MISCELLANEOUS PAPER SL-81-29

EVALUATION OF TESTS FOR DETERMINING THE PUMPABILITY OF CONCRETE MIXTURES

by

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Miscellaneous Paper SL-81-29

EVALUATION OF TESTS FOR DETERMINING THE PUMPABILITY OF CONCRETE MIXTURES

KEY

Manufacturer	Symbol	Product
Marquette Cement Co. Brandon, Miss.	RC-728	Type I portland cement
American Sand and Gravel Co. Hattiesburg, Miss.	WES-1 S-4(51)	Natural fine aggregate
Traxler Sand and Gravel Co. Crystal Springs, Miss.	CRD G-42	Natural coarse aggregate
Vulcan Materials Co. Calera Quarry Birmingham, Ala.	CRD MS-27 CL-2 G-1 and CRD G-40	Manufactured limestone, fine aggregate Crushed limestone, coarse aggregates
Hunt Process Corp. - Southern Ridgeland, Miss.	AEA-956	Air-entraining admixture ("Air-In")
Amax Fly Ash Co. Wilsonville, Ala.	AD-474	Fly ash
American Admixtures Corp. Chicago, Ill.	--	High-range water-reducing admixture ("Melment")
Haliburton Services Duncan, Okla.	--	Pumping aid ("CFR-2")
United States Steel Corp. Pittsburgh, Pa.	--	Steel fibers
River Cement Co. Festus, Mo.	NO-14 C-3	Type I portland cement
Hollaway Sand and Gravel Co. St. Francisville, La.	NO-14 S-2 NO-14 G-8	Natural fine and coarse aggregate
Universal Atlas Cement Co. Independence, Kans.	STL-43 C-1	Type II portland cement
Central Stone Co. Huntington, Mo.	STL-43 S-1 STL-43 G-1	Crushed limestone fine and coarse aggregate
Master Builders Co. Springfield, Mo.	STL-43 AEA-1 STL-43 AD-1	Air-entraining admixture ("MB-VR") Type B retarding admixture ("Pozzolith 122R")

KEY (Continued)

Manufacturer	Symbol	Product
Thomsen Equipment Co. Gardena, Calif.	Laboratory pump No. 1	"Model 600," mobile concreting pump
Hercules Concrete Pumps, Inc. Laurel, Miss.	Laboratory pump No. 2	"Model HCP 73D" concrete pump
Whiteman Mfg Co. Pacoima, Calif.	Field pump No. 1	"Model P-110 TB" concrete pump
Engineered Concrete Placer, Inc. Midland, Tex.	Field pump No. 2	"E-Con-Placer" concrete pump

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This report presents the results of an investigation to evaluate two methods currently proposed for determining concrete pumpability: (a) the pressure bleed test method and (b) a checklist analysis which examines 10 variables of concrete mixtures and their effects on concrete pumpability. Part of the investigation consisted of a laboratory study in which 14 mixtures containing a combination of both rounded (natural) and angular (crushed) coarse aggregate, natural and manufactured fine aggregate, mineral admixtures, steel fibers, and a

(Continued)

20. ABSTRACT (Continued).

high-range water-reducing admixture were analyzed using both proposed procedures and then pumped. The other part comprised a field study in which two concrete mixtures were analyzed and then pumped at two project locations. One contained natural coarse and fine aggregate and the other contained manufactured coarse and fine aggregate. All concrete mixtures were air entrained.

It was concluded that the pressure bleed test method is effective only in determining the pumpability of concrete using a poorly maintained and leaky pump. The checklist analysis, although conservative, is a better indicator of pumpability and should be considered for inclusion in an appropriate Engineer Manual or Engineer Technical Letter.

PREFACE

This investigation was conducted in the Structures Laboratory (SL), U. S. Army Engineer Waterways Experiment Station (WES), under the sponsorship of the Office, Chief of Engineers, U. S. Army (OCE), as a part of Civil Works Investigational Studies Work Unit No. 31138, "New Technologies for Testing and Evaluating Concrete." Messrs. James A. Rhodes and Fred Anderson of the Structures Branch, Engineering Division, OCE, served as Technical Monitors.

The investigation was conducted under the direction of Mr. Bryant Mather, Chief, SL, and Mr. John Scanlon, Chief, Concrete Technology Division (CTD), SL. Messrs. K. L. Saucier, S. A. Ragan, W. B. Lee, and J. B. Eskridge actively participated in the investigation, and Mr. Ragan prepared the report.

The Commanders and Directors of WES during this investigation and the preparation and publication of this report were COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, INCH-POUND TO METRIC (SI)
UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
cubic yards per hour	0.76455486	cubic metres per hour
feet	0.3048	metres
inches	2.54	centimetres
inches	25.4	millimetres
ounces (U. S. fluid)	29.57353	cubic centimetres
pounds (force) per square inch	0.00689476	megapascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic yard	0.59327642	kilograms per cubic metre

EVALUATION OF TESTS FOR DETERMINING THE PUMPABILITY OF CONCRETE MIXTURES

PART I: INTRODUCTION

Background

1. Pumping has been used as a means of transporting freshly mixed concrete in the United States since the early 1930's. There has been a large increase in the quantity of concrete conveyed by pumping since the mid-1960's primarily due to the development of mobile hydraulic pumps; the introduction of rubber, plastic, and flexible metal hoses; and the use of power-assisted booms.

2. The increased acceptance of concrete pumping was accompanied by the realization that normal-weight concrete mixtures suitable for transporting and placing by conventional methods were not always pumpable with available equipment. The failure of a mixture to pump normally results from either (Parker et al. 1973):

- a. Excessive pumping pressures force excess water to bleed through the mixture without moving the mass.
- b. The capacity of the pump is exceeded by the combination of head, pipeline friction, and resistance of the mixture to internal deformation.

A number of laboratory procedures have been proposed for analyzing and comparing the pumpability of concrete mixtures (Parker et al. 1973, Gray 1962, Best and Lane 1980). Currently, however, evaluation under actual field conditions is the only accepted method of testing a mixture for pumpability. A test method which could be performed quickly either in the laboratory or in the field and which would correctly evaluate the relative pumpability of a concrete mixture would be of benefit.

Purpose

3. The purpose of this investigation was to evaluate the effectiveness and feasibility of the following two currently proposed methods of determining the pumpability of concrete mixtures:

- a. The pressure bleed test.
- b. A checklist analysis which examines 10 variables of concrete mixtures and their effects on concrete pumpability.

Scope

4. The investigation consisted of a laboratory and a field study. Fourteen mixtures were analyzed for potential pumpability in the laboratory study using both of the proposed procedures and then pumped to determine actual pumpability. The mixtures contained a combination of both rounded (natural) and angular (crushed) coarse aggregate, natural and manufactured fine aggregate, mineral admixtures, steel fibers, and a high-range water-reducing admixture. All laboratory mixtures were air entrained. The field study consisted of using the proposed methods to evaluate the pumpability of concrete mixtures which were then pumped for use at two project locations. One of the mixtures contained a 1-1/2-in.* (38.1-mm) maximum-size rounded coarse aggregate and a natural fine aggregate, while the second contained a 1-1/2-in. (38.1-mm) maximum-size crushed coarse aggregate and a manufactured fine aggregate. Both of the field mixtures were air entrained.

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* A table of factors for converting inch-pound units of measurement to metric (SI) units is presented on page 3.

PART II: MATERIALS, MIXTURES, APPARATUS, AND PROCEDURES

Materials

Laboratory study

5. Type I portland cement (RC-728)* was used in the laboratory study. Table 1 gives the chemical and physical properties of the cement. Natural sand fine aggregate (WES-1 S-4(51)) and natural rounded gravel coarse aggregate (CRD G-42) from Mississippi were used in seven of the laboratory mixtures. Crushed limestone fine aggregate (CRD MS-27) and crushed limestone coarse aggregates (CL-2 G-1 and CRD G-40) from Alabama were used in the remaining seven laboratory mixtures. The physical properties and gradings of the aggregates are given in Tables 2 and 3. The air-entraining admixture (AEA-956) used was a solution of neutralized Vinsol resin. Other materials used in the laboratory mixtures included:

a. Pozzolan (fly ash, AD-474); the chemical and physical properties are presented in Table 4.

b. A high-range water-reducing admixture consisting of a condensation product of melamine and formaldehyde.

c. A commercially available "pump aid" marketed as a cement slurry friction reducer.

d. Straight steel fibers having nominal dimensions 0.010 by 0.022 by 1.0 in. (0.25 by 0.56 by 25.4 mm).

Field study

6. Morganza Control Structure Stilling Basin, New Orleans District. The stilling basin was constructed of concrete containing Type I portland cement (NO-14 C-3). Natural gravel coarse aggregate (NO-14 G-8) and natural sand fine aggregate (NO-14 S-2) from Louisiana were used in the concrete mixture. The physical properties and gradings of the aggregates are given in Table 5. The air-entraining admixture used was a solution of neutralized Vinsol resin.

7. Clarence Cannon Reservoir, Re-Regulation Dam and Spillway, St. Louis District. This structure was constructed of concrete containing

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* Structures Laboratory materials identification number.

Type II portland cement (STL-43 C-1). The physical and chemical properties of the cement are given in Table 6. Crushed limestone coarse and fine aggregates (STL-43 G-1 and STL-43 S-1, respectively) from Missouri were used in the concrete mixture. The physical properties and gradings of the aggregates are given in Table 7. The air-entraining admixture (STL-43 AEA-1) was a solution of neutralized Vinsol resin. A Type B retarding admixture (STL-43 AD-1) conforming to the requirements of ASTM C-494 (American Society for Testing and Materials 1980) was also used in the mixture.

Mixtures

Laboratory study

8. The following 14 concrete mixtures were proportioned in the laboratory study and used to evaluate the proposed test procedures:

Mixture	Water-Cement Ratio by Mass	Cement Content lb/yd³	Cement Content kg/m³	Slump (ASTM C-143)* in.	Slump (ASTM C-143)* mm	Air Content, Pressure Method (ASTM C-231)* %
1	0.55	400	237	7	175	4.5
2	0.53	400	237	5	125	7.5
3	0.46	400	237	3	75	3.0
4	0.53	400	237	3-3/4	95	5.3
5	0.53	400	237	5	125	6.5
6	0.48	650	386	6-3/4	170	3.5
7	0.40	518	307	3	75	4.6
8	0.71	400	237	4	100	4.4
9	0.71	400	237	2-1/4	55	3.5
10	0.71	400	237	3-1/4	80	2.5
11	0.73	400	237	4-1/2	115	3.5
12	0.73	400	237	6-1/4	160	2.5
13	0.50	518**	307	4-3/4	120	2.7
14	0.43	700	415	3	75	4.5

* ASTM (1980).
** Fly ash, 25 percent by solid volume of cement.

The proportions for each mixture are given in Table 8.

Field study

9. The following two concrete mixtures were used in the field study to investigate the effectiveness of the two proposed test methods:

Project	Water-Cement Ratio by Mass	Cement Content		Slump (ASTM C-143)*		Air Content Pressure Method (ASTM C-231)*
		lb/yd^3	kg/m^3	in.	mm	%
Morganza Stilling Basin	0.53	450	267	2	50	5.0
Clarence Cannon Re-Regulating Dam	0.50	662	393	4	100	4.5

* ASTM (1980).

The proportions for each mixture are given in Table 9.

Apparatus and Procedures

Pressure bleed test

10. The bleed test apparatus used in the investigation was developed by Browne and Bamforth (1977) and a schematic of it is shown in Figure 1. It consists of a 5-in.-diam (125-mm) cylinder with a removable top and base. The top portion of the device houses a piston which is attached to the plunger of a double-acting hydraulic jack. The hand-operated pump which supplies pressure to the jack has a four-way valve which allows for the movement of the piston in two directions. The base of the apparatus has a tap inserted into a small bleed hole. This hole is covered with a No. 50-mesh wire gauze to prevent tap blockages.

11. Concrete is placed into the cylinder in two equal layers, each of which is lightly tamped. The level of the top layer is brought to within 1/2 in. (12 mm) of the top of the cylinder, and the top of the apparatus then attached. The bleed tap is closed and concrete is subjected to a pressure of 500 psi (3.5 MPa) using the hand pump. This value is defined by Browne and Bamforth as a typical pressure at the pump end

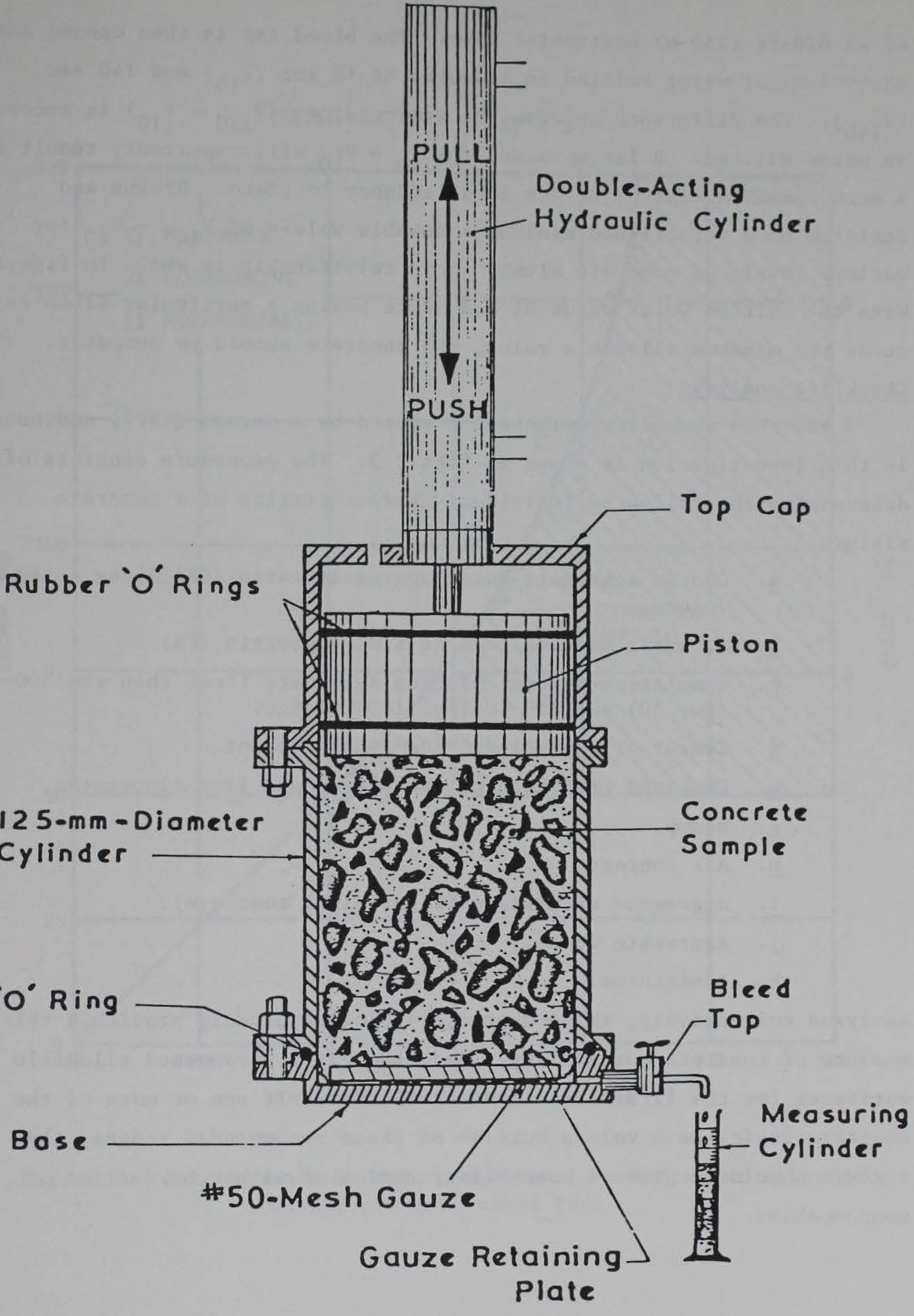

Figure 1. Pressure bleed test apparatus

of an 820-ft (250-m) horizontal line. The bleed tap is then opened and the volume of water emitted is measured at 10 sec (V_{10}) and 140 sec (V_{140}). The difference between the two readings ($V_{140} - V_{10}$) is recorded as water emitted. A large value of $V_{140} - V_{10}$ will reportedly result in a more pumpable mixture having less tendency to bleed. Browne and Bamforth have established minimum allowable values of $V_{140} - V_{10}$ for various levels of concrete slump. This relationship is shown in Figure 2. When the emitted water value of a mixture having a particular slump exceeds the minimum allowable value, the concrete should be pumpable.

Checklist analysis

12. The checklist worksheet prepared by Anderson (1977) and used in this investigation is shown in Figure 3. The procedure consists of determining the following individual characteristics of a concrete mixture:

a. Coarse aggregate-total aggregate ratio (CA/TA) by solid volume.

b. Fineness modulus (FM) of fine aggregate (FA).

c. Cumulative percent of fine aggregate finer than the 300-μm (No. 50) and 150-μm (No. 100) sieves.

d. Cement or equivalent fine-fines content.

e. Combined gradation of the coarse and fine aggregates.

g. Slump.

h. Air content.

i. Aggregate saturation (lightweight concrete).

j. Aggregate shape.

k. Admixtures.

Analyzed collectively, these characteristics reportedly provide a relative measure of concrete pumpability. Anderson gives recommeded allowable variances for the first seven characteristics. If one or more of the characteristics have values outside of these recommended ranges, the mixture should be given a pumpability rating of either borderline or nonpumpable.

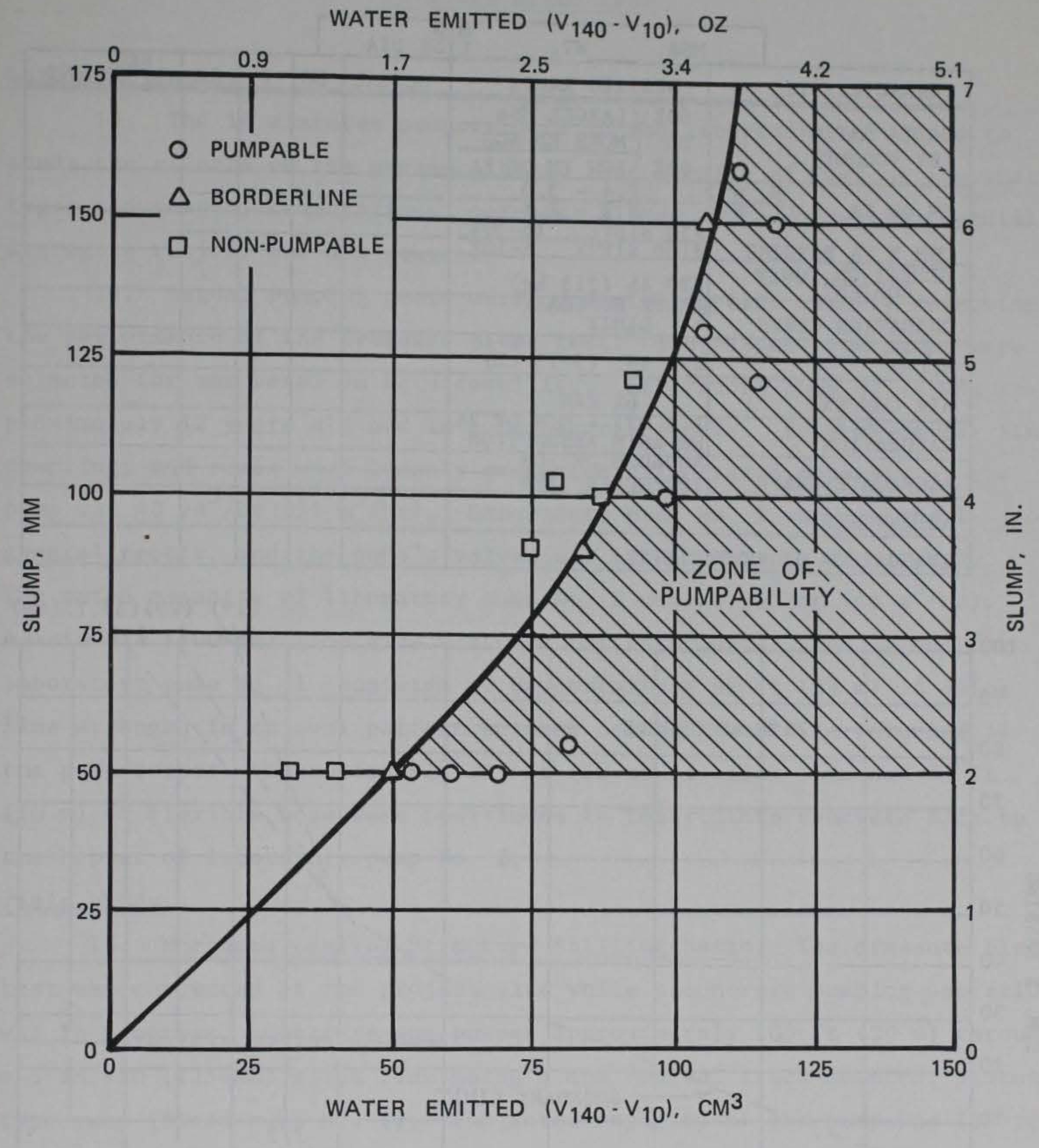

Figure 2. Relationship between concrete slump and water emitted during pressure bleed test

MSA, ___ WT, ___ MIN. LINE DIA

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% (LARGER MSA / MORE RD AGG / LOW FM OF FA)					
FM OF FA N. WT.	2.4 - 3.0					
FM OF FA LT. WT.	2.2 - 2.8					
CUM % FA PASSING	#50 SIEVE 15-30%					
	#100 SIEVE 5-10%					
CEMENT OR EQUIV CONTENT	470 lb (213 kg)					
GRADATION CURVE	ABOVE BOUNDARY LIMIT					
SLUMP	2-6 IN. (5-15 cm)					
AIR CONTENT	6% MAX					
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION					
AGGREGATE SHAPE	ROUNDED OR IRREGULAR CA					
	ROUNDED OR IRREGULAR FA					
ADMIXTURES						
EVALUATION OF PUMPABILITY						

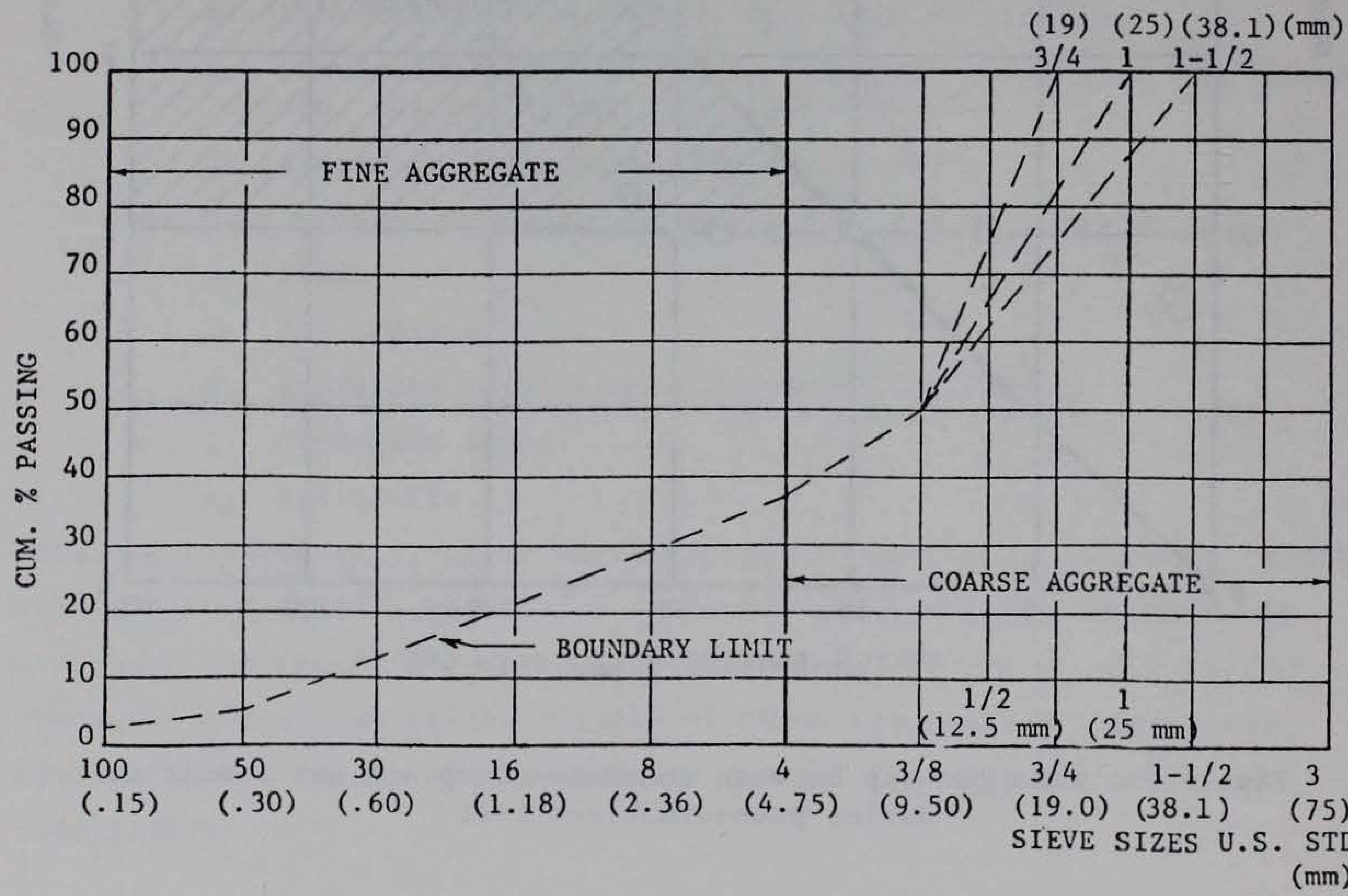

Figure 3. Checklist analysis worksheet

PART III: TESTS

Pressure Bleed Test

Laboratory study

13. The 14 mixtures proportioned in the laboratory were used to study the effects on the pressure bleed test results of various aggregate types and shapes, cementitious contents, slumps, fine aggregate-to-total-aggregate ratios, and admixtures.

14. Actual pumping tests were conducted on each mixture following the performance of the pressure bleed test. Two piston-type pumps were selected for use based on serviceability. Laboratory pump No. 1 was approximately 12 years old and in poor general repair. Several of the line couplings and seals were loosely connected. The rated capacity of the pump was 40 yd^3/hr (31 m^3/hr). Laboratory pump No. 2 was new and in good general repair, and the pump's valves and line couplings fit tightly. The rated capacity of laboratory pump No. 2 was 60 yd^3/hr (46 m^3/hr). A 4-in.-ID (100-mm) line size was used for both pumps. The layout for laboratory pump No. 1 consisted of approximately 82 ft (25 m) of slick line arranged in an oval pattern so that concrete would be returned to the pump hopper. Approximately 213 ft (65 m) of slick line and 33 ft (10 m) of flexible hose were positioned to recirculate concrete back to the hopper of laboratory pump No. 2.

Field study

15. Morganza Control Structure Stilling Basin. The pressure bleed test was conducted at the project site while a concrete pumping operation was in progress. Concrete was pumped approximately 100 ft (30 m) through a 5-in.-ID (125-mm) slick line using a dual-valve, truck-mounted, piston-type pump (field pump No. 1). The rated capacity of the pump was 110 yd^3/hr (84 m^3/hr). The concrete samples tested were obtained by diverting truck mixer discharge from the pump hopper into a sample container. Two pressure bleed tests were conducted.

16. Clarence Cannon Reservoir, Re-Regulation Dam and Spillway. The pressure bleed test was conducted at this project site also during

the progress of a concrete pumping operation. A dual-valve, truck-mounted piston-type pump (field pump No. 2) having a rated capacity of 95 yd^3/hr (73 m^3/hr) pumped the concrete through a 5-in.-ID (125-mm) slick line for approximately 120 ft (37 m). Concrete samples used in the tests were obtained by interrupting the flow from bottom-dump buckets with a sample receptacle. Three tests were conducted at the site. Two of these were performed using unmodified samples. One of the tests was conducted on a sample which was wet-sieved over a 25.0-mm (1-in.) sieve in order to evaluate the effects of different maximum aggregate sizes on the bleed test results.

Checklist Analysis

17. Each of the mixtures investigated in the laboratory and field studies was evaluated using the checklist analysis. Those mixtures having 1 or more of the 10 characteristics outside the recommended range were generally rated as "borderline" or "not good" with respect to relative pumpability.

PART IV: DISCUSSSION OF TEST RESULTS

Pressure Bleed Test

Laboratory study

18. The results of the pressure bleed and pumping tests conducted in the laboratory investigation are shown in Table 10. Although each of the 14 mixtures was not tested in each pump, similar mixtures were evaluated in both pumps and mixture No. 13 was tested in both. Laboratory pump No. 1 leaked badly and subsequently failed or experienced difficulty in pumping those mixtures with larger slumps and smaller cementitious contents (mixtures No. 1, 4, 11, and 12). Mixture No. 5 proved to be pumpable only after the addition of a pump aid admixture. Each of the mixtures tested in laboratory pump No. 2 pumped successfully. Although small amounts of bleed water were noted at some of the couplings, no stoppages occurred in this pump. Aggregate type had no apparent effect on the pumpability of any of the mixtures tested in either pump.

19. Figure 4 presents the laboratory results based on the relationship established by Browne and Bamforth (1977). The plotted data indicate that an extension of the pumpability zone, as shown by the dashed curve in the figure, is necessary for laboratory pump No. 1. Air entrainment in the mixtures tested may be responsible for this extension. The Browne and Bamforth original zone of pumpability was established from test results obtained from nonair-entrained concrete mixtures (Saucier 1977). Laboratory pump No. 2 pumped all mixtures tried. Therefore, a zone of "nonpumpability" could not be defined for laboratory pump No. 2. These results suggest that the pressure bleed test may accurately evaluate the relative pumpability of air-entrained concrete mixtures when they are to be pumped in poorly maintained and leaky pumps.

Field study

20. The pressure bleed test results obtained at both the Morganza Control Structure and the Clarence Cannon Re-Regulating Dam are presented in Table 11. No difficulty in pumping the respective concrete mixtures was experienced by field pump No. 1 (Morganza Control Structure) or field

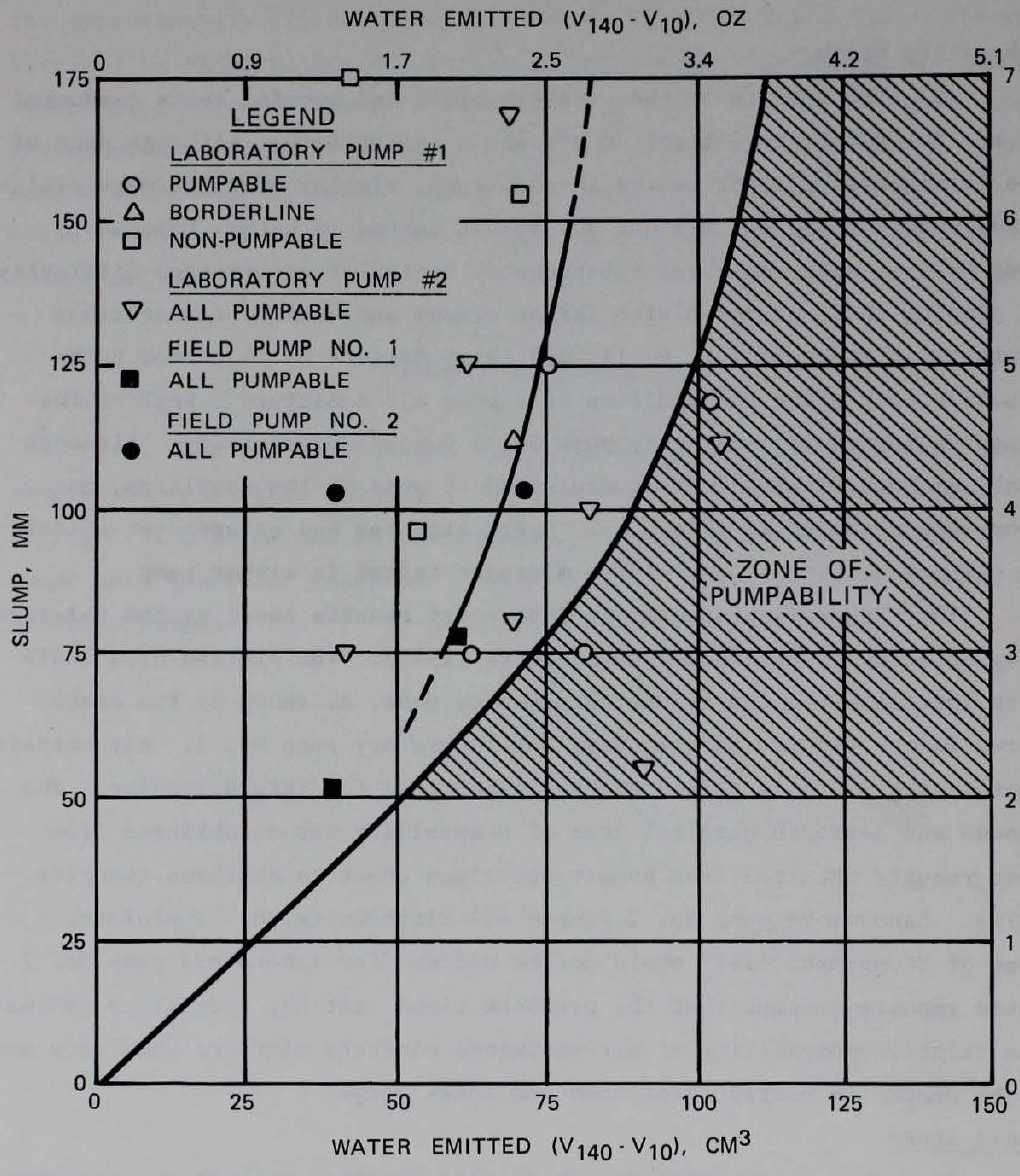

Figure 4. Bleed tests results

pump No. 2 (Clarence Cannon Re-Regulating Dam). The field test data are plotted in Figure 4. A zone of nonpumpability also could not be defined for field pump No. 1 or field pump No. 2 since both successfully pumped the respective concrete mixtures. No significant changes in pressure bleed test results were noted between the unmodified Clarence Cannon mixture and Clarence Cannon wet-sieved mixture.

21. The values of $V_{140} - V_{10}$ generally increased as the air contents of both laboratory and field mixtures increased showing that, according to the Browne and Bamforth relationship, the use of an air-entraining admixture enhances the pumpability of a concrete mixture.

Checklist Analysis

Laboratory study

22. The results of the analyses of the mixtures investigated in the laboratory are given in Table 12. The individual mixture evaluation sheets are shown in Figures 5-18. Six of the mixtures were rated either "not good" (NG) or "OK." The remaining eight mixtures were rated "borderline" (?) because their characteristics taken collectively were neither highly favorable nor unfavorable. For example, mixtures No. 3, 4, 5, 6, 8, 9, 10, and 11 generally had favorable characteristics for pumping, but were deficient in cement or fines. The three mixtures which were rated "not good" were deficient in cement and fines, and contained aggregates which fell below the established grading boundary limit. The three mixtures rated "OK" had only questionable coarse aggregate shape and grading.

Field study

23. The results of the checklist analyses of the field concrete mixtures are also given in Table 12. The individual mixture evaluation sheets are shown in Figures 19 and 20. The Morganza Control Structure mixture was rated "borderline" due to its apparent deficiency in portland cement and fines. The Clarence Cannon Re-Regulating Dam mixture was rated "OK" and was questionable only with respect to aggregate shape and coarse aggregate grading.

MIXTURE NO. 1
(Did Not Pump)

1-1/2" MSA (38.1 mm), N WT, 4" MIN. LINE DIA (100 mm)

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% (LARGER MSA / MORE RD AGG / LOW FM OF FA)	60%			X	
FM OF FA N. WT. / LT. WT.	2.4 - 3.0 / 2.2 - 2.8	2.79			X	
CUM % FA PASSING	#50 SIEVE 15-30% / #100 SIEVE 5-10%	15 / 3	X (#100)	X (#50)		
CEMENT OR EQUIV CONTENT	470 lb (213 kg)	400 lb (181 kg)	X			
GRADATION CURVE	ABOVE BOUNDARY LIMIT			X		
SLUMP	2-6 IN. (5-15 cm)	7 in. (18 cm)	X			
AIR CONTENT	6% MAX	4.5%			X	
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE	ROUNDED OR IRREGULAR CA / FA	Natural / Natural			X / X	
ADMIXTURES	AEA				X	
EVALUATION OF PUMPABILITY			X			

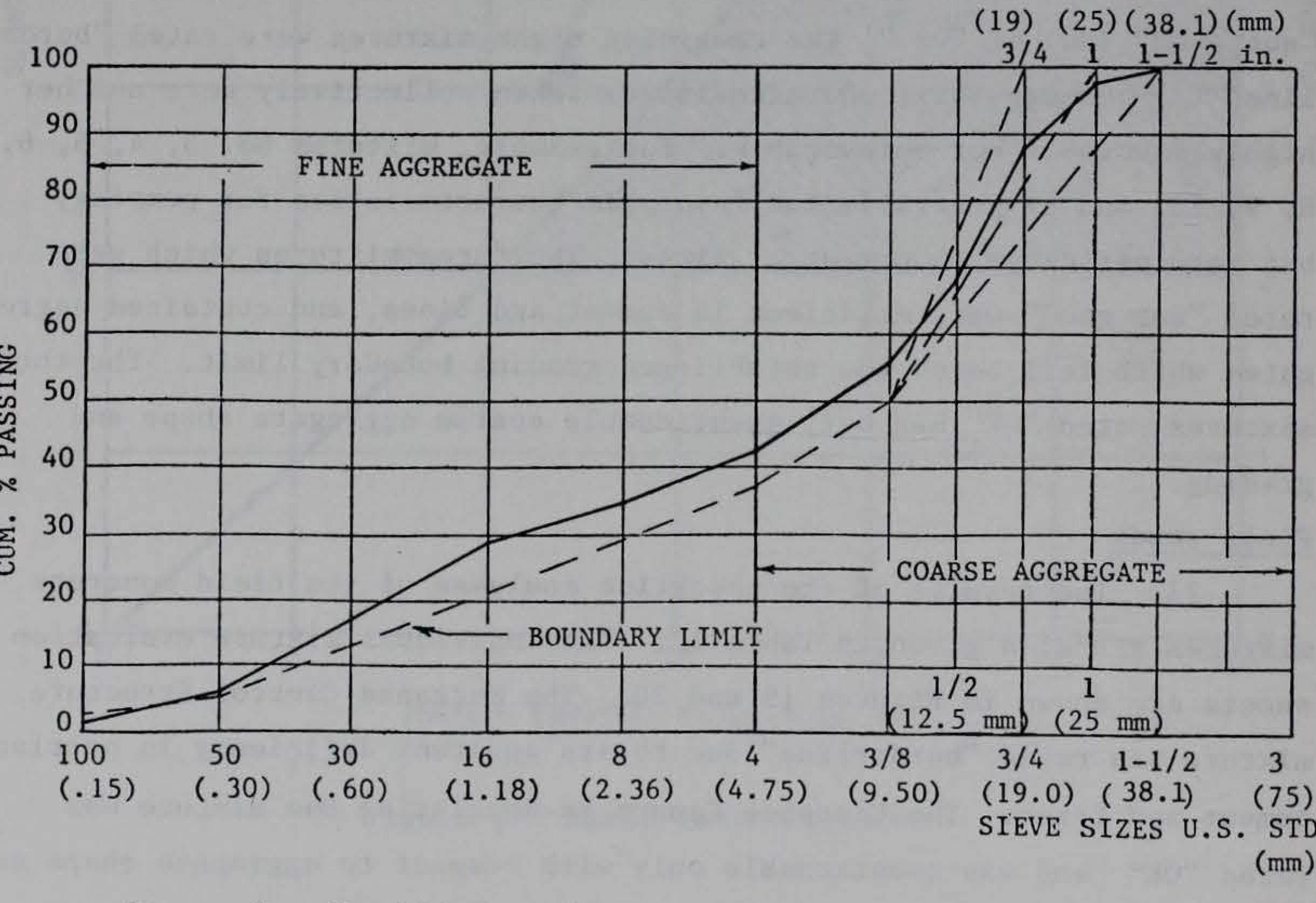

Figure 5. Checklist analysis worksheet, mixture No. 1

MIXTURE NO. 2
(Pumped)

1-1/2"MSA (38.1 mm), N WT, 4" (100 mm) MIN. LINE DIA

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% (LARGER MSA / MORE RD AGG / LOW FM OF FA)	60%			X	
FM OF FA (N. WT. / LT. WT.)	2.4 - 3.0 / 2.2 - 2.8	2.79	—	—	X	
CUM % FA PASSING	#50 SIEVE 15-30%	15		X	—	
	#100 SIEVE 5-10%	3	X			
CEMENT OR EQUIV CONTENT	470 lb (213 kg)	400 lb (181 kg)	X			
GRADATION CURVE	ABOVE BOUNDARY LIMIT			X		
SLUMP	2-6 IN. (5-15 cm)	5 in. (12.5 cm)			X	
AIR CONTENT	6% MAX	7.5%	X			
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE	ROUNDED OR IRREGULAR CA	Natural	—	—	X	
	ROUNDED OR IRREGULAR FA	Natural			X	
ADMIXTURES	AEA				X	
EVALUATION OF PUMPABILITY			X			

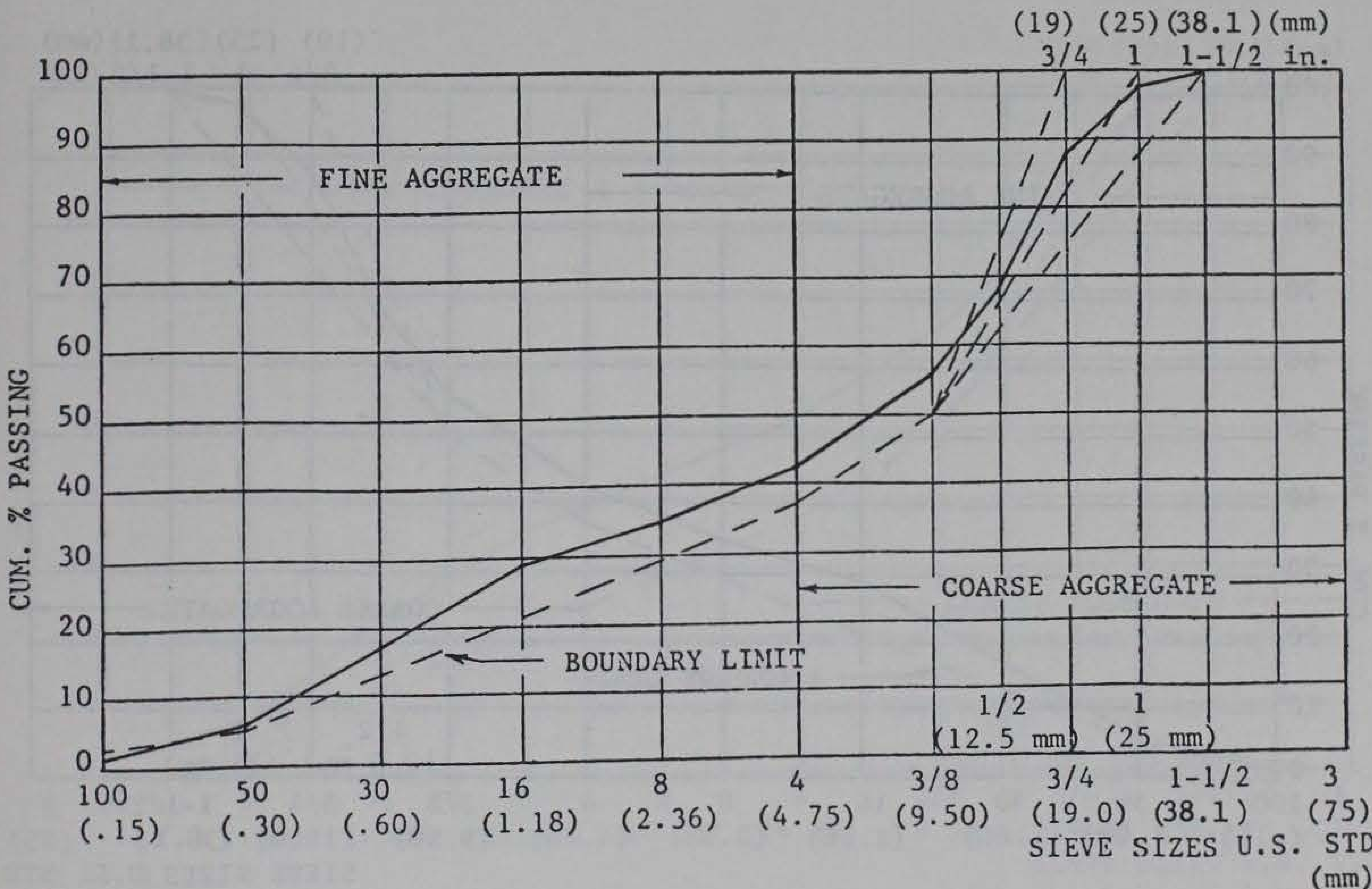

Figure 6. Checklist analysis worksheet, mixture No. 2

MIXTURE NO. 3
(Pumped)

1-1/2" MSA (38.1 mm), N WT, 4" MIN. LINE DIA (100 mm)

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% — LARGER MSA / MORE RD AGG / LOW FM OF FA	60%			X	
FM OF FA — N. WT. / LT. WT.	2.4 - 3.0 / 2.2 - 2.8	2.79			X	
CUM % FA PASSING	#50 SIEVE 15-30% / #100 SIEVE 5-10%	15 / 3	X (#100)	X (#50)		
CEMENT OR EQUIV CONTENT	470 lb (213 kg)	400 lb (181 kg)	X			
GRADATION CURVE	ABOVE BOUNDARY LIMIT			X		
SLUMP	2-6 IN. (5-15 cm)	3 in. (7.5 cm)			X	
AIR CONTENT	6% MAX	3.0%			X	
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE	ROUNDED OR IRREGULAR — CA / FA	Natural / Natural			X / X	
ADMIXTURES	AEA, HRWR				X	
EVALUATION OF PUMPABILITY				X		

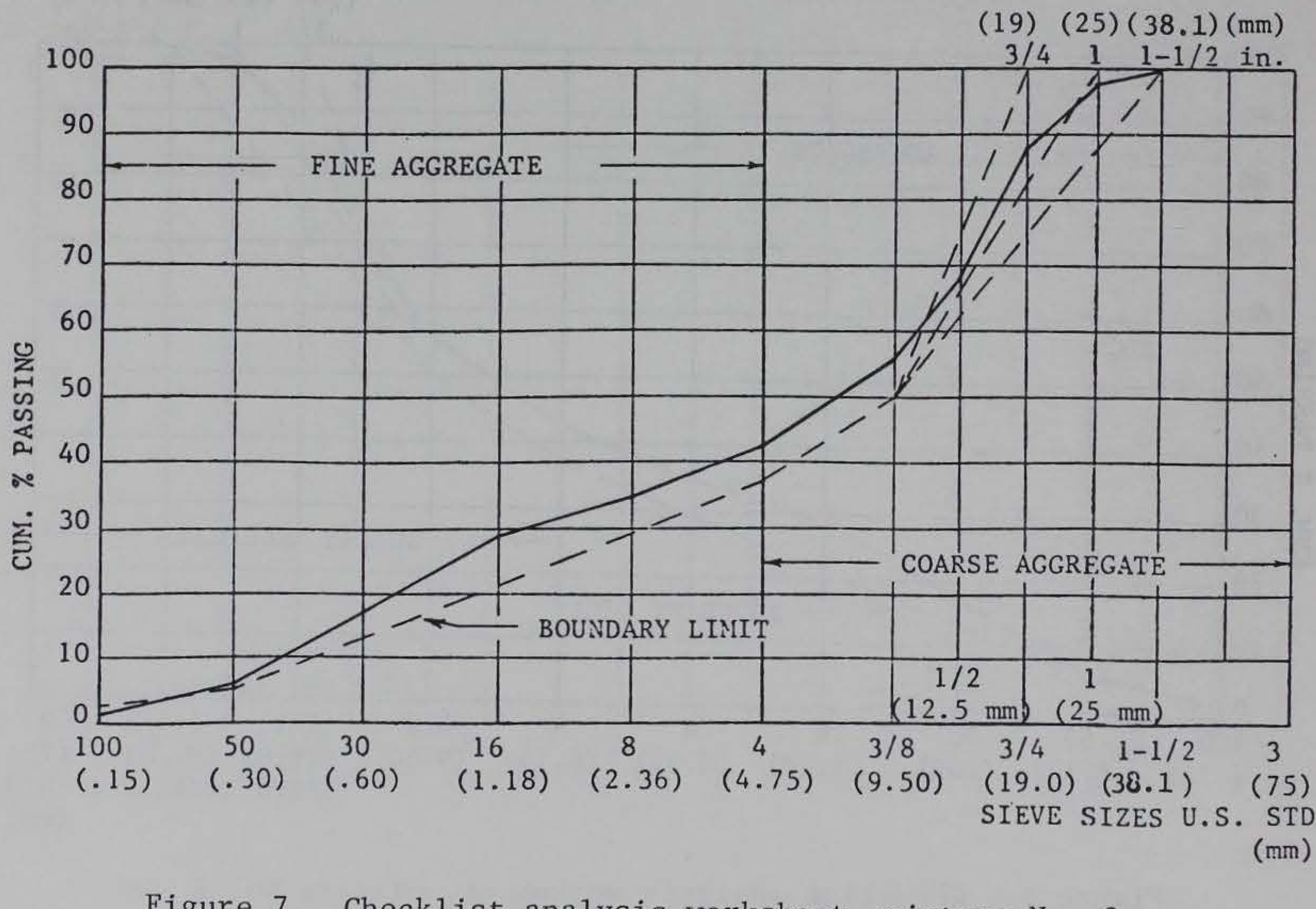

Figure 7. Checklist analysis worksheet, mixture No. 3

MIXTURE NO. 4
(Did Not Pump)

1-1/2" (38.1 mm) MSA, N WT, 4" (100 mm) MIN. LINE DIA

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% (LARGER MSA / MORE RD AGG / LOW FM OF FA)	50%		X		
FM OF FA N. WT. / LT. WT.	2.4 - 3.0 / 2.2 - 2.8	2.79			X	
CUM % FA PASSING	#50 SIEVE 15-30%	15		X		
	#100 SIEVE 5-10%	3	X			
CEMENT OR EQUIV CONTENT	470 lb (213 kg)	400 lb (181 kg)	X			
GRADATION CURVE	ABOVE BOUNDARY LIMIT			X		
SLUMP	2-6 IN. (5-15 cm)	3-3/4 in. (9.5 cm)			X	
AIR CONTENT	6% MAX	5.3%			X	
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE	ROUNDED OR IRREGULAR CA	Natural			X	
	FA	Natural			X	
ADMIXTURES	AEA				X	
EVALUATION OF PUMPABILITY				X		

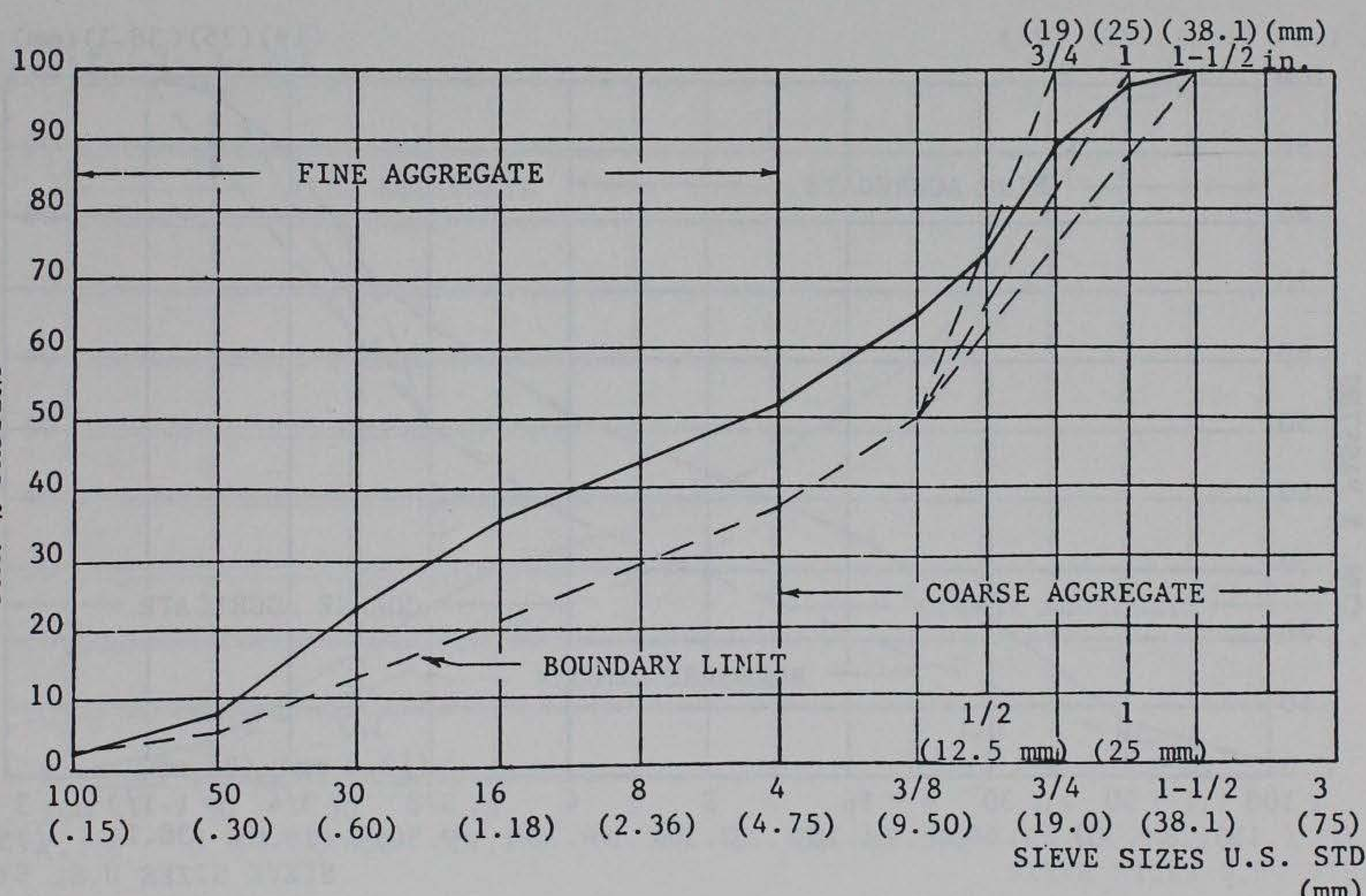

Figure 8. Checklist analysis worksheet, mixture No. 4

MIXTURE NO. 5
(Pumped)

(38.1 mm) 1-1/2" MSA, N WT, 4" (100 mm) MIN. LINE DIA

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% (LARGER MSA / MORE RD AGG / LOW FM OF FA)	50%		X		
FM OF FA N. WT. / LT. WT.	2.4 - 3.0 / 2.2 - 2.8	2.79			X	
CUM % FA PASSING	#50 SIEVE 15-30% / #100 SIEVE 5-10%	15 / 3	X	X		
CEMENT OR EQUIV CONTENT	470 lb (213 kg)	400 lb (181 kg)	X			
GRADATION CURVE	ABOVE BOUNDARY LIMIT			X		
SLUMP	2-6 IN. (5-15 cm)	5 in. (12.5 cm)			X	
AIR CONTENT	6% MAX	6.5%		X		
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE	ROUNDED OR IRREGULAR CA / FA	Natural / Natural			X / X	
ADMIXTURES	AEA, Pump Aid				X	
EVALUATION OF PUMPABILITY				X		

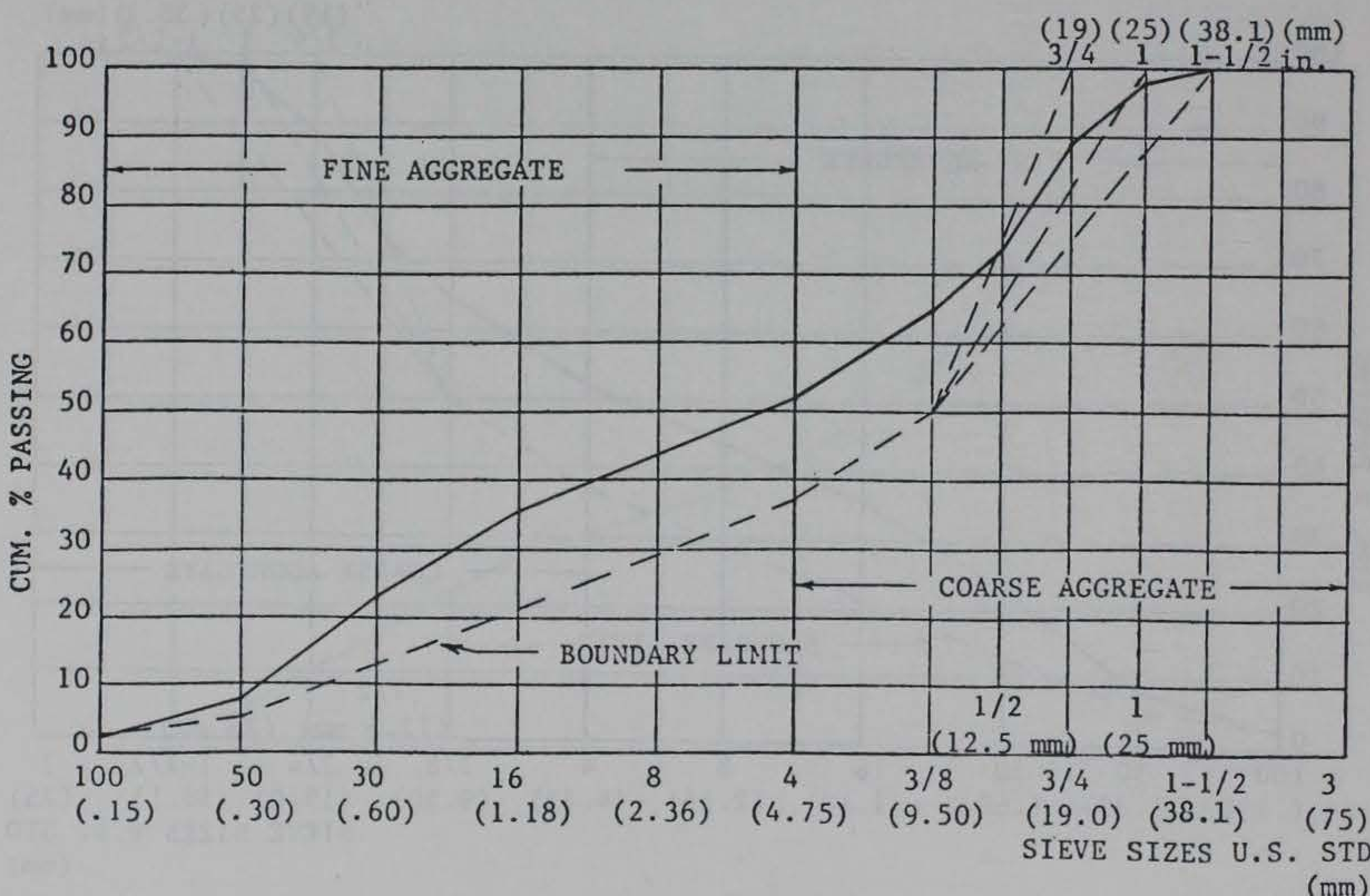

Figure 9. Checklist analysis worksheet, mixture No. 5

MIXTURE NO. 6
(Pumped)

1-1/2" (38.1 mm) MSA, N WT, 4" (100 mm) MIN. LINE DIA

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% (LARGER MSA / MORE RD AGG / LOW FM OF FA)	57%			X	
FM OF FA — N. WT. / LT. WT.	2.4 - 3.0 / 2.2 - 2.8	2.79			X	
CUM % FA PASSING	#50 SIEVE 15-30% / #100 SIEVE 5-10%	15 / 3	X	X	X	
CEMENT OR EQUIV CONTENT	470 lb (213 kg)	650 lb (295 kg)	+6.5%		X	650-470 / 2773(TA) = 6.5%
GRADATION CURVE	ABOVE BOUNDARY LIMIT			X	X	
SLUMP	2-6 IN. (5-15 cm)	6-3/4 in. (17 cm)		X		
AIR CONTENT	6% MAX	3.5%			X	
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE	ROUNDED OR IRREGULAR — CA / FA	Natural / Natural			X / X	
ADMIXTURES	AEA, Steel Fibers			X		
EVALUATION OF PUMPABILITY				X		

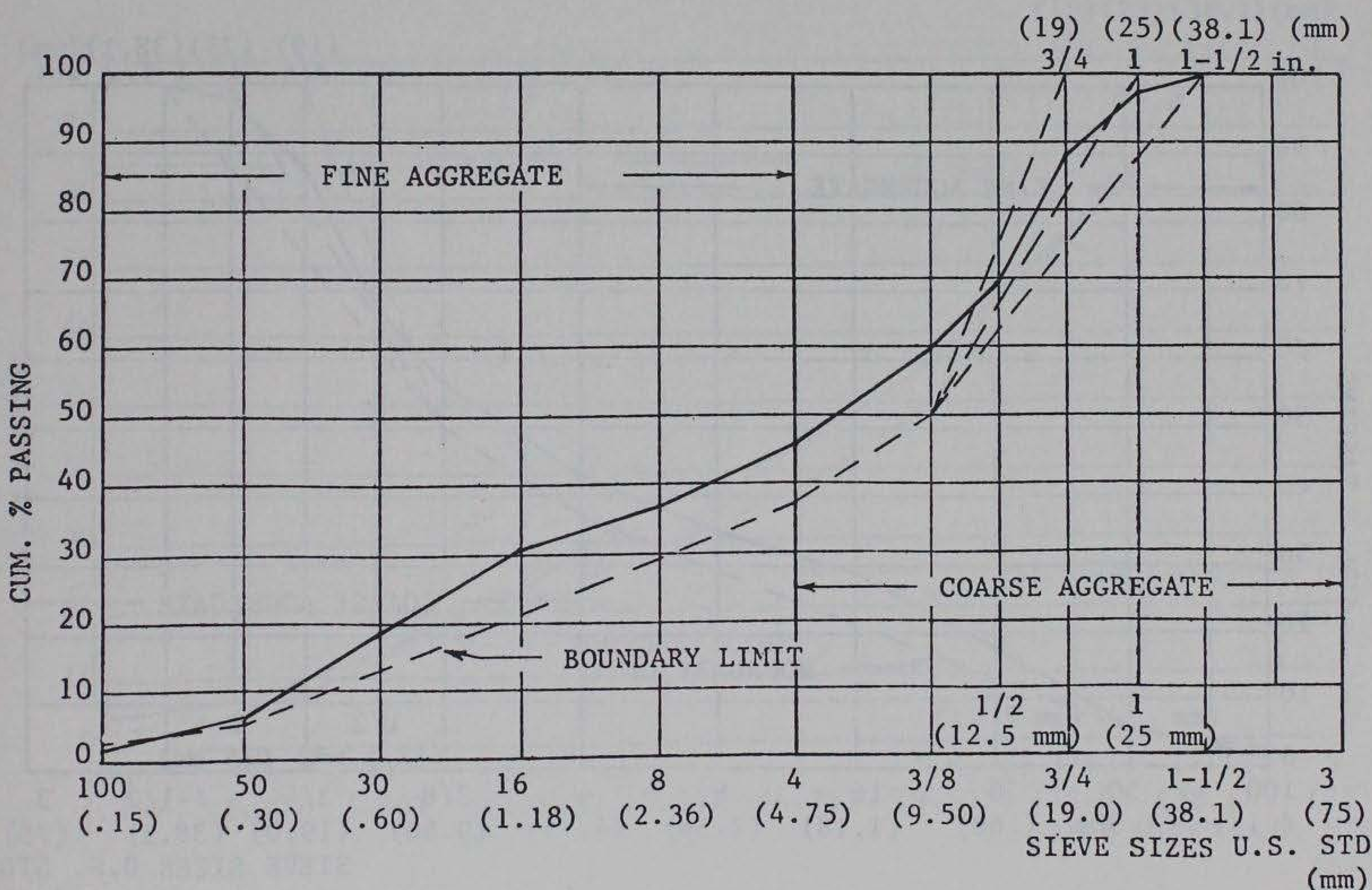

Figure 10. Checklist analysis workheet, mixture No. 6

MIXTURE NO. 7
(Pumped)

1-1/2" (38.1 mm) MSA, N WT, 4" (100 mm) MIN. LINE DIA

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% (LARGER MSA / MORE RD AGG / LOW FM OF FA)	60%			X	
FM OF FA — N. WT. / LT. WT.	2.4 - 3.0 / 2.2 - 2.8	2.79	—	—	X	
CUM % FA PASSING	#50 SIEVE 15-30% / #100 SIEVE 5-10%	15 / 3	— / X	X / X	—	
CEMENT OR EQUIV CONTENT	470 lb (213 kg)	+1.5% 518 lb (235 kg)			X	$\frac{518-470}{3192(TA)}$ =1.5%
GRADATION CURVE	ABOVE BOUNDARY LIMIT			X		
SLUMP	2-6 IN. (5-15 cm)	3 in. (7.5 cm)			X	
AIR CONTENT	6% MAX	4.6%			X	
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE	ROUNDED OR IRREGULAR — CA / FA	Natural / Natural	—	—	X / X	
ADMIXTURES	AEA, Fly Ash				X	
EVALUATION OF PUMPABILITY					X	

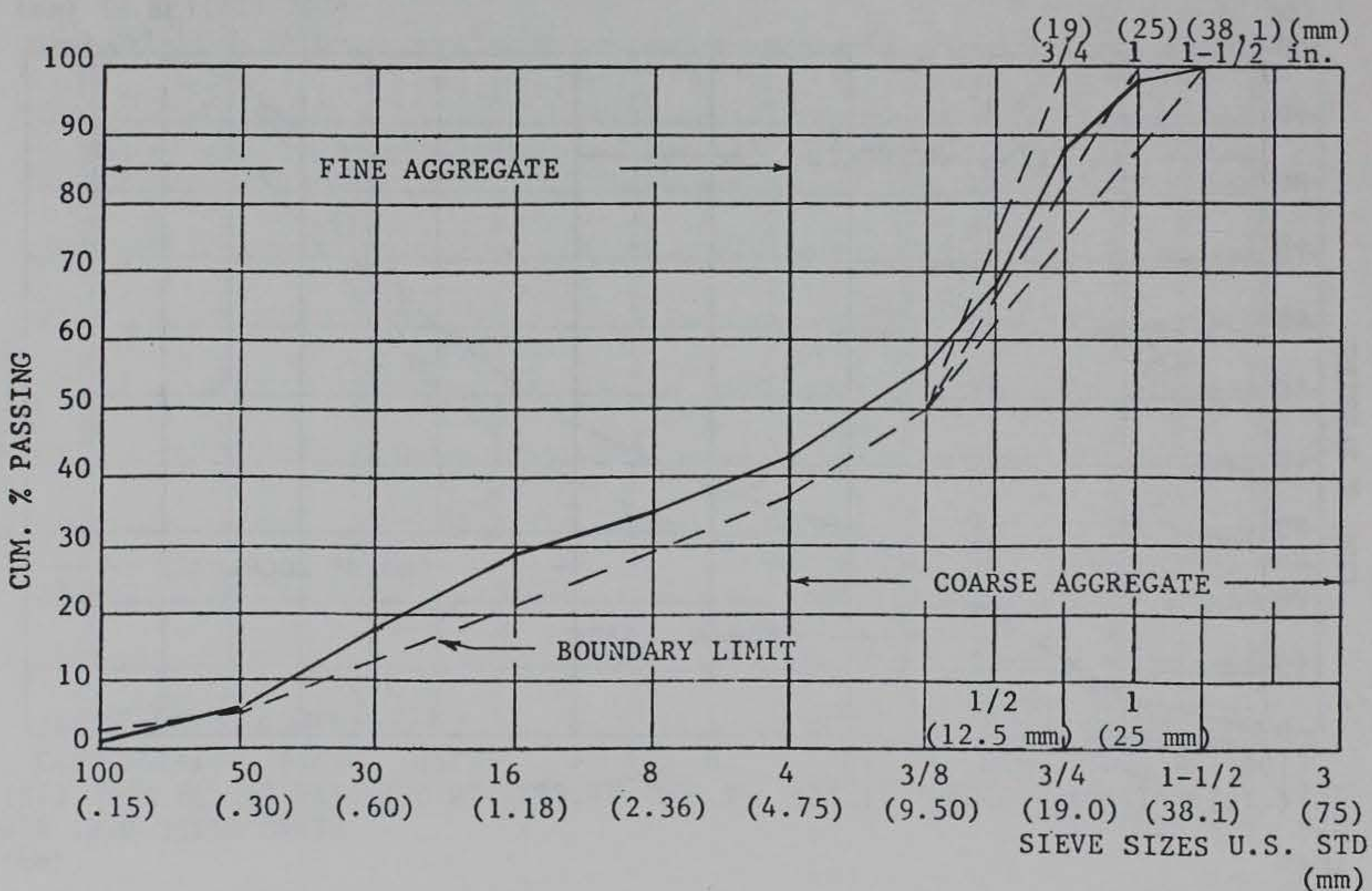

Figure 11. Checklist analysis worksheet, mixture No. 7

MIXTURE NO. 8
(Pumped)

(38.1 mm) (100 mm)
1-1/2" MSA, N WT, 4" MIN. LINE DIA

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% (LARGER MSA / MORE RD AGG / LOW FM OF FA)	58%			X	
FM OF FA N. WT.	2.4 - 3.0	3.03	—	—	X	
FM OF FA LT. WT.	2.2 - 2.8					
CUM % FA PASSING	#50 SIEVE 15-30%	18	—	—	X	
	#100 SIEVE 5-10%	9			X	
CEMENT OR EQUIV CONTENT	470 lb (213 kg)	400 lb (181 kg)	X			
GRADATION CURVE	ABOVE BOUNDARY LIMIT			X		
SLUMP	2-6 IN. (5-15 cm)	4 in. (10 cm)			X	
AIR CONTENT	6% MAX	4.4			X	
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE	ROUNDED OR IRREGULAR CA	Crushed	—	X	—	
	ROUNDED OR IRREGULAR FA	Crushed	X			
ADMIXTURES	AEA				X	
EVALUATION OF PUMPABILITY				X		

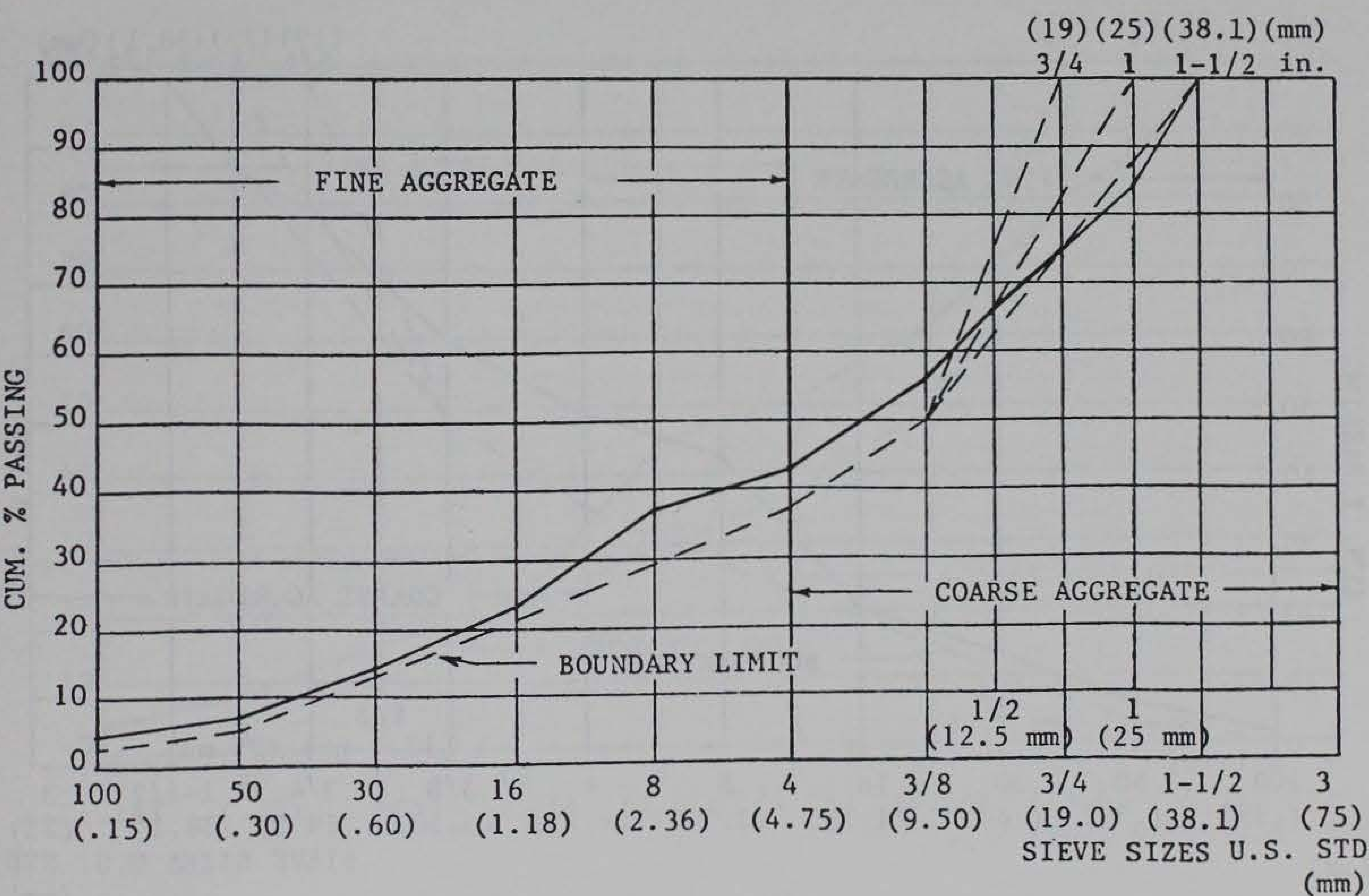

Figure 12. Checklist analysis worksheet, mixture No. 8

MIXTURE NO. 9
(Pumped)

1-1/2" (38.1 mm) MSA, N WT, 4" (100 mm) MIN. LINE DIA

CHARACTERISTIC		DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)		50% TO 65% (LARGER MSA / MORE RD AGG / LOW FM OF FA)	50%			X	
FM OF FA	N. WT.	2.4 - 3.0	3.03			X	
	LT. WT.	2.2 - 2.8					
CUM % FA PASSING		#50 SIEVE 15-30%	18			X	
		#100 SIEVE 5-10%	9			X	
CEMENT OR EQUIV CONTENT		470 lb (213 kg)	400 lb (181 kg)	X			
GRADATION CURVE		ABOVE BOUNDARY LIMIT			X		
SLUMP		2-6 IN. (5-15 cm)	2-1/4 in. (5.5 cm)			X	
AIR CONTENT		6% MAX	3.5%			X	
AGGREGATE SATURATION		(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE		ROUNDED OR IRREGULAR — CA	Crushed		X		
		ROUNDED OR IRREGULAR — FA	Crushed	X			
ADMIXTURES		AEA				X	
EVALUATION OF PUMPABILITY					X		

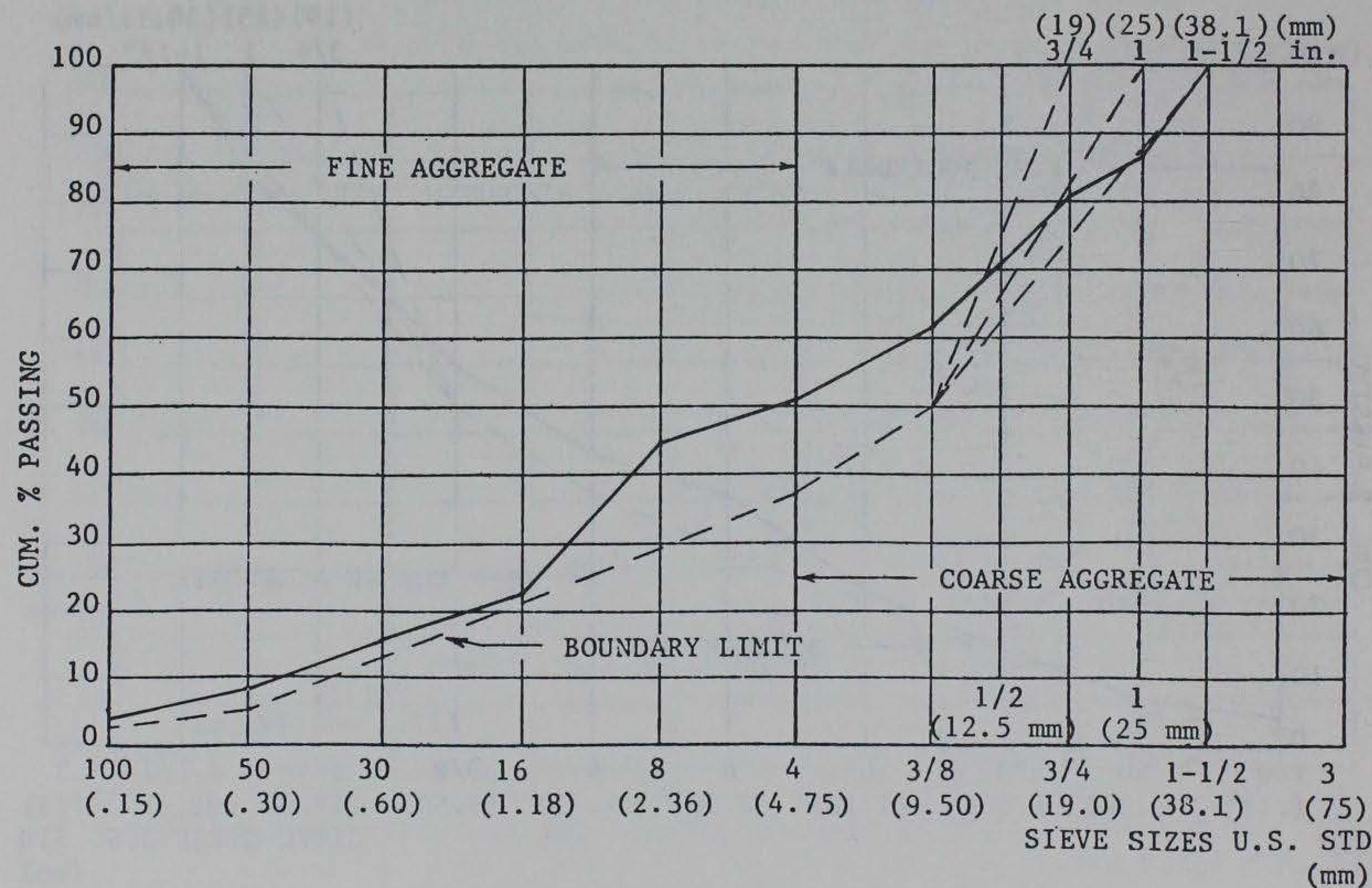

Figure 13. Checklist analysis worksheet, mixture No. 9

MIXTURE NO. 10
(Pumped)

(38.1 mm) (100 mm)
1-1/2" MSA, N WT, 4" MIN. LINE DIA

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% — LARGER MSA / MORE RD AGG / LOW FM OF FA	50%			X	
FM OF FA N. WT. / LT. WT.	2.4 - 3.0 / 2.2 - 2.8	3.03			X	
CUM % FA PASSING	#50 SIEVE 15-30% / #100 SIEVE 5-10%	18 / 9			X / X	
CEMENT OR EQUIV CONTENT	470 lb (213 kg)	400 lb (181 kg/)	X			
GRADATION CURVE	ABOVE BOUNDARY LIMIT			X		
SLUMP	2-6 IN. (5-15 cm)	3-1/4 in. (8.5 cm)			X	
AIR CONTENT	6% MAX	2.5%			X	
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE	ROUNDED OR IRREGULAR — CA / FA	Crushed / Crushed	— / X	X / —		
ADMIXTURES	AEA, Pump Aid				X	
EVALUATION OF PUMPABILITY				X		

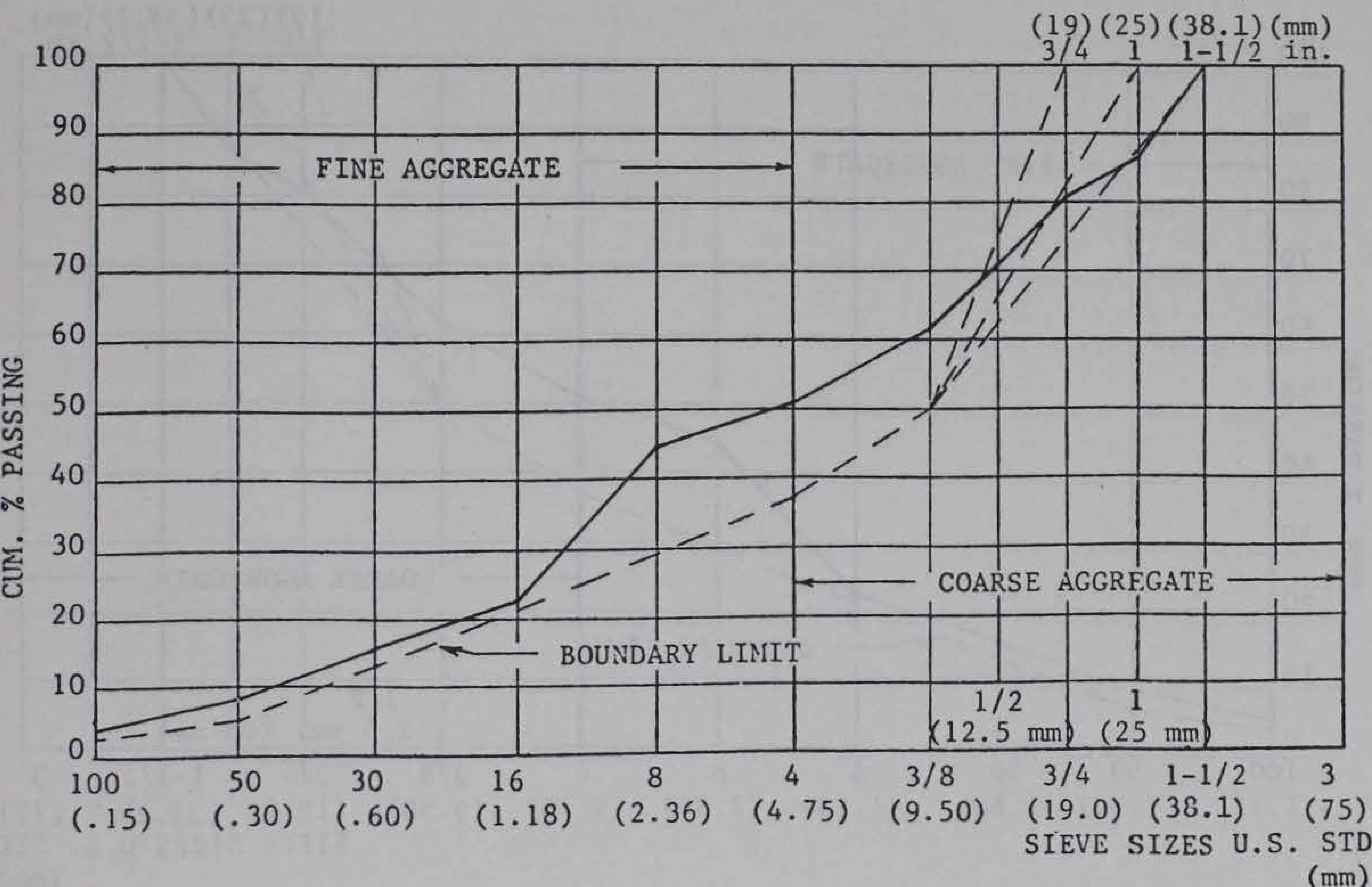

Figure 14. Checklist analysis worksheet, mixture No. 10

MIXTURE NO. 11
(Pumped With Difficulty)

1-1/2" (38.1 mm) MSA, N WT, 4" (100 mm) MIN. LINE DIA

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% (LARGER MSA / MORE RD AGG / LOW FM OF FA)	50%			X	
FM OF FA N. WT.	2.4 - 3.0	3.03			X	
FM OF FA LT. WT.	2.2 - 2.8					
CUM % FA PASSING	#50 SIEVE 15-30%	18			X	
	#100 SIEVE 5-10%	9			X	
CEMENT OR EQUIV CONTENT	470 lb (213 kg)	400 lb (181 kg)	X			
GRADATION CURVE	ABOVE BOUNDARY LIMIT			X		
SLUMP	2-6 IN. (5-15 cm)	4-1/2 in. (11.5 cm)			X	
AIR CONTENT	6% MAX	3.5%			X	
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE	ROUNDED OR IRREGULAR CA	Crushed		X		
	FA	Crushed	X			
ADMIXTURES	AEA				X	
EVALUATION OF PUMPABILITY				X		

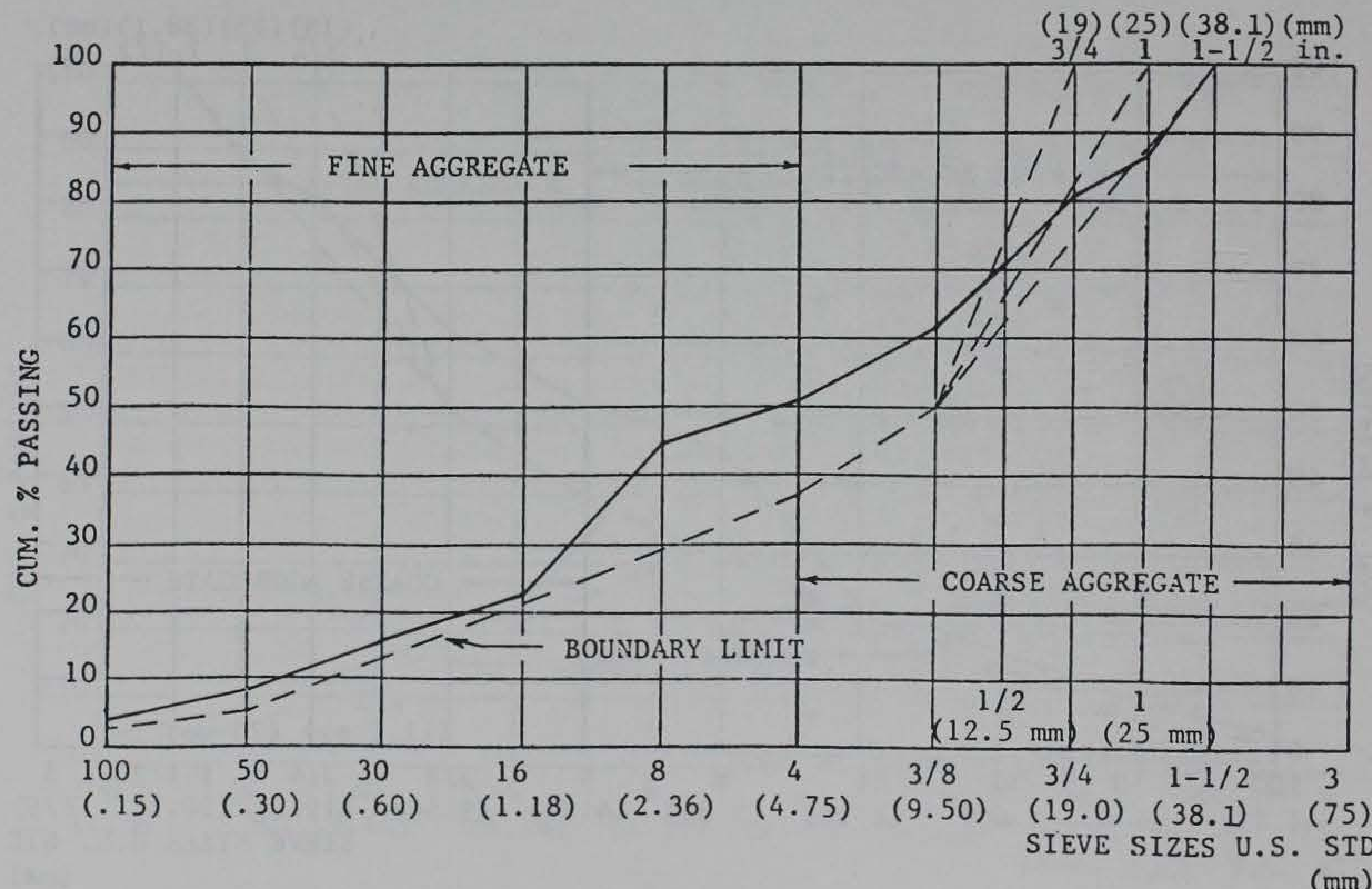

Figure 15. Checklist analysis worksheet, mixture No. 11

MIXTURE NO. 12
(Did Not Pump)

1-1/2" (38.1 mm) MSA, N WT, 4" (100 mm) MIN. LINE DIA

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% (LARGER MSA / MORE RD AGG / LOW FM OF FA)	50%			X	
FM OF FA (N. WT. / LT. WT.)	2.4 - 3.0 / 2.2 - 2.8	3.03			X	
CUM % FA PASSING	#50 SIEVE 15-30% / #100 SIEVE 5-10%	18 / 9			X / X	
CEMENT OR EQUIV CONTENT	470 lb (213 kg)	400 lb (181 kg)	X			
GRADATION CURVE	ABOVE BOUNDARY LIMIT			X		
SLUMP	2-6 IN. (5-15 cm)	6-1/4 in. (16 cm)	X			
AIR CONTENT	6% MAX	2.5%			X	
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE	ROUNDED OR IRREGULAR (CA / FA)	Crushed / Crushed	X (FA)	X (CA)		
ADMIXTURES	AEA, Pump Aid				X	
EVALUATION OF PUMPABILITY			X			

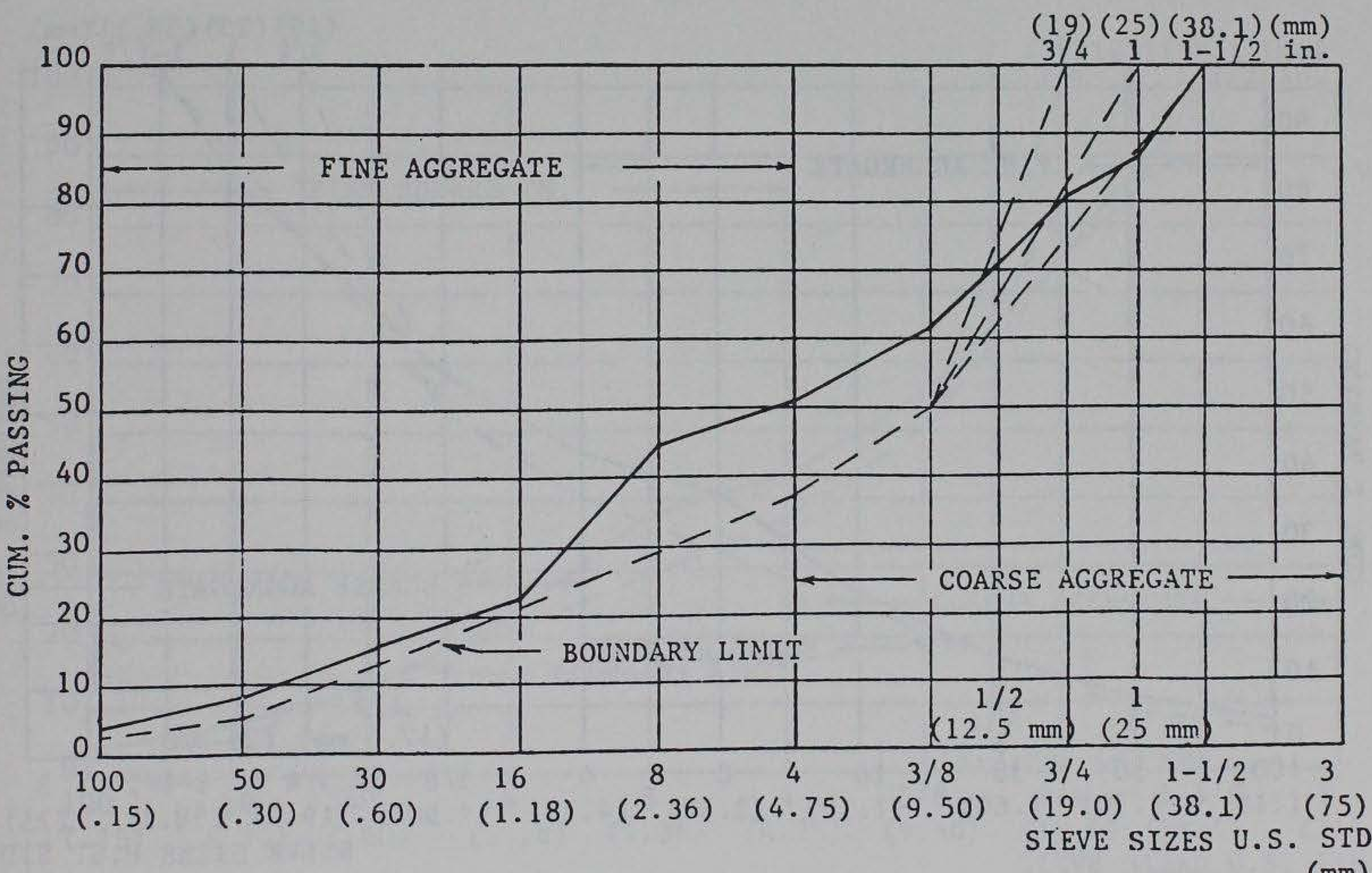

Figure 16. Checklist analysis worksheet, mixture No. 12

MIXTURE NO. 13
(Pumped)

1-1/2" (38.1 mm) MSA, N WT, 4" (100 mm) MIN. LINE DIA

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% (LARGER MSA / MORE RD AGG / LOW FM OF FA)	58%			X	
FM OF FA (N. WT. / LT. WT.)	2.4 - 3.0 / 2.2 - 2.8	3.03			X	
CUM % FA PASSING	#50 SIEVE 15-30% / #100 SIEVE 5-10%	18 / 9			X / X	
CEMENT OR EQUIV CONTENT	470 lb (213 kg)	518 lb (235 kg)			X	$\frac{518-470}{3082}$=1.6%
GRADATION CURVE	ABOVE BOUNDARY LIMIT			X		
SLUMP	2-6 IN. (5-15 cm)	4-1/2 in. (11.5 cm)			X	
AIR CONTENT	6% MAX	2.4%			X	
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE	ROUNDED OR IRREGULAR (CA / FA)	Crushed / Crushed	X (FA)	X (CA)		
ADMIXTURES	AEA, Fly Ash				X	
EVALUATION OF PUMPABILITY					X	

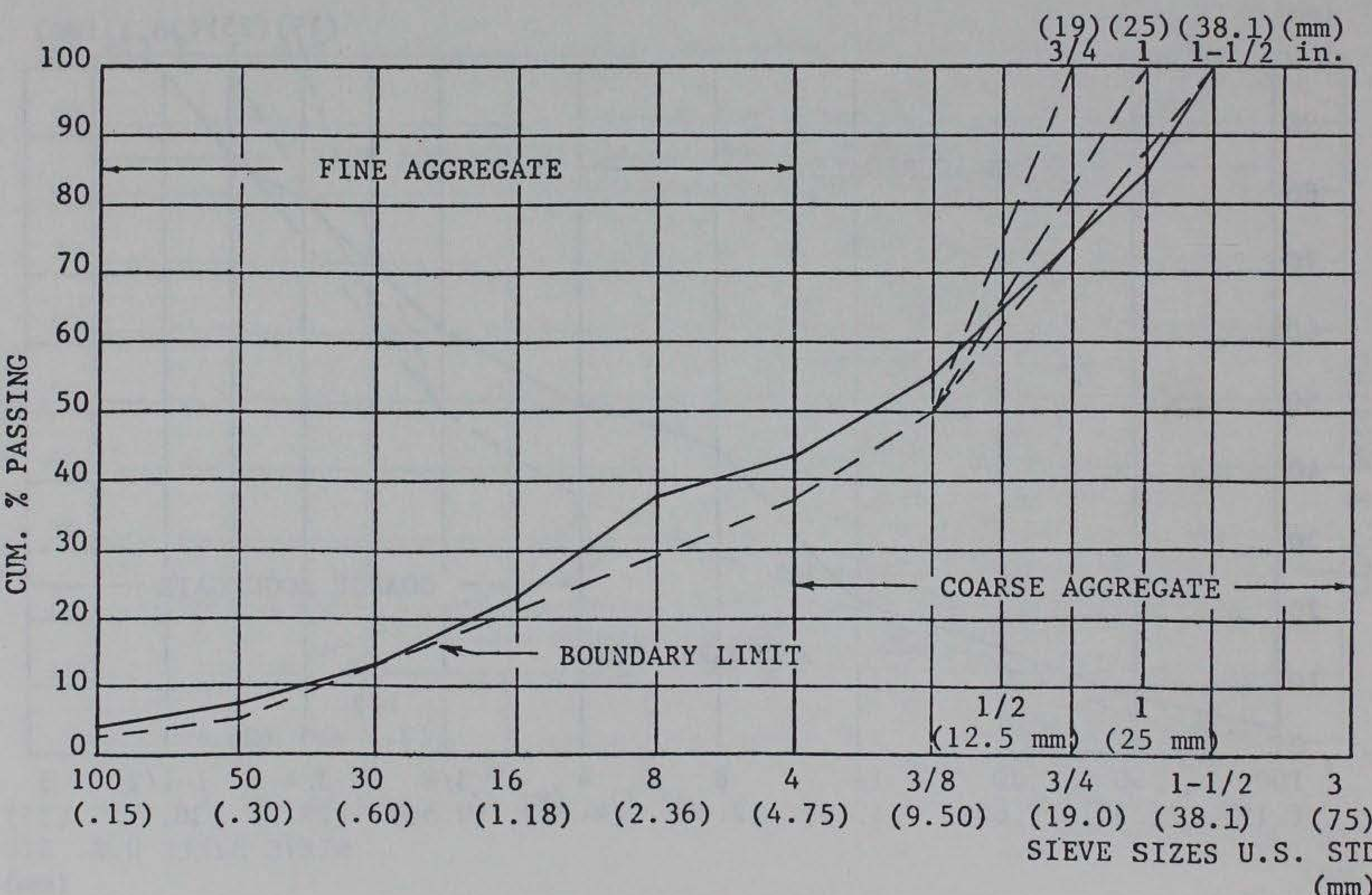

Figure 17. Checklist analysis worksheet, mixture No. 13

MIXTURE NO. 14
(Pumped)

1-1/2" (38.1 mm) MSA, N WT, 4" (100 mm) MIN. LINE DIA

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% (LARGER MSA / MORE RD AGG / LOW FM OF FA)	58%			X	
FM OF FA N. WT. / LT. WT.	2.4 - 3.0 / 2.2 - 2.8	3.03			X	
CUM % FA PASSING	#50 SIEVE 15-30%	18			X	
	#100 SIEVE 5-10%	9			X	
CEMENT OR EQUIV CONTENT	470 lb (213 kg)	700 lb (318 kg)			X	700-470 / 2913(TA) =7.9%
GRADATION CURVE	ABOVE BOUNDARY LIMIT			X		
SLUMP	2-6 IN. (5-15 cm)	3 in. (7.5 cm)			X	
AIR CONTENT	6% MAX	4.5%			X	
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE	ROUNDED OR IRREGULAR CA	Crushed		X		
	ROUNDED OR IRREGULAR FA	Crushed	X			
ADMIXTURES	AEA					
EVALUATION OF PUMPABILITY					X	

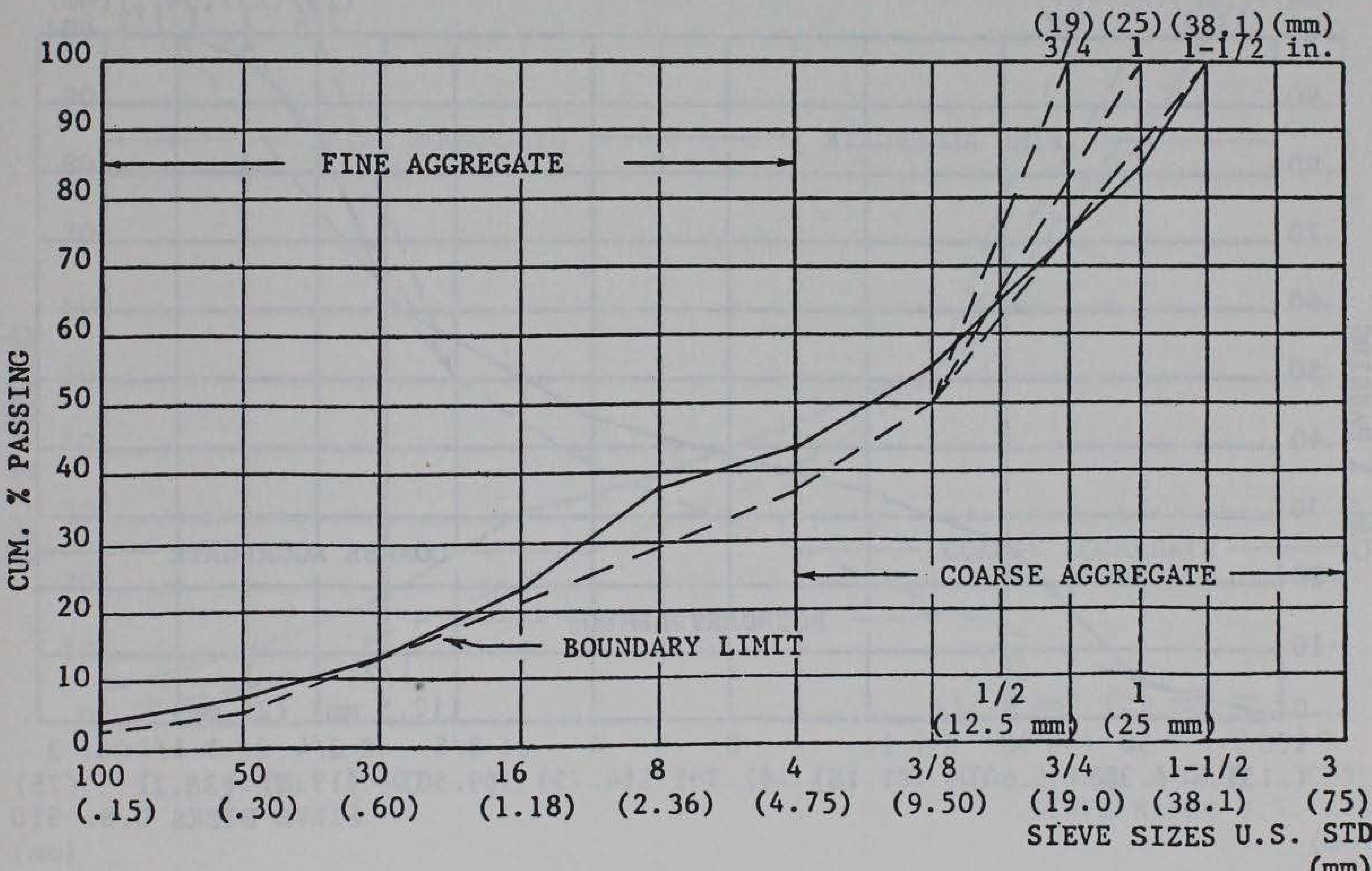

Figure 18. Checklist analysis worksheet, mixture No. 14

MORGANZA CONTROL STRUCTURE STILLING BASIN
(Pumped)

1-1/2" (38.1 mm) MSA, N WT, 5" (125 mm) MIN. LINE DIA

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% (LARGER MSA / MORE RD AGG / LOW FM OF FA)	55%			X	
FM OF FA N. WT.	2.4 - 3.0	2.72			X	
FM OF FA LT. WT.	2.2 - 2.8					
CUM % FA PASSING #50 SIEVE	15-30%	5.0	X			
CUM % FA PASSING #100 SIEVE	5-10%	0.0	X			
CEMENT OR EQUIV CONTENT	470 lb (213 kg)	450 lb (204 kg)	X			
GRADATION CURVE	ABOVE BOUNDARY LIMIT			X		
SLUMP	2-6 IN. (5-15 cm)	2 in. (5 cm)			X	
AIR CONTENT	6% MAX	5.0%			X	
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE CA	ROUNDED OR IRREGULAR	Natural			X	
AGGREGATE SHAPE FA	ROUNDED OR IRREGULAR	Natural			X	
ADMIXTURES	AEA				X	
EVALUATION OF PUMPABILITY				X		

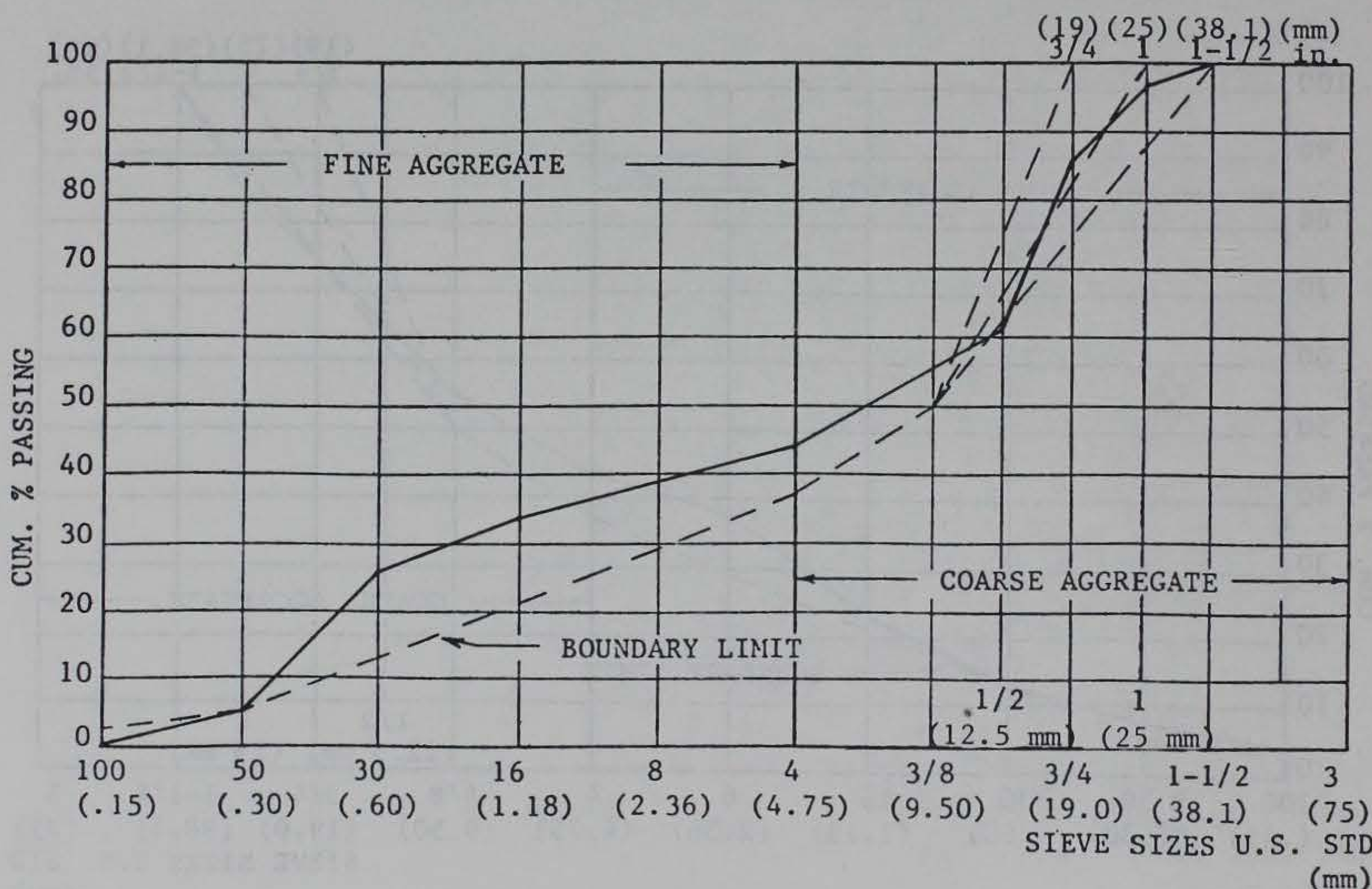

Figure 19. Checklist analysis worksheet, Morganza Control Structure

CLARENCE CANNON RE-REGULATION DAM
(Pumped)

1-1/2" (38.1 mm) MSA, N WT, 5" (125 mm) MIN. LINE DIA

CHARACTERISTIC	DESIRED RANGE	ACTUAL	NG	?	OK	REC ADJUSTMENT
CA/TA RATIO (BY VOLUME)	50% TO 65% (LARGER MSA / MORE RD AGG / LOW FM OF FA)	60%			X	
FM OF FA — N. WT. / LT. WT.	2.4 - 3.0 / 2.2 - 2.8	2.48			X	
CUM % FA PASSING	#50 SIEVE 15-30% / #100 SIEVE 5-10%	32 / 11			X / X	
CEMENT OR EQUIV CONTENT	470 lb (213 kg)	662 lb (300 kg)			X	$\frac{662-470}{2796(TA)}$ =6.9%
GRADATION CURVE	ABOVE BOUNDARY LIMIT			X		
SLUMP	2-6 IN. (5-15 cm)	10 cm			X	
AIR CONTENT	6% MAX	4.8%			X	
AGGREGATE SATURATION	(LT WT) - MIN OF 24 HR ASTM ABSORPTION				X	
AGGREGATE SHAPE	ROUNDED OR IRREGULAR — CA / FA	Crushed / Crushed	FA: X	CA: X		
ADMIXTURES	AEA, Retarder				X	
EVALUATION OF PUMPABILITY					X	

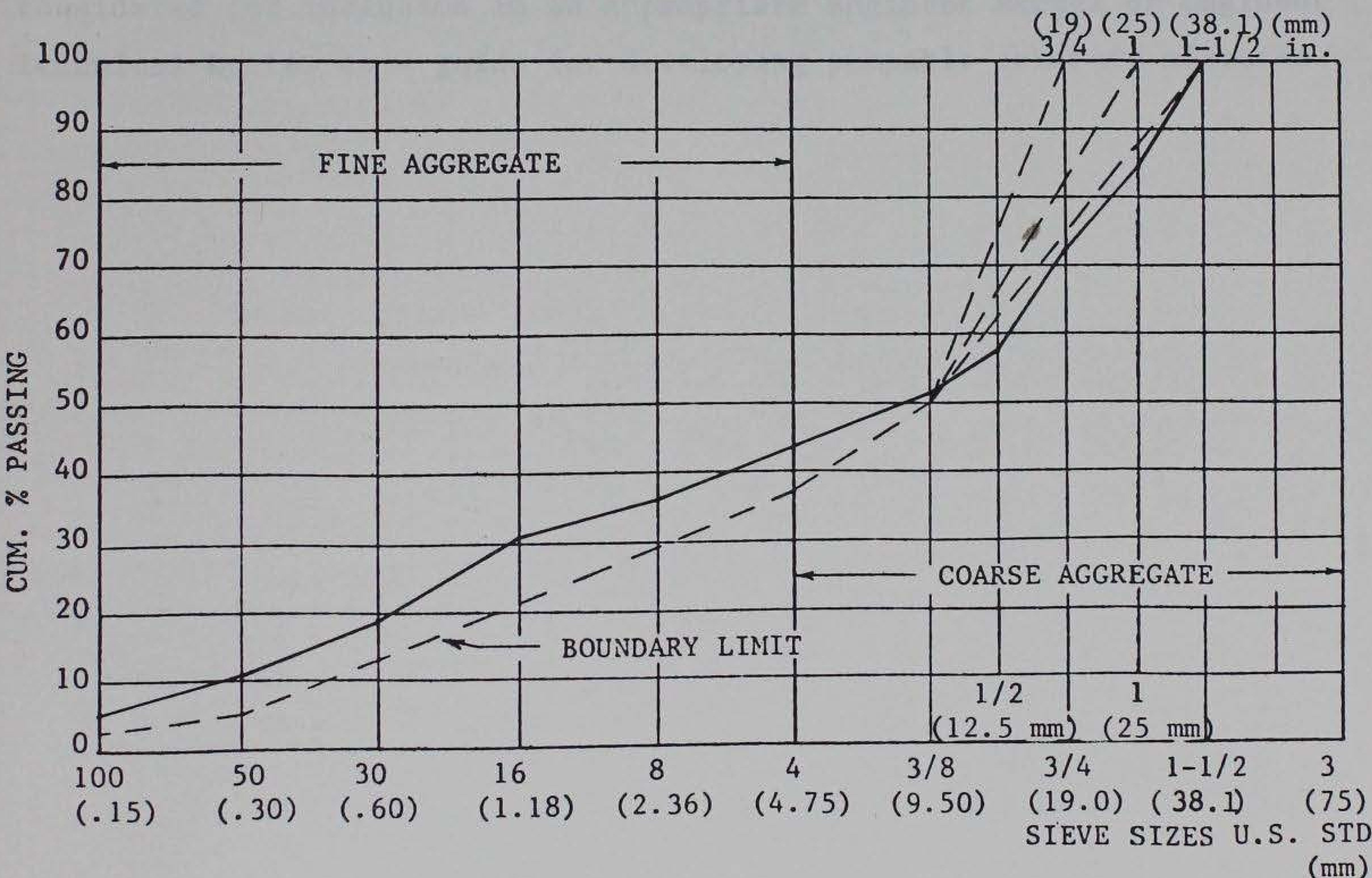

Figure 20. Checklist analysis worksheet, Clarence Cannon Re-Regulating Dam

24. The laboratory and field data indicate that the checklist analysis is conservative in its ability to measure the relative pumpability of concrete mixtures. The relative importance of each characteristic must be considered in order to effectively rate the pumpability of a concrete mixture. For example, the amount of fines present in the mixture appears to be more significant to pumpability than does aggregate shape. No specific efforts in this investigation were directed toward determining the relative importance of the individual characteristics. Future investigations might consider addressing this question.

PART V: CONCLUSIONS AND RECOMMENDATIONS

25. If a poorly maintained and leaky pump is to be used, the Browne and Bamforth (1977) pressure bleed test apparatus will indicate the relative pumpability of various air-entrained concrete mixtures.

26. If a well maintained pump is to be used, the pressure bleed test apparatus may not accurately evaluate the pumpability of air-entrained concrete mixtures. Many mixtures which the pressure bleed test indicates are borderline or nonpumpable will actually be pumpable.

27. The personnel formulating the concrete mixture proportions, whether for a contractor mixture design or a government mixture design, will probably not know the condition of the pump to be used in the field. Therefore, the pressure bleed test might be most effectively used to provide a means for field personnel to identify those concrete mixtures that would present problems for the selected pump.

28. The checklist analysis, although conservative, should be considered for inclusion in an appropriate Engineer Manual or Engineer Technical Letter as a guide for developing pumpable concrete mixtures.

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Table 1

Chemical and Physical Properties of Portland Cement, RC-728

Chemical Properties	Percent
SiO_2	20.6
Al_2O_3	4.7
Fe_2O_3	3.8
CaO	64.3
MgO	1.9
SO_3	2.9
Ignition loss	1.3
Insoluble residue	0.24
Na_2O	0.11
K_2O	0.22
Total alkali, as Na_2O	0.25
C_3S	60.1
C_2S	13.7
C_3A	6.0
C_4AF	11.4
Physical Properties	
Fineness, air permeability, cm^2/g	4090
Compressive strength, psi (MPa)	
3 days	3540 (24.4)
7 days	4480 (30.9)
Autoclave expansion, percent	-0.01
Initial setting time, hr/min	2:50
Final setting time, hr/min	4:40

Table 2

Physical Properties and Gradings

of Natural Fine and Coarse Aggregates

Test	Fine (WES-1 S-4(51))	No. 4 to 1 in. (4.75 to 38.1 mm) (CRD G-42)
Bulk specific gravity, saturated surface-dry	2.64	2.57
Absorption, %	0.2	1.9
	Cumulative Percent Passing	
Sieve size		
38.1 mm (1-1/2 in.)		100
25.0 mm (1 in.)		96
19.0 mm (3/4 in.)		78
12.5 mm (1/2 in.)		46
9.5 mm (3/8 in.)		29
4.75 mm (No. 4)	98	6
2.36 mm (No. 8)	87	
1.18 mm (No. 16)	72	
600 µm (No. 30)	46	
300 µm (No. 50)	15	
150 µm (No. 100)	3	
75 µm (No. 200)		

Table 3

Physical Properties and Gradings

of Crushed Limestone Fine and Coarse Aggregates

Test	Fine (CRD MS-27)	No. 4 to 3/4 in. (4.75 to 19 mm) (CL-2 G-1)	3/4 in. to 1-1/2 in. (19.0 to 38.1 mm) (CRD G-40)	Combined* Coarse Aggregate
Bulk specific gravity, saturated surface dry	2.71	2.74	2.73	
Absorption, %	0.7	0.5	0.5	
		Cumulative Percent Passing		
Sieve size				
50 mm (2 in.)			100	100
38.1 mm (1-1/2 in.)			98	99
25.0 mm (1 in.)		100	42	74
19.0 mm (3/4 in.)		98	10	59
12.5 mm (1/2 in.)		74	3	42
9.5 mm (3/8 in.)		41	2	24
4.75 mm (No. 4)	99	4	2	2
2.36 mm (No. 8)	90			
1.18 mm (No. 16)	55			
600 μm (No. 30)	32			
300 μm (No. 50)	18			
150 μm (No. 100)	9			
75 μm (No. 200)	5			

* The two size ranges of coarse aggregates were combined in the following proportions: 44 percent, 3/4 to 1-1/2 in. (19.0 to 38.1 mm); 56 percent, No. 4 to 3/4 in. (4.75 to 19.0 mm).

Table 4

Chemical and Physical Properties

of Fly Ash, AD-474

Chemical Properties	Percent
$SiO_2 + Al_2O_3 + Fe_2O_3$	87.8
MgO	1.4
SO_3	0.1
Available alkalies, as Na_2O	0.8
Moisture content	0.4
Ignition loss	3.8
Physical Properties	
Fineness, air permeability, cm^2/g	6690
Specific gravity	2.18
Lime pozzolan strength, psi (MPa), 7 days	1265 (8.72)
Autoclave expansion, percent	-0.02

Table 5

Physical Properties and Gradings of Natural Fine and Coarse Aggregates, Morganza Control Structure

Test	Fine (NO-14 S-2)	No. 4 to 1 in. (4.75 to 25.0 mm) (NO-14 G-8)
Bulk specific gravity, saturated surface-dry	2.64	2.52
Absorption, %	0.3	2.1
	Cumulative Percent Passing	
Sieve size		
38.1 mm (1-1/2 in.)		100
25.0 mm (1 in.)		96
19.0 mm (3/4 in.)		74
12.5 mm (1/2 in.)		29
9.5 mm (3/8 in.)	100	17
4.75 mm (No. 4)	97	1
2.36 mm (No. 8)	86	
1.18 mm (No. 16)	75	
600 mm (No. 30)	59	
300 mm (No. 50)	11	
150 mm (No. 100)	0	
75 mm (No. 200)		

Table 6

Chemical and Physical Properties

of Portland Cement, STL-43 C-1

Chemical Properties	
	Percent
SiO_3	22.7
Al_2O_3	4.5
Fe_2O_3	3.7
CaO	63.8
MgO	1.5
SO_3	1.6
Ignition loss	1.4
Insoluble residue	0.15
Na_2O	0.20
K_2O	0.40
Total alkali, as Na_2O	0.46
C_3S	47.5
C_2S	29.2
C_3A	5.6
C_4AF	11.2
Physical Properties	
Fineness, air permeability, cm^2/g	3700
Compressive strength, psi (MPa)	
3 days	2200 (15.2)
7 days	3550 (24.5)
Autoclave expansion, percent	-0.01
Initial setting time, hr/min	2:50
Final setting time, hr/min	5:30

Table 7

Physical Properties and Gradings of Crushed Limestone Fine and Coarse Aggregates, Clarence Cannon Reservoir, Re-Regulation Dam

Test	Fine (STL-43 MS-1)	No. 4 to 3/4 in. (4.75 to 19.0 mm) (STL-43 G-1)	3/4 in. to 1-1/2 in. (19.0 to 38.1 mm) (STL-43 G-1)	Combined* Coarse Aggregate
Bulk specific gravity, saturated surface-dry	2.64	2.63	2.65	
Absorption, %	1.6	1.7	1.1	
Sieve size				
50 mm (2 in.)			100	100
38.1 mm (1-1/2 in.)			99	100
25.0 mm (1 in.)		100	42	74
19.0 mm (3/4 in.)		91	8	54
12.5 mm (1/2 in.)		52	3	30
9.5 mm (3/8 in.)		31	2	18
4.75 mm (No. 4)	100	8	2	5
2.36 mm (No. 8)	92	5		3
1.18 mm (No. 16)	76			
600 µm (No. 30)	48			
300 µm (No. 50)	26			
150 µm (No. 100)	11			
75 µm (No. 200)	6			

* The two size ranges of coarse aggregates were combined in the following proportions: 45 percent, 3/4 to 1-1/2 in. (19.0 to 38.1 mm); 55 percent, No. 4 to 3/4 in. (4.75 to 19.0 mm).

Table 8

Laboratory Study Mixture Proportions

Mixture No.		Portland Cement	Fly Ash	Fine Aggregate	Coarse Aggregate	Water	Air	Pumping Aid	High-Range Water-Reducing Admixture	Steel Fibers	Total
		Material									
1	Solid volume, ft^3 (m^3)	2.035		8.036	12.053	3.526	1.350				27.000
		(0.058)		(0.228)	(0.341)	(0.100)	(0.038)				(0.765)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	400.0		1323.8	1932.9	220.0					3876.7
		(237.3)		(785.4)	(1146.7)	(130.5)					(2300.0)
2	Solid volume, ft^3 (m^3)	2.035		8.087	12.125	3.397	1.350				27.000
		(0.058)		(0.229)	(0.343)	(0.096)	(0.038)				(0.765)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	400.0		1332.3	1944.5	212.0					3888.8
		(237.3		(3090.3)	(1153.6)	(125.8)					(2307.1)
3	Solid volume, ft^3 (m^3)	2.035		8.226	12.400	2.949	1.350				27.000
		(0.058)		(0.234)	(0.351)	(0.084)	(0.038)				(0.765)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	400.0		1343.9	1962.6	176.8			7.2 (4.3)		3890.5
		(237.3)		(797.3)	(1164.4)	(104.9)					(2308.1)
4	Solid volume, ft^3 (m^3)	2.035		10.109	10.109	3.397	1.350				27.000
		(0.058)		(0.286)	(0.286)	(0.096)	(0.038)				(0.765)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	400.0		1659.0	1608.5	212.0					3879.5
		(237.3)		(984.2)	(954.3)	(125.8)					(2301.6)
5	Solid volume, ft^3 (m^3)	2.035		10.109	10.109	3.397	1.350				27.000
		(0.058)		(0.286)	(0.286)	(0.096)	(0.038)				(0.765)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	400.0		1659.0	1608.5	211.6		0.4 (0.2)			3879.5
		(237.3)		(984.2)	(954.3)	(125.5)					(2301.6)
6	Solid volume, ft^3 (m^3)	3.307		7.350	9.742	5.000	1.350			0.251	27.000
		(0.094)		(0.208)	(0.276)	(0.142)	(0.038)			(0.007)	(0.765)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	650.0		1210.8	1562.3	312.0				120.0	3855.1
		(385.6)		(718.3)	(926.9)	(185.1)				(71.2)	(2287.1)

(Continued)

Table 8 (Continued)

Mix-ture No.		Material: Portland Cement	Fly Ash	Fine Aggregate	Coarse Aggregate	Water	Air	Pumping Aid	High-Range Water-Reducing Admixture	Steel Fibers	Total
7	Solid volume, ft^3 (m^3)	2.646		7.875	11.812	3.317	1.350				27.000
		(0.075)		(0.223)	(0.334)	(0.094)	(0.038)				(0.765)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	517.5		1297.3	1894.3	207.0					3916.1
		(307.0)		(769.7)	(1123.8)	(122.8)					(2323.3)
8	Solid volume, ft^3 (m^3)	2.035		7.951	10.979	4.551	1.485				27.000
		(0.058)		(0.225)	(0.311)	(0.129)	(0.042)				(0.765)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	400.0		1344.5	1874.1	284.0					3902.6
		(237.3)		(797.7)	(1111.9)	(168.5)					(0.765)
9	Solid volume, ft^3 (m^3)	2.035		9.465	9.464	4.551	1.485				27.000
		(0.058)		(0.268)	(0.268)	(0.129)	(0.042)				(0.765)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	400.0		1600.5	1615.5	284.0					3900.0
		(237.3)		(949.5)	(958.4)	(168.5)					(2313.8)
10	Solid volume, ft^3 (m^3)	2.035		9.465	9.464	4.551	1.485				27.000
		(0.058)		(0.268)	(0.268)	(0.129)	(0.042)				(0.765)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	400.0		1600.5	1615.5	283.6		0.4 (0.2)			3900.0
		(237.3)		(949.5)	(958.4)	(168.3)					(2313.8)
11	Solid volume, ft^3 (m^3)	2.035		9.401	9.400	4.679	1.485				27.000
		(0.058)		(0.266)	(0.266)	(0.132)	(0.042)				(0.765)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	400.0		1589.7	1604.6	292.0					3886.3
		(237.3)		(943.1)	(952.0)	(173.2)					(2305.6)
12	Solid volume, ft^3 (m^3)	2.035		9.401	9.400	4.679	1.485				27.000
		(0.058)		(0.266)	(0.266)	(0.132)	(0.042)				(0.765)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	400.0		1589.7	1604.6	291.6		0.4 (0.2)			3886.3
		(237.3)		(943.1)	(952.0)	(173.0)					(2305.6)

(Continued)

Table 8 (Concluded)

Mix-ture No.		Material: Portland Cement	Fly Ash	Fine Aggregate	Coarse Aggregate	Water	Air	Pumping Aid	High-Range Water-Reducing Admixture	Steel Fibers	Total
13	Solid volume, ft^3 (m^3)	2.127	0.742	7.613	10.514	4.519	1.485				27.000
		(0.060)	(0.021)	(0.216)	(0.298)	(0.128)	(0.042)				(0.765)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	418.0	100.9	1287.4	1794.7	282.0					3883.0
		(248.0)	(59.9)	(763.8)	(1064.8)	(167.3)					(2303.7)
14	Solid volume, ft^3 (m^3)	3.561		7.195	9.935	4.824	1.485				27.000
		(0.101)		(0.204)	(0.281)	(0.137)	(0.042)				(0.765)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	700.0		1216.7	1696.0	301.0					3913.7
		(415.3)		(721.8)	(1006.2)	(178.6)					(2321.9)

Table 9

Field Study Mixture Proportions

Project		Portland Cement	Fly Ash	Fine Aggregate	Coarse Aggregate	Water	Air	Total
		Material						
Morganza Control Structure	Solid volume, ft^3 (m^3)	2.289 (0.065)		8.782 (0.247)	10.733 (0.304)	3.846 (0.109)	1.350 (0.038)	27.000 (0.765)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	450.0 (267.0)		1447.0 (858.5)	1668.0 (1001.5)	240.0 (142.4)		3825.0 (2269.3)
Clarence Cannon Re-Regulating Dam	Solid volume, ft^3 (m^3)	3.369 (0.095)		6.790 (0.192)	10.185 (0.288)	5.306 (0.150)	1.350 (0.038)	27.000 (0.764)
	Bulk density, saturated surface-dry, lb/yd^3 (kg/m^3)	662.2 (392.9)		1118.6 (663.6)	1677.2 (995.0)	331.1 (196.4)		3789.1 (2248.0)

Table 10

Results of Pressure Bleed Tests Conducted in the Laboratory Study

Mixture No.	Aggregate Type	Cementitious Material Content lb/yd^3	Cementitious Material Content kg/m^3	Water-Cementitious Material Ratio by Mass	Sand-Aggregate Ratio Percent by Volume	Slump in.	Slump mm	Air Content Pressure Method Percent	Water Emitted, $V_{140} - V_{10}$ oz	Water Emitted, $V_{140} - V_{10}$ cm^3	Pumped	Type Admixture
Laboratory Pump No. 1												
1	Natural	400	237	0.55	40	7	175	4.5	1.4	43	No	Air entraining
4	Natural	400	237	0.53	50	3-3/4	95	5.3	1.8	55	No	Air entraining
5	Natural	400	237	0.53	50	5	125	6.5	2.5	75	Yes	Air entraining, pumping aid
7	Natural	518	307	0.40	40	3	75	4.6	2.1	63	Yes	Air entraining
11	Crushed	400	237	0.73	50	4-1/2	115	3.5	2.3	68	With difficulty	Air entraining
12	Crushed	400	237	0.73	50	6-1/4	160	2.5	2.4	71	No	Air entraining, pumping aid
13	Crushed	518	307	0.50	42	4-3/4	120	2.7	3.5	105	Yes	Air entraining, fly ash
14	Crushed	700	415	0.43	42	3	75	4.5	2.7	80	Yes	Air entraining
Laboratory Pump No. 2												
2	Natural	400	237	0.53	40	5	125	3.6	2.0	60	Yes	Air entraining
3	Natural	400	237	0.46	40	3	75	3.0	1.4	41	Yes	Air entraining, high-range water-reducing
6	Natural	650	386	0.48	43	6-3/4	170	3.5	2.3	68	Yes	Air entraining, steel fibers
8	Crushed	400	237	0.71	42	4	100	4.4	2.8	82	Yes	Air entraining
9	Crushed	400	237	0.71	50	2-1/4	55	3.5	3.1	93	Yes	Air entraining
10	Crushed	400	237	0.71	50	3-1/4	85	2.5	2.3	67	Yes	Air entraining, pumping aid
13	Crushed	518	307	0.50	42	4-1/2	115	2.4	3.5	105	Yes	Air entraining, fly ash

Table 11

Results of Pressure Bleed Tests Conducted in the Field Study

Project	Aggregate Type	Cement Content lb/yd3	Cement Content kg/m3	Water-Cement Ratio by Mass	Sand-Aggregate Ratio Percent by Volume	Slump in.	Slump mm	Air Content Pressure Method Percent	Water Emitted $V_{140} - V_{10}$ oz	Water Emitted $V_{140} - V_{10}$ cm^3	Pumped	Type Admixture
Field Pump No. 1												
Morganza Control Structure	Natural	450	267	0.53	45	2	50	5.0	1.3	40	Yes	Air entraining
						3	75	5.0	2.0	59	Yes	
Field Pump No. 2												
Clarence Cannon Re-Regulating Dam	Crushed	662	393	0.50	37	4	100	7.0	2.3	68	Yes	Air entraining, retarding
						4	100	4.8	1.3	40	Yes	
						4	100*	5.6	1.7	50		

* Wet-sieved over a 25.0-mm (1-in.) sieve.

Table 12

Relative Pumpability of Laboratory and Field Mixtures Based on the Checklist Analysis

Mixture No.	Pumped Successfully	Checklist Analysis Not Good	?	OK
Laboratory Pump No. 1				
1	No	X		
4	No		X	
5	Yes		X	
7	Yes			X
11	With difficulty		X	
12	No	X		
13	Yes			X
14	Yes			X
Laboratory Pump No. 2				
2	Yes	X		
3	Yes		X	
6	Yes		X	
8	Yes		X	
9	Yes		X	
10	Yes		X	
13	Yes			X
Field Pump No. 1				
	Yes		X	
Field Pump No. 2				
	Yes			X