All the computations are done using psi units. In order to use the program code for results in SI units, the necessary conversion have to be incorporated in the program steps.

NECESSARY EQUATIONS

The equations used for the computation of f'_{cr} depend on the records available from the concrete production facility. The following 4 cases are identified by the ACI code [1].

(i) Concrete production facility has a record on test results on the cylinders made of concrete comparable (within 1000 psi) to the concrete to be produced and made of comparable materials and proportions. The available number of consecutive tests equals or exceeds 30.

(ii) Records are available for 2 consecutive test sets, the total of which is greater than or equal to 30.

(iii) Records are avialable for consecutive tests ranging from 15 to 30.

(iv) Records for comparable concrete are not available or the number of consecutive tests available is less than 15.

For case (i), f'_{cr} is taken as the larger of the two values computed by the equations:

$$f'_{cr} = (f'_c + 1.34s) \text{ psi} \qquad (1)$$

$$f'_{cr} = (f'_c + 2.33s - 500) \text{ psi} \qquad (2)$$

The standard deviation, s, should be computed using the equation:

$$s = \left[\frac{(x_i - \bar{x})^2}{n - 1} \right]^{1/2} \qquad (3)$$

in which,

x_i = individual strength test

$\bar{x}$ = average of n strength test results

n = number of consecutive strength tests.

For cases (ii) and (iii), equations (1) and (2) are still valid, but with a standard deviation computed using the following procedure.

For case (ii), the standard deviation s is computed using the equation:

$$s = \left[\frac{(n_1 - 1)(s_1)^2 + (n_2 - 1)(s_2)^2}{(n_1 + n_2 - 2)} \right]^{1/2}$$

in which,

s_1, s_2 = standard deviations calculated from two test records, 1 and 2, respectively

and n_1, n_2 = number of tests in each test record, respectively.

For case (iii), the standard deviation has to be magnified using the factors listed in Table 1, adopted from ACI 318-83 [1].

For case (iv), required average strength, f'_{cr} is taken as:

$(f'_c + 1000)$ psi for $f'_c \leq 3000$ psi,
$(f'_c + 1200)$ psi for 3000 psi $< f'_c \leq 5000$ psi, and
$(f'_c + 1400)$ psi for $f'_c > 5000$ psi.

FLOW CHART

Fig 1. presents the flow of computations used for the program steps. The necessary equations are repeated in the flow chart to make the chart more comprehensive. The basic set up of the chart is same as the one in the ACI 318-83 commentary [2].

Basically, the program is set up to read the specified strength, f'_c, and the available data, compute the average, standard deviation and the required strength, f'_{cr}. If the average of the field data supplied is not with in 1000 psi of f'_c, the program prints the error message "The field strength test records are not with in 1000 psi of the specified class of concrete". If two sets of data are supplied and their sum is not equal to or greater than 30, the program chooses the bigger of the two sets and treats it as a single data set.

PROGRAM STEPS

The program steps are presented in Fig 2. As presented, the program is dimensioned to read a maximum of 200 test values. The capacity can be modified by changing the line 120 in the program.

INPUT-OUTPUT DATA AND SAMPLE RUNS

The input-output data are presented using the example problems presented subsequently. Examples are presented for the standard four cases explained in the text, two additional cases in which either two data sets do not add to 30 or the number of

data points are less than 15, and finally a case in which the average of the available data is not within 1000 psi of the specified strength.

The input data consists of f'_c, appropriate answers for the questions, and the test data. The output data consists of the number of tests used, f'_c and f'_{cr} or the appropriate error message.

CONCLUDING REMARKS

With the advent of microprocessors (personal and professional computers), now it is economically feasible for even the small offices to own stand alone computers. In the case of concrete production facilities these personal computers can be effectively used to analyze and store the data for the various concrete strengths they produce. For instance the records of a concrete supplied to a particular project can be stored in a set of floppy discs and stored. These data can be used to design the required average strength, f'_{cr} when the necessity arises. The authors believe the program steps presented here can be used to compute the required average strength, f'_{cr} with minimum amount of labor. The output can also be used as a part of the design report for submission and for future reference.

REFERENCES

1. ACI Committee 318, Building Code Requirements for Reinforced Concrete (ACI 318-83), American Concrete Institute, Detroit, Michigan, pp. 318-14-318-15.

2. ACI Committee 318, Commentary on Building Code Requirements for Reinforced Concrete (ACI 318-83), American Concrete Institute, Detroit, Michigan, pp. 318R-17-318R-19.

EXAMPLE PROBLEMS

Compute the required average compressive strength, f'_{cr} for the following cases. The specified compressive strength is 4000 psi. Strength test records available are presented in the following table. Note that each case represents a different problem.

Test Number	case (i)	case (ii)	case (iii)	case (iv)	case (v)	case (vi)	case (vii)
1	3800	3800	3800	None in	3800	3800	5100
2	3820	3820	3820		3820	3820	5200
3	3830	3830	3830	the range	3830	3830	5300
4	3840	3840	3840		3840	3840	5500
5	3850	3850	3850	between	3850	3850	5700
6	3900	3900	3900		3900	3900	5900
7	3920	3920	3920	3000 psi	3920	3920	5000
8	3930	3930	3930		3930	3930	5800
9	3940	3940	3940	and	3940	3940	5660
10	3950	3950	3950		3950	3950	5120
11	4000	4000	4000	5000 psi	4000		5140
12	4020	4020	4020		4020		5160
13	4030	4030	4030		4030		5180
14	4040	4040	4040		4040		5210
15	4050	4050	4050		4050		5230
16	4100	4100	4100		4100		
17	4120	4120	4120		4120		
18	4130	4130	4130		4130		
19	4140	4140	4140		4140		
20	4150	4150	4150		4150		
21	4200	4200	4200		4200		
22	4220	4220	4220		4220		
23	4230	4230	4230		4230		
		Group 2			Group 2		
24	4240	4240			4240		
25	2450	4250			4250		
26	4300	4300			4300		
27	4320	4320			4320		
28	4330	4330					
29	4340	4340					
30	4350	4350					

TABLE 1--MODIFICATION FACTOR FOR STANDARD DEVIATION WHEN LESS THAN 30 TESTS ARE AVAILABLE [1]

No. of tests*	Modification factor for Standard Deviation.
15	1.16
20	1.08
25	1.03
30 or more	1.00

*Interpolate for intermediate numbers of tests.

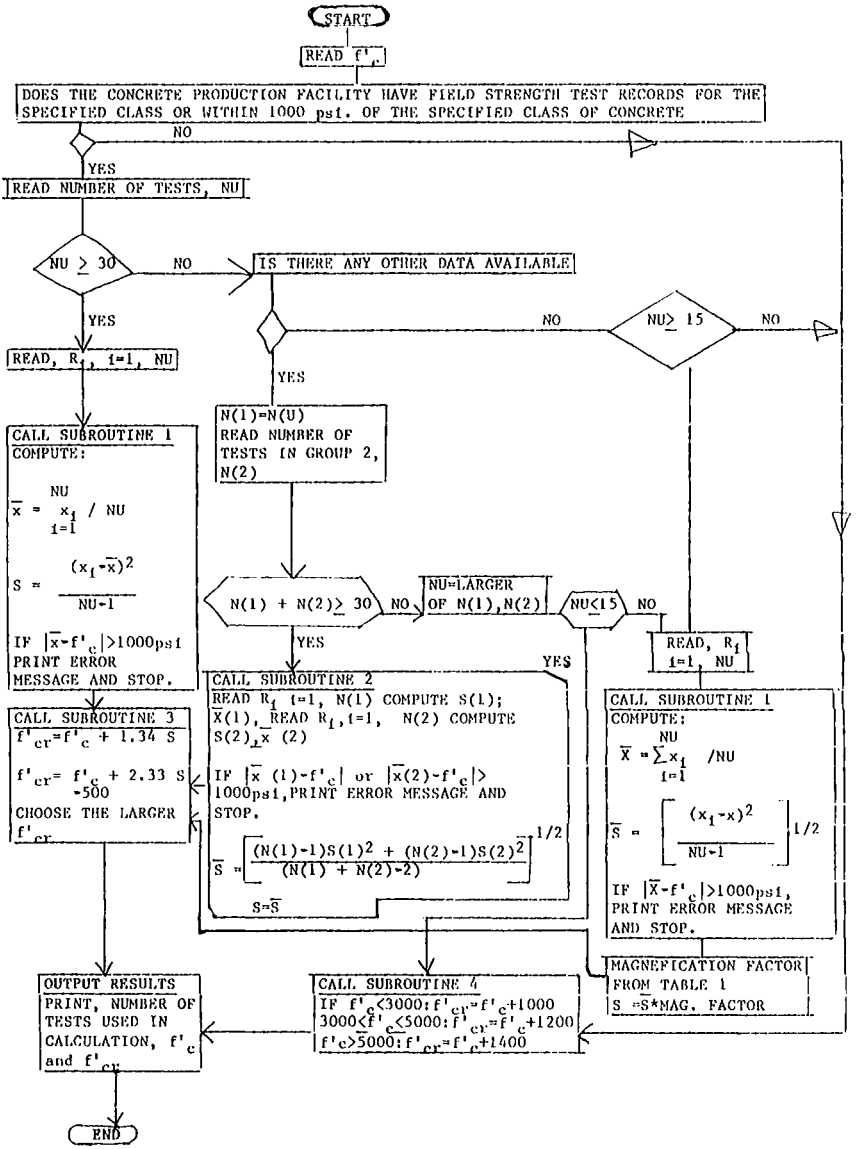

Fig. 1--Flow chart: computation of f'_{cr}

```
10  REM  ******************************
20  REM  * PROPORTIONING OF CONCRETE *
30  REM  *   ON THE BASIS OF FIELD   *
40  REM  *        EXPERIENCE         *
50  REM  *  AND/OR TRIAL MIXTURES    *
60  REM  ******************************
70  REM
80  REM  --PURPOSE:THIS PROGRAM READS THE NUMBER(MAX 200),AND VALUES OF
90  REM            SUITABLE TESTS RECORDS,AND COMPUTES
100  REM           STANDARD DEVIATION(s),AND THE REQUIRED AVERAGE
110  REM           STRENGTH(f'cr)BASED ON THE ACI 318-83
120  DIM T1(4,2),R(200),N(2),S(2),XA(2)
130  REM
140  REM  --READ TABLE 4.3.1.2,ACI 318-83
150  REM   ******************************
160  FOR I = 1 TO 4
170  FOR J = 1 TO 2
180  READ T1(I,J)
190  NEXT J
200  NEXT I
210  REM
220  REM  --READ OF CONTROLING DATA
230  REM   ************************
240  PRINT "THE SPECIFIED COMPRESSIVE STRENGTH?"
250  INPUT FC: PRINT : PRINT
260  PRINT "DOES THE CONCRETE PRODUCTION FACILITY HAVE FIELD STRENGTH TES
     T RECORDS FOR THE SPECIFIED CLASS OR WITHIN 1000 psi OF THE SPECIFIE
     D CLASS OF CONCRETE?(Y/N)"
270  INPUT A$: PRINT : PRINT
280  IF A$ = "N" THEN 370
290  PRINT "THE TOTAL NUMBER OF CONSECUTIVE TESTS?"
300  INPUT NU: PRINT : PRINT
310  IF NU >  = 30 THEN 410
320  PRINT : PRINT "IS THERE ANY DATA AVAILABLE FROM DIFFERENT GROUP?(Y/N
     )"
330  INPUT B$: PRINT : PRINT
340  IF B$ = "Y" THEN 630
350  IF NU < 15 THEN 370
360  GOTO 410
370  IF FC < 3000 THEN FR = FC + 1000: GOTO 1100
380  IF FC <  = 5000 THEN FR = FC + 1200: GOTO 1100
390  IF FC > 5000 THEN FR = FC + 1400: GOTO 1100
400  REM
410  REM  --CASE OF ONE GROUP OF CONSECUTIVE TESTS
420  REM   ***************************************
430  PRINT "START INPUTING THE DATA ONE VALUE AT A TIME (GOVERNING GROUP
     IF TWO DATA SETS ARE USED FOR COMPUTATION )"
440  PRINT "-------------------------------------------------------------
     -----------------"
450  FOR I = 1 TO NU
460  IF I > 1 THEN  PRINT "                    N";I;":": GOTO 480
470  PRINT "ENTER DATA VALUEN";I;":"
480  INPUT "                          ";R(I)
490  NEXT I
500 XA = 0
510  FOR I = 1 TO NU
520 XA = XA + R(I)
530  NEXT I
540 XA(1) = XA / NU
550  IF  ABS (XA(1) - FC) >  = 1000 THEN  PRINT "THE FIELD STRENGTH TEST
     RECORDS ARE NOT WITHIN 1000psi OF THE SPECIFIED CLASS OF CONCRETE": PRINT
     "AVERAGE VALUE OF GIVEN DATA=";XA(1): PRINT "SPECIFIED COMPRESSIVE S
     TRENGTH=";FC: GOTO 9999
560 S = 0
570  FOR I = 1 TO NU
580 S = S + (R(I) - XA(1)) ^ 2
590  NEXT I
600 S =  SQR (S / (NU - 1))
610  GOTO 970
620  REM
630  REM  --CASE OF TWO GROUPS OF CONSECUTIVE TESTS
640  REM   ***************************************
650 N(1) = NU
660  PRINT : PRINT : PRINT "THE NUMBER OF TESTS IN SECOND GROUP?"
670  INPUT N(2)
680 NU = N(1) + N(2)
690  IF NU >  = 30 THEN 740
700  IF N(1) >  = N(2) THEN NU = N(1): GOTO 720
```

Fig. 2--Program steps

```
710 NU = N(2)
720  IF NU < 15 THEN 370
730  GOTO 410
740  FOR J = 1 TO 2
750  PRINT "START INPUTING THE DATA OF GROUP#";J;" ONE VALUE AT A TIME"
760  PRINT "------------------------------------------------------------"
770  FOR I = 1 TO N(J)
780  IF I > 1 THEN  PRINT "                    #";I;":": GOTO 800
790  PRINT "ENTER DATA VALUE#";I;":"
800  INPUT "                          ";R(I)
810  NEXT I
820 XA = 0
830  FOR I = 1 TO N(J)
840 XA = XA + R(I)
850  NEXT I
860 XA(J) = XA / N(J)
870  IF  ABS (XA(J) - FC) >  = 1000 THEN  PRINT "THE FIELD STRENGTH TEST
     RECORDS OF GROUP#";J;" ARE NOT WITHIN 1000 psi OF THE SPECIFIED CLAS
     S OF CONCRETE": PRINT : PRINT "AVERAGE VALUE OF GIVEN DATA=";XA(J): PRINT
     "SPECIFIED COMPRESSIVE STRENGTH=";FC: GOTO 9999
880 S(J) = 0
890  FOR I = 1 TO N(J)
900 S(J) = S(J) + (R(I) - XA(J)) ^ 2
910  NEXT I
920 S(J) =  SQR (S(J) / (N(J) - 1))
930  NEXT J
940 S = ((N(1) - 1) * S(1) ^ 2 + (N(2) - 1) * S(2) ^ 2) / (N(1) + N(2) -
    2)
950 S =  SQR (S)
960  REM
970  REM  --CALCULATION OF STANDARD DEVIATION
980  REM  ************************************
990  IF NU >  = 30 THEN MF = 1: GOTO 1040
1000  FOR I = 1 TO 4
1010  IF NU < T1(1,I) THEN 1030
1020  NEXT I
1030 MF = (T1(I,2) - T1(I - 1),2)) / 5 * (NU - T1(I - 1),1)) + T1(I -
     1),2)
1040 S = S * MF
1050 F1 = FC + 1.34 * S
1060 F2 = FC + 2.33 * S - 500
1070  IF F1 >  = F2 THEN FR = F1: GOTO 1100
1080 FR = F2
1090  REM
1100  REM  --OUTPUT RESULTS
1110  REM  ****************
1120  PRINT  TAB( 5);"**FINAL RESULTS**": PRINT  TAB( 5);"****************
     **": PRINT : PRINT
1130  IF NU >  = 15 THEN 1160
1140  PRINT "CONCRETE PRODUCTION FACILITY DOES NOT HAVE ENOUGH TEST RECOR
     DS ((15)": PRINT : PRINT
1150  GOTO 1180
1160  IF B$ = "Y" THEN 1250
1170  PRINT "ONE GROUP OF CONSECUTIVE TESTS": PRINT "--------------------
     ----------": PRINT : PRINT
1180  PRINT "NUMBER OF TESTS USED IN CALCULATION"
1190  PRINT  TAB( 10)"*****": PRINT  TAB( 10)"*";NU;" *": PRINT  TAB( 10)
     "*****"
1200  PRINT "SPECIFIED COMPRESSIVE STRENGTH(f'c)"
1210  PRINT  TAB( 10)"******": PRINT  TAB( 10)"*"; INT (FC);"*": PRINT  TAB(
     10)"******"
1220  PRINT "REQUIRED AVERAGE COMPRESSIVE STRENGTH(f'cr)"
1230  PRINT  TAB( 10);"******": PRINT  TAB( 10);"*"; INT (FR);"*": PRINT
      TAB( 10)"******"
1240  GOTO 9999
1250  PRINT "TWO GROUPS OF CONSECUTIVE TESTS": PRINT "--------------------
     ------------": PRINT : PRINT
1260  PRINT "NUMBER OF TESTS IN FIRST GROUP  =";N(1)
1270  PRINT "NUMBER OF TESTS IN SECOND GROUP =";N(2)
1280  GOTO 1180
1290  DATA  15,1.16,20,1.08,25,1.03,30,1
9999  END
```

Fig. 2--Program steps (continued)

Case (i)

```
RUN
THE SPECIFIED COMPRESSIVE STRENGTH?
?4000

DOES THE CONCRETE PRODUCTION FACILITY HAVE FIELD STRENGTH TEST RECORDS FOR THE S
PECIFIED CLASS OR WITHIN 1000 psi OF THE SPECIFIED CLASS OF CONCRETE?(Y/N)
?Y

THE TOTAL NUMBER OF CONSECUTIVE TESTS?
?30

START INPUTING THE DATA ONE VALUE AT A TIME (GOVERNING GROUP IF TWO DATA SETS AR
E USED FOR COMPUTATION )
-------------------------------------------------------------------------------
ENTER DATA VALUE#1:
                    3800
                #2:
                    3820
                #3:
                    3830
                #4:
                    3840
                #5:
                    3850
                #6:
                    3900
                #7:
                    3920
                #8:
                    3930
                #9:
                    3940
               #10:
                    3950
               #11:
                    4000
               #12:
                    4020
               #13:
                    4030
               #14:
                    4040
               #15:
                    4050
               #16:
                    4100
               #17:
                    4120
               #18:
                    4130
               #19:
                    4140
               #20:
                    4150
               #21:
                    4200
               #22:
                    4220
               #23:
                    4230
               #24:
                    4240
               #25:
                    4250
               #26:
                    4300
               #27:
                    4320
               #28:
                    4336
               #29:
                    4340
               #30:
                    4350
```

INPUT

OUTPUT

```
**FINAL RESULTS**
******************

ONE GROUP OF CONSECUTIVE TESTS
------------------------------

NUMBER OF TESTS USED IN CALCULATION
          *****
          *30 *
          *****
SPECIFIED COMPRESSIVE STRENGTH(f'c)
          ******
          *4000*
          ******
REQUIRED AVERAGE COMPRESSIVE STRENGTH(f'cr)
          ******
          *4233*
          ******
```

Case (ii)

```
)RUN
THE SPECIFIED COMPRESSIVE STRENGTH?
?4000

DOES THE CONCRETE PRODUCTION FACILITY HAVE FIELD STRENGTH TEST RECORDS FOR THE S
PECIFIED CLASS OR WITHIN 1000 psi OF THE SPECIFIED CLASS OF CONCRETE?(Y/N)
?Y

THE TOTAL NUMBER OF CONSECUTIVE TESTS?
?23

IS THERE ANY DATA AVAILABLE FROM DIFFERENT GROUP?(Y/N)
?Y

THE NUMBER OF TESTS IN SECOND GROUP?
?7
START INPUTING THE DATA OF GROUP#1 ONE VALUE AT A TIME
-------------------------------------------------------
ENTER DATA VALUE#1:
                    3800
                #2:
                    3820
                #3:
                    3830
                #4:
                    3840
                #5:
                    3850
                #6:
                    3900
                #7:
                    3920
                #8:
                    3930
                #9:
                    3940
               #10:
                    3950
               #11:
                    4000
               #12:
                    4020
               #13:
                    4030
               #14:
                    4040
               #15:
                    4050
               #16:
                    4100
               #17:
                    4120
               #18:
                    4130
               #19:
                    4140
               #20:
                    4150
               #21:
                    4200
               #22:
                    4220
               #23:
                    4230
START INPUTING THE DATA OF GROUP#2 ONE VALUE AT A TIME
-------------------------------------------------------
ENTER DATA VALUE#1:
                    4240
                #2:
                    4250
                #3:
                    4300
                #4:
                    4320
                #5:
                    4330
                #6:
                    4340
                #7:
                    4350
```

INPUT

OUTPUT

```
     **FINAL RESULTS**
     ******************


 TWO GROUPS OF CONSECUTIVE TESTS
 -------------------------------


 NUMBER OF TESTS IN FIRST GROUP  =23
 NUMBER OF TESTS IN SECOND GROUP =7
 NUMBER OF TESTS USED IN CALCULATION
          *****
          *30 *
          *****
 SPECIFIED COMPRESSIVE STRENGTH(f'c)
          ******
          *4000*
          ******
 REQUIRED AVERAGE COMPRESSIVE STRENGTH(f'cr)
          ******
          *4163*
          ******
```

Case (iii)

```
RUN
THE SPECIFIED COMPRESSIVE STRENGTH?
?4000

DOES THE CONCRETE PRODUCTION FACILITY HAVE FIELD STRENGTH TEST RECORDS FOR THE S
PECIFIED CLASS OR WITHIN 1000 psi OF THE SPECIFIED CLASS OF CONCRETE?(Y/N)
?Y

THE TOTAL NUMBER OF CONSECUTIVE TESTS?
?23

IS THERE ANY DATA AVAILABLE FROM DIFFERENT GROUP?(Y/N)
?N

START INPUTING THE DATA ONE VALUE AT A TIME (GOVERNING GROUP IF TWO DATA SETS AR
E USED FOR COMPUTATION )
-------------------------------------------------------------------------------
ENTER DATA VALUE#1:
                    3800
               #2:
                    3820
               #3:
                    3830
               #4:
                    3840
               #5:
                    3850
               #6:
                    3900
               #7:
                    3920
               #8:
                    3930
               #9:
                    3940
              #10:
                    3950
              #11:
                    4000
              #12:
                    4020
              #13:
                    4030
              #14:
                    4040
              #15:
                    4050
              #16:
                    4100
              #17:
                    4120
              #18:
                    4130
              #19:
                    4140
              #20:
                    4150
              #21:
                    4200
              #22:
                    4220
              #23:
                    4230
```

INPUT

OUTPUT

```
    **FINAL RESULTS**
    ******************

ONE GROUP OF CONSECUTIVE TESTS
------------------------------

NUMBER OF TESTS USED IN CALCULATION
          *****
          *23 *
          *****
SPECIFIED COMPRESSIVE STRENGTH(f c)
          ******
          *4000*
          ******
REQUIRED AVERAGE COMPRESSIVE STRENGTH(f cr)
          ******
          *4190*
          ******
```