Calculator Program for Determining Properties of Built-up or Composite Members

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The advent of programmable calculators has increased the productivity of structural engineers considerably. Presented herein is a calculator program (written for the Hewlett-Packard HP-41C, utilizing its unique alpha-numeric capability) which eliminates the time-consuming calculations involved in determining the section properties of (a) built-up steel members or (b) composite sections. The program requires 314 program lines and 24 storage registers for execution. This article presents a brief description of the program, a printout of the program listing (Fig. 1), and a flowchart (Fig. 2). It also includes appropriate examples utilizing the HP 82143A printer.

BUILT-UP STEEL MEMBERS

In industrial structures, it is often desirable to increase a steel beam's load-carrying capacity, usually because of some change in the function served by the structure. This is typically accomplished by field welding either a cover plate, a WT section, or a wide-flange shape to the bottom of the existing beam (the top flange is usually not accessible because of equipment or floor slabs). Because the resulting section is unsymmetric, the structural engineer is faced with several minutes of calculations to determine the section moduli for the top and bottom fibers of the section in order to check stresses. In addition, the engineer may need to try several different sections before he finds one that will work. This program will do these calculations in seconds and will output location of the neutral axis, moment of inertia, and section moduli for the combined built-up section. Knowing the shear on the beam, it will also aid in the selection of the intermittent welds for welding the pieces of steel together. The only limitation is that the existing beam must be a symmetrical section (i.e., usually a wide-flange). The reinforcing piece can be either a wide-flange, a WT, or a plate. Once the existing beam properties are entered, any number of trials can be made. Once the desired combinati is found, one can go on to the weld sizing portion of t program.

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COMPOSITE DESIGN

On pages 2-96 thru 2-109 of the 8th Edition of the AI *Manual of Steel Construction*, a table is presented whi gives the transformed section modulus for selected wid flange beams acting compositely with concrete slabs. T table is somewhat limited, as noted on p. 2-98, in that (3000 psi concrete is required, (b) the effective slab flang width is assumed to be $16t + b_f$, (c) it is set up for only $4\frac{1}{2}$, 5, $5\frac{1}{2}$, and 6-in. slabs, and (d) it is for selected st beams. Therefore, interpolation is required for situatio not included in the table. Also, the designer still has to ha calculate the transformed moment of inertia if live lo deflections are to be checked. This program is good for a symmetrical steel member, any grade of normal weig concrete, and any slab thickness. It checks all three quirements noted in Sect. 1.11.1 of the AISC Specificati for determining effective flange-width of the slab. It a outputs location of the neutral axis and the transform moment of inertia. In addition, it outputs the number $\frac{3}{4}$-in. diameter studs required on either side of the poi of maximum moment to develop full composite action the assumed simply supported and uniformly loac composite member.

EXAMPLE 1: BUILT-UP SECTION

Given: Due to a proposed increase in load, an existi W16x36 (S_x = 56.5 in.^{3}) is to be unloaded and reinfor to carry a moment of 135 kip-ft and a shear of 27 ki Therefore, the built-up section must have a sect modulus (top and bottom fibers) of (135 × 12)/22 = 7 in.^{3} Find a WT section that will give the required sect modulus and size the intermittent weld.

Solution: See Fig. 3 for an actual printout of the progr input and output.

Discussion: A WT4x9 was tried first, but its section modulus for the top fiber was only 70.36 in.^{3} < 73.6 in.^{3} A WT5x11 was successfully tried next; it was found that ¼-in. welds, 1¾ in. long, spaced at 12 in. (or ¼-in. welds, 1¼ in. long, spaced at 9 in.) along both sides of the WT stem would be sufficient to carry the shear load.

EXAMPLE 2: COMPOSITE DESIGN

Given: Determine the section properties of a W18x46 spanning 24 ft, using a 5-in. concrete slab (f'_c = 5000 psi) with an 8-ft beam spacing. Also, determine the number of ¾-in. studs required on either side of the point of maximum moment to develop full composite action.

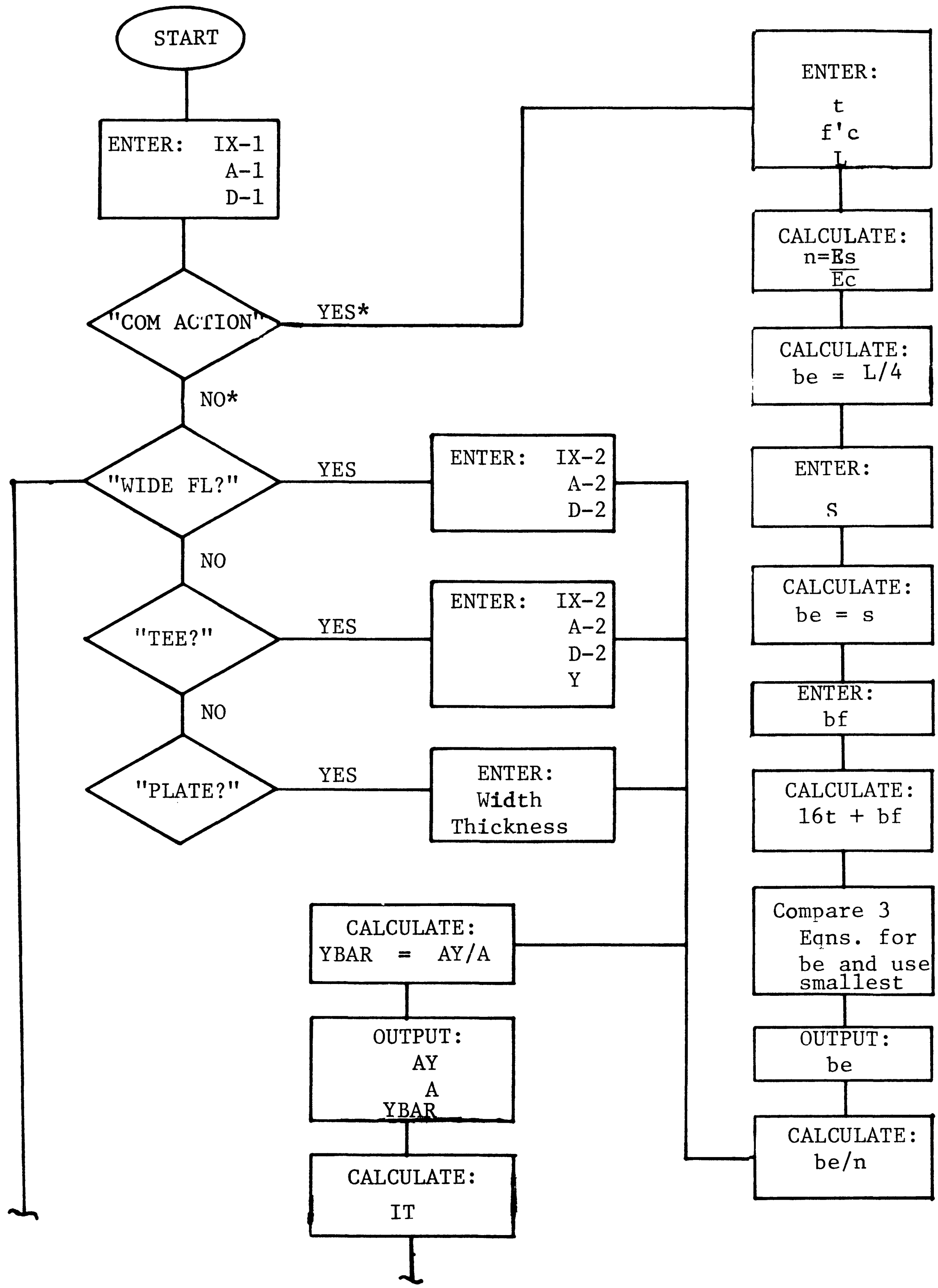
Solution: See Fig. 3 for the printout of the input and output.

PROGRAM NOMENCLATURE

A = total area of built-up or composite section
Ac = actual area of effective concrete flange as defined in AISC Specification Sect. 1.11.1
As = area of steel beam in composite section
AY = sum of first moments of areas of built-up section relative to top, or of composite section relative to bottom
A-1 = cross-sectional area of existing symmetrical section
A-2 = cross-sectional area of added wide-flange or WT
be = effective composite member width
bf = steel beam flange width
D-1 = overall depth of existing symmetrical section
D-2 = overall depth of added wide-flange or WT
Ec = elastic modulus for concrete = 57,000/*f′c* psi
Es = elastic modulus for steel = 29,000,000 psi
f′c = concrete compressive strength
fy = steel beam yield stress, assumed as 36,000 psi
IT = total moment of inertia of built-up or composite section
IX-1 = moment of inertia of existing symmetrical steel section
IX-2 = moment of inertia of added wide-flange or WT
L = composite member span length
Q = first moment of added section area shear load about built-up section neutral axis
q = maximum allowable shear load for ¾-in. diameter stud connector with no reductions = 11,500 lb
s = beam spacing
ST = section modulus of transformed composite section relative to top
STR = section modulus of transformed composite section relative to bottom
S-BOT = section modulus of built-up section with respect to top
S-TOP = section modulus of built-up section with respect to bottom
t = composite slab thickness
V = design shear load
Vh = horizontal shear to be resisted between point of maximum positive moment and point of zero moment
Y = centroidal distance of WT relative to top of flange
YBAR = centroidal distance of built-up section relative to top, or of composite section relative to bottom

```
01♦LBL "COM SEC"
02 "IX-1=?"
03 PROMPT
04 STO 01
05 "A-1=?"
06 PROMPT
07 STO 02
08 "D-1=?"
09 PROMPT
10 STO 12
11 2
12 /
13 STO 03
14♦LBL 07
15 "COM ACTION?"
16 PROMPT
17 STO 20
18 X=0?
19 GTO 08
20♦LBL 06
21 "WIDE FL?"
22 PROMPT
23 X=0?
24 GTO 01
25 "TEE?"
26 PROMPT
27 X=0?
28 GTO 02
29 "PLATE?"
30 PROMPT
31 X=0?
32 GTO 03
33♦LBL 01
34 "IX-2=?"
35 PROMPT
36 STO 04
37 "A-2=?"
38 PROMPT
39 STO 05
40 "D-2=?"
41 PROMPT
42 STO 11
43 2
44 /
45 STO 06
46 GTO 04
47♦LBL 02
48 "IX-2=?"
49 PROMPT
50 STO 04
51 "A-2=?"
52 PROMPT
53 STO 05
54 "D-2=?"
5 PROMPT
5 STO 11
7 "Y=?"
8 PROMPT
9 STO 06
0 GTO 04
61♦LBL 03
2 "WIDTH=?"
53 PROMPT
64 STO 17
65 "THICKNES=?"
66 PROMPT
67 STO 11
68 2
69 /
70 STO 06
71♦LBL 09
72 RCL 11
73 3
74 Y↑X
75 RCL 17
76 *
77 12
78 /
79 STO 04
80 RCL 17
81 RCL 11
82 *
83 STO 05
84 GTO 04
85♦LBL 08
86 "SLAB THICK?"
87 PROMPT
88 STO 11
89 2
90 /
91 STO 06
92 "FC=? PSI"
93 PROMPT
94 STO 15
95 STO 24
96 SQRT
97 57000
98 *
99 29000000
100 /
101 STO 16
102 "SPAN=? FT
103 PROMPT
104 .25
105 *
106 12
107 *
108 STO 17
109 "BM SPACING"
110 PROMPT
111 12
112 *
113 RCL 17
114 X<>Y
115 X<=Y?
116 STO 17
117 "BF=?"
118 PROMPT
119 RCL 11
120 16
121 *
122 +
123 RCL 17
124 X<>Y
125 X<=Y?
126 STO 17
127 RCL 17
128 STO 23
129 "be="
130 ARCL X
131 AVIEW
132 PSE
133 RCL 16
134 *
135 STO 17
136 GTO 09
137♦LBL 04
138 RCL 02
139 RCL 03
140 *
141 STO 07
142 RCL 03
143 2
144 *
145 RCL 11
146 RCL 06
147 -
148 +
149 RCL 05
150 *
151 RCL 07
152 +
153 STO 13
154 "ΣAY="
155 ARCL X
156 AVIEW
157 PSE
158 RCL 02
159 RCL 05
160 +
161 STO 08
162 "ΣA="
163 ARCL X
164 AVIEW
165 PSE
166 RCL 13
167 RCL 08
168 /
169 STO 09
170 "YBAR="
171 ARCL X
172 AVIEW
173 PSE
174 RCL 03
175 -
176 X↑2
177 RCL 02
178 *
179 STO 10
180 RCL 12
181 RCL 11
182 +
183 RCL 09
184 -
185 STO 15
186 RCL 06
187 -
188 STO 16
189 X↑2
190 RCL 05
191 *
192 RCL 10
193 +
194 RCL 01
195 +
196 RCL 04
197 +
198 STO 14
199 "IT="
200 ARCL X
201 AVIEW
202 TONE 9
203 STOP
204 RCL 09
205 /
206 STO 22
207 RCL 20
208 X=0?
209 GTO 10
210 RCL 22
211 "S TOP="
212 ARCL X
213 AVIEW
214 STOP
215 RCL 14
216 RCL 15
217 /
218 "S BOT="
219 ARCL X
220 AVIEW
221 STOP
222 "TRY AGAIN?"
223 PROMPT
224 X=0?
225 GTO 06
226 RCL 16
227 RCL 05
228 *
229 STO 18
230 "Q="
231 ARCL X
232 AVIEW
233 STOP
234 "V=?"
235 PROMPT
236 *
237 RCL 14
238 /
239 STO 19
240♦LBL 05
241 "SIZE WELD=?"
242 PROMPT
243 .707
244 *
245 21
246 *
247 1/X
248 RCL 19
249 *
250 "SPACING=?"
251 PROMPT
252 *
253 2
254 /
255 "REQ LTH="
256 ARCL X
257 AVIEW
258 STOP
259 "TRY AGAIN?"
260 PROMPT
261 X=0?
262 GTO 05
263 "THE END"
264 AVIEW
265 STOP
266♦LBL 10
267 RCL 22
268 "STR="
269 ARCL X
270 AVIEW
271 STOP
272 RCL 14
273 RCL 15
274 /
275 "ST="
276 ARCL X
277 AVIEW
278 STOP
279 RCL 23
280 RCL 11
281 *
282 RCL 24
283 *
284 .85
285 *
286 2
287 /
288 1000
289 /
290 STO 21
291 RCL 02
292 18
293 *
294 RCL 21
295 X<>Y
296 X>Y?
297 GTO 11
298 11.5
299 /
300 "NO STUDS="
301 ARCL X
302 AVIEW
303 STOP
304 GTO 12
305♦LBL 11
306 RCL 21
307 11.5
308 /
309 "NO STUDS="
310 ARCL X
311 AVIEW
312 STOP
313♦LBL 12
314 .END.
```

Fig. 1. Program listing



*Enter 0 if the answer to the question is yes
or 1 if the answer is no.

Fig. 2. Flowchart

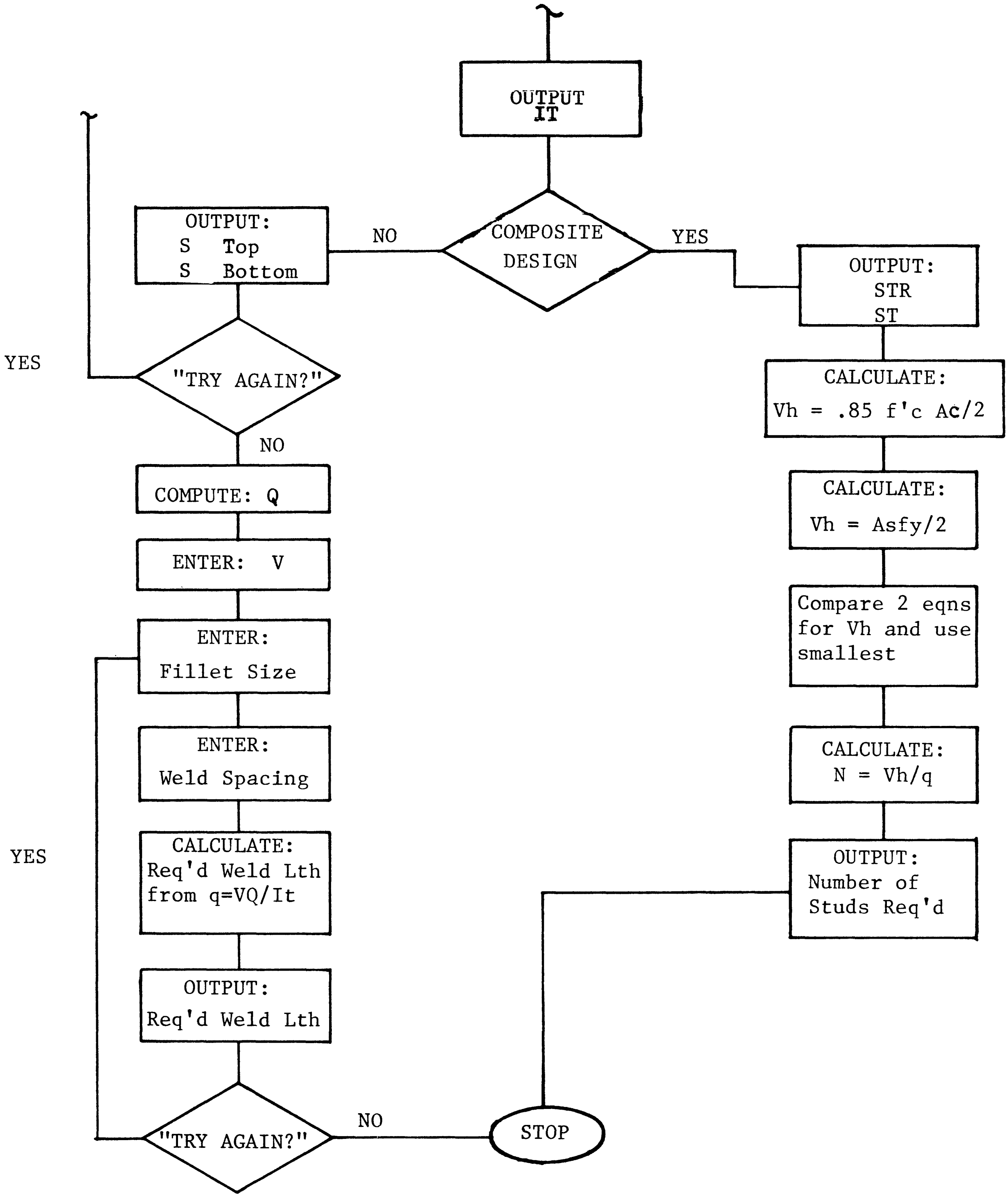


Fig. 2 (cont'd). Flowchart

Example 1

```
            XEQ "COM SEC"
IX-1=?
            448.00    RUN
A-1=?
             10.60    RUN
D-1=?
             15.86    RUN
COM ACTION?
              1.00    RUN
WIDE FL?
              1.00    RUN
TEE?
              0.00    RUN
IX-2=?
              3.41    RUN
A-2=?
              2.63    RUN
D-2=?
              4.07    RUN
Y=?
              .834    RUN
ΣAY=134.28
ΣA=13.23
YBAR=10.15
IT=714.13
                      RUN
S TOP=70.36
                      RUN
S BOT=73.02
                      RUN
TRY AGAIN?
              0.00    RUN
WIDE FL?
              1.00    RUN
TEE?
              0.00    RUN
IX-2=?
              6.88    RUN
A-2=?
              3.24    RUN
D-2=?
             5.085    RUN
Y=?
              1.07    RUN
ΣAY=148.45
ΣA=13.84
YBAR=10.73
IT=808.95
                      RUN
S TOP=75.42
                      RUN
S BOT=79.16
                      RUN
TRY AGAIN?
              1.00    RUN
Q=29.64
                      RUN
Y=?
             27.00    RUN
SIZE WELD=?
               .25    RUN
SPACING=?
             12.00    RUN
REQ LTH=1.60
                      RUN
TRY AGAIN?
              0.00    RUN
SIZE WELD=?
               .25    RUN
SPACING=?
              9.00    RUN
REQ LTH=1.20
                      RUN
TRY AGAIN?
              1.00    RUN
THE END
```

Example 2

```
            XEQ "COM SEC"
IX-1=?
            712.00    RUN
A-1=?
             13.50    RUN
D-1=?
             18.06    RUN
COM ACTION?
              0.00    RUN
SLAB THICK?
              5.00    RUN
FC=? PSI
          5,000.00    RUN
SPAN=? FT
             24.00    RUN
BM SPACING?
              8.00    RUN
BF=?
              6.06    RUN
be=72.00
ΣAY=1,150.60
ΣA=63.53
YBAR=18.11
IT=2,229.59
                      RUN
STR=123.11
                      RUN
ST=450.43
                      RUN
NO STUDS=21.13
```

Fig. 3. Printout of input and output, Examples 1 and 2