	sa	sa.calc	film.calc.um	n200oac
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	0	0.5	0	45	NA	49	32	5	7.1	2.9	1.031	2.432	2.664	2.64	2.656	NA	14.9581	22.4882	0.4085
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	0	0.5	0	NA	NA	NA	37	5.3	6.8	3.4	1.031	2.433	2.625	2.639	2.63	NA	18.4238	17.4864	0.5000
07-0P7904	Dist07	HMA-A_12.5mm	pg64-10	cem-3513	10	0.5	0	NA	NA	NA	39	4.1	5.55	6.4	NA	2.488	2.663	2.625	2.628	NA	32.4948	8.3428	1.1532
07-2Y6304	Dist07	HMA-A_12.5mm	pg64-10	cem-3512	0	0	0	NA	NA	NA	37	3.7	5.6	4.9	1.031	2.498	2.68	2.63	2.649	NA	28.7922	9.2148	0.8750
07-2Y6304	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	0	0.5	0	NA	NA	NA	31	4.1	7.7	2.2	1.031	2.421	2.64	2.596	2.623	NA	13.5388	26.9453	0.2857
07-2Y6304	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	0	0.5	0	NA	NA	NA	32	4.8	7.2	2.2	1.031	2.444	2.656	2.669	2.65	NA	12.4253	27.4536	0.3056
07-0P7903	Dist07	HMA-A_19mm	pg64-10	cem-3513	15	0	0	46	NA	NA	NA	NA	4.65	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
07-117074	Dist07	HMA-A_19mm	pg64-10	cem-3512	0	1	0	71	NA	75	46	4.7	5	5.5	1.0231	2.542	2.71	2.682	2.696	NA	26.8691	8.8844	1.1000
07-117074	Dist07	HMA-A_19mm	pg64-10	cem-3513	0	1	0	39	NA	NA	41	4.4	4.79	5.8	1.0231	2.543	2.714	2.674	2.692	NA	29.0005	7.8857	1.2109
07-3Y3404	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	0	0	0	72	NA	NA	30	3.7	8.2	3	1.03	2.362	2.521	2.572	2.541	NA	14.1517	27.4787	0.3659
07-3Y3404	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	0	0	0	NA	NA	NA	27	5.1	7.4	2.9	NA	2.457	2.693	2.657	2.678	NA	13.5506	25.8981	0.3919
07-2Y5304	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	0	0	0	72	NA	NA	27	4.9	7.8	3	1.03	2.419	2.648	2.614	2.635	NA	14.3988	25.6898	0.3846
07-2Y5304	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	0	0	0	NA	NA	NA	36	4.9	7.83	1.7	1.03	2.433	2.658	2.62	2.645	NA	9.4100	39.4606	0.2171
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	0	0	0	72	NA	NA	30	3.7	8.2	3	1.03	2.362	2.521	2.572	2.541	NA	14.1517	27.4787	0.3659
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	0	0	0	75	NA	NA	27	3.7	7.4	2.9	1.03	2.457	2.693	2.657	2.678	NA	13.5506	25.8981	0.3919
07-3Y7504	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	0	0	0	NA	NA	NA	27	4.9	7.8	3	1.03	2.419	2.648	2.614	2.635	NA	14.3988	25.6898	0.3846
07-3Y7504	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	0	0	0	NA	NA	NA	36	4.6	7.83	3	1.03	2.433	2.658	2.62	2.645	NA	9.4100	39.4606	0.3831
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	0	1	0	NA	NA	83	NA	NA	7.1	NA	NA	2.417	NA	NA	NA	NA	NA	NA	NA
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	0	1	0	NA	NA	40	NA	NA	7.1	NA	NA	2.448	NA	NA	NA	NA	NA	NA	NA
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	0	0	0	25	NA	NA	NA	NA	7.1	NA	NA	2.443	NA	NA	NA	NA	NA	NA	NA
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	0	0	0	24	NA	NA	NA	NA	7.1	NA	NA	2.443	NA	NA	NA	NA	NA	NA	NA
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	0	0	0	35	NA	NA	NA	NA	7.1	NA	NA	2.443	NA	NA	NA	NA	NA	NA	NA
07-3Y2403	Dist07	HMA-A_09.5mm	pg64-10	cem-3513	0	0	0	51	NA	NA	NA	NA	7	NA	NA	2.335	NA	NA	NA	NA	NA	NA	NA
08-472304	Dist08	HMA-A_19mm	pg64-28pm	cem-3512	10	0	0	72	NA	NA	45	4.1	4.8	5	1.028	2.501	2.674	2.633	2.655	NA	25.9585	8.7861	1.0417
08-472304	Dist08	HMA-A_19mm	pg64-28pm	cem-3513	10	0	0	NA	NA	NA	39	3.59	5.08	3.4	1.028	2.507	2.706	2.611	2.662	NA	22.2683	10.8396	0.6693
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	0	0.5	0	50	NA	52	29	5.3	7	3	1.031	2.449	2.672	2.66	2.668	NA	15.6028	21.2553	0.4286
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3513	0	0.5	0	NA	NA	NA	29	4.46	7.37	3.1	1.031	2.414	2.662	2.545	2.615	NA	15.6658	22.2888	0.4206
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3512	0	0.5	0	55	NA	71	44	4.1	5.3	4	1.031	2.498	2.65	2.589	2.623	NA	22.1208	11.3513	0.7547
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	0	0.5	0	55	NA	71	44	4.1	5.3	5	1.031	2.498	2.65	2.589	2.623	NA	22.1208	11.3513	0.9434
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3512	0	0.5	0	62	NA	70	32	4.4	7.5	3	1.031	2.429	2.65	2.613	2.638	NA	15.3061	23.2150	0.4000
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	0	0.5	0	62	NA	70	32	4.4	7.5	3	1.031	2.429	2.65	2.613	2.638	NA	15.3061	23.2150	0.4000
09-258014	Dist09	HMA-A_19mm	pg64-28pm	cem-3512	15	0	0	77	NA	NA	41	4	4.52	4.8	1.0056	2.452	2.616	2.595	2.611	5.237	24.4777	8.9696	1.0619
09-258014	Dist09	HMA-A_19mm	pg64-28pm	cem-3513	15	0	0	77	NA	NA	41	4	4.52	4.8	1.0056	2.462	2.616	2.595	2.611	5.237	24.4777	8.9696	1.0619
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3512	0	0	1	29.6	47.7	NA	27	4	7.3	3.4	1.0263	2.386	2.632	2.57	2.61	NA	16.7054	21.3450	0.4658
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3513	0	0	1	NA	NA	NA	23	2.7	8.2	1.37	NA	2.443	2.69	2.725	2.652	NA	11.0236	36.3346	0.1671
10-0S4104	Dist10	HMA-A_19mm	pg64-10	cem-3512	0	0	0	NA	NA	NA	44	4.1	5.8	3.2	1.0214	2.534	2.806	2.672	2.736	NA	18.7723	15.0918	0.5517
10-0S4104	Dist10	HMA-A_19mm	pg64-10	cem-3513	0	0	0	NA	NA	NA	38	4.5	5.7	3	NA	NA	2.804	2.67	2.734	NA	18.4450	15.0948	0.5263
12-0J0903	Dist12	RHMA-G_12.5mm	pg64-16r	cem-3513	0	0	0	41	NA	NA	NA	NA	NA	NA	NA	2.43	NA	NA	NA	NA	NA	NA	NA

Table A.2: CT 371-TSR Dry/Wet strength Listed by Project Expenditure Account, District, Mix Type, Binder, Form Type, and Tsr.type

ea	dist	mix.type	binder	form.type	tsr.type	strength (kPa)
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	1.tsr.dry	636.6
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	1.tsr.dry	621.3
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	1.tsr.dry	651.7
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	1.tsr.dry	611.1
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	1.tsr.wet	520.4
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	1.tsr.wet	511.4
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	1.tsr.wet	516
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	1.tsr.wet	524
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	2.tsr.lime.dry	730.9
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	2.tsr.lime.dry	720
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	2.tsr.lime.dry	717.7
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	2.tsr.lime.dry	728.8
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	2.tsr.lime.wet	651.7
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	2.tsr.lime.wet	649.3
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	2.tsr.lime.wet	669.3
02-378904	Dist02	HMA-A_19mm	pg64-28	cem-3512	2.tsr.lime.wet	688
02-3846U4	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	690
02-3846U4	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	703.5
02-3846U4	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	686.7
02-3846U4	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	692
02-3846U4	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	605.4
02-3846U4	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	606.6
02-3846U4	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	639.3
02-3846U4	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	693.1
02-0E3103	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	581.5
02-0E3103	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	593.8
02-0E3103	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	639.2
02-0E3103	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	620.7
02-0E3103	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	507.7
02-0E3103	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	508.5
02-0E3103	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	527.3
02-0E3103	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	532.7
02-0E1203	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	841.5
02-0E1203	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	885.8
02-0E1203	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	881
02-0E1203	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	873.4
02-0E1203	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	803.5
02-0E1203	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	818.6
02-0E1203	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	729.2
02-0E1203	Dist02	HMA-A_12.5mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	841.2
02-0E3103	Dist02	HMA-A_19mm	pg70-10	Prod.Start.Up.Eval	2.tsr.lime.dry	955.5
02-0E3103	Dist02	HMA-A_19mm	pg70-10	Prod.Start.Up.Eval	2.tsr.lime.dry	946.7
02-0E3103	Dist02	HMA-A_19mm	pg70-10	Prod.Start.Up.Eval	2.tsr.lime.dry	1011.8
02-0E3103	Dist02	HMA-A_19mm	pg70-10	Prod.Start.Up.Eval	2.tsr.lime.dry	1005.9
02-0E3103	Dist02	HMA-A_19mm	pg70-10	Prod.Start.Up.Eval	2.tsr.lime.wet	831.5
02-0E3103	Dist02	HMA-A_19mm	pg70-10	Prod.Start.Up.Eval	2.tsr.lime.wet	875.8
02-0E3103	Dist02	HMA-A_19mm	pg70-10	Prod.Start.Up.Eval	2.tsr.lime.wet	916.9
02-0E3103	Dist02	HMA-A_19mm	pg70-10	Prod.Start.Up.Eval	2.tsr.lime.wet	891.6
02-0E0604	Dist02	HMA-A_12.5mm	pg64-28pm	cem-3513	2.tsr.lime.dry	799.8
02-0E0604	Dist02	HMA-A_12.5mm	pg64-28pm	cem-3513	2.tsr.lime.dry	774.8
02-0E0604	Dist02	HMA-A_12.5mm	pg64-28pm	cem-3513	2.tsr.lime.dry	845.3
02-0E0604	Dist02	HMA-A_12.5mm	pg64-28pm	cem-3513	2.tsr.lime.dry	854.1
02-0E0604	Dist02	HMA-A_12.5mm	pg64-28pm	cem-3513	2.tsr.lime.wet	710.3
02-0E0604	Dist02	HMA-A_12.5mm	pg64-28pm	cem-3513	2.tsr.lime.wet	736.8
02-0E0604	Dist02	HMA-A_12.5mm	pg64-28pm	cem-3513	2.tsr.lime.wet	711.1
02-0E0604	Dist02	HMA-A_12.5mm	pg64-28pm	cem-3513	2.tsr.lime.wet	711.3
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	1.tsr.dry	1086.3
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	1.tsr.dry	1154.8
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	1.tsr.dry	1108.8
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	1.tsr.dry	1145.9
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	1.tsr.wet	859.5
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	1.tsr.wet	888.6
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	1.tsr.wet	944.2
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	1.tsr.wet	1030.8
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	2.tsr.lime.dry	1281.4

Table A.2: CT 371-TSR Dry/Wet strength Listed by Project Expenditure Account, District, Mix Type, Binder, Form Type, and Tsr.type *(cont.).*

ea	dist	mix.type	binder	form.type	tsr.type	strength (kPa)
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	2.tsr.lime.dry	1194.4
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	2.tsr.lime.dry	1223.9
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	2.tsr.lime.dry	1181.8
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	2.tsr.lime.wet	1101.8
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	2.tsr.lime.wet	1128.7
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	2.tsr.lime.wet	1145.9
02-0E0604	Dist02	HMA-A_19mm	pg70-10	cem-3512	2.tsr.lime.wet	1147.7
02-0E6204	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	715.3
02-0E6204	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	719
02-0E6204	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	758.5
02-0E6204	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	731.8
02-0E6204	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	723.7
02-0E6204	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	476.1
02-0E6204	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	522
02-0E6204	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	541.7
02-0E6204	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	538.9
02-0E6204	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	466.3
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	506.1
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	514
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	522.1
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	527.1
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	517
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	519
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	446
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	418.6
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	335.1
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	381.4
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	391.1
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	401.1
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	321.9
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	347.1
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	287.2
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	313
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.dry	567.7
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.dry	574.9
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.dry	582.3
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.dry	692
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.wet	499.2
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.wet	535.7
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.wet	594.7
02-2C5804	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.wet	608.3
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	506.1
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	514
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	522.1
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	527.1
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	335.1
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	381.4
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	391.1
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	401.1
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.dry	567.7
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.dry	574.9
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.dry	582.3
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.dry	692
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.wet	499.2
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.wet	535.7
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.wet	594.7
02-371004	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.wet	608.3
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.dry	647.8
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.dry	712
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.dry	689.1
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.dry	658
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.wet	568.2
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.wet	578
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.wet	530.3
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3512	2.tsr.lime.wet	513.3

Table A.2: CT 371-TSR Dry/Wet strength Listed by Project Expenditure Account, District, Mix Type, Binder, Form Type, and Tsr.type *(cont.)*

ea	dist	mix.type	binder	form.type	tsr.type	strength (kPa)
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.dry	439.1
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.dry	564
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.dry	534.6
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.dry	514.2
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.wet	373.2
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.wet	340.9
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.wet	346.8
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.wet	347.4
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	2.tsr.lime.dry	946.1
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	2.tsr.lime.dry	987.6
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	2.tsr.lime.dry	973.1
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	2.tsr.lime.dry	975.3
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	2.tsr.lime.wet	694.7
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	2.tsr.lime.wet	710.8
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	2.tsr.lime.wet	742.1
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	cem-3513	2.tsr.lime.wet	715.5
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	664.5
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	574.6
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	437.2
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.dry	709.2
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	521.1
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	507.1
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	406.6
02-1E0704	Dist02	HMA-A_19mm	pg64-28pm	Prod.Start.Up.Eval	2.tsr.lime.wet	651.1
03-367824	Dist03	HMA-A_19mm	pg64-10	cem-3512	1.tsr.dry	1086
03-367824	Dist03	HMA-A_19mm	pg64-10	cem-3512	1.tsr.dry	1108
03-367824	Dist03	HMA-A_19mm	pg64-10	cem-3512	1.tsr.dry	1139
03-367824	Dist03	HMA-A_19mm	pg64-10	cem-3512	1.tsr.dry	1145
03-367824	Dist03	HMA-A_19mm	pg64-10	cem-3512	1.tsr.wet	470
03-367824	Dist03	HMA-A_19mm	pg64-10	cem-3512	1.tsr.wet	501
03-367824	Dist03	HMA-A_19mm	pg64-10	cem-3512	1.tsr.wet	519
03-367824	Dist03	HMA-A_19mm	pg64-10	cem-3512	1.tsr.wet	569
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	1.tsr.dry	1033
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	1.tsr.dry	1053.2
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	1.tsr.dry	1056.3
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	1.tsr.dry	1115.4
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	1.tsr.wet	567.7
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	1.tsr.wet	594.4
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	1.tsr.wet	603.7
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	1.tsr.wet	655.8
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	3.tsr.las.dry	1153.3
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	3.tsr.las.dry	1183.8
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	3.tsr.las.dry	1216.8
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	3.tsr.las.dry	1234.4
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	3.tsr.las.wet	851.8
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	3.tsr.las.wet	854.3
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	3.tsr.las.wet	921.5
04-4A5204	Dist04	HMA-A_19mm	pg64-10	cem-3512	3.tsr.las.wet	967.9
06-0J3804	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3512	3.tsr.las.dry	1006.2
06-0J3804	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3512	3.tsr.las.dry	1040.8
06-0J3804	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3512	3.tsr.las.dry	1084.7
06-0J3804	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3512	3.tsr.las.dry	1095
06-0J3804	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3512	3.tsr.las.dry	990
06-0J3804	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3512	3.tsr.las.dry	992
06-0J3804	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3512	3.tsr.las.wet	635
06-0J3804	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3512	3.tsr.las.wet	707.9
06-0J3804	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3512	3.tsr.las.wet	658.8
06-0J3804	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3512	3.tsr.las.wet	729.6
06-0J3804	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3512	3.tsr.las.wet	701.7
06-0J3804	Dist06	RHMA-G_12.5mm	pg64-16r	cem-3512	3.tsr.las.wet	647.7
07-2Y5304	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	1094.5
07-2Y5304	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	1121.6
07-2Y5304	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	1130.1
07-2Y5304	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	1110.4
07-2Y5304	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.wet	795.8

Table A.2: CT 371-TSR Dry/Wet strength Listed by Project Expenditure Account, District, Mix Type, Binder, Form Type, and Tsr.type *(cont.)*

ea	dist	mix.type	binder	form.type	tsr.type	strength (kPa)
07-2Y5304	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.wet	800.5
07-2Y5304	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.wet	834.7
07-2Y5304	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.wet	787.6
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.dry	898.1
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.dry	865.6
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.dry	910.7
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.dry	949.9
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.wet	401.9
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.wet	389.6
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.wet	449.8
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.wet	373.9
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.dry	743
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.dry	729
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.dry	682
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.dry	795
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.wet	336
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.wet	308
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.wet	481
07-0P7904	Dist07	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.wet	309
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	1094.5
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	1121.6
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	1130.1
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	1110.4
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.dry	1218.2
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.dry	1230.7
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.dry	1215.6
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.dry	1204.7
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.wet	795.8
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.wet	800.5
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.wet	834.7
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.wet	787.6
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.wet	931.6
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.wet	907.1
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.wet	897.3
07-3Y8104	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.wet	928.8
07-3Y3404	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	1094.5
07-3Y3404	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	1121.6
07-3Y3404	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	1130.1
07-3Y3404	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	1110.4
07-3Y3404	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.wet	795.8
07-3Y3404	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.wet	800.5
07-3Y3404	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.wet	834.7
07-3Y3404	Dist07	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.wet	787.6
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.dry	870.8
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.dry	727.6
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.dry	929.3
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.dry	774.5
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.dry	1181.1
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.dry	1206.9
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.dry	1259.6
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.dry	769.8
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.dry	1181.1
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.dry	1206.9
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.dry	1259.6
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.dry	769.8
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.wet	200.9
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.wet	170
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.wet	241.6
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.wet	208
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.wet	533.8
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.wet	172.5
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.wet	201.8
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.wet	173.3
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.wet	533.8
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.wet	360.4

Table A.2: CT 371-TSR Dry/Wet strength Listed by Project Expenditure Account, District, Mix Type, Binder, Form Type, and Tsr.type *(cont.)*

ea	dist	mix.type	binder	form.type	tsr.type	strength (kPa)
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.wet	454.7
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	1.tsr.wet	201.3
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.dry	1201.3
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.dry	991.3
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.dry	1005.6
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.dry	998.6
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.dry	864.1
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.dry	883.9
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.dry	833.9
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.dry	805.5
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.wet	911.2
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.wet	859.4
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.wet	843.2
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.wet	862.4
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.wet	269.9
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.wet	333.7
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.wet	381
07-266703	Dist07	RHMA-G_19mm	pg64-16r	cem-3513	3.tsr.las.wet	363.8
07-3Y2403	Dist07	HMA-A_09.5mm	pg64-10	cem-3513	1.tsr.dry	1488.5
07-3Y2403	Dist07	HMA-A_09.5mm	pg64-10	cem-3513	1.tsr.dry	1487.2
07-3Y2403	Dist07	HMA-A_09.5mm	pg64-10	cem-3513	1.tsr.dry	1578.1
07-3Y2403	Dist07	HMA-A_09.5mm	pg64-10	cem-3513	1.tsr.dry	1578.5
07-3Y2403	Dist07	HMA-A_09.5mm	pg64-10	cem-3513	1.tsr.wet	691.5
07-3Y2403	Dist07	HMA-A_09.5mm	pg64-10	cem-3513	1.tsr.wet	784
07-3Y2403	Dist07	HMA-A_09.5mm	pg64-10	cem-3513	1.tsr.wet	810.6
07-3Y2403	Dist07	HMA-A_09.5mm	pg64-10	cem-3513	1.tsr.wet	833.3
07-0P7903	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.dry	1200.7
07-0P7903	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.dry	1077
07-0P7903	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.dry	1263.8
07-0P7903	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.dry	1151.4
07-0P7903	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.wet	532.1
07-0P7903	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.wet	519
07-0P7903	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.wet	570.8
07-0P7903	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.wet	543.4
07-117074	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.dry	1104.5
07-117074	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.dry	1076.3
07-117074	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.dry	1055
07-117074	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.dry	1157.2
07-117074	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.wet	309.5
07-117074	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.wet	291.6
07-117074	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.wet	536.8
07-117074	Dist07	HMA-A_19mm	pg64-10	cem-3513	1.tsr.wet	566.9
08-472304	Dist08	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	314
08-472304	Dist08	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	311
08-472304	Dist08	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	335
08-472304	Dist08	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.dry	311
08-472304	Dist08	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	220
08-472304	Dist08	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	242
08-472304	Dist08	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	237
08-472304	Dist08	HMA-A_19mm	pg64-28pm	cem-3512	1.tsr.wet	213
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.dry	828
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.dry	884
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.dry	845
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.dry	828
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.wet	456
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.wet	444
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.wet	412
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	1.tsr.wet	396
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.dry	830
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.dry	813
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.dry	754
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.dry	685
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.wet	379
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.wet	462
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.wet	357

Table A.2: CT 371-TSR Dry/Wet strength Listed by Project Expenditure Account, District, Mix Type, Binder, Form Type, and Tsr.type *(cont.)*

ea	dist	mix.type	binder	form.type	tsr.type	strength (kPa)
08-472304	Dist08	RHMA-G_19mm	pg64-16r	cem-3512	3.tsr.las.wet	392
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	1.tsr.dry	738.1
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	1.tsr.dry	750.8
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	1.tsr.dry	700.7
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	1.tsr.dry	688.8
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	1.tsr.wet	392.8
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	1.tsr.wet	394.3
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	1.tsr.wet	404
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	1.tsr.wet	405.9
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	3.tsr.las.dry	742.6
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	3.tsr.las.dry	716.1
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	3.tsr.las.dry	724.9
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	3.tsr.las.dry	666.2
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	3.tsr.las.wet	499.7
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	3.tsr.las.wet	517.1
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	3.tsr.las.wet	502.7
09-269014	Dist09	HMA-A_19mm	pg64-28	cem-3513	3.tsr.las.wet	507.4
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	1.tsr.dry	1186.2
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	1.tsr.dry	1189.3
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	1.tsr.dry	1184.2
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	1.tsr.dry	1183.8
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	1.tsr.wet	734.3
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	1.tsr.wet	721.5
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	1.tsr.wet	731.3
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	1.tsr.wet	735.1
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	3.tsr.las.dry	1229
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	3.tsr.las.dry	1242.3
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	3.tsr.las.dry	1251.4
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	3.tsr.las.dry	1253
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	3.tsr.las.wet	861.8
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	3.tsr.las.wet	879.2
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	3.tsr.las.wet	873.2
09-269014R	Dist09	RHMA-G_19mm	pg58-22r	cem-3513	3.tsr.las.wet	853.2
09-258014	Dist09	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.dry	542.7
09-258014	Dist09	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.dry	560
09-258014	Dist09	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.dry	561.6
09-258014	Dist09	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.dry	538.6
09-258014	Dist09	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.wet	413.2
09-258014	Dist09	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.wet	431
09-258014	Dist09	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.wet	432.1
09-258014	Dist09	HMA-A_19mm	pg64-28pm	cem-3513	1.tsr.wet	430.2
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	510.6
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	517.5
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	503.7
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.dry	531.3
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3512	1.tsr.wet	151.8
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3512	2.tsr.lime.dry	745.2
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3512	2.tsr.lime.dry	765.9
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3512	2.tsr.lime.dry	745.2
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3512	2.tsr.lime.dry	724.5
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3512	2.tsr.lime.dry	772.8
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3512	2.tsr.lime.dry	696.9
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3512	2.tsr.lime.wet	296.7
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3512	2.tsr.lime.wet	400.2
10-0G7504	Dist10	RHMA-G_12.5mm	pg64-16r	cem-3512	2.tsr.lime.wet	365.7
12-0J0903	Dist12	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.dry	1042.7
12-0J0903	Dist12	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.dry	915.4
12-0J0903	Dist12	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.dry	1128.8
12-0J0903	Dist12	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.dry	1019.4
12-0J0903	Dist12	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.wet	357.4
12-0J0903	Dist12	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.wet	431.8
12-0J0903	Dist12	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.wet	435.3
12-0J0903	Dist12	RHMA-G_12.5mm	pg64-16r	cem-3513	1.tsr.wet	447.9

Figure A.1: The Tree Structure of CT 371-TSR Strength

```
> print(z.strength)
node), split, n, deviance, yval
      * denotes terminal node

  1) root 388 32040000  725.2
    2) tsr.type:1.tsr.wet,2.tsr.lime.wet,3.tsr.las.wet 191  9364000  574.0
      4) binder:pg64-10,pg64-16r,pg64-28,pg64-28pm 171  6518000  535.0
        8) mix.type:HMA-A_19mm,RHMA-G_19mm 121  3454000  474.4
         16) tsr.type:1.tsr.wet 68   989800  398.6
           32) binder:pg64-16r,pg64-28pm 44   412200  342.9
             64) dist:Dist07,Dist08 24   351700  320.3
              128) form.type:cem-3513 12   225400  287.7 *
              129) form.type:cem-3512 12   100800  352.9 *
             65) dist:Dist02,Dist09 20    33440  370.1 *
           33) binder:pg64-10,pg64-28 24   190500  500.8 *
         17) tsr.type:2.tsr.lime.wet,3.tsr.las.wet 53  1575000  571.5
           34) binder:pg64-16r,pg64-28pm 41  1035000  536.8
             68) form.type:Prod.Start.Up.Eval,cem-3512 29   241000  493.8 *
             69) form.type:cem-3513 12   610700  640.6 *
           35) binder:pg64-10,pg64-28 12   322100  690.1 *
        9) mix.type:HMA-A_09.5mm,HMA-A_12.5mm,RHMA-G_12.5mm 50  1541000  681.8
         18) dist:Dist10,Dist12 8    67560  360.9 *
         19) dist:Dist02,Dist06,Dist07 42   492500  742.9
           38) dist:Dist02,Dist06 22   191300  671.1 *
           39) dist:Dist07 20    62540  822.0 *
      5) binder:pg58-22r,pg70-10 20   359900  907.6
       10) form.type:Prod.Start.Up.Eval,cem-3513 12    58710  825.5 *
       11) form.type:cem-3512 8    98600 1031.0 *
    3) tsr.type:1.tsr.dry,2.tsr.lime.dry,3.tsr.las.dry 197 14080000  871.7
      6) binder:pg64-28,pg64-28pm 81  1771000  643.6
       12) tsr.type:1.tsr.dry 32   401500  530.1
         24) binder:pg64-28pm 24   158400  481.9 *
         25) binder:pg64-28 8    19560  674.9 *
       13) tsr.type:2.tsr.lime.dry,3.tsr.las.dry 49   688700  717.7
         26) form.type:Prod.Start.Up.Eval,cem-3512 37   331400  680.0
           52) mix.type:HMA-A_19mm 25   150800  658.9 *
           53) mix.type:HMA-A_12.5mm 12   146100  724.1 *
         27) form.type:cem-3513 12   143000  833.8 *
      7) binder:pg58-22r,pg64-10,pg64-16r,pg70-10 116  5155000 1031.0
       14) dist:Dist08,Dist10 18   262900  721.1 *
       15) dist:Dist02,Dist03,Dist04,Dist06,Dist07,Dist09,Dist12 98  2847000 1088.0
         30) binder:pg64-16r 54  1377000 1016.0
           60) mix.type:RHMA-G_19mm 28   894400  939.1
            120) form.type:cem-3512 8    67140  821.7 *
            121) form.type:cem-3513 20   672800  986.1
              242) tsr.type:3.tsr.las.dry 8   116400  948.0 *
              243) tsr.type:1.tsr.dry 12   537200 1011.0 *
           61) mix.type:RHMA-G_12.5mm 26   140800 1098.0 *
         31) binder:pg58-22r,pg64-10,pg70-10 44   845200 1176.0
           62) mix.type:HMA-A_19mm 32   214800 1122.0 *
           63) mix.type:HMA-A_09.5mm,RHMA-G_19mm 12   285300 1321.0 *
>
```

Figure A.2: The Tree Structure of CT 371-TSR Value

```
> print(z.xtsr)
node), split, n, deviance, yval
      * denotes terminal node

 1) root 65 18120.0 66.50
   2) dist:Dist03,Dist04,Dist06,Dist07,Dist08,Dist09,Dist10 43  8898.0 58.98
     4) binder:pg64-16r 19  3697.0 51.28
       8) dist:Dist04,Dist06,Dist08,Dist10 13  1342.0 45.33
        16) ac<7.18 8   806.0 49.50 *
        17) ac>7.18 5   174.5 38.66 *
       9) dist:Dist07 6   898.8 64.17 *
     5) binder:pg58-22r,pg64-10,pg64-16,pg64-28,pg64-28pm,pg70-10 24  3180.0 65.08
      10) film.calc.um<8.87376 5   620.8 53.80 *
      11) film.calc.um>8.87376 19  1755.0 68.05
        22) ac<5.2 7   394.0 73.00 *
        23) ac>5.2 12  1090.0 65.17
          46) xlas<0.25 7   739.4 60.71 *
          47) xlas>0.25 5    17.2 71.40 *
   3) dist:Dist02 22  2049.0 81.18
     6) xlime<0.5 9   340.9 72.89 *
     7) xlime>0.5 13   660.9 86.92
      14) xlime<1.1 8    34.0 91.50 *
      15) xlime>1.1 5   191.2 79.60 *
>
```