COMPARATIVE STRENGTH EVALUATION OF CRUSHED AND UNCRUSHED AGGREGATE IN CONCRETE

by

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CONTENTS

LIST OF COMPUTER PROGRAM AND GRAPHS

LIST OF TABLES

List of Tables, continued

LIST OF FIGURES

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ABSTRACT

The scope of this thesis was to determine the difference in concrete strength from using two different aggregates, crushed and uncrushed. The surface texture of the aggregate used is the primary factor that influences the strength of the mortar-aggregate bond. In this attempt the thesis has been divided in two parts.

The first part deals with laboratory work done by the author. One hundred fifty-six specimens were constructed. The specimens were then tested under compression loading.

The second part of this thesis analyzed the data obtained in the laboratory, through the useofstatistical methods.

The results demonstrate that the use of crushed aggregate increases the concrete strength by approximately ten per cent over the use of uncrushed.

INTRODUCTION

Research studies[4] have indicated that the mortar-aggregate bond influences the strength and deformation of concrete. However, such effects are not easy to observe experimentally due to difficulties involved in isolating bond strength as a single aggregate variable. The principal approach has been via the use of aggregate coatings and some early studies on that reported very large decreases in the compressive strength of concrete. Studies done by Kaplan[2] show that the shape and texture of the aggregate are particularly significant in the case of high strength concrete. Although the full role of shape and texture of the aggregate in the development of concrete is not known, the consensus is that a rougher texture results in a greater adhesive force between the particles and cement matrix.

The approach used by the author was throuqh the construction and testing of six sets of specimens. Each set consisted of twenty-six specimens, one half of those made with crushed aggreqate and the other half with uncrushed.** The primary factor used in developing the concrete strength in each set was throuqh the variation of the water-cement ratio.

The data from these tests were analyzed using statistical methods in order to find the percent difference between the mean values of the two groups in each set.

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*Superscript number indicates reference cited in bibliography.

** The aggregate was essentially the same river gravel, except one was crushed and the other uncrushed. However, the soundness of the two types of aggreqate was not taken into account.

CHAPTER I

EXPERIMENTAL PROCEDURE

1.1 Objective

One hundred fifty-six specimens were constructed with two different types of aggregate and tested under compression loading.

The author realizes that testing only one hundred fifty-six specimens would not encompass all variables. Thus, the conclusions and recommendations made from these experiments are of limited value. Hence, it is advisable that more specimens should be made and additional testing done.

1.2 Concrete Mix:

Since the ultimate goal was to compare the effects on concrete strength resulting from the use of two different types of aggregates (crushed and uncrushed), the mix proportion was purposely kept constant throughout each set of specimens.

The concrete mixes were designed for an interval of compressive strengths from 3000 to 5500 psi and average density of 130-145 lb. per cubic ft. The following materials were used:

a) Ordinary Portland Cement Type I

b) Gravel (crushed and uncrushed) as an aggregate

c) Natural Sand with specific gravity of 2.62

The effective absorptions of the crushed and uncrushed gravels used were 2.84% and 1.54% respectively. The average size of coarse gravel was one-half inch. The figures that follow show the crushed and uncrushed gravel.

Step 5. Then the mixture containing the gravel and one third of the water was added into the mixer and all the ingredients were mixed together for an additional three minutes, followed by three minutes rest, followed by two minutes final mixing.

The top of the mixer was covered at all times in order to prevent any loss of fines while mixing and evaporation during the rest period. In order to eliminate segregation the machine-mixed concrete was deposited in a clean, damp mixing pan and remixed manually by a shovel until it appeared to be uniform.

1.4 Making the specimens:

Using the same trial mixes as previously discussed it was found that the most reliable way of placing the concrete into the molds was as follows:

The concrete was placed into the molds through the use of a scoop, and each scoopful of concrete was selected in such a way that it was a good representation of the batch. The concrete in each mold was placed in three equal layers and each layer compacted 25 times using a end-rounded rod 5/8" in diameter.

1.5 Curing the specimens:

The specimens were removed from the molds 36 hours after casting and cured in saturated lime water for 27 days. The specimens were then removed from the water, capped and tested. Figures 2, 3, and 4 show sets 1 and 2 ready to be tested, sets 3 and 4 just after they were capped and sets 5 and 6 in the molds respectively. The temperature of the curing water was maintained at 72°F ± 1°.

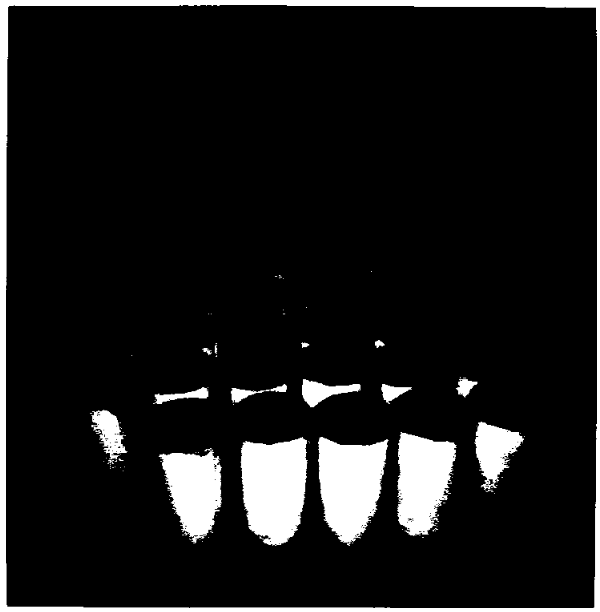

Figure 2 Sets 1 and 2 ready to be tested.

1.6 Proportions of ingredients:

The proportions of the ingredients for each set of concrete mix were selected based purely on the strength desired. In order to achieve different strengths, the water to cement ratio was varied. This was accomplished by keeping the aggregate content constant and varying the cement and the water content, in order to achieve a workable mix. At the same time the sand content was varied in order to keep the total weight of each set of concrete mix constant.

Tables 1 through 6 show the proportions of the ingredients used for each set of concrete mix.

1.7 Testing the specimens:

The specimens were tested 28 days after casting. Figure 5 shows a specimen ready to be tested under the 250,000 pound Formey Concrete Compression Tester. The testing machine is motorized and the loading rate that was used was approximately 35 psi/min. which is within the limits of ASTM Designation C 39-66.[1] Figure 6 shows the same specimen after failure.

Tables 7 through 18 show the ultimate loads and corresponding stresses for each set.

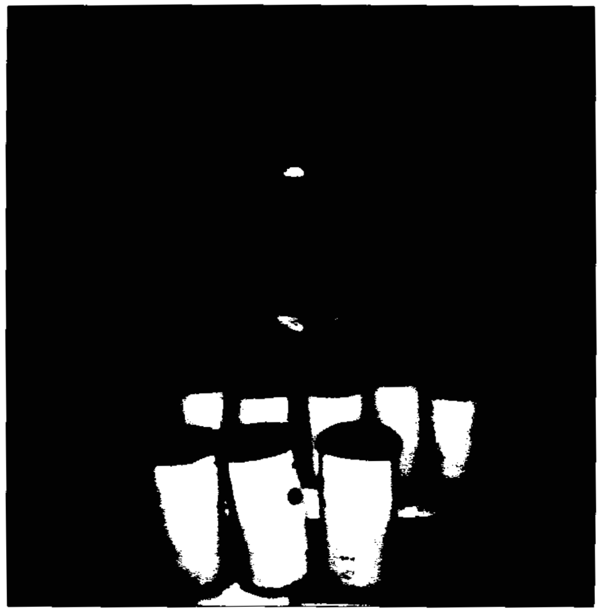

Figure 3 Sets 3 and 4 just after they were capped.

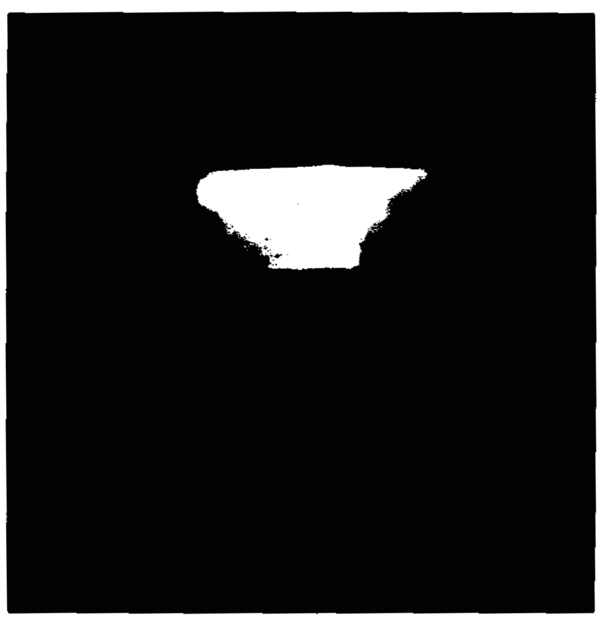

Figure 4 Sets 5 and 6 in the molds.

TABLE 1 Set 1. *

INGREDIENTS	WEIGHT
Aggregate 1/4 in	60 lb
Aggregate 1/2 in	100 lb
3and	130 lb
Cement	120 lb
Water	46.4 lb
Water / cement	0.387

TABLE 2 Set 2.

INGREDIENTS	WEIGHT
Aggregate 1/4 in	6C lo
Aggregate 1/2 in	100 lb
Sand	130 lb
Cement	90 lb
Water	41 lb
dater / Cement	0.456

* Each set contains 13 crushed and 13 uncrushed

- aggregate specimens

TABLE 1 Set 1.*

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Cement	90 lb
Water	41 lb
Water / Cement	0.456

* Each set contains 13 crushed and 13 uncrushed aggregate specimens

TABLE 5 Set 5

INGREDIENTS	WEIGHT
Aggregate 1/4 in	60 lb
Aggregate 1/2 in	700 lb
Sand	160 lb
Cement	60 lb
Water	36 lb
Water / Cement	0.6

TABLE 6 Set 6

INGREDIENTS	WEIGHT
Aggregate 1/4 in	60 lb
Aggregate 1/2 in	100 lb
Sand	170 lb
Cement	50 lb
Water	35 lb
Water / Cement	0.7

CHAPTER 11

DATA ANALYSIS

2.1 Introduction

Therearemany factors which are involved in the production of high quality concrete: materials, quality proportioning, handling and placing, curing and testing. It should, therefore, come as no surprise that concrete, in common with some engineering materials, is inherently not a homogeneous and isotropic material.

The data from the' laboratory work substantiatesthis observation. Hence, in order to find the difference in strength between crushed and uncrushed aggregate some statistical methods were used.

2.2 Statistical methods used for analysis

In order to estimate the magnitude of difference between the respective means of the two groups in each set, the following equation was used (see Ref. 3):

$$(ma-mb) = Xa - Xb \pm ta/2 \sqrt{\frac{(na-1)sa^2 + (nb-1)sb^2}{na+nb-2}} \sqrt{\frac{na+nb}{(na)(nb)}} \qquad (1)$$

where:

$$(Xa) \text{ or } (Xb) = \frac{x1+x2+x3+. . . . . . . .xi}{n}$$

and n - Total number of specimens in the group

Xa - Mean of qroup A

Xb - Mean of qroup B

$$(sa^2) \text{ or } (sb^2) = \frac{(x1-X)+(x2-X)+(x3-X)+....(xi-X)}{n-1}$$

and sa - Sample variance in group A

sb - Sample variance in group B

x - Xa or Xb (depends on the group)

i - From 1 to 13

na - Sample size in group A

nb - Sample size in group B

ma-mb - Confidence interval for the difference between means using small independent samples.

ta/2 - Value taken from table A for na+nb-2 degrees of freedom.

Also in order to calculate the t-distribution with 2(n-1) degrees of freedom the following equation was'used (Ref.3):

$$t = \frac{Xa - Xb}{\sqrt{\frac{(na-1)sa^2 + (nb-1)sb2}{na+nb-2}} \sqrt{\frac{na+nb}{(na)(nb)}}} \quad (2)$$

In order to calculate ma-mb and the t-distribution for each set, a computer program was made using equations (1) and (2) (see pg. 13) and the results from it are shown on Page 33.

PROGRAM - Watfiv program using equations (1) and (2).

```
$JOB
      DIMENSION X(13),Y(13),SA(13),SB(13),B(13),C(13),D(13),E(13)
      DO 1 J=1,4
      READ(5,*) (X(I),I=1,13),(Y(I),I=1,13)
      DO 5 I=1,13
      B(I)=(X(I)*1000)/28.27
      C(I)=(Y(I)*1000)/28.27
    5 CONTINUE
      PRINT,' THIS IS SET NO. ',J
      PRINT,'                        ','---------'
      DO 3 I=1,13
      PRINT,'   ',B(I),C(I)
    3 CONTINUE
      PRINT,'**************************************************************'
      XA=(X(1)+X(2)+X(3)+X(4)+X(5)+X(6)+X(7)+X(8)+X(9)+X(10)+X(11)+
     *X(12)+X(13))/13
      YB=(Y(1)+Y(2)+Y(3)+Y(4)+Y(5)+Y(6)+Y(7)+Y(8)+Y(9)+Y(10)+Y(11)+
     *Y(12)+Y(13))/13
      DO 2 I=1,13
      SA(I)=(X(I)-XA)**2
      SB(I)=(Y(I)-YB)**2
    2 CONTINUE
      SF=(SA(1)+SA(2)+SA(3)+SA(4)+SA(5)+SA(6)+SA(7)+SA(8)+SA(9)
     *+SA(10)+SA(11)+SA(12)+SA(13))/12
      SS=(SB(1)+SB(2)+SB(3)+SB(4)+SB(5)+SB(6)+SB(7)+SB(8)+SB(9)+
     *SB(10)+SB(11)+SB(12)+SB(13))/12
      A1=XA-YB
      DO 6 I =1,13
      D(I)=((X(I)*100)/XA)-100
      E(I)=((Y(I)*100)/YB)-100
    6 CONTINUE
      DO 7 I=1,13
      PRINT,'   ',D(I),E(I)
    7 CONTINUE
          E1=(XA-YB)+(2.064*(((((12*(SF+SS))/24)*(2./13.))**0.5))
          E2=(XA-YB)-(2.064*(((((12*(SF+SS))/24)**0.5)*((2./13.)**0.5)))
            F1=((SF+SS)/13)**0.5
            G1=A1/F1
      T=(XA-YB)/(((((12*(SF+SS))/24)*(2./13.))**0.5)
      PRINT,'ADVANTAGE DIFFERENCE=',E1,'DISADV. DIFFERENCE=',E2
      PRINT,'-------------------------------------------------------------
     *-------------------'
      PRINT,'THEREFORE THE INTERVAL USING 95% CONFINDENCE IS:'
     *,E1,'<  M1-M2 <',E2
      PRINT,'PERCENT DIFFERENCE BETWEEN MEAN VALUES IS =',A1
      XAF=(XA/28.27)*1000
      YBF=(YB/28.27)*1000
      PRINT,'MEAN VALUE FOR CRUSHED IS =',XAF
      PRINT,'MEAN VALUE FOR UNCRUSHED IS =',YBF
      PRINT,'T VALUE IS=',T
    1 CONTINUE
      STOP
      END
```

2.3 Discussion and evaluation of results

In order to evaluate the results from WATFIV program, four different graphs were plotted.

In graph 1 the "stress" vs. "w/c ratio" was plotted using the method of least squares. From this graph it can be observed that the influence of the coarse aggregate on the strength of concrete varies in magnitude and depends on the water/cement ratio of the mix. For water/cement ratios of about 0.4, the use of crushed gravel resulted in strengths of about 10 percent higher than for the uncrushed. As water/cement ratios increase, of about 0.65-0.70, only a relatively small difference in the strengths of the concrete made with either crushed or uncrushed gravel were observed. With an increase in water/cement ratio, the influence of the type of crushed gravel, decreased, presumably because the strength of the paste itself became significant.

In graph 2 the "interval of the difference between "means" vs. "stress" was plotted. The observations made from this graph were as follows:

a) At stresses of approximately 5000 psi the interval of the difference of the means calculated showed a magnitude of 0-15 per cent increase. This increase indicates that at high stresses the crushed aggregate would increase the strength of concrete by that percentage over uncrushed.

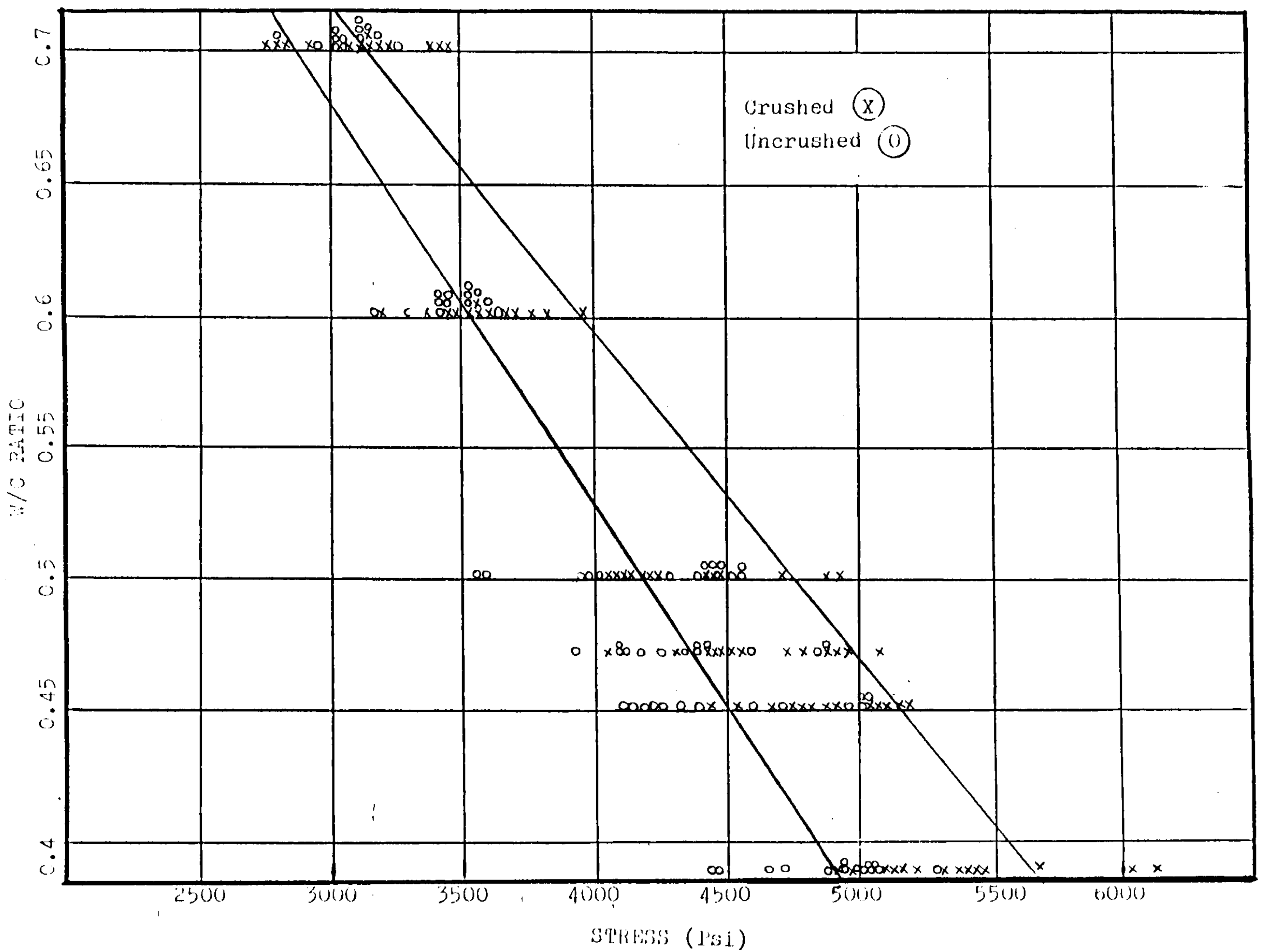
b) At low stresses (approximately 3000 psi) the interval of the difference of the means span a length of -4 to 5 per cent. This means that at low stresses the difference between the use of crushed or uncrushed aggregate is relatively minimal.

In graph 3 the "difference between mean value and individual specimen stress in each group" vs. "stress" was plotted. From this graph it can be also verified'that at high stresses the use of the crushed gravel can provide a considerable advantage in concrete strength. As can be seen the horizontal span (stress variation) between the respective groups in each set increases as stress increases. The length of the horizontal span between the two groups of each set indicates the advantage of crushed over the uncrushed at a particular stress interval.

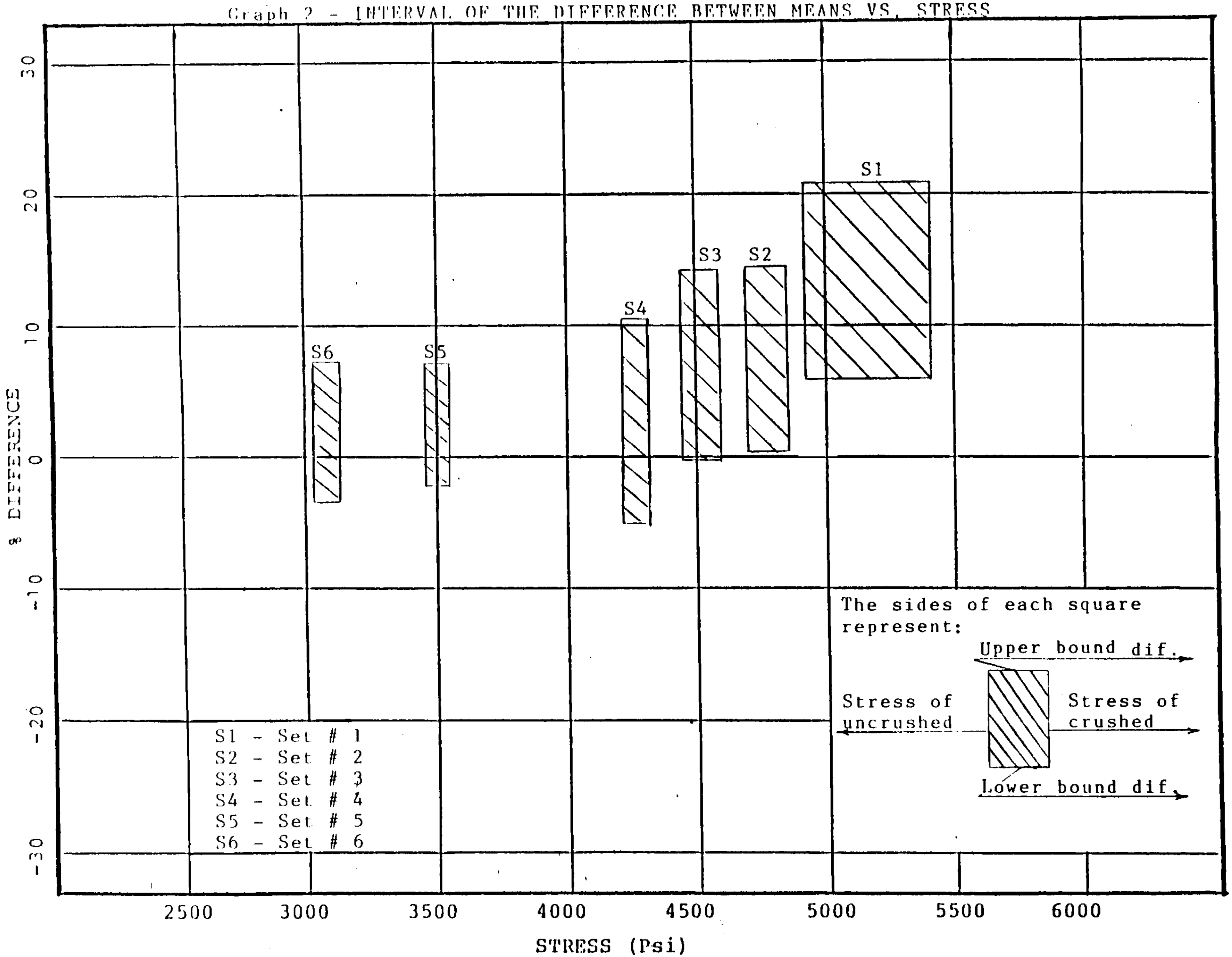
In graph 4 the "probability of a larger value" vs. "stress" was plotted using the method of least squares. The probability values plotted on this graph were obtained through the use cf the t-distribution values from pg. 33 along with Table B in the Appendix. From this graph it can be seen that at stresses exceeding 4500 psi there is almost a 100 per cent probability that the use of crushed aggregate will give a higher concrete strength over uncrushed. This probability decreases to 55 percent as stresses go below 4500 psi.

Generally, the benefit from using the crushed aggregate over crushed becomes most significant at higher levels of stress - 4500 psi and higher.

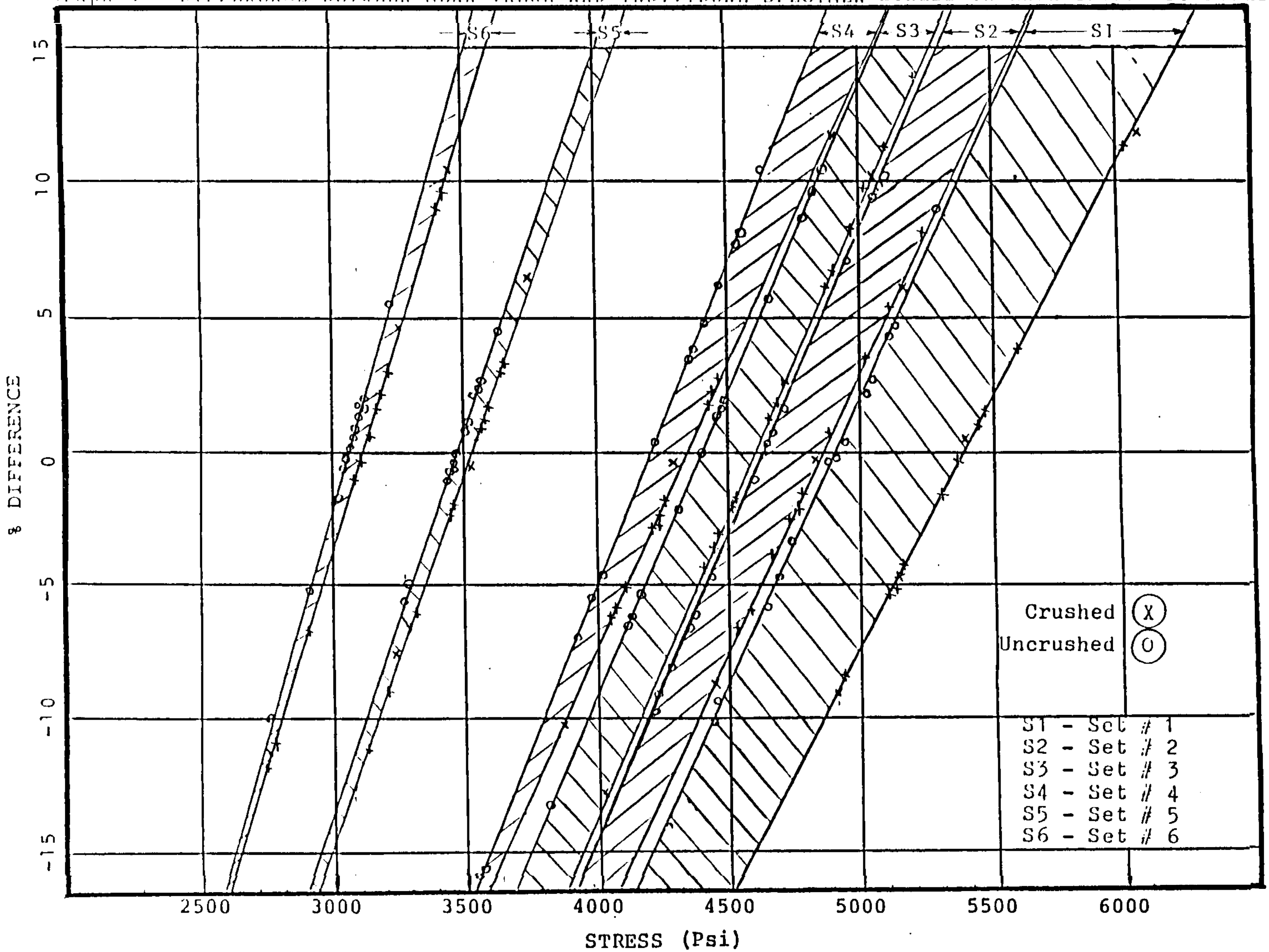
Graph 1 - W/C RATIO VS. STRESS



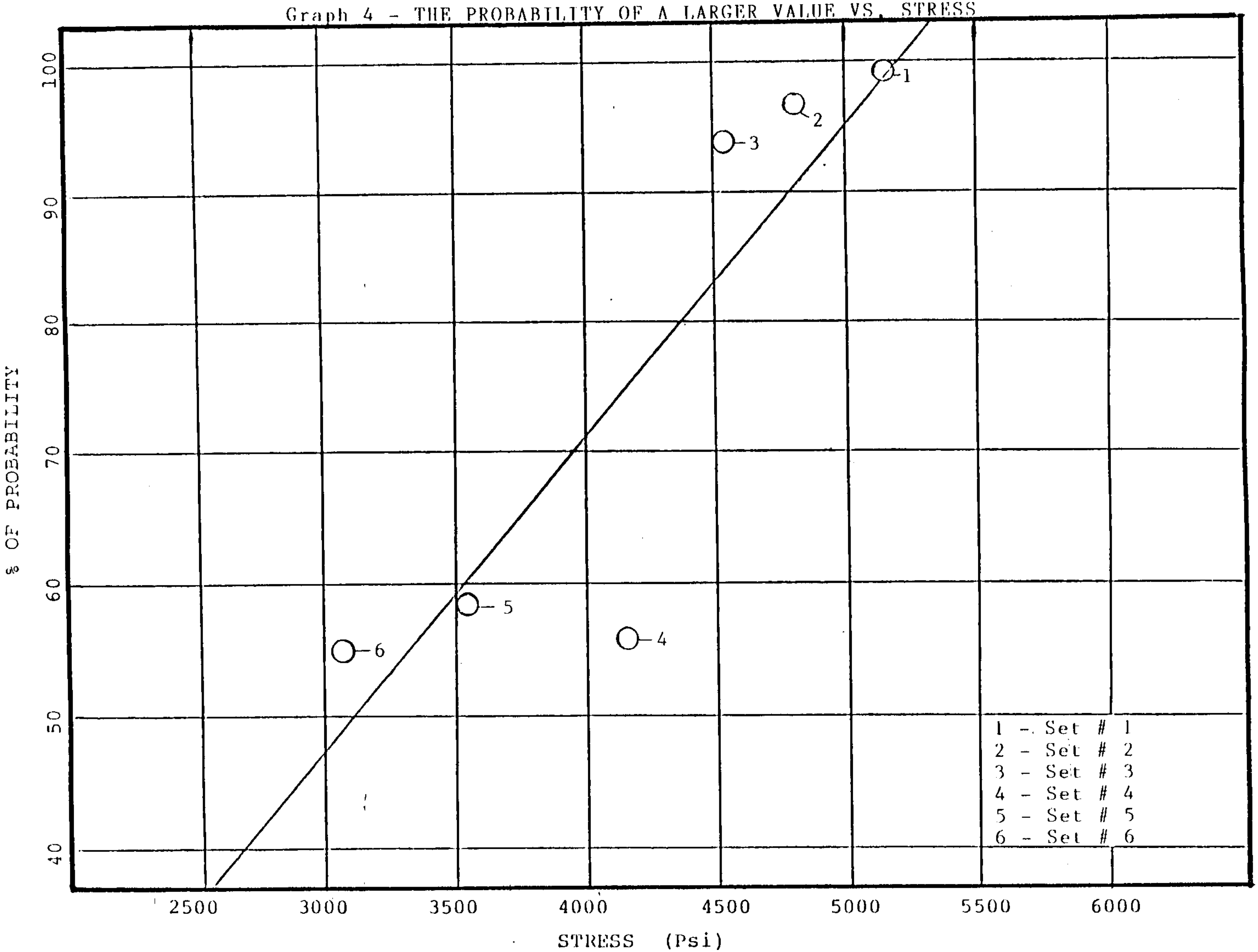
Graph 2 - INTERVAL OF THE DIFFERENCE BETWEEN MEANS VS. STRESS



Graph 3 - DIFFERENCE BETWEEN MEAN VALUE AND INDIVIDUAL SPECIMEN STRESS IN EACH GROUP VS. STRESS



Graph 4 - THE PROBABILITY OF A LARGER VALUE VS. STRESS



2.4 CONCLUSION

The following conclusions apply to concretes containing either crushed or uncrushed gravel and Portland Cement Type I.

The strength of the concrete made with crushed gravel exceeds the one made with uncrushed. Furthermore, this higher strength from the crushed gravel varies with the water/cement ratio. Generally as the w/c ratio increases,

a) The difference between the mean values decreases.

b) The interval of the difference between means using 95% confidence level decreases.

c) The probability of the crushed gravel to have a higher stress than uncrushed decreases.

These conclusions are based on admittedly limited testing. Hence, some additional research should be carried out in order to determine how strength differences in concrete vary with a) aggregate (percent) content b) aggregate type c) time of testing d) cement type and e) cement (percent) content.

TABLE 7 - SET NO.1 (crushed)

SPECIMEN NO.	LOAD (LBS)	STRESS (PSI)
1	141000	4987.6
2	148000	5235.2
3	172000	6084.1
4	160000	5659.7
5	171500	6066.5
6	155000	5482.8
7	151000	5341.3
8	145000	5129.1
9	155000	5482.8
10	145000	5129.1
11	139000	4916.8
12	154000	5447.4
13	146000	5164.4
Average	152122.0	5394.4

TABLE 8 - SET NO.1 (uncrushed)

SPECIMEN NO.	LOAD (LBS)	STRESS (PSI)
1	126000	4457.0
2	133000	4704.6
3	145000	5129.1
4	150000	5305.9
5	144000	5093.7
6	136500	4828.4
7	125500	4439.3
8	143000	5058.3
9	141000	4987.6
10	139500	4934.5
11	144000	5093.7
12	143500	5076.0
13	132000	4669.2
Average	138348.6	4905.98

TABLE 9 - SET NO.2 (crushed)

SPECIMEN NO.	LOAD (LBS)	STRESS (PSI)
1	145000	5129.1
2	126000	4457.0
3	144000	5093.7
4	136000	4810.7
5	137000	4846.1
6	142000	5022.9
7	128000	4527.7
8	135000	4775.3
9	132500	4686.9
10	146000	5164.4
11	135500	4793.0
12	134500	4757.6
13	147000	5199.8
Average	137235.3	4866.6

TABLE 10 - SET NO.2 (uncrushed)

SPECIMEN NO.	LOAD (LBS)	STRESS (PSI)
1	130000	4598.5
2	120500	4262.4
3	124000	4386.2
4	135000	4775.3
5	125000	4421.6
6	141000	4987.6
7	119500	4227.0
8	141500	5005.3
9	142000	5022.9
10	131000	4633.8
11	123000	4350.8
12	141500	5005.3
13	120000	4244.7
Average	129973.8	4609.39

TABLE 11 - SET No.3 (crushed)

SPECIMEN NO.	LOAD (LBS)	STRESS (PSI)
1	126500	4474.7
2	122500	4333.2
3	114000	4032.5
4	144000	5093.7
5	137500	4863.8
6	128000	4527.7
7	133000	4704.6
8	127500	4510.0
9	126000	4457.0
10	134500	4757.6
11	140000	4952.2
12	132500	4686.9
13	138500	4899.1
Average	130790.4	4637.96

TABLE 12 - SET NO.3 (uncrushed)

SPECIMEN NO.	LOAD (LBS)	STRESS (PSI)
1	133500	4722.3
2	121500	4297.8
3	123000	4350.8
4	136500	4828.4
5	131000	4633.8
6	117500	4156.3
7	116000	4103.2
8	116000	4103.2
9	138000	4881.4
10	127000	4492.3
11	108000	3820.3
12	124500	4403.9
13	126500	4474.7
Average	124230.0	4405.32

TABLE 13 - SET NO. 4 (crushed)

SPECIMEN NO.	LOAD (LBS)	SRESS (PSI)
1	109500	3873.3
2	126000	4457.0
3	125000	4421.6
4	121250	4288.9
5	115000	4067.9
6	138000	4881.4
7	126000	4457.0
8	120500	4262.4
9	115000	4067.9
10	116000	4103.2
11	120000	4244.7
12	119000	4209.4
13	139000	4916.8
Average	122023.6	4327.08

TABLE 14 - SET NO. 4 (uncrushed)

SPECIMEN NO.	LOAD (LBS)	STRESS (PSI)
1	122000	4315.5
2	113500	4014.8
3	112500	3979.4
4	129000	4563.1
5	130000	4598.5
6	127000	4492.3
7	100000	3537.3
8	126500	4474.7
9	123000	4350.8
10	101000	3572.6
11	110000	3891.0
12	132000	4669.3
13	125000	4421.6
Average	119050.2	4221.64

TABLE 15 - SET NO.5 (crushed)

SPECIMEN NO.	LOAD (LBS)	STRESS (PSI)
1	93500	3307.3
2	101500	3590.3
3	102000	3608.0
4	99500	3519.6
5	105500	3731.8
6	94500	3342.7
7	106500	3767.2
8	92000	3254.3
9	98000	3466.5
10	98000	3466.5
11	101000	3572.6
12	102000	3608.0
13	104500	3696.4
Average	99636.2	3533.23

TABLE 16 - SET NO. 5 (uncrushed)

SPECIMEN NO.	LOAD (LBS)	STRESS (PSI)
1	93500	3307.3
2	98500	3484.2
3	101000	3572.6
4	98500	3484.2
5	102500	3625.7
6	93000	3289.7
7	99000	3501.9
8	97500	3448.8
9	97500	3448.8
10	102000	3608.0
11	99000	3501.9
12	97000	3431.1
13	101500	3590.3
Average	98254.4	3484.25

TABLE 17 - SET NO.6 (crushed)

SPECIMEN NO.	LOAD (LBS)	STRESS (PSI)
1	90000	3183.5
2	92000	3254.3
3	96500	3413.5
4	89500	3165.8
5	87500	3095.1
6	92500	3272.0
7	97000	3431.1
8	98000	3466.5
9	77500	2741.4
10	92000	3254.3
11	82000	2900.6
12	77000	2723.7
13	79000	2794.4
Average	88280.6	3130.52

TABLE 18 - SET NO. 6 (uncrushed)

SPECIMEN NO.	LOAD (LBS)	STRESS (PSI)
1	85000	3006.7
2	78000	2759.1
3	82000	2900.6
4	87000	3077.4
5	86000	3042.0
6	86500	3059.8
7	88000	3112.8
8	86500	3059.8
9	88500	3130.6
10	88500	3130.6
11	90000	3183.5
12	89500	3165.8
13	92000	3254.3
Average	86515.9	3067.94

RESULTS FROM THE WATFIV PROGRAM

	Set #1	Set #2	Set#4	Set #6	Set #3	Set #5
Interval for the difference between means using 95% confindence.	From 6.43% to 21.1%	From 0.83% to 13.7%	From -4.94% to 10.9%	From -2.94 to 6.48%	From -0.29 to 13.45%	From -1.71 to 4.48%
Percent difference between mean values.	13.8%	7.26%	2.98%	1.76%	6.57%	1.38%
Mean value for crushed (psi).	5394.4	4866.5	4327.0	3130.5	4637.9	3533.2
Mean value for uncrushed (psi).	4905.9	4609.3	4221.6	3067.9	4405.3	3484.2
t-distribution value	3.86	2.33	0.77	0.77	1.97	0.92

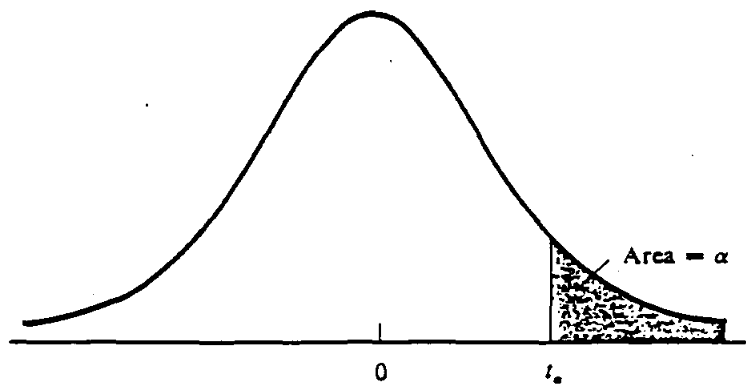


TABLE A (The following table provides the values of t_α that correspond to a given upper-tail area a and a specified number of degrees of freedom.,

Degrees of Freedom	Upper-Tail A m a									
	.4	.25	.1	.05	.025	.01	.005	.0025	.001	.0005
1	.325	1.000	3.078	6.314	12.706	31.821	63.657	127.32	318.31	636.62
2	.289	.816	1.886	2.920	4.303	6.965	9.925	14.089	22.327	31.598
3	.277	.765	1.638	2.353	3.182	4.541	5.841	7.453	10.214	12.924
4	.271	.741	1.533	2.132	2.776	3.747	4.604	5.598	7.173	8.610
5	.267	.727	1.476	2.015	2.571	3.365	4.032	4.773	5.893	6.869
6	.265	.718	1.440	1.943	2.447	3.143	3.707	4.317	5.208	5.959
7	.263	.711	1.415	1.895	2.365	2.998	3.499	4.029	4.785	5.408
8	.262	.706	1.397	1.860	2.306	2.896	3.355	3.833	4.501	5.041
9	.261	.703	1.383	1.833	2.262	2.821	3.250	3.690	4.297	4.781
10	.260	.700	1.372	1.812	2.228	2.764	3.169	3.581	4.144	4.587
11	.260	.697	1.363	1.796	2.201	2.718	3.106	3.497	4.025	4.437
12	.259	.695	1.356	1.782	2.179	2.681	3.055	3.428	3.930	4.318
13	.259	.694	1.350	1.771	2.160	2.650	3.012	3.372	3.852	4.221
14	.258	.692	1.345	1.761	2.145	2.624	2.977	3.326	3.787	4.140
15	.258	.691	1.341	1.753	2.131	2.602	2.947	3.286	3.733	4.073
16	.258	.690	1.337	1.746	2.120	2.583	2.921	3.252	3.686	4.015
17	.257	.689	1.333	1.740	2.110	2.567	2.898	3.222	3.646	3.965
IS	.257	.688	1.330	1.734	2.101	2.552	2.878	3.197	3.610	3.922
19	.257	.688	1.328	1.729	2.093	2.539	2.861	3.174	3.579	3.883
20	.257	.687	1.325	1.725	2.086	2.528	2.845	3.153	3.552	3.850
21	.257	.686	1.323	1.721	2.080	2.518	2.831	3.135	3.527	3.819
22	.256	.686	1.321	1.717	2.074	2.508	2.819	3.119	3.505	3.792
23	.256	.685	1.319	1.714	2.069	2.500	2.807	3.104	3.485	3.767
24	.256	.685	1.318	1.711	2.064	2.492	2.797	3.091	3.467	-3.745
25	.256	.684	1.316	1.708	2.060	2.485	2.787	3.078	3.450	3.725
26	.256	.684	1.315	1.706	2.056	2.479	2.779	3.067	3.435	3.707
27	.256	.684	1.314	1.703	2.052	2.473	2.771	3.057	3.421	3.690
28	.256	.683	1.313	1.701	2.048	2.467	2.763	3.047	3.408	3.674
29	.256	.683	1.311	1.699	2.045	2.462	2.756	3.038	3.396	3.659
30	.256	.683	1.310	1.697	2.042	2.457	2.750	3.030	3.385	3.646
40	.255	.681	1.303	1.684	2.021	2.423	2.704	2.971	3.307	3.551
60	.254	.679	1.296	1.671	2.000	2.390	2.660	2.915	3.232	3.460
120	.254	.677	1.289	1.658	1.980	2.358	2.617	2.860	3.160	3.373
∞	.253	.674	1.282	1.645	1.960	2.326	2.576	2.807	3.090	3.291

TABLE B

THE DISTRIBUTION OF *t (TWO-TAILED TESTS)**

Degrees of Freedom	Probability of a Larger Value. Sign Ignored								
	0.500	0.400	0.200	0.100	0.050	0.025	0.010	0.005	0.001
1	1.000	1.376	3.078	6.314	12.706	25.452	63.657		
2	0.816	1.061	1.886	2.920	4.303	6.205	9.925	14.089	31.598
3	.765	0.978	1.638	2.353	3.182	4.176	5.841	7.453	12.941
4	.741	.941	1.533	2.132	2.776	3.495	4.604	5.598	8.610
5	.727	.920	1.476	2.015	2.571	3.163	4.032	4.773	6.859
6	.718	.906	1.440	1.943	2.447	2.969	3.707	4.317	5.959
7	.711	.896	1.415	1.895	2.365	2.841	3.499	4.029	5.405
8	.706	.889	1.397	1.860	2.306	2.752	3.355	3.832	5.041
9	.703	.883	1.383	1.833	2.262	2.685	3.250	3.690	4.781
10	.700	.879	1.372	1.812	2.228	2.634	3.169	3.581	4.587
11	.697	.876	1.363	1.796	2.201	2.593	3.106	3.497	4.437
12	.695	.873	1.356	1.782	2.179	2.560	3.055	3.428	4.318
13	.694	.870	1.350	1.771	2.160	2.533	3.012	3.372	4.221
14	.692	.868	1.345	1.761	2.145	2.510	2.977	3.326	4.140
15	.691	.866	1.341	1.753	2.131	2.490	2.947	3.286	4.073
16	.690	.865	1.337	1.746	2.120	2.473	2.921	3.252	4.015
17	.689	.863	1.333	1.740	2.110	2.458	2.898	3.222	3.965
18	.688	.862	1.330	1.734	2.101	2.445	2.878	3.197	3.922
19	.688	.861	1.328	1.729	2.093	2.433	2.861	3.174	3.883
20	.687	.860	1.325	1.725	2.086	2.423	2.845	3.153	3.850
21	.686	.859	1.323	1.721	2.080	2.414	2.831	3.135	3.819
22	.686	.858	1.321	1.717	2.074	2.406	2.819	3.119	3.792
23	.685	.858	1.319	1.714	2.069	2.398	2.807	3.104	3.767
24	.685	.857	1.318	1.711	2.064	2.391	2.797	3.090	3.745
25	.684	.856	1.316	1.708	2.060	2.385	2.787	3.078	3.725
26	.684	.856	1.315	1.706	2.056	2.379	2.779	3.067	3.707
27	.684	.855	1.314	1.703	2.052	2.373	2.771	3.056	3.690
28	.683	.855	1.313	1.701	2.048	2.368	2.763	3.047	3.674
29	.683	.854	1.311	1.699	2.045	2.364	2.756	3.038	3.659
30	.683	.854	1.310	1.697	2.042	2.360	2.750	3.030	3.646
35	.682	.852	1.306	1.690	2.030	2.342	2.724	2.996	3.591
40	.681	.851	1.303	1.684	2.021	2.329	2.704	2.971	3.551
45	.680	.850	1.301	1.680	2.014	2.319	2.690	2.952	3.520
50	.680	.849	1.299	1.676	2.008	2.310	2.678	2.937	3.496
55	.679	.849	1.297	1.673	2.004	2.304	2.669	2.925	3.476
60	.679	.848	1.296	1.671	2.000	2.299	2.660	2.915	3.460
70	.678	.847	1.294	1.667	1.994	2.290	2.648	2.899	3.435
80	.678	.847	1.293	1.665	1.989	2.284	2.638	2.887	3.416
90	.678	.846	1.291	1.662	1.986	2.279	2.631	2.878	3.402
100	.677	.846	1.290	1.661	1.982	2.276	2.625	2.871	3.390
120	.677	.845	1.289	1.658	1.980	2.270	2.617	2.860	3.373
∞	.6745	.8416	1.2816	1.6448	1.9600	2.2414	2.5758	2.8070	3.2905