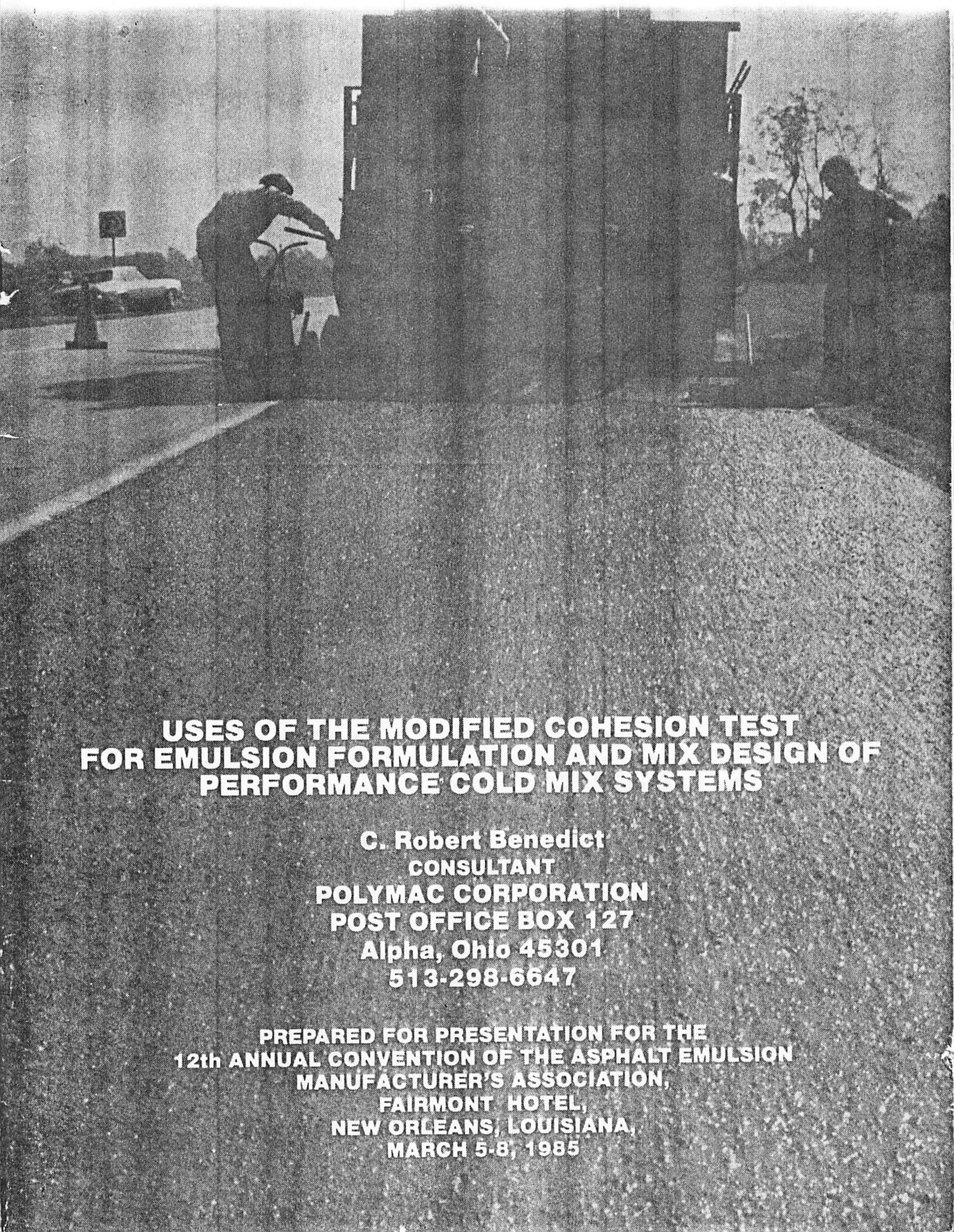

USES OF THE MODIFIED COHESION TEST FOR EMULSION FORMULATION AND MIX DESIGN OF PERFORMANCE COLD MIX SYSTEMS

C. Robert Benedict
CONSULTANT
POLYMAC CORPORATION
POST OFFICE BOX 127
Alpha, Ohio 45301
513-298-6647

PREPARED FOR PRESENTATION FOR THE
12th ANNUAL CONVENTION OF THE ASPHALT EMULSION
MANUFACTURER'S ASSOCIATION,
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presented by

C. ROBERT BENEDICT

CONSULTANT
ISSA DIRECTOR OF RESEARCH

Polymac Corporation
Post Office Box 127
Alpha, Ohio 45301
513-298-6647
513-426-0668

TO THE

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International Slurry Seal Association
1101 Connecticut Avenue, N.W., Suite 700
Washington, D.C. 20036
202/857-1160

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BY

C. ROBERT BENEDICT, CONSULTANT
ISSA DIRECTOR OF RESEARCH
320 NORTHVIEW ROAD
DAYTON, OHIO 45419
513-298-6647

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INTRODUCTION

WE ARE PLEASED TO REPRESENT ISSA AT THIS 12th ANNUAL MEETING OF AEMA AS OUR PART IN THE CONTINUING AEMA-ISSA LIAISON. AEMA MEMBER GEORGE MARIANIS JR's REMARKS WERE WELL RECEIVED AT OUR ISSA MEETING IN ORLANDO LAST MONTH. TWO YEARS AGO AT PHOENIX AEMA MEMBER BILL BALLOU OF HY-WAY ASPHALT AND CHAIRMAN OF OUR INTER-INDUSTRY LIAISON COMMITTEE PRESENTED A PROGRAM FOR TECHNICAL COOPERATION BETWEEN ISSA & AEMA. INCLUDED IN HIS SUGGESTED PROGRAM WAS AN EVALUATION AND STANDARDIZATION OF ISSA's THEN NEW MODIFIED COHESION TESTER. THIS PAPER IS CONCERNED WITH PRESENTING A REVIEW OF COHESION TESTER METHODS AND PROGRESS.

IT IS OUR OPINION THAT A VERY LARGE, GROWING AND SCARCELY TAPPED MARKET EXISTS FOR THIN-LAYERED EMULSION- AGGREGATE COLD MIXES AND SLURRY SEALS. THE COMPANION PRESENCE OF WATER PROBLEMS OF 1. "MIX-TIME," AND 2. "SET TIME," 3. "WATER RESISTANCE TIME," 4. "CURE TIME," AND 5. "TRAFFIC TIME" HAVE CAUSED GREAT CONCERN OVER THE YEARS BUT HAVE BEEN INADEQUATELY ADDRESSED BY OUR RESPECTIVE INDUSTRIES. THIS FACT PREVENTS BOTH OUR INDUSTRIES FROM ENJOYING THE FRUITS PROMISED BY THIS MARKET.

WHAT HAS BEEN NEEDED IN OUR OPINION IS AN OBJECTIVE METHOD OF MEASURING THESE CHARACTERISTICS; i.e., MEASURING & PLACING HARD, UNIVERSALLY UNDERSTANDABLE NUMBERS TO THE DESIRED CHARACTERISTICS. TOWARDS THIS END WE WILL, HERE:

(1) REVIEW OUR 1983 ISSA PAPER, "CLASSIFICATION OF ASPHALT EMULSION/AGGREGATE MIXTURE SYSTEMS BY COHESION TESTER MEASUREMENT OF SET AND CURE CHARACTERISTICS"
(2) REVIEW SEVERAL EXAMPLES OF THE USE OF THE MODIFIED ASTM COHESION TESTER IN EXAMINING THE EFFECT OF A NUMBER OF VARIABLES SUCH AS EMULSIFIER TYPE, PERCENT AND pH, AND AGGREGATE SOURCE, ETC. ON SET & TRAFFIC TIME OR "WET COHESIVE STRENGTH"
(3) INTRODUCE A COMPANION INSTRUMENT WHICH MEASURES THE MIXING CHARACTERISTICS OF VARIOUS EMULSION-AGGREGATE SYSTEMS AND THE EFFECT OF MIX VARIABLES ON THE MIXING CHARACTERISTICS.

HISTORICAL REVIEW

AT OUR 1969 MIAMI, FLORIDA ISSA MEETING, CHARLES G. SCHMITZ et. al. (1) PRESENTED IN HIS PAPER, "PRACTICAL QUICK-SET SLURRY SEAL COASTS" A MODIFIED BLUNT-NOSED GREASE CONE PENETROMETER (FIGURE 1) TO MEASURE RATE OF CURE OF VARIOUS SLURRY SYSTEMS. MANY CURVES (FIGURE 2) WERE PRESENTED TO SHOW THE EFFECTS OF DIFFERENT AGGREGATES, ADDITIVES, FILLERS AND TEMPERATURE ON THE CHEMICAL SET OR RELATIVE COHESIVE STRENGTH OR RESISTANCE TO COMPACTION BY HIS PENETROMETER DURING THE INITIAL SET AND CURE. HOWEVER, NO MEANINGFUL NUMBERS WERE PRESENTED.

LES HARKNESS (2) INTRODUCED TO US HIS ARMAK DEAD WEIGHT POWER STEERING SIMULATOR OR COHESION TESTER AT OUR EL PASO MEETING IN 1971. HE LATER REPORTED TO US AT MEXICO CITY IN 1974 (3) AND IN THE ARMAK HIGHWAY CHEMICAL NEWSLETTER OF FALL 1980 (4) (FIGURE 3). HIS FINDINGS WERE, ESSENTIALLY, THAT, IN ALL THE SLURRY SYSTEMS TESTED, MAXIMUM COHESION IS NOT REACHED UNTIL THE WATER CONTENT OF THE CURING MIX REACHES BETWEEN 5 AND 6%. HE ALSO REPORTED THE DEVELOPMENT OF COHESIVE STRENGTH TO BE LINEAR AND PROPORTIONAL TO THE LOSS OF WATER (FIGURE 4).

LEE (5) IN HIS EXTENSIVE RESEARCH "LABORATORY STUDY OF SLURRY SEAL COATS" SHOWS THAT AFTER AN INITIAL RAPID LOSS OF WATER, THEN ONLY DOES THE LOSS OF WATER BECOME LINEAR (FIGURE 5).

AT OUR FIRST WORLD CONGRESS HELD IN MADRID, SPAIN IN 1977, PEDRO FERREE FRANQUET (6) PRESENTED IN HIS PAPER, "THE INFLUENCE OF BITUMEN ACIDITY IN CATIONIC SLURRY SEAL", A "SLURRY PENETROMETER" (FIGURE 6) THE USE OF WHICH GENERATED DATA POINTS SHOWING THE RATE OF CURING OR THE RATE OF RESISTANCE TO PENETRATION. THE RESULTING CURVES WERE MEANINGFUL DEMONSTRATORS OF THE "RATE OF SET OR CURE" BUT MEASURED ONLY VERY THICK OR ATYPICAL SAMPLES (FIGURE 7). NOTE THE SIMILARITY TO LEE'S EVAPORATION CURVES BUT SIGNIFICANT EVAPORATION COULD NOT OCCUR IN THE VERY THICK AND CONFINED SPECIMENS USED BY FRANQUET. CLEARLY, THE EFFECT OF WATER CONTENT IS OVERCOME BY SOME "CHEMICAL" ACTIVITY.

IN ISSA's "DESIGN TECHNICAL BULLETINS-1978 AND 1980" (7) THE SCHMITZ-CHEVRON BLOTTER METHOD OF DETERMINING SET TIME AND WATER RESISTANCE TIME IS PUBLISHED AS TECHNICAL BULLETIN No. 102-76 "MIXING, SETTING AND WATER RESISTANCE TEST TO IDENTIFY QUICK-SET EMULSIFIED ASPHALTS". ISSA ALSO ISSUED IN DTB-78 & 80 TECHNICAL BULLETIN #116-78 "SPECIFICATIONS FOR QUICK-SET EMULSIFIED ASPHALT SLURRY SEAL SYSTEMS" AND THE FORMALIZED HARKNESS-ARMAK METHOD AS TECHNICAL BULLETIN #135-80 "CURE TIME MEASUREMENT BY ARMAK COHESION TESTER." THIS METHOD IS NOW INCLUDED IN ASTM D3910-80a. IN 1984, TECHNICAL BULLETIN #139, "PROPOSED TEST METHOD TO CLASSIFY EMULSIFIER ASPHALT/AGGREGATE MIXTURE SYSTEMS BY MODIFIED COHESION TESTER MEASUREMENT OF SET AND CURE CHARACTERISTICS" WAS PUBLISHED BY ISSA.

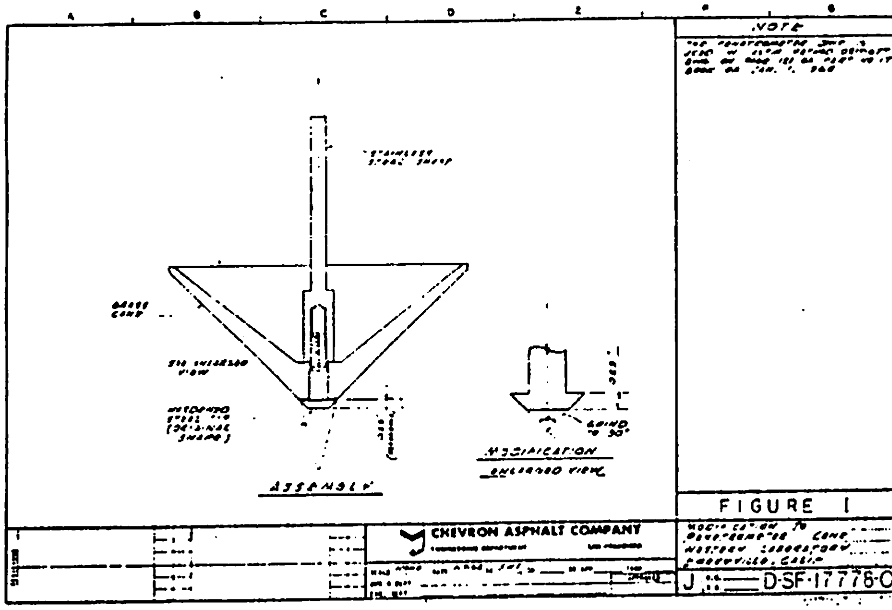


Fig. 1. V. Schmitz/Chevron
Blunt-nosed slurry penetrometer

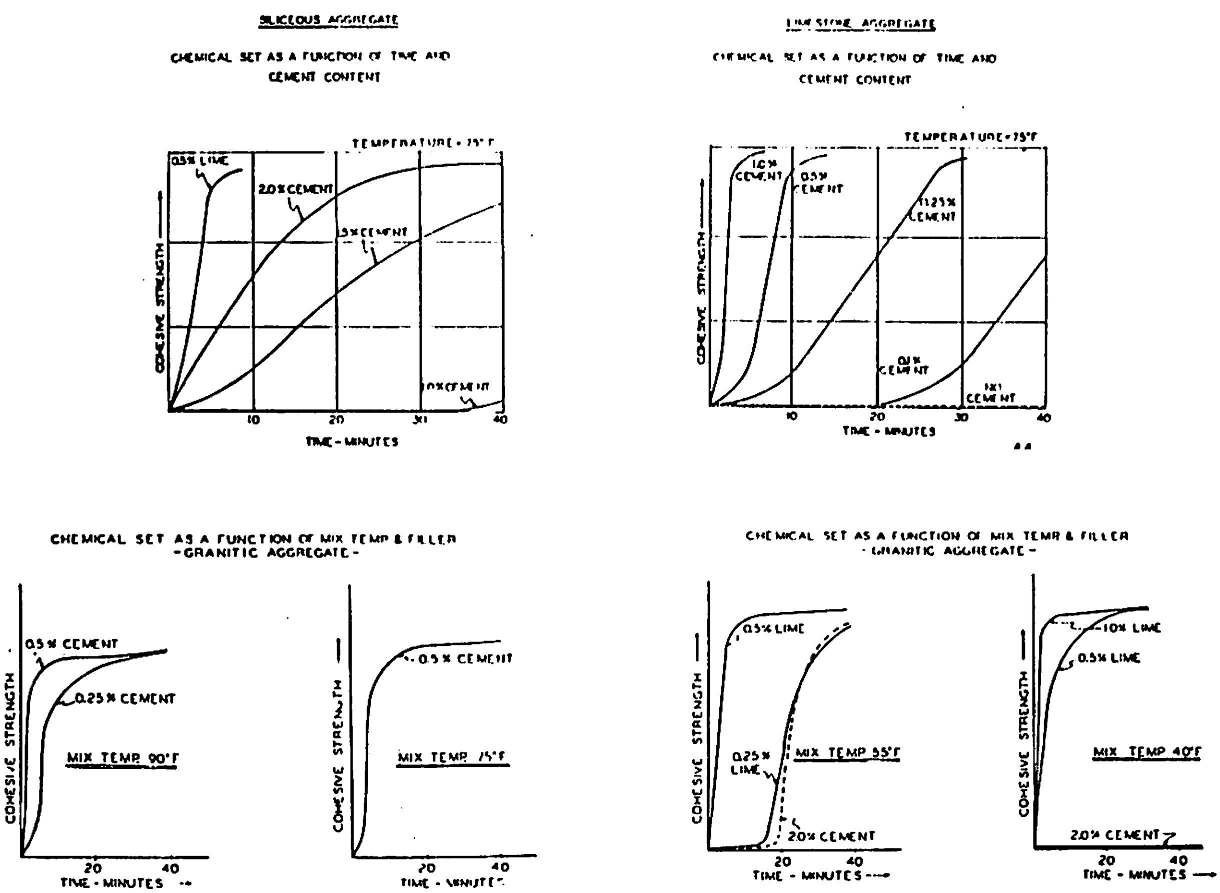


Fig. 2 Generalized slurry set curves (Schmitz 1969)

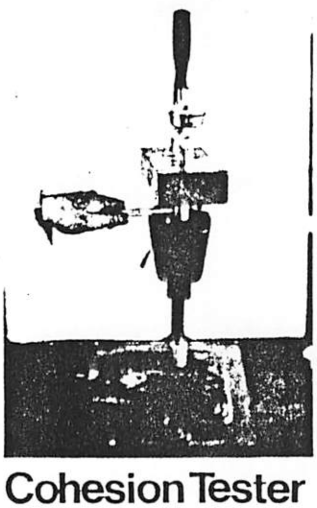


Fig. 3 ARMAK/Harkness Cohesion Tester

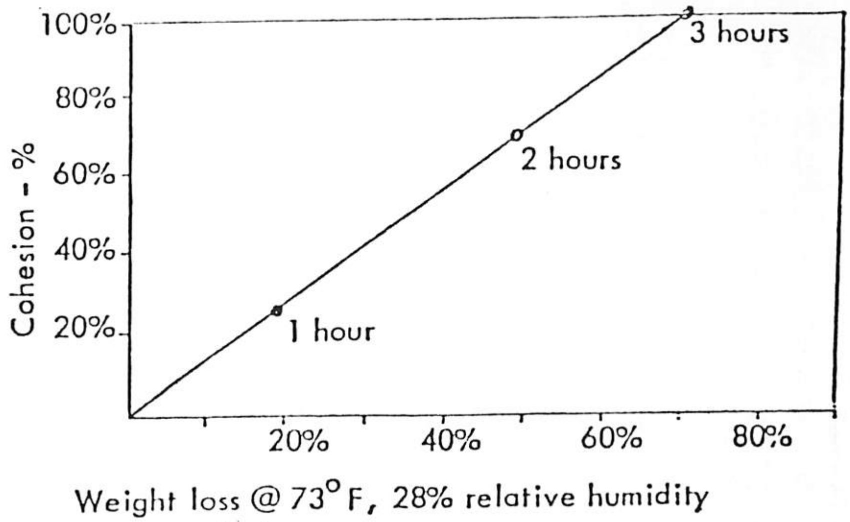


Fig. 4 Relationship between cohesion development and water loss in a typical ARMAK Slurry Formulation with Illinois limestone.

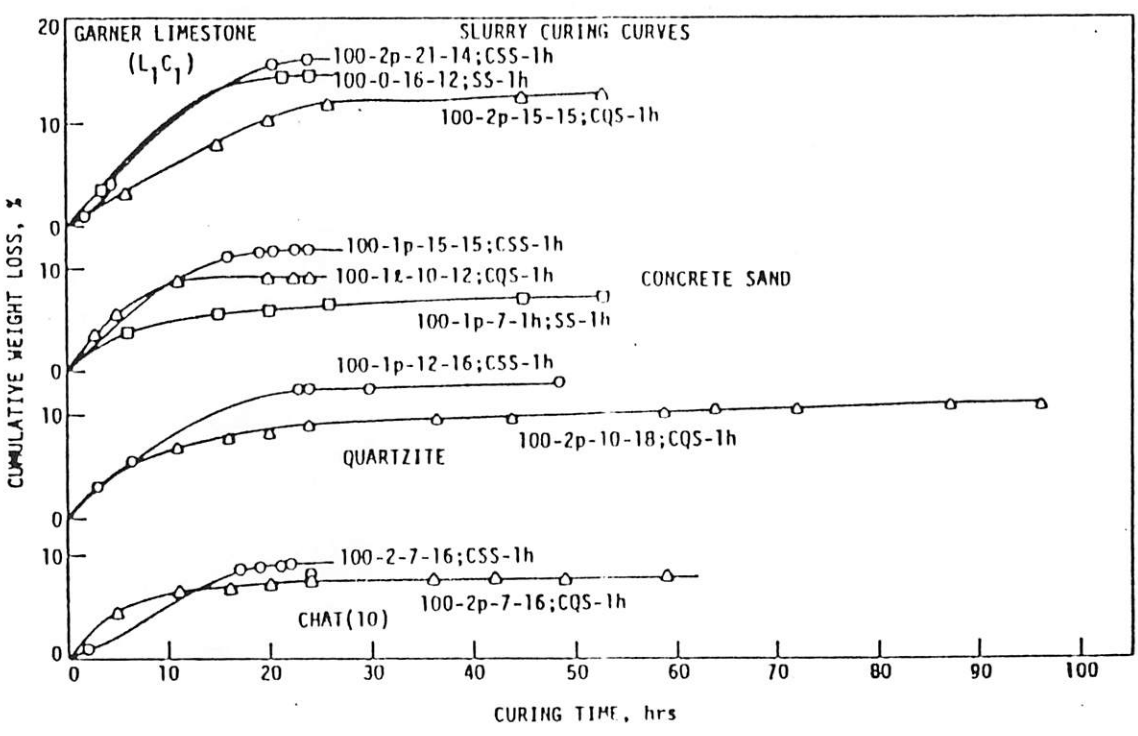


Fig. 5 Typical evaporative slurry curing curves (Lee)

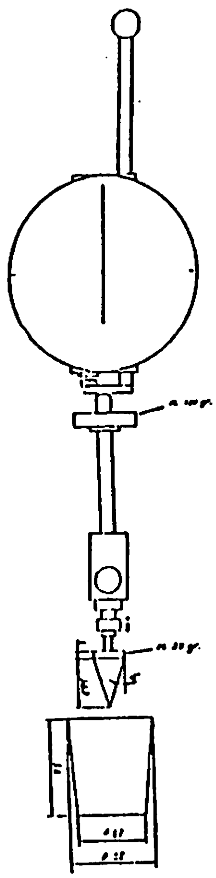


Fig. 6 Deep cup slurry penetrometer
(Feree Franquet 1977)

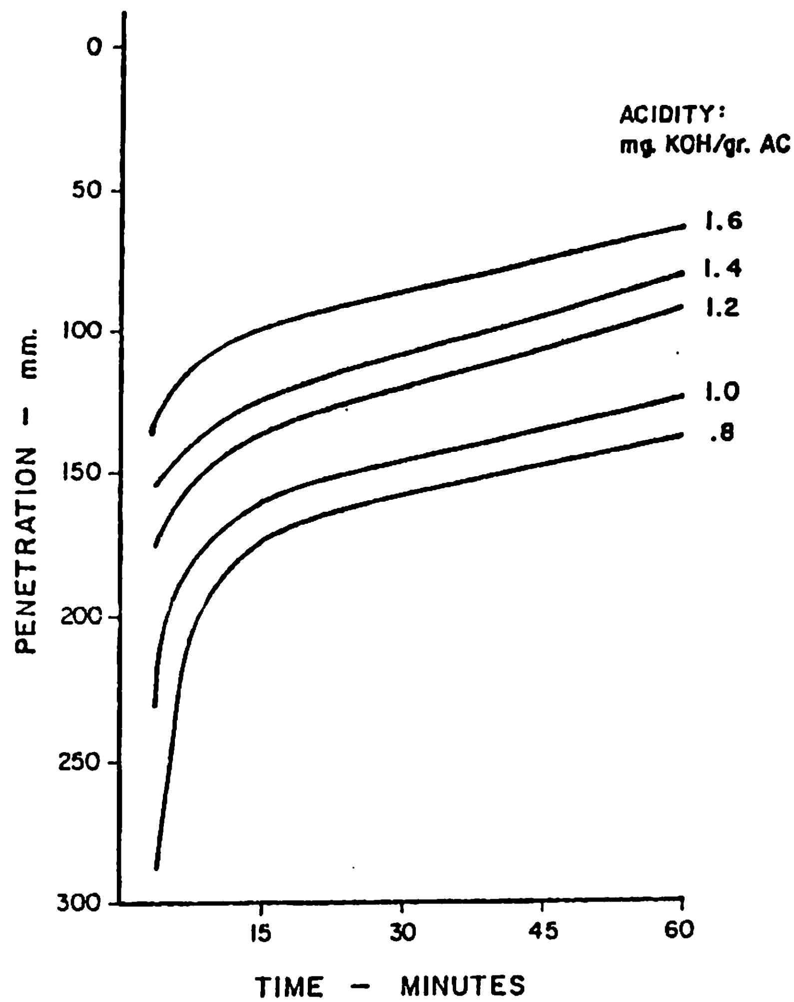


FIGURE 7. RATE OF CONE PENETRATION VS. BITUMEN ACIDITY

(Adapted from Pedro Feree Franquet, 1977)

THIS LATTER METHOD HAS SINCE BEEN INCORPORATED INTO ASTM D-3910-80a. (8), "STANDARD PRACTICES FOR DESIGN, TESTING AND CONSTRUCTION OF SLURRY SEAL", WHERE "CURE-TIME" IS DEFINED AS THE TIME REQUIRED "FOR THE HIGHEST TORQUE READINGS TO REMAIN CONSTANT".

A DISCUSSION OF MANY APPROACHES TO THE PROBLEM OF SET-TIME AND CURE-TIME TITLES "QUICK-SET, QUICK-CURE SLURRY SEAL SYSTEMS---STATE OF THE ART", (9) WAS PRESENTED TO THE 1978 ATLANTA ISSA "SYMPOSIUM QS QC SLURRY SYSTEM". (10) MANY OTHER USEFUL REFERENCES ARE CONTAINED IN THE SYMPOSIUM PROCEEDINGS.

THE MODIFIED ASTM D-3910 COHESION TESTER

THE MODIFIED COHESION TESTER (FIGURE 8) CONSISTS ESSENTIALLY OF (1) A FRAME, (2) INSTRUMENT PANEL, (3) PRESSURE GAUGE, (4) PRESSURE REGULATOR, (5) 4-WAY AIR VALVE AND (6) A DOUBLE-ROD AIR CYLINDER MOUNTED VERTICALLY SO THAT A (7) RUBBER FACED FOOT WHEN LOWERED BY AIR PRESSURE AGAINST A SPECIMEN MAY BE MANUALLY TWISTED TO FAILURE BY A (8) PEAK-READING TORQUE WRENCH.

SPECIMENS ARE PREPARED AND CAST IN A 60 mmO MOLD. A 6 mm-DEEP MOLD IS USED FOR AGGREGATES 100% PASSING THE 4.75 mm (#4 OR 3/16") SIEVE AND A 10 mm-DEEP MOLD IS USED FOR AGGREGATES 100% PASSING THE 8 mm (5/16") SIEVE. THE SPECIMENS ARE CAST ON 10 cm. (4") SQUARES OF NON-ABSORPTIVE 15-POUND BITUMEN SATURATED ROOFING FELT. THIS FELT HAS BEEN USED FOR SPECIMEN MOUNTINGS OF ALL THE DATA PRESENTED IN THIS PAPER.

THE MODIFIED COHESION TESTER IS SIMILAR TO THE ARMAK ASTM D 3910-80 INSTRUMENT EXCEPT THAT IT IS DESIGNED FOR A CONSTANT REGULATED AIR SUPPLY, CONVENIENT 4-WAY CYLINDER VALVE TO OPERATE THE CYLINDER AT CONTROLLED RATE OF SPEED. THE CYLINDER IS LARGER AND MORE RUGGED. THE CONTACT FOOT USED HERE IS A FLAT 1/4" NEOPRENE DISC OF 50-60 DUROMETER HARDNESS, 1-1/8"O RATHER THAT A 1"O PLUG CUT FROM AN AUTOMOBILE TIRE. THE PROCEDURES USED MAY BE FOUND IN ISSA TECHNICAL BULLETIN TB#139 12/82. THE PRESSURE EXERTED ON THE FOOT IS 92.3% OF THE GAUGE READING. THE TEST PRESSURE IS SET @ 200 kPa (28.44 psi) AND THE CYLINDER FOOT IS LOWERED AGAINST THE CENTERED SPECIMEN AND ALLOWED TO COMPACT THE SPECIMEN FOR 5 TO 6 SECONDS. THE TORQUE METER IS PLACED ON THE UPPER CYLINDER ROD END AND TWISTED BY HAND IN A FIRM SMOOTH HORIZONTAL MOTION THROUGH 90° TO 120° OF ARC WITHIN .7 TO 1.0 SECONDS. THE MAXIMUM TORQUE FOLLOW-UP POINTER IS READ AND THE RESULTS RECORDED, THE FOOT RAISED AND CLEANED AND THE FOLLOW-UP POINTER IS RESET.

A SERIES OF SPECIMENS ARE PREPARED BY CASTING A FRESH MIXTURE INTO 60 mm0 RINGS 6 OR 10 mm THICK AND CENTERED ON A NON-ABSORBENT SURFACE SUCH AS 10 cm. SQUARES OF 15-POUND SATURATED ROOFING FELT. THE NUMBER OF DATA POINTS DURING A SPECIFIED TIME SPAN DETERMINES, OF COURSE, THE NUMBER OF SPECIMENS AND AMOUNT OF MIX REQUIRED.

PEAK TORQUES ARE RECORDED AT 30, 60, 90, 120 MINUTES AND SO ON. MOISTURE CONTENTS MAY ALSO BE DETERMINED FOR EACH TEST. THE DATA ACQUIRED MAY BE CONVENIENTLY RECORDED ON A DATA FORM OR ON A GRAPH FORM AS IN FIGURE 9.

THE VERTICAL AXIS SHOWS THE TORQUE AS KILOGRAM-CENTIMETERS OR POUND-INCHES AT THE 200 kPa PRESSURE WHILE THE HORIZONTAL AXIS RECORDS TIME. SHOWN ON THE GRAPH FORMS ARE TORQUE VALUES FOR:

1. INSTRUMENT LIMIT
2. FULLY CURED SLIP TORQUE
3. ASSUMED "EARLY ROLLING TRAFFIC TORQUE" OF 20 kg-cm.
4. CALIBRATION TORQUE FOR 100 GRIT SAND PAPER
5. CALIBRATION TORQUE FOR 220 GRIT SAND PAPER
6. ASSUMED "SET TORQUE" OF 12 kg-cm.
7. THE TORQUE VALUE OF THE DRY AGGREGATE BEING TESTED
8. OTTOWA SAND 20-30 MESH
9. FRICTION FREE CYLINDER PRESSURE TORQUE

AFTER ALL DATA IS RECORDED, GRAPHIC PLOTS MAY BE MADE SHOWING:

1. TORQUE-TIME (RATE OF COHESIVE STRENGTH DEVELOPMENT IN kg/cm OR lb/in UNITS)

2. TORQUE-MOISTURE (RATE OF WET STRENGTH DEVELOPMENT)

3. MOISTURE-TIME (RATE OF MOISTURE LOSS)

"SET", "SET-TIME" AND "QUICK-SET SYSTEM" DEFINED

FROM OUR INITIAL RESEARCH WE HAVE OBSERVED THAT THE "SET" OF ANY SYSTEM, QUICK-SET OR SLOW-SET, OCCURS AT THE 12 TO 13 kg/cm TORQUE LEVEL. OUR OLD DEFINITION OF THE "SET" OF AN EMULSION AGGREGATE SYSTEM IS: "THE POINT IN TIME WHERE NO FREE EMULSION REMAINS TO LUBRICATE THE MIXTURE OR TO STAIN BLOTTER PAPER, IS INCAPABLE OF BEING RE-MIXED INTO A FLUID MIXTURE AND IS WATER RESISTANT, AND, UPON DEPRESSING THE SPECIMEN SURFACE THERE IS NO HORIZONTAL DISPLACEMENT (THE FINGER TEST)." SIMPLY STATED, <u>THE SET OF AN EMULSION AGGREGATE SYSTEM IS 12 kg/cm</u> WHEN MEASURED NY THE MODIFIED COHESION TESTER.

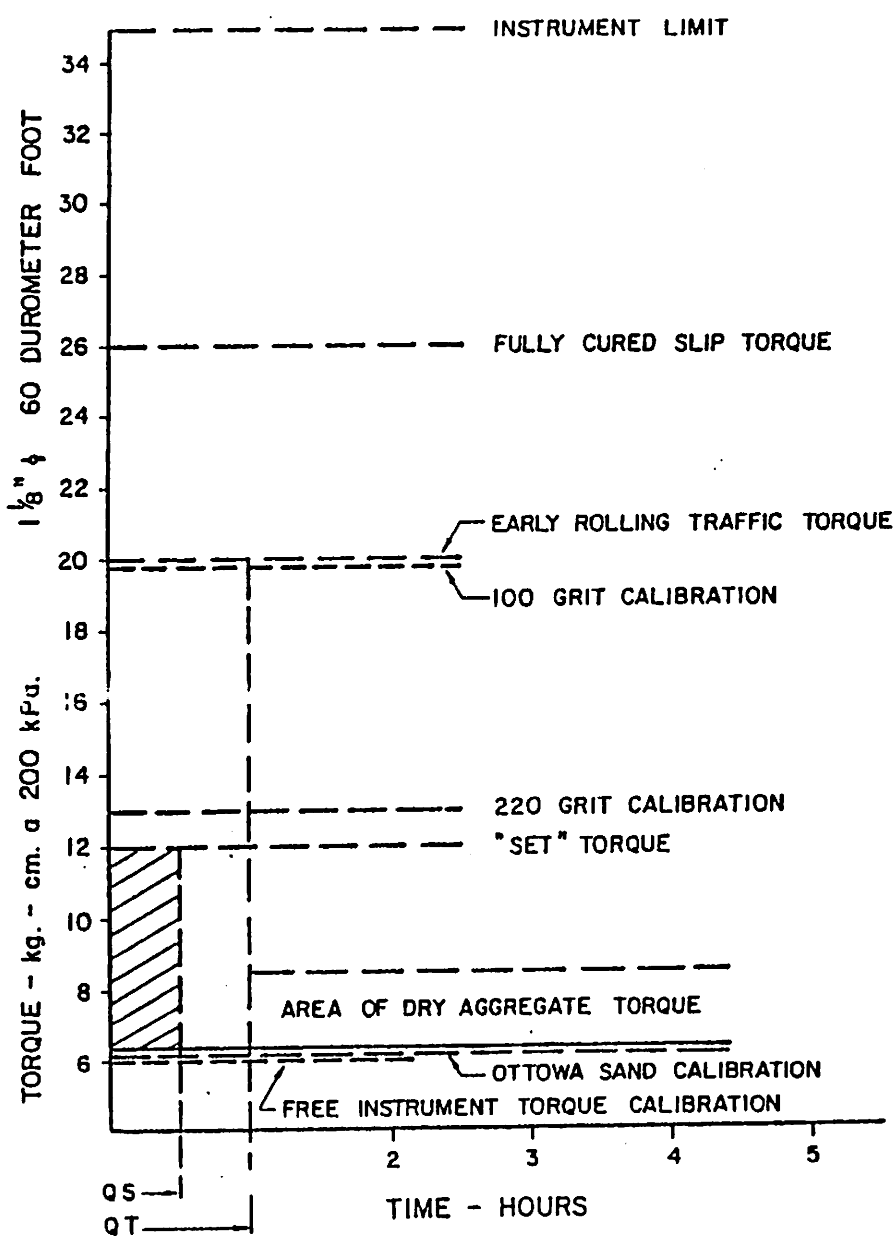


FIGURE 9. COHESION TESTER TORQUE LEVELS

BY LIMITING THE TIME REQUIRED TO REACH A SET, A QUICK-SET SYSTEM MAY BE DEFINED AS A BITUMINOUS EMULSION/AGGREGATE MIXTURE WHICH DEVELOPS A COHESIVE STRENGTH OF 12 kg/cm TORQUE WITHIN 30 MINUTES.

"TRAFFIC TIME" AND "QUICK-TRAFFIC SYSTEM" DEFINED

ALSO, DURING OUR RESEARCH WE HAVE OBSERVED THAT EARLY ROLLING TRAFFIC MAY BE SUPPORTED BY THE FRESHLY LAID EMULSION/AGGREGATE SYSTEM WHEN THE COHESIVE STRENGTH AS MEASURED BY THE MODIFIED COHESION TESTER REACHES THE 20-22 kg/cm TORQUE LEVEL.

A QUICK-TRAFFIC SYSTEM, THEN, MAY BE DEFINED AS A BITUMEN EMULSION-AGGREGATE SYSTEM WHICH DEVELOPS A COHESIVE STRENGTH OF 20 kg/cm TORQUE WITHIN 60 MINUTES.

THESE VALUES OF 12 AND 20 kg/cm FOR SET AND EARLY ROLLING TRAFFIC MAY BE SHOWN ON THE GRAPH ALONG WITH SET AND TRAFFIC TIME LINES AND CALIBRATION LINES.

CLASSIFICATION OF EMULSION-AGGREGATE MIX SYSTEMS

THE GENERALIZED CURVES SHOWN IN (FIGURE 10) REPRESENT 5 TYPES OR CATEGORIES OF COHESIVE STRENGTH DEVELOPMENT. ALL OF THE INITIAL SYSTEM CURVES INVESTIGATED SEEM TO FIT INTO ONE OF THESE GENERALIZED CATEGORIES, WHICH, USING THE PREVIOUS DEFINITIONS OF SET TIME AND TRAFFIC TIME, MAY BE DETERMINED:

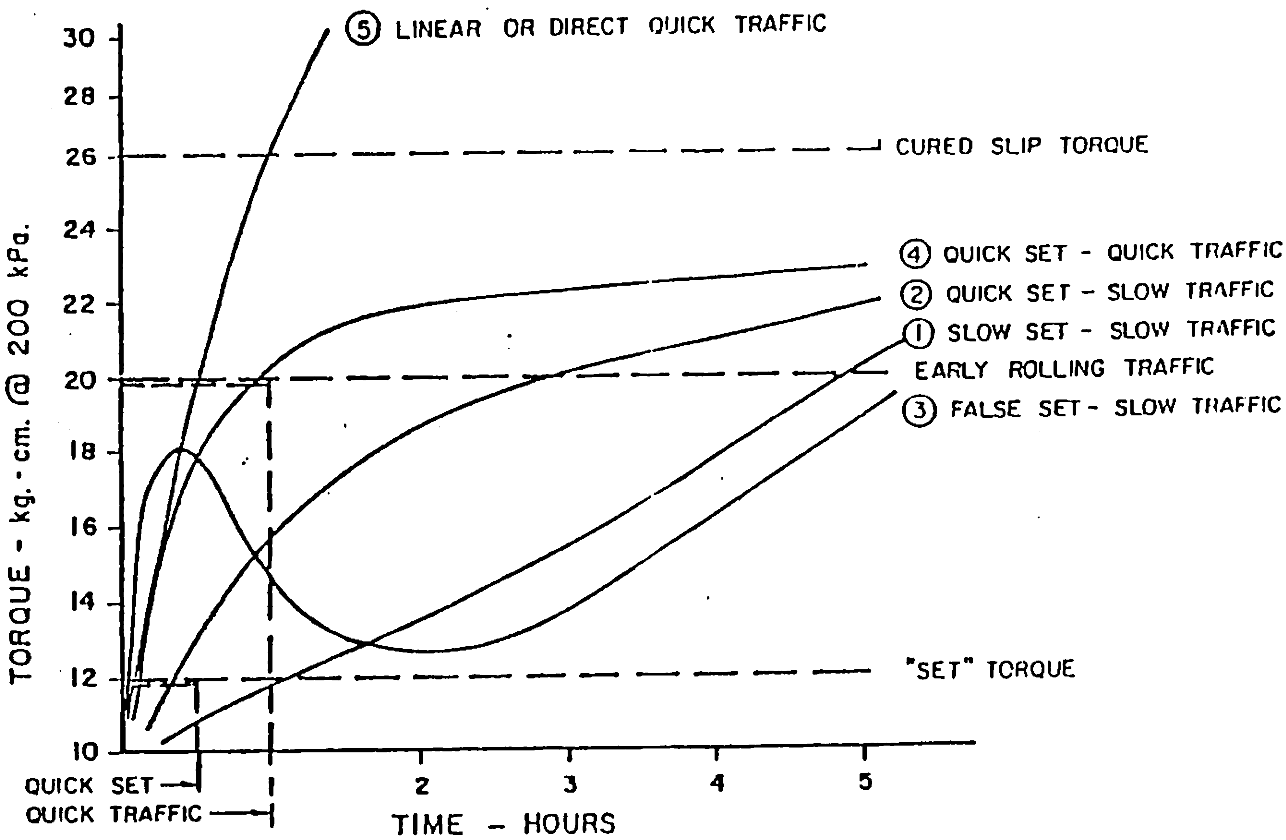


FIGURE 10. CLASSIFICATION OF MIX SYSTEMS BY MODIFIED COHESION TEST CURVES

VARIABLES AFFECTING COHESION CURVES

AS STATED, THE RATE OF SET AND TRAFFIC CURE IN EMULSION MIXES IS A COMPLEX PHENOMENON. THE FOLLOWING PARTIAL LIST OF 28 VARIABLES SHOWS THE COMPLEXITY. A SMALL CHANGE IN ANY ONE OF THESE VARIABLES WILL AFFECT THE SET AND CURE CHARACTERISTICS OF A PARTICULAR MIX SYSTEM---SOMETIMES DRAMATICALLY:

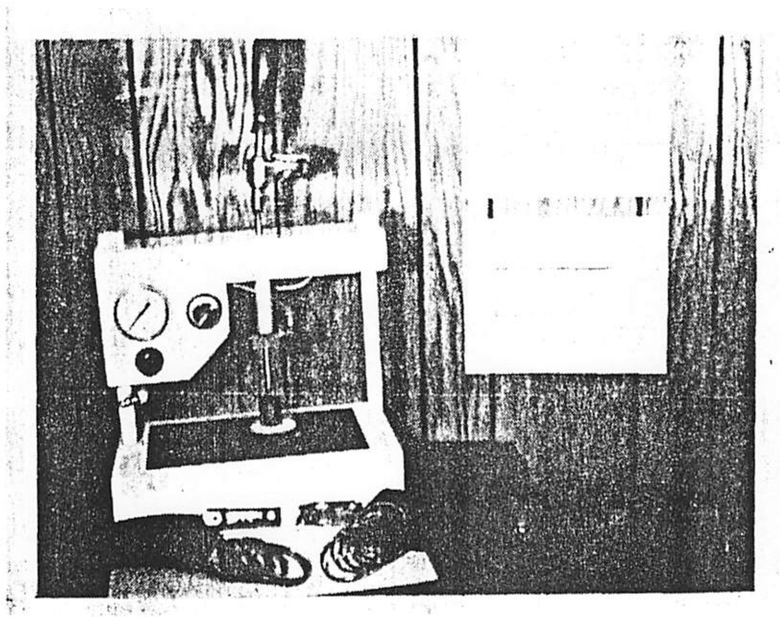
1. BITUMEN TYPE
2. BITUMEN CHEMICAL ACTIVITY OR PROPERTIES
3. EMULSIFIER TYPE
4. EMULSIFIER CONCENTRATION
5. pH OF EMULSIFIER
6. EMULSION PARTICLE SIZE DISTRIBUTION
7. EMULSION AGE AND STABILITY
8. VISCOSITY-PERCENT BITUMEN RELATIONSHIPS
9. BITUMEN EMULSION DESIGN, % ADDED TO MIXTURE
10. AGGREGATE CHEMICAL TYPE
11. AGGREGATE CHEMISTRY OR CHEMICAL REACTIVITY
12. AGGREGATE GRADATION
13. AGGREGATE SAND EQUIVALENT
14. AGGREGATE SURFACE AREA
15. AGGREGATE IMPURITIES & CONTAMINATION
16. AGGREGATE ABSORPTION, INTERNAL AND EXTERNAL MOISTURE
17. MINERAL FILLER TYPE (PORTLAND CEMENT TYPE, HYDRATED LIME, ALUMINUM SULFATE, ETC...)
18. CONCENTRATION OF MINERAL FILLER
19. CHEMICAL ADDITIVE TYPE, ACCELERATOR, RETARDER, SET INITIATOR, ETC...
20. CONCENTRATION OF CHEMICAL ADDITIVE
21. MIX WATER PERCENT
22. SALTS AND ORGANIC IMPURITIES IN WATER
23. SUBSTRATE SURFACE ABSORPTION
24. ATMOSPHERIC TEMPERATURE
25. SURFACE TEMPERATURE
26. HUMIDITY
27. EXTERNAL ENERGY SOURCES OR LACK THEREOF, SUN, SHADE, BASE, WIND
28. MIXING SEQUENCE, MIXING TIME AND SHEAR EXPOSURE

THE PREPONDERANCE OF VARIABLES MAY HELP TO EXPLAIN WHY EMULSION MANUFACTURING AND ITS APPLICATION REMAINS AN ART REQUIRING CONSTANT SUBJECTIVE JUDGEMENTS.

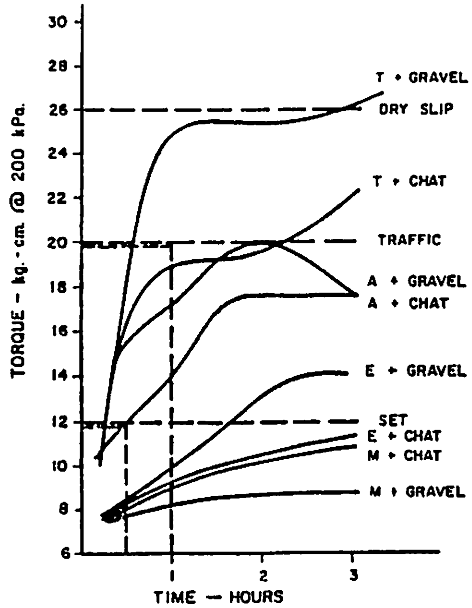
USES OF THE COHESION TESTER

THE MOST IMPORTANT FACT WE HAVE DEMONSTRATED IN OUR INITIAL RESEARCHES IS THAT EACH SYSTEM IS ITS "OWN THING". AT OUR PRESENT STATE-OF-THE-ART THERE ARE NO UNIVERSAL FACTS WHICH CAN BE APPLIED TO ALL SYSTEMS. FURTHER, THERE IS NO SUCH THING AS A "QUICK-SET EMULSION". THERE ARE, HOWEVER, "QUICK SET" OR "QUICK TRAFFIC" EMULSION-AGGREGATE MIXTURE SYSTEMS. THAT IS, THE SET AND TRAFFIC TIMES ARE DEPENDENT ON THE INTEREACTION OF ALL THE INGREDIENTS OF A PARTICULAR SYSTEM.

THE FOLLOWING TWENTY EXAMPLES ARE USED TO ILLUSTRATE THIS ASSERTION AS WELL AS TO SHOW HOW THE COHESION TESTER MAY BE USED TO HELP FORMULATE AN EMULSION AND TO DESIGN AN EMULSION-AGGREGATE SYSTEM TO ACHIEVE A GIVEN SET TIME OR TRAFFIC TIME REQUIREMENT AND TO COMPENSATE FOR FIELD VARIABLES.

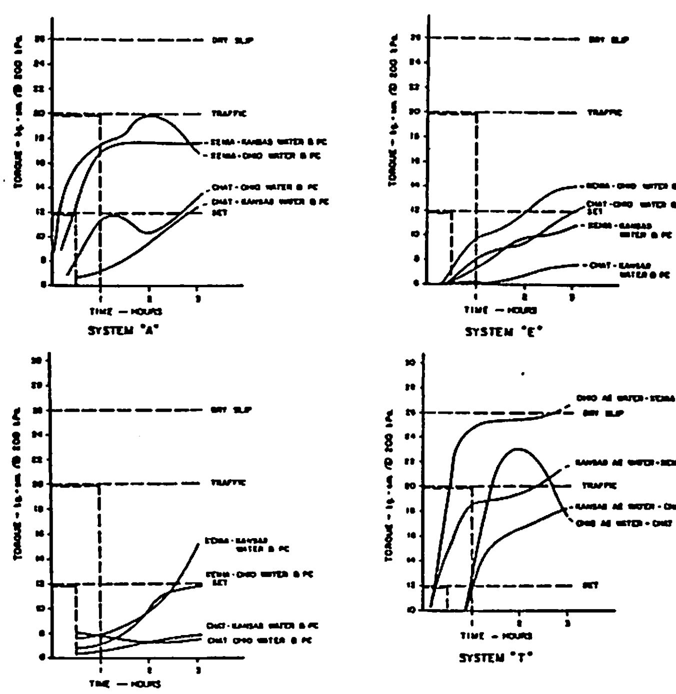


The Modified ASTM D3910-80a Cohesion Tester



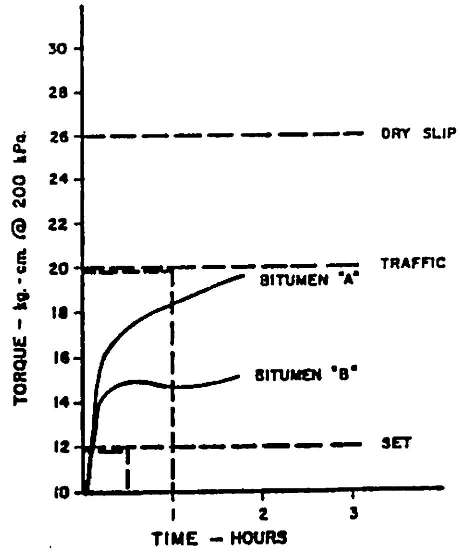
EXAMPLE I. RESPONSE OF FOUR EMULSIFIERS TO TWO AGGREGATE TYPES

EXAMPLE 1 THE RESPONSE OF 4 DIFFERENT TYPES OF EMULSIFIER TO TWO DIFFERENT AGGREGATES AS MEASURED BY THE COHESION TEST. THE SETTING CHARACTERISTICS (RAIN RESISTANCE) AND TRAFFIC TIME REQUIRED BY THE CUSTOMER GOVERNS THE SELECTION OF THE EMULSION-AGGREGATE SYSTEM. THIS GRAPH IS FAIRLY REPRESENTATIVE OF THE PERFORMANCE RANGE OF EMULSIFIERS AVAILABLE FROM VARIOUS EMULSIFIER MANUFACTURERS IN THE U.S. AND ABROAD.



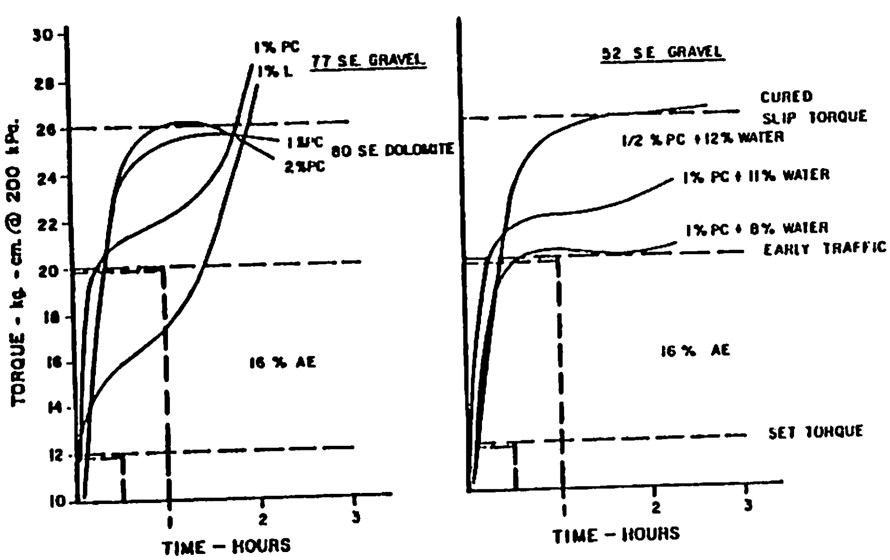
EXAMPLE 2. EFFECT OF WATER & CEMENT SOURCE - FOUR EMULSIFIERS, TWO AGGREGATES

EXAMPLE 2 SHOWS COHESION TEST PLOTS OF FOUR DIFFERENT EMULSIFIERS USED WITH TWO AGGREGATES: XENIA CALCAREOUS GRAVEL AND JOPLIN LEAD MINE CHAT. COMPARISONS WITH TWO SOURCES OF MIX WATER AND CEMENT ARE SHOWN WHICH INDICATE THAT THE SOURCES OF MIX WATER AND CEMENT SHOULD BE CONSIDERED. SYSTEM "T" SHOWS THE IMPORTANCE OF EMULSIFIER WATER SOURCE ON THE MIX PERFORMANCE.



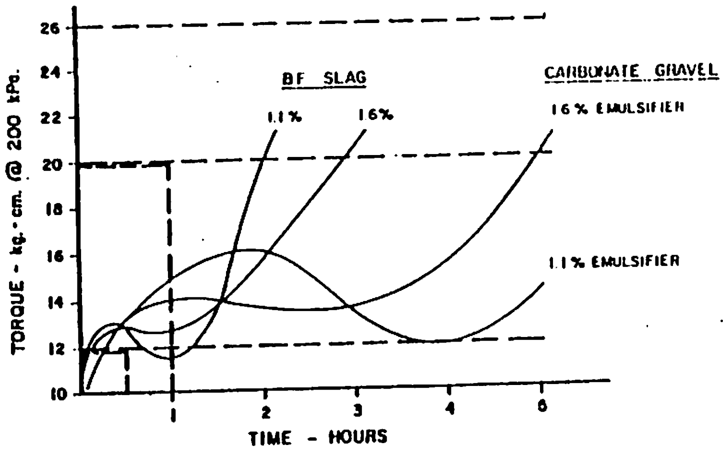
EXAMPLE 3. EFFECT OF BITUMEN SOURCE

EXAMPLE 3 SHOWS THE EFFECT OF BITUMEN SOURCE ON THE SETTING CHARACTERISTICS. BITUMEN "B" SET-QUICKLY BUT IS SOON EXHAUSTED AND GOES NOWHERE WHILE BITUMEN "A" NOT ONLY SETS QUICKLY BUT CONTINUES TO DEVELOP COHESIVE STRENGTH.



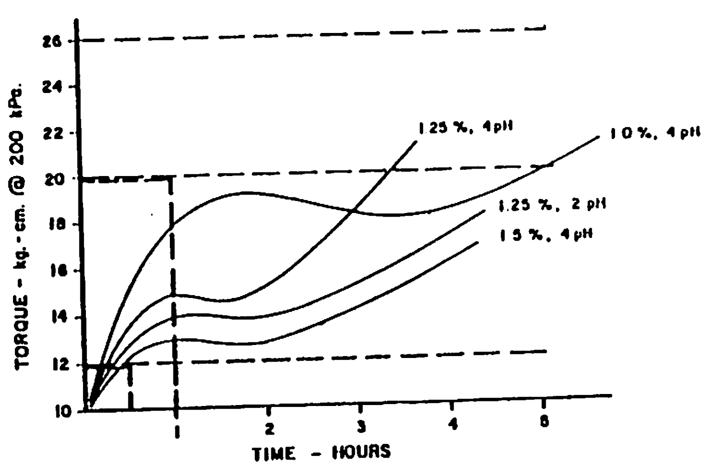
EXAMPLE 4. EFFECT OF FIELD VARIABLES: AGGREGATE SOURCE, SAND EQUIVALENT, FILLER AND WATER CONTENT

EXAMPLE 4 a. SHOWS THE EFFECT OF VARIATIONS IN AGGREGATE SOURCE, SAND EQUIVALENT, CEMENT OR LIME AND MIX WATER. NOTE HOW THE INCREASE IN WATER AND AND DECREASE IN PC IMPROVES THE 52 SE GRAVEL COHESION. COMPARE THE 1% PC, 77 SE GRAVEL. THIS INDICATES THAT A PORTION OF THE FINES IN THE 52 SE GRAVEL REACT THE SAME AS CEMENT.



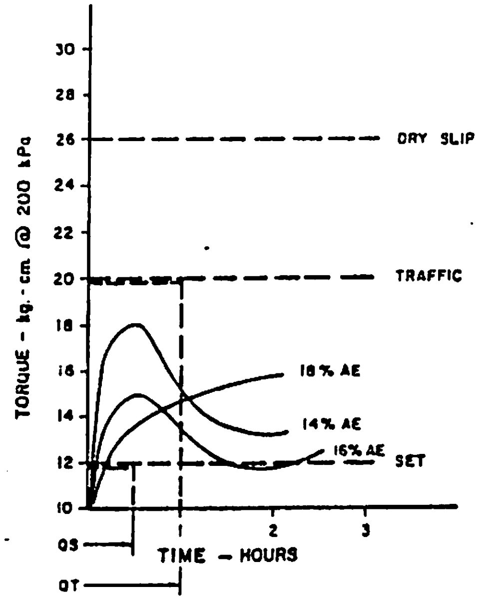
EXAMPLE 5. EFFECT OF EMULSIFIER CONTENT AND AGGREGATE TYPE ON SETTING CHARACTERISTICS

EXAMPLE 5 THE 1.1% AND 1.6% EMULSIFIER ROLES ARE REVERSED WHEN THE AGGREGATE TYPES ARE CHANGED FROM BLAST FURNACE SLAG TO A CARBONATE GRAVEL. INCIDENTALLY THESE ARE ALL QUICK SET SYSTEMS BUT RELAPSE INTO A FALSE SET AND SLOW TRAFFIC CLASSIFICATION AND THIS PARTICULAR SYSTEM RESPONSE IS SOMETIMES IDENTIFIED WITH BOTH POOR ADHESION AND POOR COHESION.



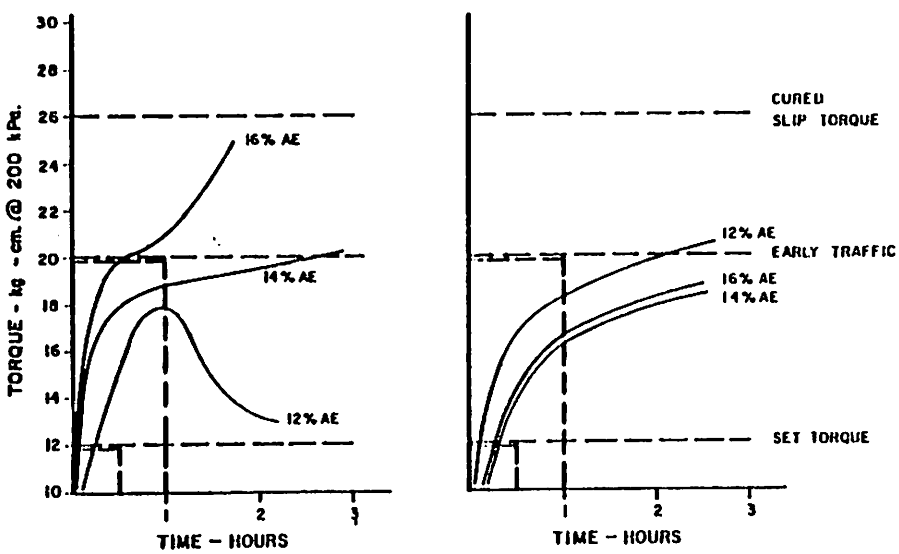
EXAMPLE 6. EFFECT OF EMULSIFIER CONTENT AND pH ON TRAFFIC TIME

EXAMPLE 6 SHOWS THE EFFECT OF EMULSIFIER CONCENTRATION AND pH WHERE: 1.0% @ 4 pH EMULSIFIER SHOWS GOOD SET AND VERY SLOW TRAFFIC AND 1.5% @ 4 pH SHOWS A WEAK SET AND A SIMILAR VERY SLOW TRAFFIC CURE. 1.25% EMULSIFIER SHOWS THE QUICKEST TRAFFIC TIME AT A HIGHER pH.



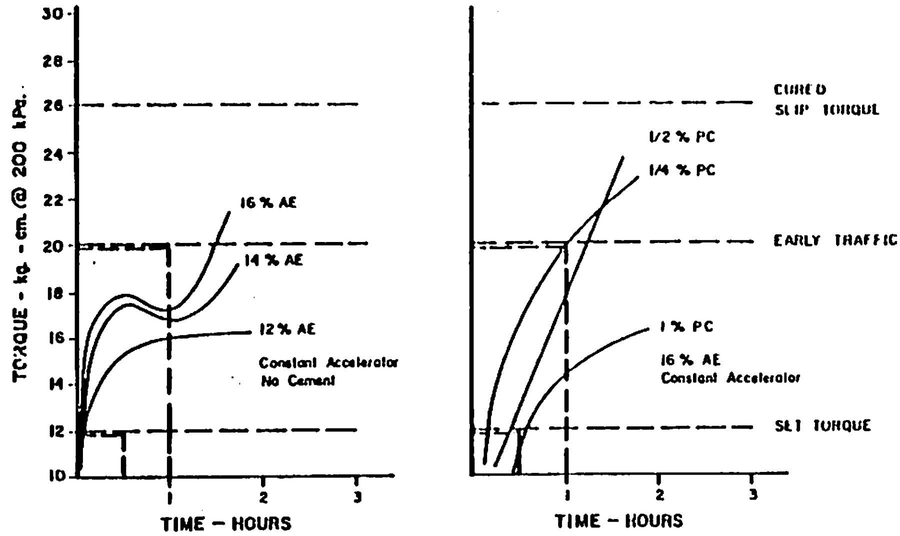
EXAMPLE 7. FALSE SET AND EFFECT OF AE CONTENT

EXAMPLE 7 MAY BOGGLE ONE'S MIND WHERE THE LOWEST AE %, 14%, SETS VERY QUICKLY BUT SHORTLY SUFFERS A RELAPSE OF SET WHILE AT 18% AE A SOMEWHAT STEADIER INCREASE IN STRENGTH OCCURS. THIS PARTICULAR CONFIGURATION---THE "FALSE SET" HAS BEEN IDENTIFIED WITH SEVERE LOW TEMPERATURE COALESCENCE PROBLEMS AND THE SUBSEQUENT LOSS OF ALL SLURRY AFTER WINTERING THROUGH REPEATED FREEZE-THAW CYCLES.



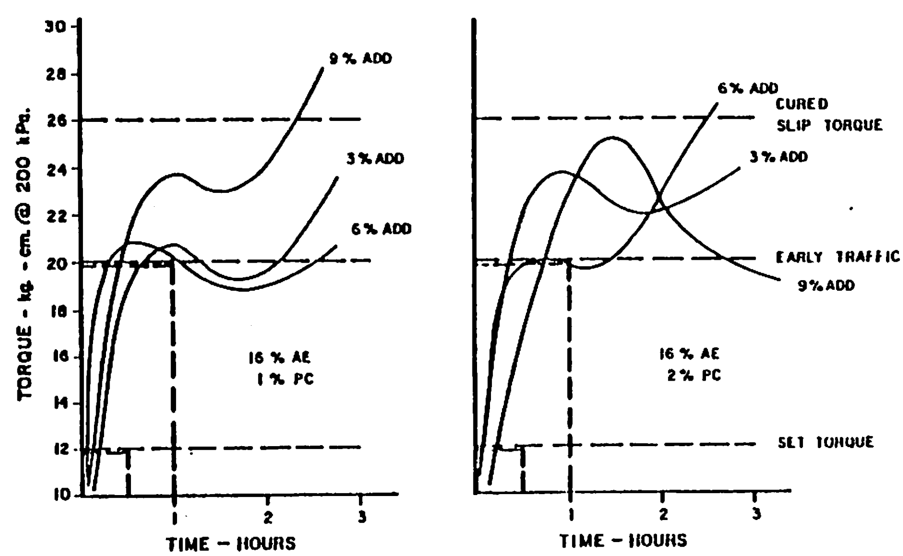
EXAMPLE 8. EFFECT OF EMULSION CONTENT ON TRAFFIC TIME

EXAMPLE 8 THE DESIGN OF SLURRY SEAL REQUIRES AN ADJUSTMENT IN AC QUANTITY FOR VARIOUS TRAFFIC COUNTS; i.e., HIGHER TRAFFIC COUNT DESIGNS REQUIRE LOWER EMULSION QUANTITIES. EXAMPLE 8 a. SHOWS A SATISFACTORY TRAFFIC TIME OF 40-60 MINUTES AT 16% EMULSION BUT WHEN IT BECOMES NECESSARY TO REDUCE THE EMULSION CONTENT TO 12% THE TRAFFIC TIME VANISHES. EXAMPLE 8 b. SHOWS THE REVERSE PHENOMENA, i.e., A REDUCTION AE CONTENT IMPROVES THE TRAFFIC TIME.



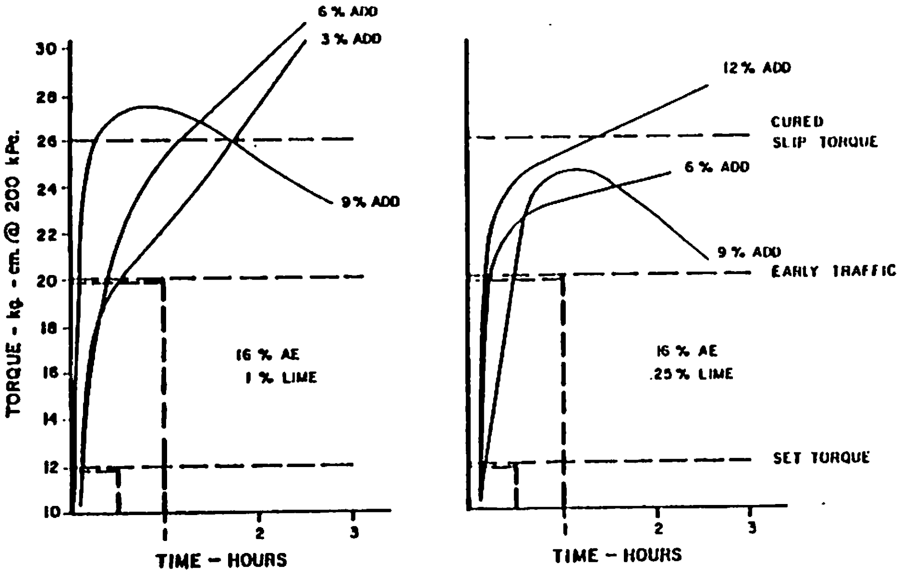
EXAMPLE 9. EFFECT OF FILLER CONTENT ON TRAFFIC TIME

EXAMPLE 9 a. SHOWS A SIMILAR EFFECT TO 8 a. WHERE REDUCED AE GIVES REDUCED TRAFFIC TIME WHEN NO CEMENT IS USED. THE SAME EMULSION IS USED IN 9 a. WITH A CONSTANT ACCELERATOR IN 9b. 1/4% PORTLAND CEMENT IS ADDED GIVES A SATISFACTORY TRAFFIC TIME, WHEN 1% PC IS ADDED A VERY POOR RESULT IS FOUND.



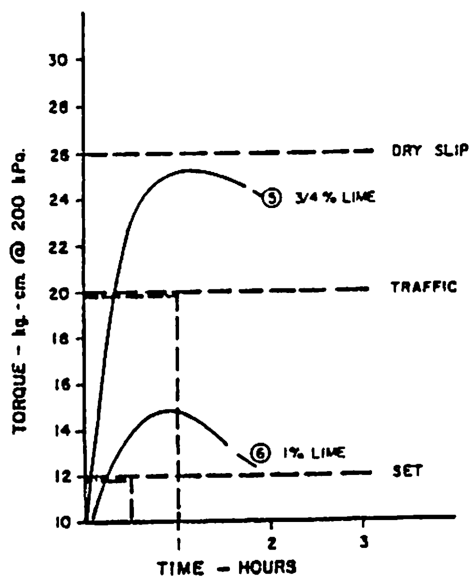
EXAMPLE 10. EFFECT OF CEMENT FILLER ON AN INITIATOR SYSTEM

EXAMPLE 10 a. AND 10 b. HAVE USED SET INITIATORS AT 16% AE AND 1% AND 2% PORTLAND CEMENT. NOTE THE REVERSAL OF THE OPTIMUM ADDITIVE % FROM 9, 3 & 6% ADDITIVE AT 1% PC TO 6, 3 & 9% ADDITIVE WHEN 2% PC IS USED.



EXAMPLE II. EFFECT OF LIME FILLER CONTENT ON AN INITIATOR SYSTEM

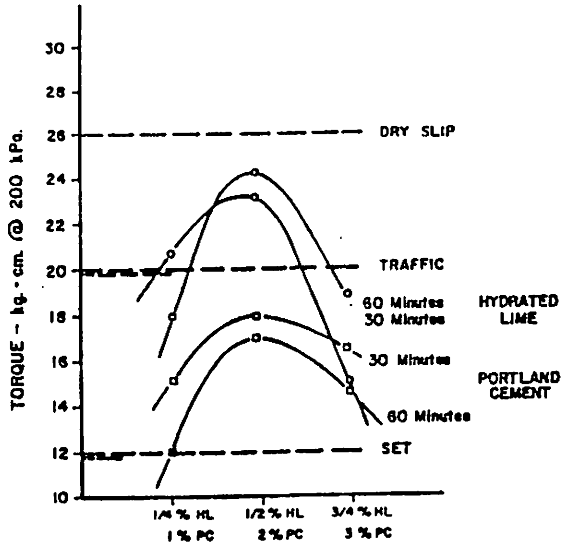
EXAMPLE 11 a. AND 11 b. SHOWS A SIMILAR SET REVERSAL WHEN 1/4% AND 1% LIME INITIATORS GIVE OPTIMUMS OF 6, 3 & 9% RESPECTIVELY.



① 100/0 - 0L - 13.5/0 - 16 10 SEC. MIX
② 100/0 - 1/4L - 13.5/0 - 16 20 SEC. MIX
③ 100/0 - 1/4L - 7.0/6 - 16 30 SEC. MIX
④ 100/0 - 1/2L - 13.0/0 - 16 30 SEC. MIX
⑤ 100/0 - 3/4L - 13.5/0 - 16 120 SEC. MIX
⑥ 100/0 - 1L - 13.5/0 - 16 300 SEC. MIX

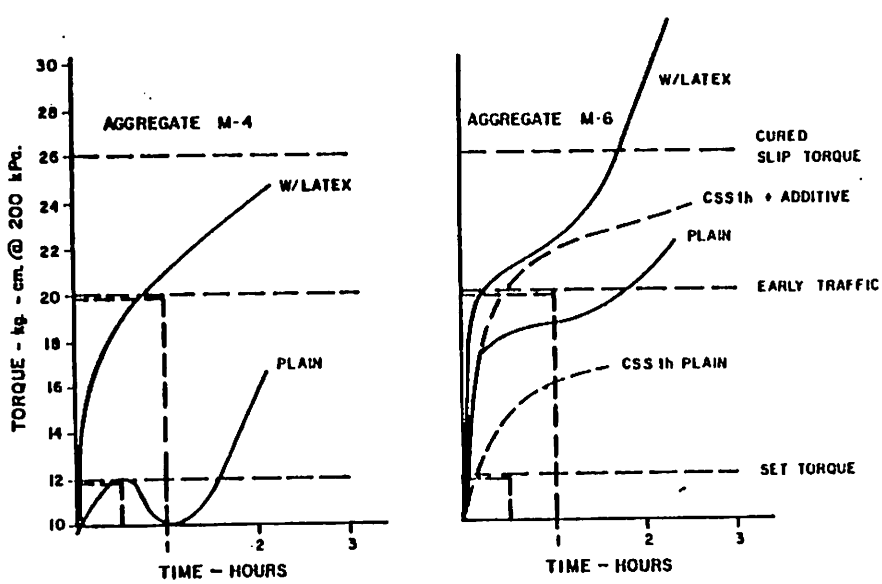
EXAMPLE 12. PRECISION RESULTS REQUIRES PRECISION

EXAMPLE 12 IS A DRAMATIC ILLUSTRATION TO SHOW THE CRITICAL NEED FOR PRECISE DESIGN AND PRECISE MATERIAL PROPORTIONING WHERE A VIRGINIA GNEISS AND LIME ARE USED. TOO SHORT A MIX TIME OCCURS AT 1/2% LIME BUT 3/4% LIME GIVES EXCELLENT MIX TIME AND TRAFFIC TIME. 1/4% MORE LIME (1%) HOWEVER, COMPLETELY DESTROYS THE QUICK TRAFFIC CHARACTERISTIC OF THIS OTHERWISE EXCELLENT SYSTEM.



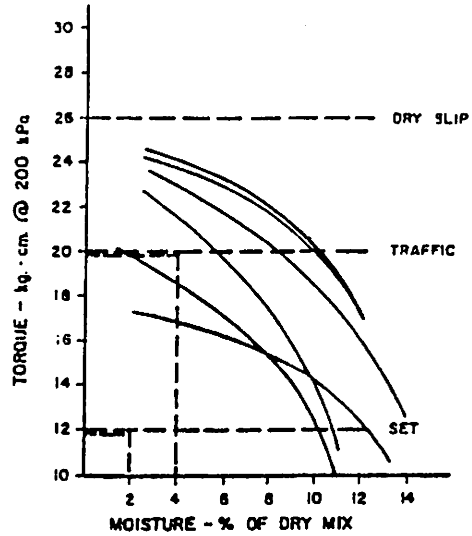
EXAMPLE 13. FILLER CONTENT OPTIMIZATION

EXAMPLE 13 PLOTS COHESIVE STRENGTH AT 30 AND 60 MINUTES AS A FUNCTION OF THE PERCENT HYDRATED LIME OR PORTLAND CEMENT. IN THIS WAY THE OPTIMUM FILLER CONTENT MAY BE SELECTED. THIS SAME METHOD MAY ALSO BE USED FOR OPTIMIZING THE EFFECT OF MIX-TIME CONTROL ADDITIVES. IT APPEARS THE 1% LIME REPLACES 4% PORTLAND CEMENT.



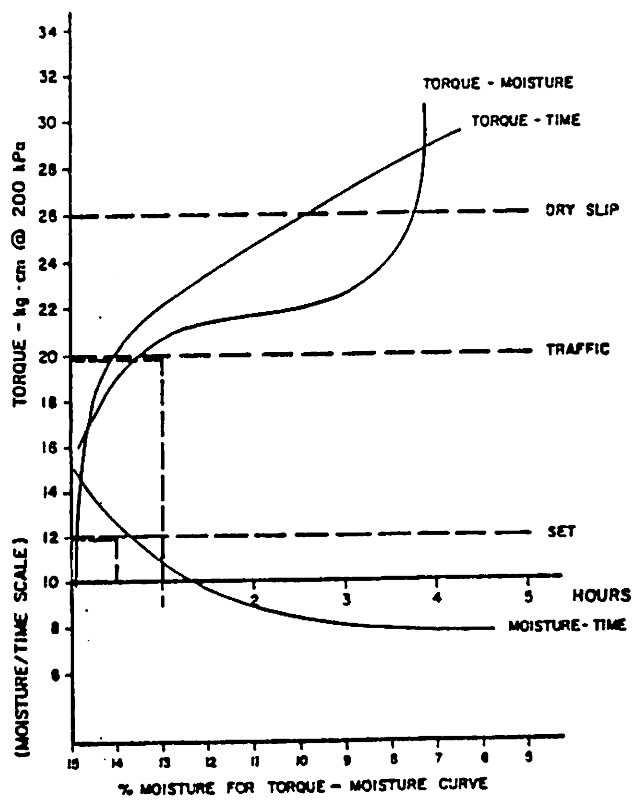
EXAMPLE 14. EFFECT OF LATEX AND ADDITIVE – TWO AGGREGATES

EXAMPLE 14 THE ADDITION OF VARIOUS TYPE OF LATEXES AND ADDITIVES RESPOND DIFFERENTLY WITH DIFFERENT AGGREGATE SOURCES AND GRADATION. USUALLY WITH IMPROVED COHESION AND TRAFFIC TIMES, AS SHOWN HERE.



EXAMPLE 15. TORQUE-MOISTURE OR WET STRENGTH VARIATIONS

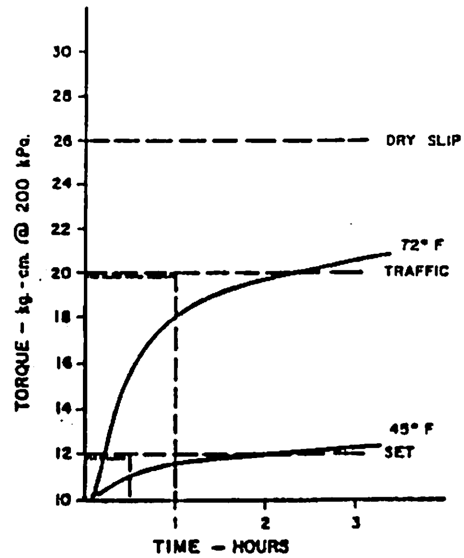
EXAMPLE 15 COMPARES THE TORQUE-MOISTURE CURVE OF 6 SYSTEMS AND ILLUSTRATES CLEARLY THAT "WET STRENGTH" IS NOT TOTALLY A FUNCTION OF THE % MOISTURE BUT RATHER A FUNCTION OF THE PARTICULAR CHEMISTRY INVOLVED.



EXAMPLE 16. TORQUE-TIME, TORQUE-MOISTURE, (WET STRENGTH) MOISTURE-TIME COMBINED CURVES

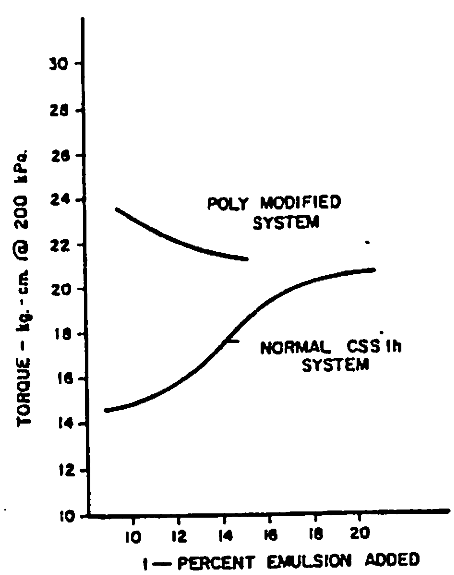
EXAMPLE 16 COMBINES ALL THE INFORMATION FROM THE COHESION TESTER INTO 1 GRAPH:

(a) TORQUE-TIME (QS-QT SYSTEM),
(b) MOISTURE-TIME (VERY TYPICAL) CURVE FOR QS SYSTEM,
(c) TORQUE-MOISTURE OR "WET STRENGTH" CURVE.
I'M NOT SURE WHAT'S HAPPENING IN THIS SYSTEM WHERE THE WET STRENGTH APPEARS TO ROCKET AT ABOUT THE 7 1/2% MOISTURE CONTENT.



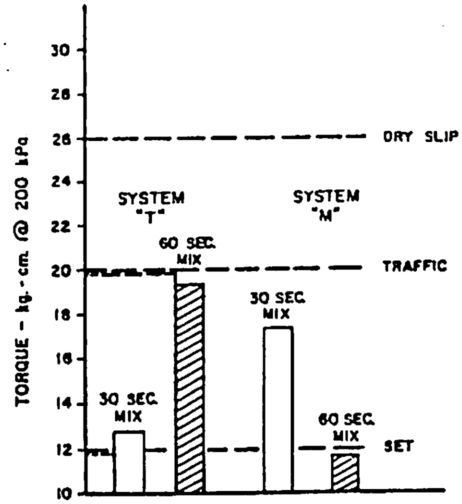
EXAMPLE 17. EFFECT OF LOW TEMPERATURE

<u>EXAMPLE 17</u> THE EFFECT OF FIELD CONDITIONS, (TEMPERATURE, HUMIDITY, LIGHT INTENSITY ETC...) HAVE NOT BEEN STUDIED EXTENSIVELY. THIS EXAMPLE OF THE EFFECT OF TEMPERATURE SHOWS A VERY PREDICTABLE SITUATION. A GOOD QUICK-SET SYSTEM IS RENDERED USELESS BY LOW TEMPERATURE.



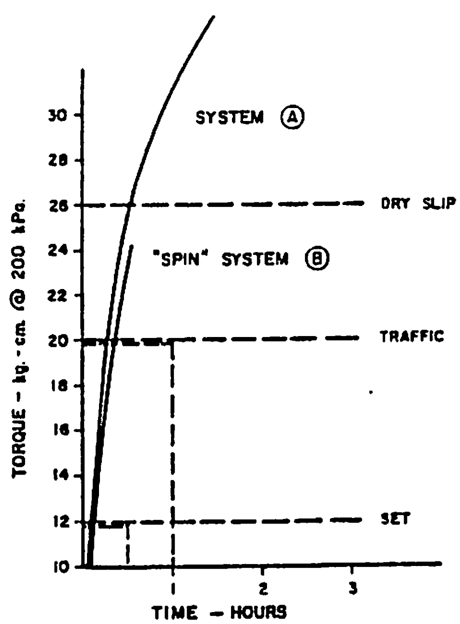
EXAMPLE 18. 140°F CURED COHESION

<u>EXAMPLE 18</u> MEASUREMENT OF DRY, CURED COHESION AT 60C OR 140F MAY INDICATE OPTIMUM AC CONTENT FOR HIGH TEMPERATURE STABILITY OR DETECT A TEMPERATURE SUSCEPTIBILITY PROBLEM.



EXAMPLE 19. EFFECT OF MIXER RESIDENCE TIME

<u>EXAMPLE 19</u> ONE OF OUR STARTLING FINDINGS IS SHOWN IN EXAMPLE 19 WHERE THE EFFECT OF MIXER RETENTION OR RESIDENCE TIME IS SHOWN WITH TWO SYSTEMS. THE RESULTS INDICATE THE IMPORTANCE OF THE MIXER TIME AND TOTAL EXPOSURE TO SHEAR FORCE IN THE DEVELOPMENT OR NON-DEVELOPMENT OF EARLY COHESIVE STRENGTH.



EXAMPLE 20. 1984 BLUE RIBBON WINNERS

<u>EXAMPLE 20</u> ANNOUNCING THE 1984 BLUE RIBBON WINNERS; TWO LINEAR QUICK-TRAFFIC SYSTEMS; A CHALLENGE TO THE EMULSION FORMULATOR.

FINALLY, WE SHOULD MENTION TWO VERY RECENT COHESION TESTER DEVELOPMENTS:

MOTORIZING THE COHESION TESTER

SOME 27 OF THESE UNITS HAVE BEEN PLACED IN USE IN THE U.S. AND IN 5 OVERSEAS COUNTRIES. THOUGH SOME USERS REPORT A CONFIDENCE LEVEL OF ± .5 kg. cm. MORE SEVERE VARIATIONS HAVE BEEN BLAMED ON THE MANUAL OPERATION. TO AVOID MANUAL OPERATIONS WE RECENTLY MOTORIZED OUR UNIT BY ADDING A CONTROLLER AND SLIP-COUPLED SERVODYNE MOTOR. TORQUE TO FAILURE IS MEASURED THROUGH A NEW INDIRECTLY REACTION TORQUE TABLE. TORQUE READINGS ARE ABOUT 5.3 ± .5 kg. cm. LESS THAN DIRECT TORQUE BECAUSE FRICTION THOUGH THE CYLINDER PACKINGS IS AVOIDED. DEVELOPMENT WORK WILL PROCEED THIS YEAR.

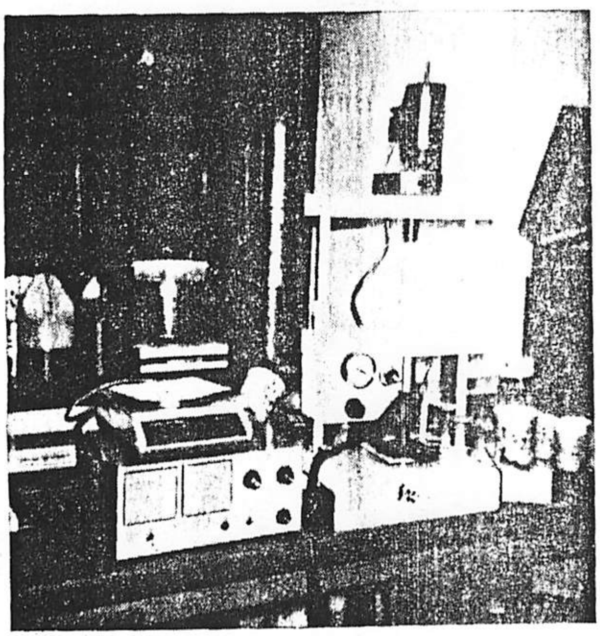


FIG. 11. MOTORIZED COHESION TESTER WITH SERVODYNE & CONTROLLER

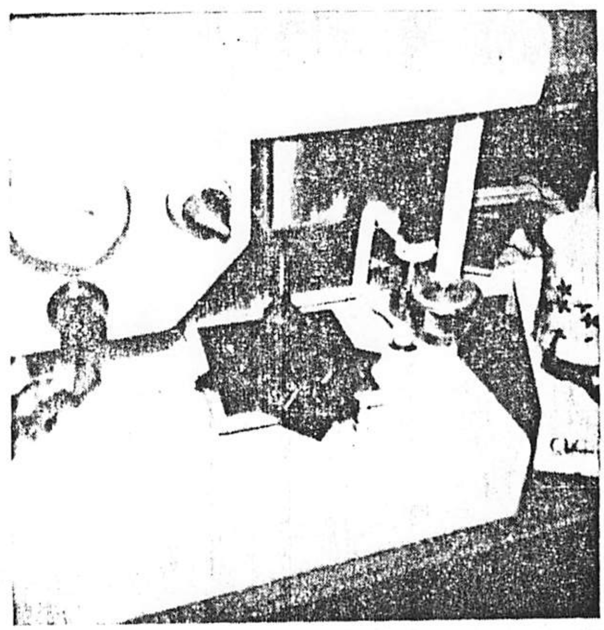


FIG. 12. COHESION TEST WITH REACTION TORQUE TABLE

MIXING CHARACTERISTICS

THE VARIABLE SPEED PRECISION DRIVE AFFORDED BY THE SERVODYNE ALLOWS CONVERSION OF THE COHESION TESTER INTO MIXER A BY REPLACEMENT OF THE COHESION FOOT WITH A MIXING BLADE BY ADDING A MIXING CUP AND STRIP CHART RECORDER, WE ARE ABLE TO RECORD THE MIXING CHARACTERISTICS OF VARIOUS SYSTEMS AND TO IDENTIFY THE VARIOUS TYPES OF SYSTEMS. IT MAY BE POSSIBLE TO CORRELATE THE MIXING CHARACTERISTICS WITH COHESION VALUES AND THUS, IN ONE SIMPLE 15-MINUTE TEST, GAIN ALL THE REQUIRED INFORMATION FOR PERFORMANCE OF THIN LAYERED COLD MIXES.

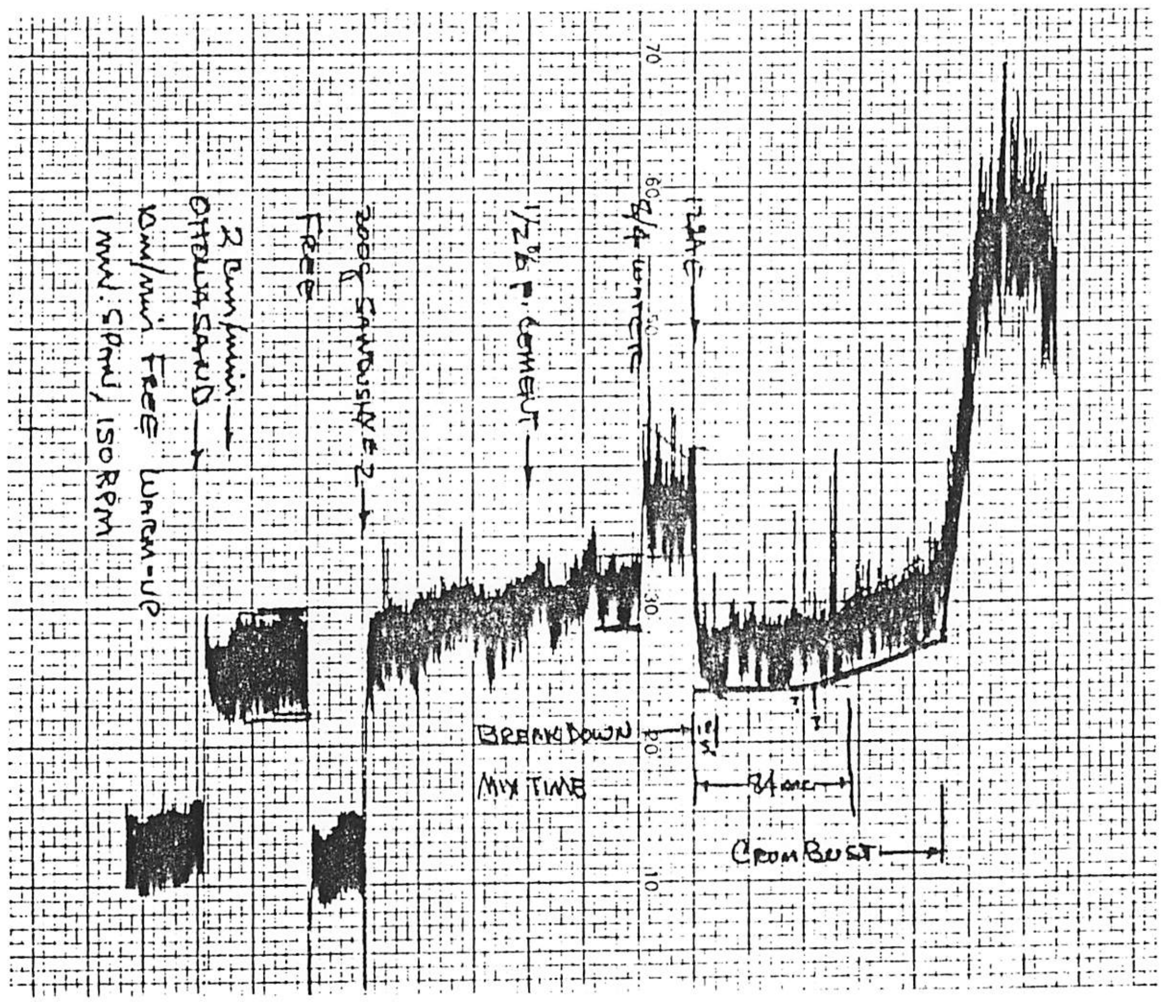
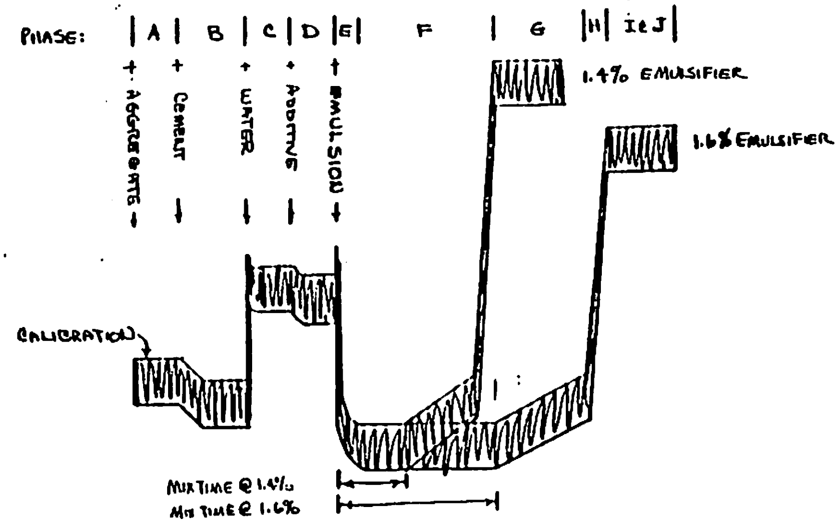
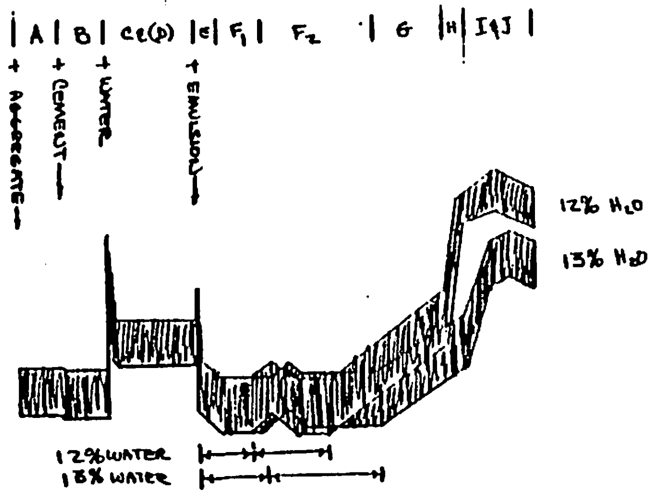


FIG. 13 STRIP CHART OF ENERGY REQUIREMENTS DURING SEVEN PHASES OF MIXING

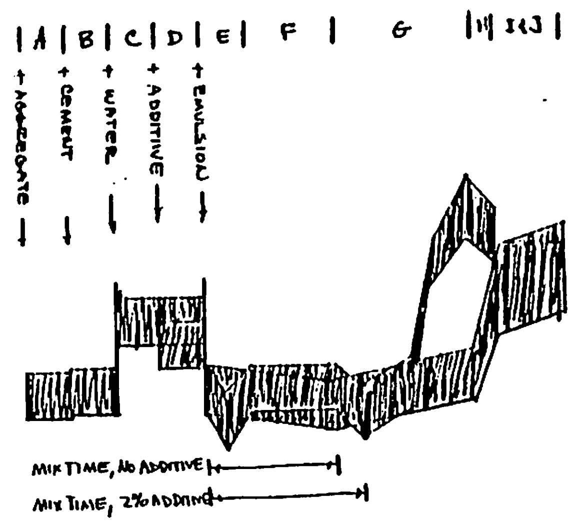
FIG. 14 (OVERLEAF) SCHEMATIC MIX CHARTS SHOWING EFFECTS OF MIX VARIABLES ON FIVE SYSTEMS



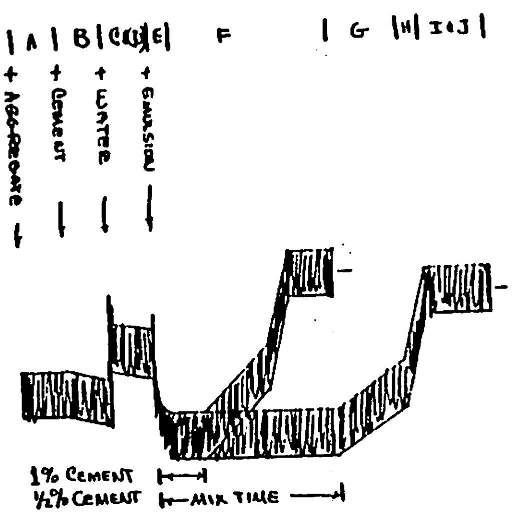
STRIP CHART MIXING CHARACTERISTIC PHASES— EFFECT OF EMULSIFIER CONCENTRATION



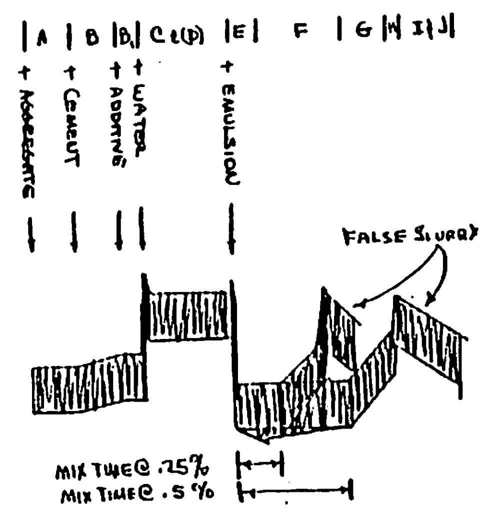
STRIP CHART MIXING CHARACTERISTICS - PHASES EFFECT OF WATER CONCENTRATION



STRIP CHART MIXING CHARACTERISTICS EFFECT OF RETARDER/ACCELERATOR



STRIP CHART MIXING CHARACTERISTIC PHASES EFFECT OF CEMENT AS AN ACCELERATOR



STRIP CHART MIXING CHARACTERISTIC PHASES EFFECT OF RETARDER CONCENTRATION

SUMMARY

1. A SIMPLE LABORATORY TEST, THE MODIFIED COHESION TEST AS PRESENTED HERE PROVIDES A METHOD TO OBJECTIVELY CLASSIFY THE SETTING AND EARLY TRAFFIC TIME CHARACTERISTICS OF BITUMINOUS EMULSION-AGGREGATE MIX SYSTEMS.
2. THE EFFECTS OF MANY VARIABLES, HAVE BEEN SHOWN: EMULSIFIER TYPE, CONTENT AND pH; BASE ASPHALT SOURCE; AGGREGATE SOURCE & SAND EQUIVALENT; WATER SOURCE; FILLER TYPE & CONTENT; INITIATORS, ACCELERATORS & LATEX; FIELD TEMPERATURE; MIXER RETENTION TIME.
3. USE OF THE COHESION TESTER GIVES TO THE EMULSION FORMULATOR OBJECTIVE & MIX DESIGN NUMBERS REQUIRED TO DEVELOP THE SYSTEMS NECESSARY TO MEET THE NEEDS OF A GROWING MARKET.

NOTES

1. MOST OF THE SYSTEMS SHOWN HAVE USED DIFFERENT EMULSION TYPES, BUT, UNLESS NOTED, THE AGGREGATE USED WAS XENIA, OHIO CALCAREOUS CRUSHED GRAVEL, 100% MINUS #4 SIEVE. ALL TESTS PERFORMED UNDER LABORATORY CONDITION OF 72-75^{o}F, NO EXTERNAL HEAT, NO WIND, WITH SPECIMENS CAST ON A NON-ABSORPTIVE SURFACE.
2. TYPE 3 GRADATIONS (0/8mm) SEEM TO COMPARE WELL WITH THE TYPE 2 (0/5mm) GRADATIONS. TYPE 1 GRADATIONS APPEAR TO OFFER SOME CORRELATION PROBLEMS, BUT NOT ENOUGH WORK HAS BEEN ACCOMPLISHED TO REPORT AT THIS STAGE OF THE RESEARCH.
3. ALL WORK HERE HAS BEEN DONE AT LABORATORY TEMPERATURES AND USING SURFACE DRY AGGREGATES. MUCH WORK NEEDS TO BE DONE TO STUDY THE EFFECT OF TEMPERATURE AND THE EFFECT OF ABSORPTIVE SURFACES.
4. WE HAVE NOTED CERTAIN SYSTEMS WHICH ARE "WATER POPPERS"; i.e., VERY SLIPPERY, SOAPY WATER IS EXPRESSED TO THE SURFACE OF THE SPECIMEN. THIS SOAPY WATER MAY LUBRICATE THE COHESION TESTER FOOT AND CAUSE LOWER THAN TRUE READINGS. WORK PROCEEDS WHICH USED A SERRATED STEEL FOOT WHICH COULD PENETRATE SUCH LUBRICATING FILMS.
5. WE HAVE ALSO NOTED CERTAIN SYSTEMS WHICH FORM A CONTINUOUS THIN SURFACE FILM COMPOSED OF FINES, SALTS AND RESIDUAL ASPHALT ON THE SPECIMEN SURFACES AND WHICH MAY "SEAL" A SOAPY LUBRICATING LAYER BETWEEN THE SURFACE FILM AND AN UNDERLYING, STRONGLY COHESIVE MIX. THIS PHENOMENA MAY ALSO CAUSE LOWER THAN TRUE READINGS.
6. THE WORK PRESENTED HERE IS OF A PRELIMINARY NATURE. THE PROCEDURES, TORQUE LEVEL, DEFINITIONS FOR "SET" AND "TRAFFIC" AND CALIBRATIONS SHOULD BE VERIFIED AND AGREED UPON BY THE INDUSTRY AS A FUTURE PROJECT. PREVIOUS WORK DONE BY ASTM D 04.4 COMMITTEE MEMBERS DURING THEIR ROUND ROBIN STUDIES OF THE COHESION TEST MAY BE HELPFUL.
7. IN A COMPLETE STUDY, THE EFFECTS OF THE ENVIRONMENT (TEMPERATURE) ON THE MIXING AND SETTING CHARACTERISTICS SHOULD BE STUDIED. THE WTAT, LWT AND COMPATIBILITY CHARACTERISTICS SHOULD ALSO BE STUDIED BEFORE A FINAL DESIGN IS SELECTED.
8. TENTATIVE DEFINITIONS AND PROCEDURES HAVE BEEN PRESENTED, BUT SHOULD BE VERIFIED BY OTHERS.

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