5.3 Tunnel Structural Analysis for Inlet and Outlet Structures

The structural analysis for the inlet structures and the transition parts at the tunnel inlet and outlet was carried out by frame analysis according to the Ecuadorian Building Code.

5.3.1 Design Conditions

The design conditions to be used for the structural analysis are as follows;

(1) Design values

(A) Design values of bedrock

Daule-Peripa ~ La Esperanza diversion tunnel

<u>Inlet side</u>

Unit weight (γ)	1.8	tf/m^3
Elasticity modulus (Er)	20,000	kgf/cm^2
Poisson's ratio (ν)	0.2	kgf/cm^2
Internal friction angle (ϕ)	40.0	degree
Cohesion (C)	5.0	kgf/cm^2

<u>Outlet side</u>

Unit weight (γ)	1.7	tf/m^3
Elasticity modulus (Er)	10,000	kgf/cm^2
Poisson's ratio (ν)	0.25	kgf/cm^2
Internal friction angle (ϕ)	35.0	degree
Cohesion (C)	2.5	kgf/cm^2

La Esperanza ~ Poza Honda diversion tunnel

<u>Inlet side</u>

Unit weight (γ)	2.0	tf/m^3
Elasticity modulus (Er)	20,000	kgf/cm^2
Poisson's ratio (ν)	0.2	kgf/cm^2
Internal friction angle (ϕ)	40.0	degree
Cohesion (C)	5.0	kgf/cm^2

<u>Outlet side</u>

Unit weight (γ)	1.8	tf/m^3
Elasticity modulus (Er)	10,000	kgf/cm^2
Poisson's ratio (ν)	0.25	kgf/cm^2
Internal friction angle (ϕ)	35.0	degree
Cohesion (C)	2.5	kgf/cm^2

Poza Honda ~ Mancha Grande diversion tunnel

<u>Inlet side</u>

Unit weight (γ)	1.8	tf/m^3
Elasticity modulus (Er)	10,000	kgf/cm^2

Poisson's ratio (ν)	0.2	kgf/cm²
Internal friction angle (φ)	30.0	degree
Cohesion (C)	2.0	kgf/cm²

<u>Outlet side</u>

Unit weight (γ)	1.8	tf/m³
Elasticity modulus (Er)	10,000	kgf/cm²
Poisson's ratio (ν)	0.25	kgf/cm²
Internal friction angle (φ)	30.0	degree
Cohesion (C)	2.0	kgf/cm²

(B) Design values of concrete

Unit weight of reinforced concrete	2.4	tf/m³
Elasticity modulus of concrete (Ec)	235,000	kgf/cm²
Elasticity modulus of reinforcing bar (Es)	2,100,000	kgf/cm²
Design compressive strength of concrete (σ_{28})	210	kgf/cm²
Tensile strength of reinforcing bar (fy)	4,200	kgf/cm²

(2) Design Loads

The design loads to be considered for the each structure are as follows;

(A) Daule-Peripa ~ La Esperanza diversion tunnel

<u>Conguillo inlet structure, inlet tunnel</u>

Case 1 : Dead weight of lining concrete(Wc) + Bedrock pressure(Pr)
+ Water pressure(Pw) + Backfill grout pressure(Pg)

<u>Conguillo inlet structure, inlet shaft</u>

Case 1 :Bedrock pressure(Pr) + Water pressure(Pw)

<u>Conguillo tunnel inlet (Tunnel transition part)</u>

Case 1 : Dead weight of lining concrete(Wc) + Bedrock pressure(Pr)
+ Water pressure(Pw) + Backfill grout pressure(Pg)

<u>Membrillo tunnel outlet (Tunnel transition part)</u>

Case 1 : Dead weight of lining concrete(Wc) + Bedrock pressure(Pr)
+ Water pressure(Pw)
Case 2 : Dead weight of lining concrete(Wc) + Bedrock pressure(Pr)
+ Water pressure(Pw) + Backfill grout pressure(Pg)

(B) La Esperanza ~ Poza Honda diversion tunnel

<u>Caña Dulce inlet culvert</u>

Case 1 : Wc + Earth pressure(Pe) + Pw

<u>Caña Dulce tunnel inlet</u>

Case 1 : Wc + Pr + Pw
Case 2 : Wc + Pr + Pw + Pg

<u>Los Cuyuyes tunnel outlet (Tunnel transition part)</u>

Case 1 : Wc + Pr + Pw
Case 2 : Wc + Pr + Pw + Pg

(C) Poza Honda ~ Mancha Grande diversion tunnel

<u>Poza Honda inlet structure, inlet culvert</u>

Case 1 : Wc + Pe + Pw

<u>Poza Honda inlet structure, inlet tunnel</u>

Case 1 : Wc + Pr + Pw
Case 2 : Wc + Pr + Pw + Pg

<u>Poza Honda inlet structure, inlet shaft</u>

Case 1 : Pr + Pw

<u>Poza Honda tunnel inlet (Tunnel transition part)</u>

Case 1 : Wc + Pr + Pw
Case 2 : Wc + Pr + Pw + Pg

<u>Mancha Grande tunnel outlet (Tunnel transition part)</u>

Case 1 : Wc + Pr + Pw
Case 2 : Wc + Pr + Pw + Pg

(3) Bedrock pressure

The maximum lateral bedrock pressure acting on the lining concrete at the tunnel inlet and outlet is given by the following formula.

$$Prh = Ka \cdot (Prv + \gamma \cdot Ht)$$

where,
- Prh : leteral bedrock pressure(tf/m)
- Ka : coefficient of lateral bedrock pressure
- Ka : $\tan^2(45 - \phi / 2)$
- ϕ : internal friction angle of bedrock
- Prv : vertical bedrock pressure(tf/m)
- γ : unit weight of bedrock(tf/m^3)
- Ht : excavation height of tunnel(m)

(4) Spring constant of bedrock

The bedrock surrounding the tunnel resist together with the concrete lining against the internal and outer pressure. The resistant force by bedrock is incorporated into the calculation as spring constant.

The spring constant is given by the following formula.

$K = A \cdot E / L$

where,
- K : spring constant(t/m)
- A : area subject to a spring(m^2)
- E : elasticity modulus of bedrock(tf/m^2)
- L : unit length of a spring(m)

(5) Load factor

The structure and structural members shall be designed to get design stress in all sections, at least equal to the required stress calculated for factored loads and the forces in combination as stipulated in Chapter 9 of the Ecuadorian Building Code.

The load factor to be applied for each load is as follows;

Dead load	1.4
Bedrock pressure	1.7
Water pressure	1.4
Earth pressure	1.7
Backfill grout pressure	1.4

Based on the design conditions mentioned above, the structural analysis was carried out by using computer program, SAP 90 (Authorized computer program in Ecuador).

5.3.2 Required Reinforcing Bar Areas

The required reinforcing bar areas for each section are conducted from the following formulas.

(1) Minimum required reinforcing bar area

$As = 0.0033 \cdot b \cdot d = (14/fy) \cdot b \cdot d$

where,
- As : minimum required reinforcing bar area(cm^2)
- b : width of section(cm)
- d : effective depth of section(cm)
- fy : specified yield strength(4,200kgf/cm^2)

(2)Maximum reinforcing bar area

$$As = 0.75 \cdot \rho_B = 0.75 \cdot \beta_1 \cdot \frac{f'c}{fy} \cdot \frac{6,115}{fy + 6,115} \cdot d \cdot b$$

$$a = As \cdot fy / (0.85 \cdot f'c \cdot b)$$

$$\phi \cdot Mu = 0.85 \cdot As \cdot fy\,(d - a/2) \text{ or } \phi \cdot Mu = (As \cdot fy \cdot d \cdot (1- 0.59 \cdot fy / f'c)$$

$$A's = 0.5\ As$$

where, ϕ : stress reduction factor
Mu : factored moment in the section
f'c : specified compressive stress of concrete(kgf/cm^2)

Required area of compressive reinforcing bar

$$Pu \,.\, e'/\phi = 0.85 \cdot f'c \cdot a \cdot b \cdot (d - c/2) + A's \cdot fy \cdot (d - d')$$

where, Pu : total axial load
c : distance of extreme compression fiber to the neutral axis
d' : distance of extreme compression fiber to centroid of compression reinforcing bar

$$f's = 6{,}120 \cdot (\frac{d - c}{c})$$

$$Pu = 0.85 \cdot f'c \cdot a \cdot b + A's \cdot fy \cdot As \cdot f's$$

Required area of tensile reinforcing bar

$$m = fy / (0.85 \cdot f'c)$$

$$Pu = 0.85 \cdot f'c \cdot b \cdot d \cdot (-(\frac{e'}{d} - 1) + (\frac{e'}{d} - 1)^2 + 2 \cdot m \cdot (\frac{1 - d'}{d}))$$

(3)Shear stress

The design of cross sections subject to shearing is based on the following formulas.

$$Vc = 0.85 \cdot 0.53 \cdot f'c^{1/2} \cdot d \cdot b$$

where, Vc : shear nominal strength(kgf/cm^2)

If $V > Vc$

Required area of diagonal bars : Av

$$Av / \phi = (V - Vc) / (fy \cdot \sin \alpha)$$

Required area of stirrups : Avs

$$Avs / \phi = (V - Vc) \cdot c / (fy \cdot d)$$

(4) Longitudinal reinforcing bars

$$As = 0.00125 \cdot b \cdot d$$

5.3.3 Structural Analysis

(1) Conguillo Inlet Structure

(A) Inlet Tunnel

Case 1 : During construction

1) Dead weight of lining concrete

Wc = 0.5 x 2.4 = 1.2 tf/m

2) Vertical bedrock pressure, water pressure and backfill grout pressure

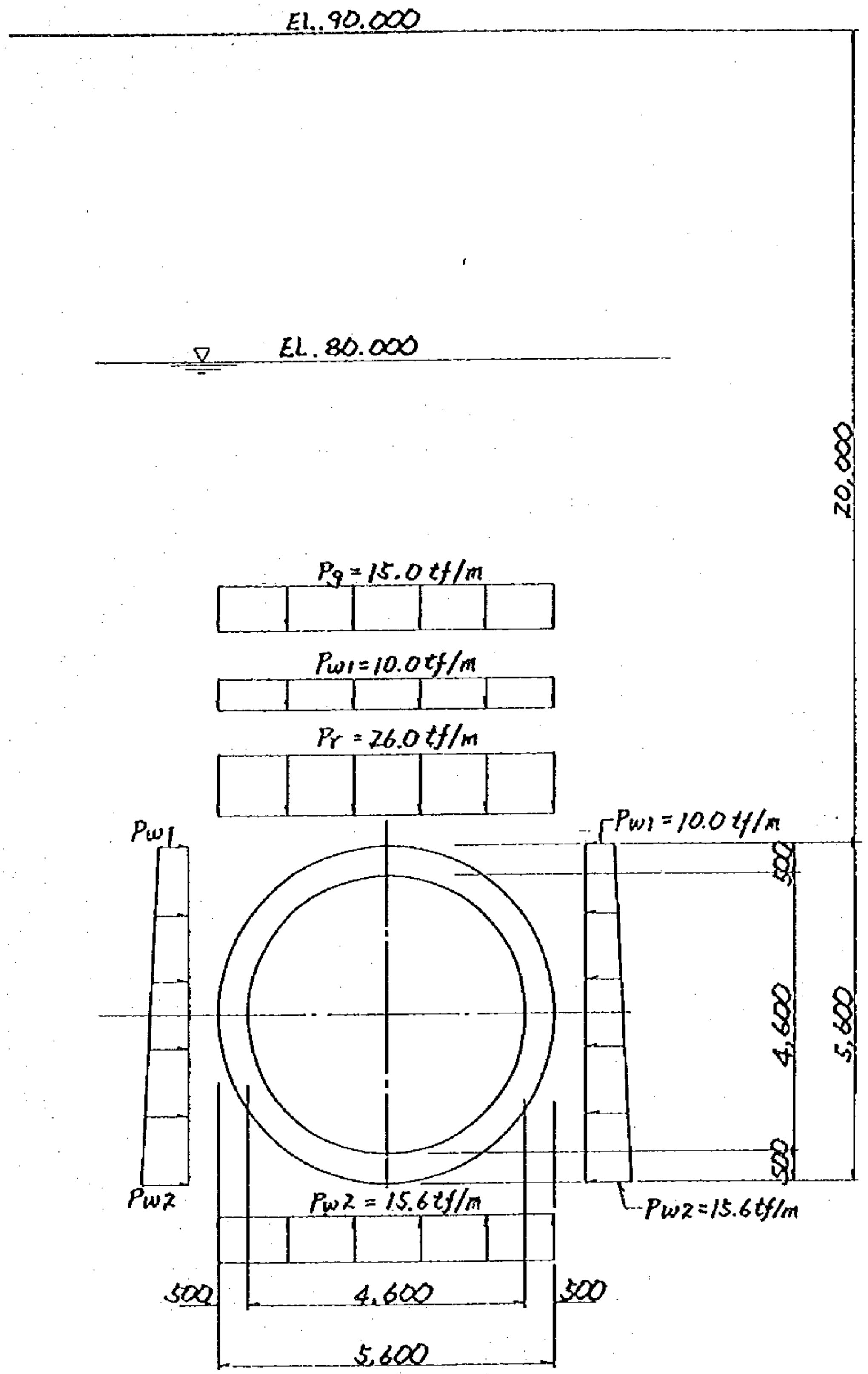
Pr = 1.8 x 10.0 + (1.8 - 1.0) x 10.0 = 26.0 tf/m
Pw = 1.0 x (El.80.0 - 70.0) = 10.0 tf/m
Pg= 15.0 tf/m

3) Lateral water pressure

Pw1 = 1.0 x 10.0 = 10.0 tf/m
Pw2 = 1.0 x 15.6 = 15.6 tf/m

4) Uplift pressure

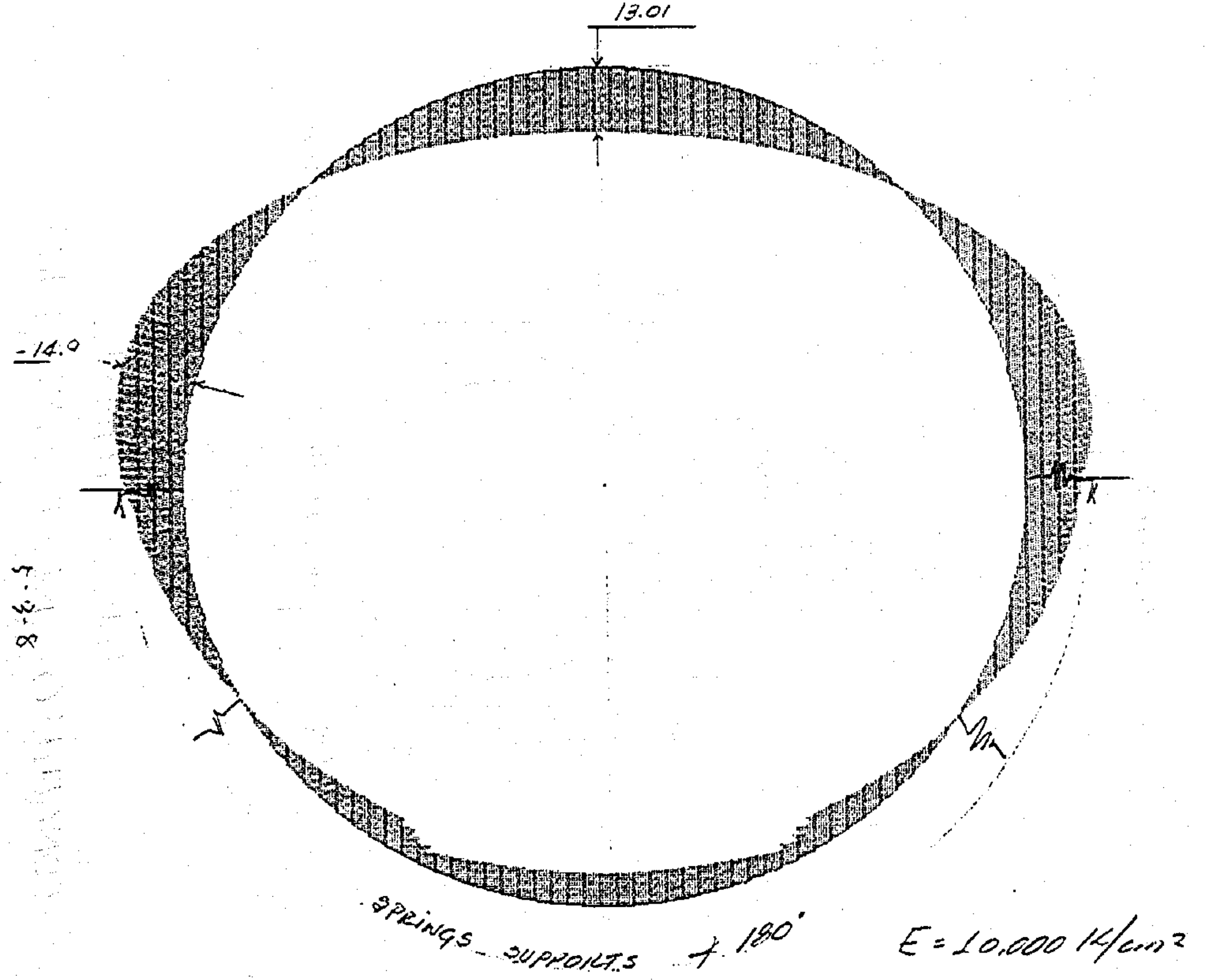
Pu = 1.0 x 15.6 = 15.6 tf/m



INLET TUNNEL

CONGUILLO INLET STRUCTURE

CONGUILLO TUNNEL INLET



MOMENT DIAGRAM

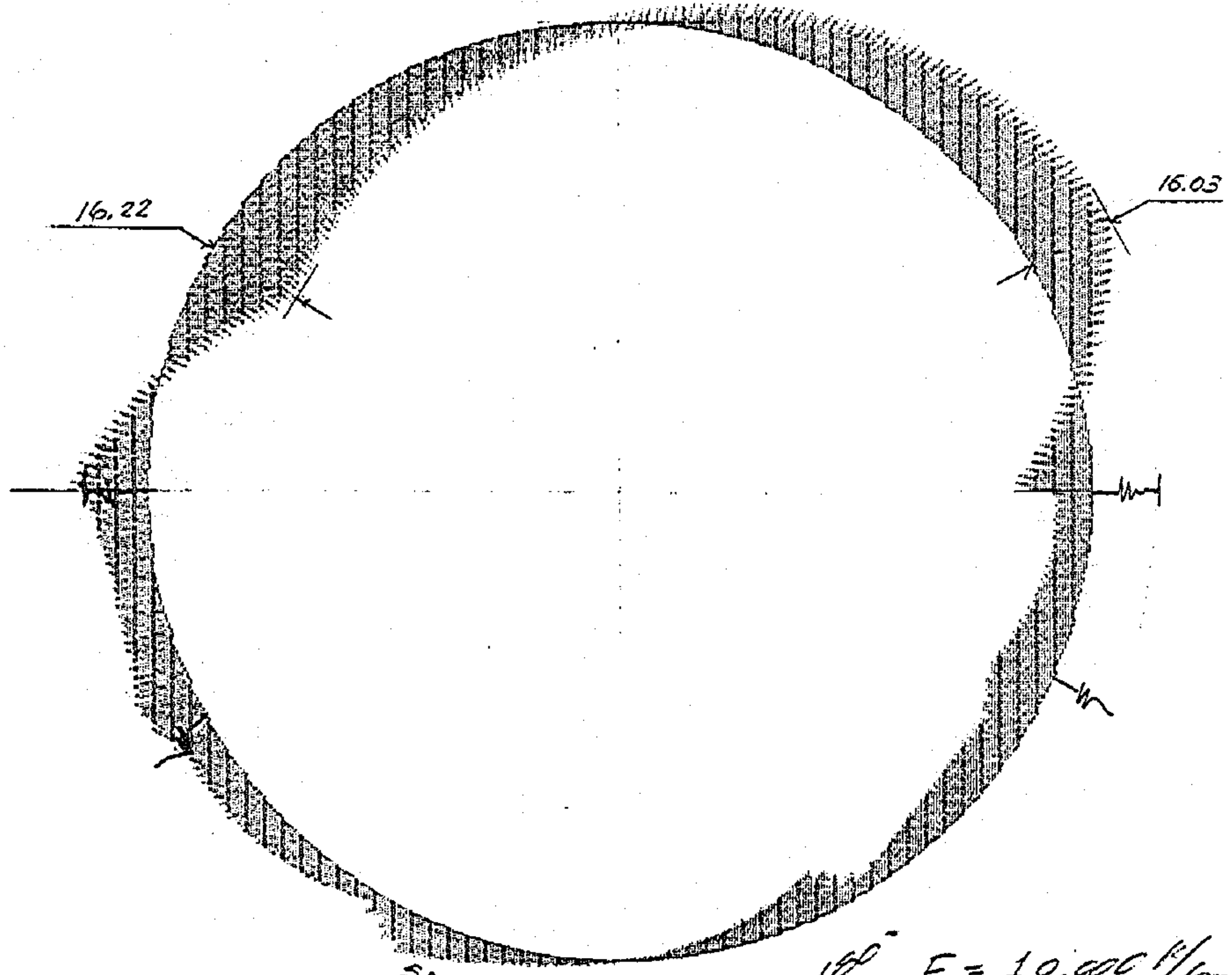
Z
Y

CONGT222
FRAME
OUTPUT M33
LOAD 1

MIN < 104>
-.1498E+02
AT .04
MAX < 181>
.1301E+02
AT .02

SAP90

CONGUILLO TUNNEL INLET



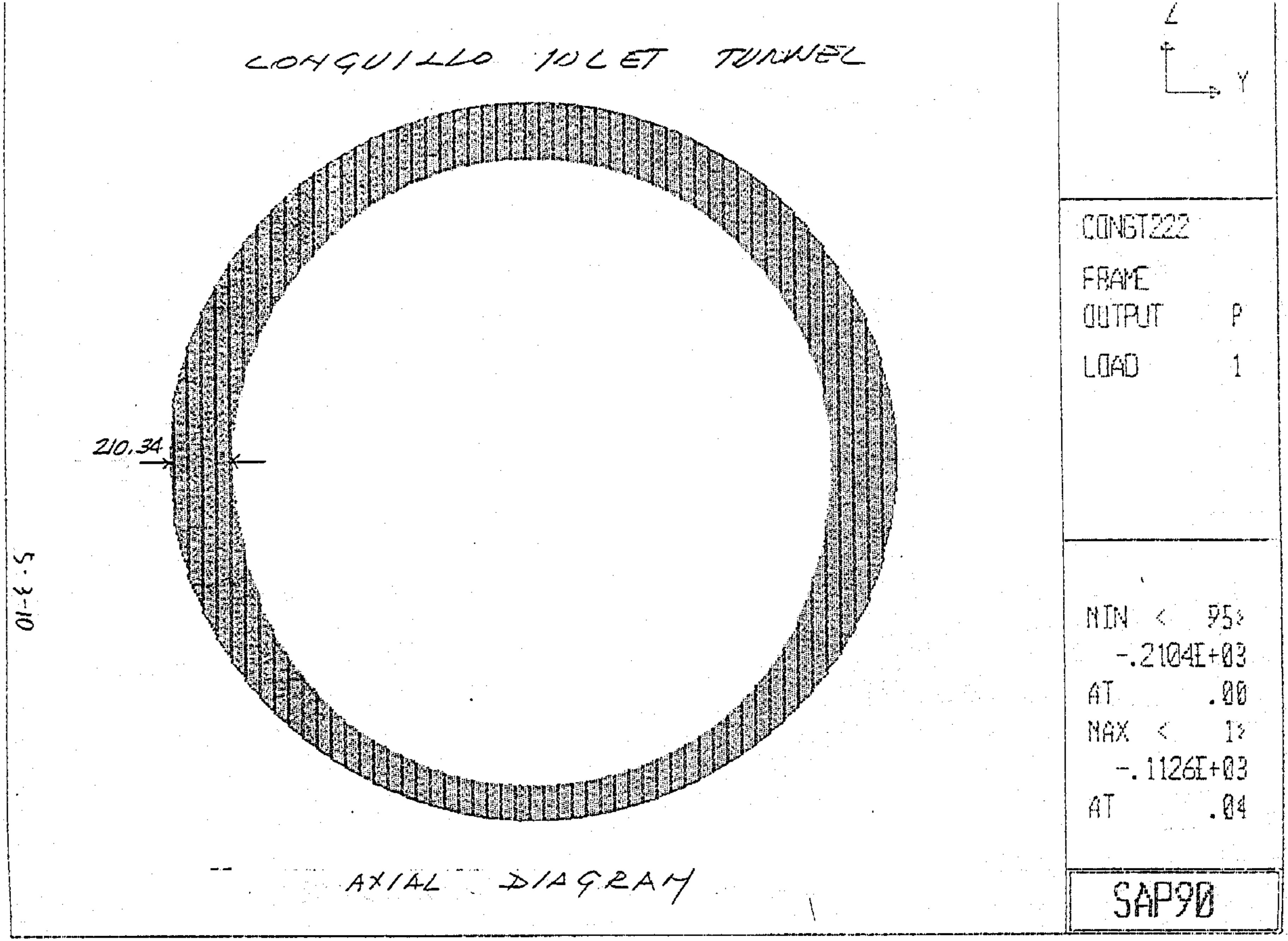
SPRING SUPPORTS @ 18° E = 10.000 t/cm²
SHEAR DIAGRAM

CONGT222
FRAME
OUTPUT V22
LOAD 1

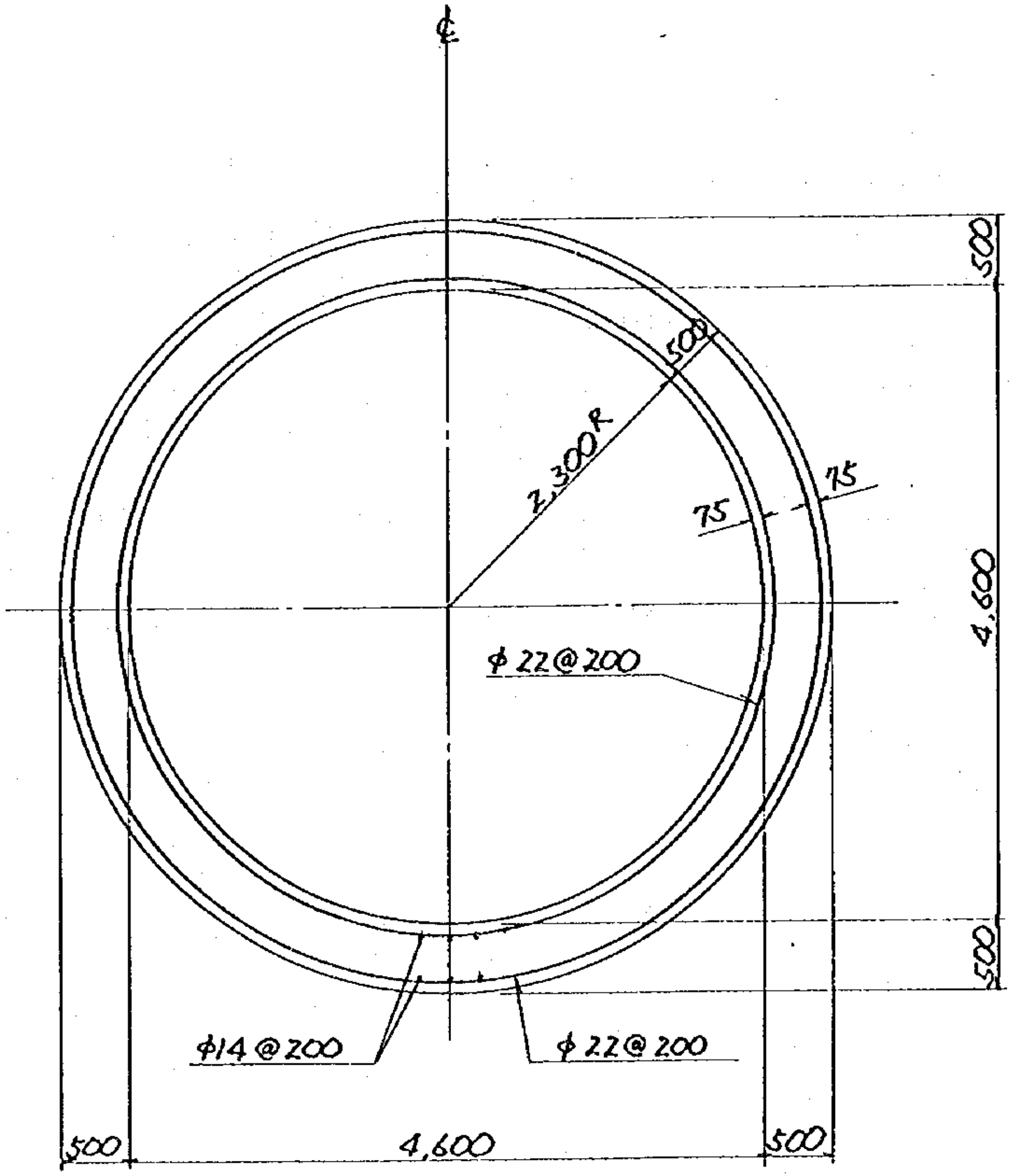
MIN < 241>
-.1603E+02
AT .04
MAX < 121>
.1622E+02
AT .00

SAP90

5-13-9



CONGUILLO INLET TUNNEL
210.34
AXIAL DIAGRAM
Z
Y
CONGT222
FRAME
OUTPUT P
LOAD 1
MIN < 95>
-.2104E+03
AT .00
MAX < 1>
-.1126E+03
AT .04
SAP90
5-3-10



Note;
φ22 means diameter of deformed bar.

INLET TUNNEL

CONGUILLO INLET STRUCTURE

(B) Inlet Shaft

Inlet Shaft, Section A - A

Case 1 : After construction

1) Lateral water pressure

Pw = 1.0 x (El.80.0 - El.56.63) = 23.37 tf/m

2) Lateral bedrock pressure

Ka = tan2(45 - 40/2) = 0.217
Pr = 0.217 x (1.8 - 1.0) x 8.3 = 1.44 tf/m

Inlet Shaft, Section B - B

Case 1 : After construction

1) Lateral water pressure

Pw = 1.0 x (El.80.0 - El.71.0) = 9.0 tf/m

2) Lateral bedrock pressure

Ka = tan2(45 - 40/2) = 0.217
Pr = 0.217 x 1.8 x 10.00 + 0.217 x (1.8 - 1.0) x 9.0 = 5.468 tf/m

Inlet Shaft, Section C - C

Case 1 : After construction

1) Lateral water pressure

Pw = 1.0 x (El.80.0 - El.74.0) = 6.0 tf/m

2) Lateral bedrock pressure

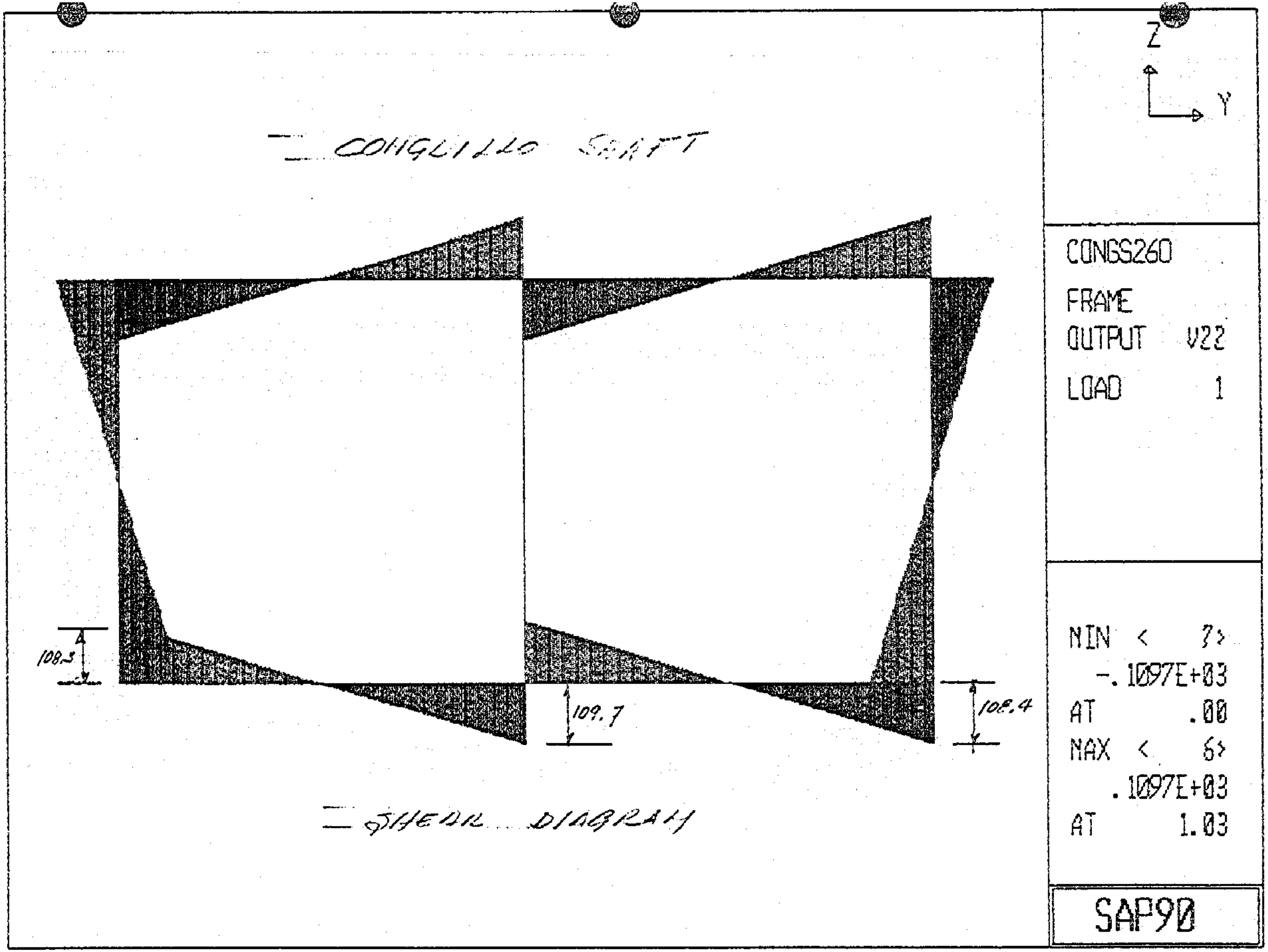
Ka = tan2(45 - 40/2) = 0.217
Pr = 0.217 x 1.8 x 10.0 + 0.217 x (1.8 - 1.0) x 6.0 = 4.948 tf/m

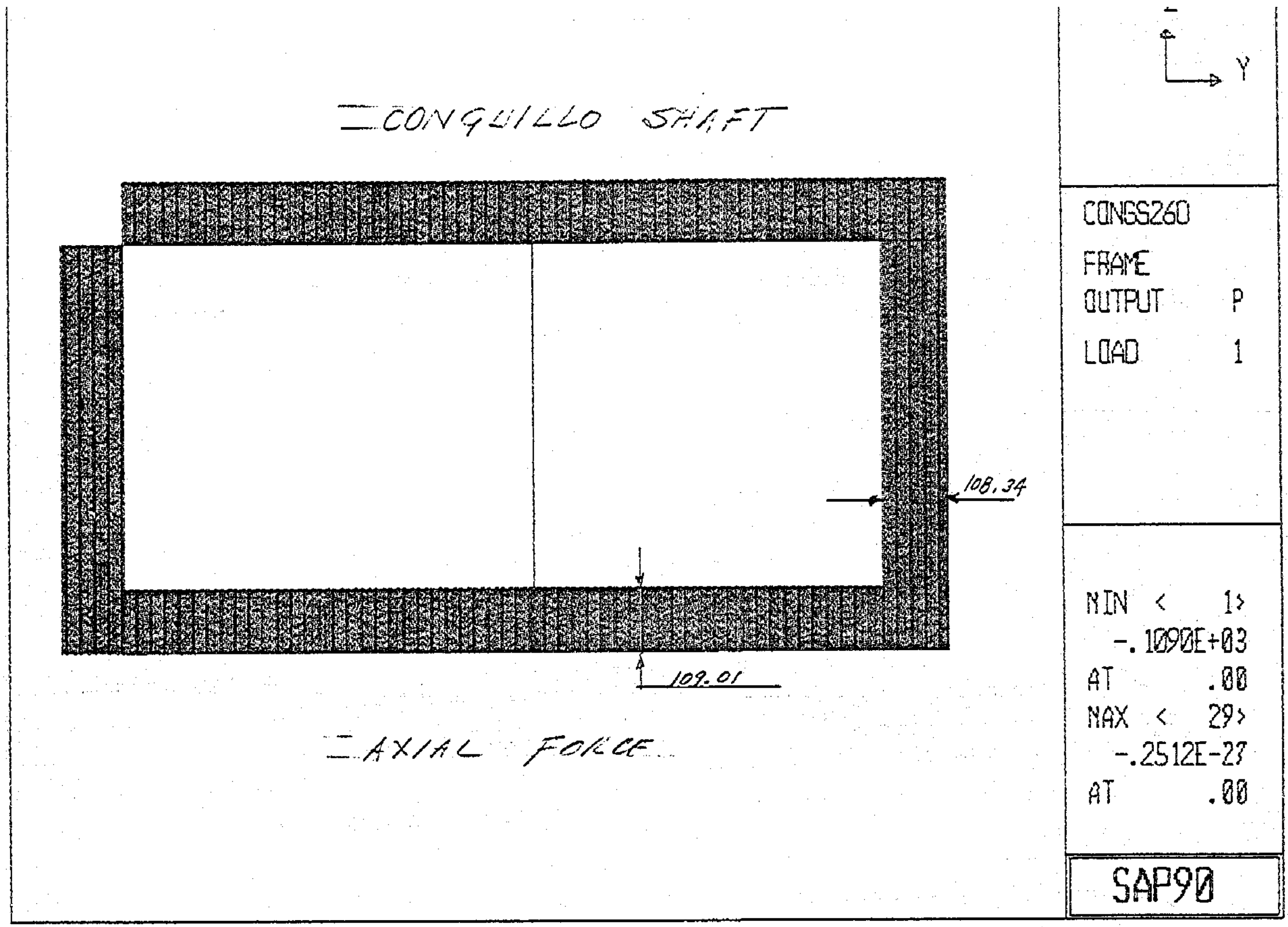
Inlet Shaft, Section D - D

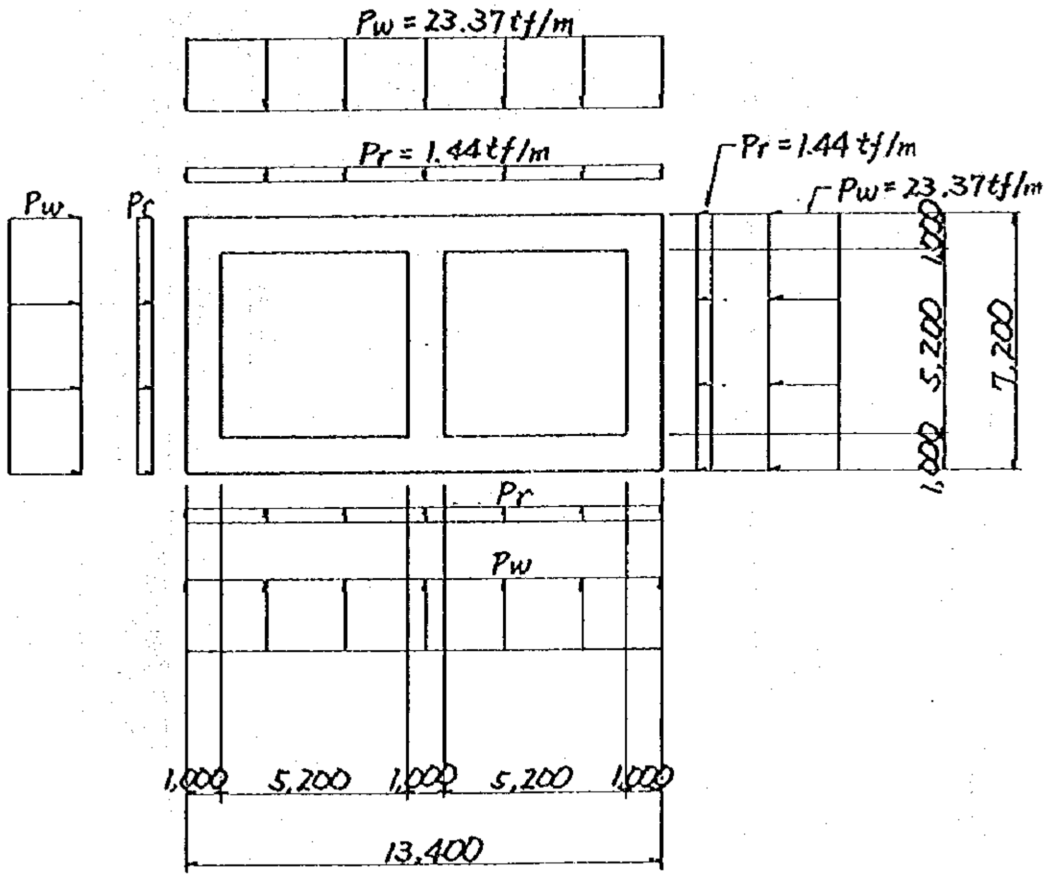
Case 1 : After construction

1) Lateral bedrock pressure

Ka = tan2(45 - 40/2) = 0.217
Pr = 0.217 x 1.8 x 8.0 = 3.125 tf/m

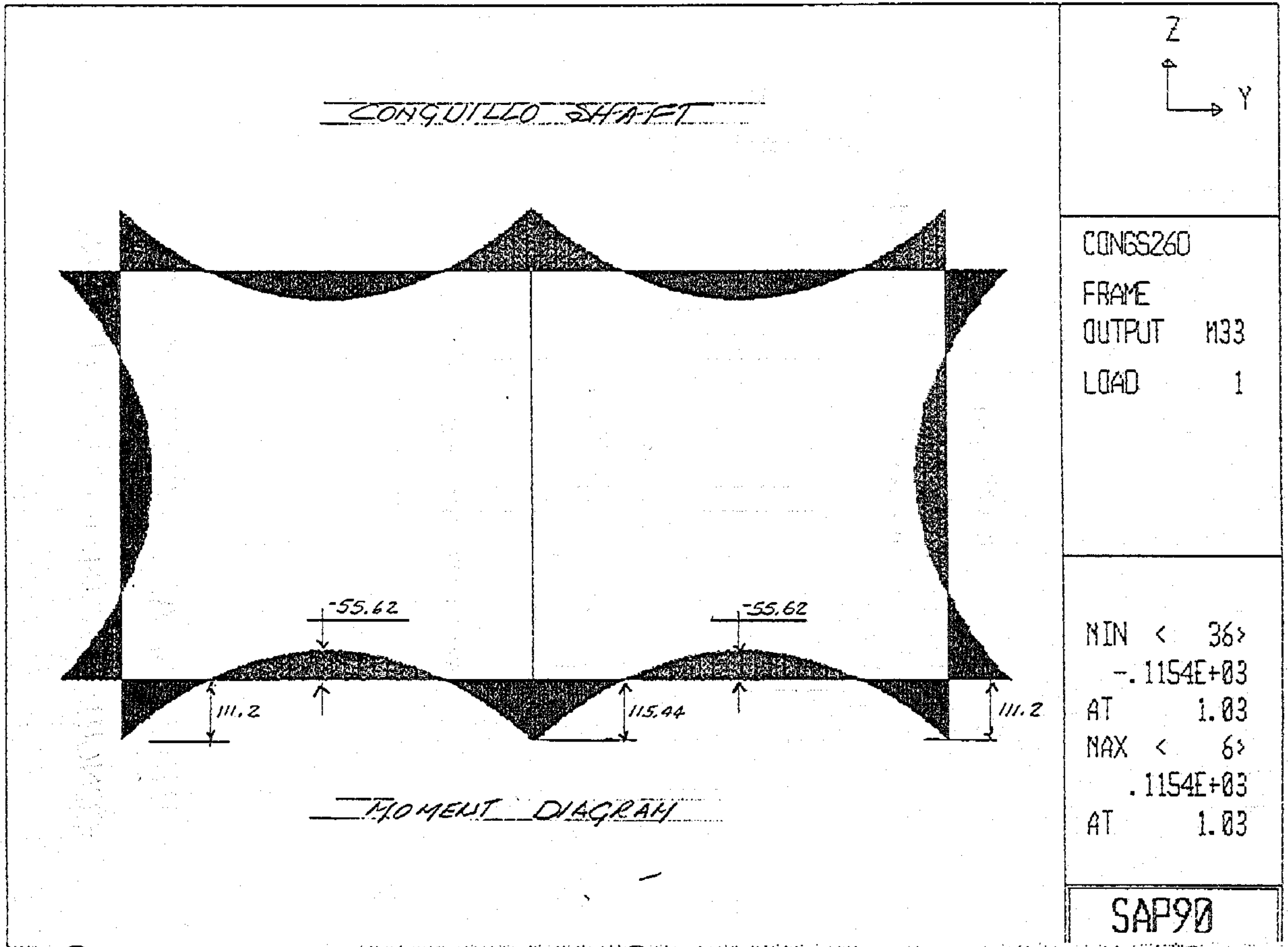

CONGLILLO SHAFT
SHEAR DIAGRAM
108.3
109.7
108.4
Z
Y
CONGS260
FRAME
OUTPUT V22
LOAD 1
MIN < 7>
-.1097E+03
AT .00
MAX < 6>
.1097E+03
AT 1.03
SAP90


CONQUILLO SHAFT
108.34
109.01
AXIAL FORCE
Y
CONGS260
FRAME
OUTPUT P
LOAD 1
MIN < 1>
-.1090E+03
AT .00
MAX < 29>
-.2512E-27
AT .00
SAP90

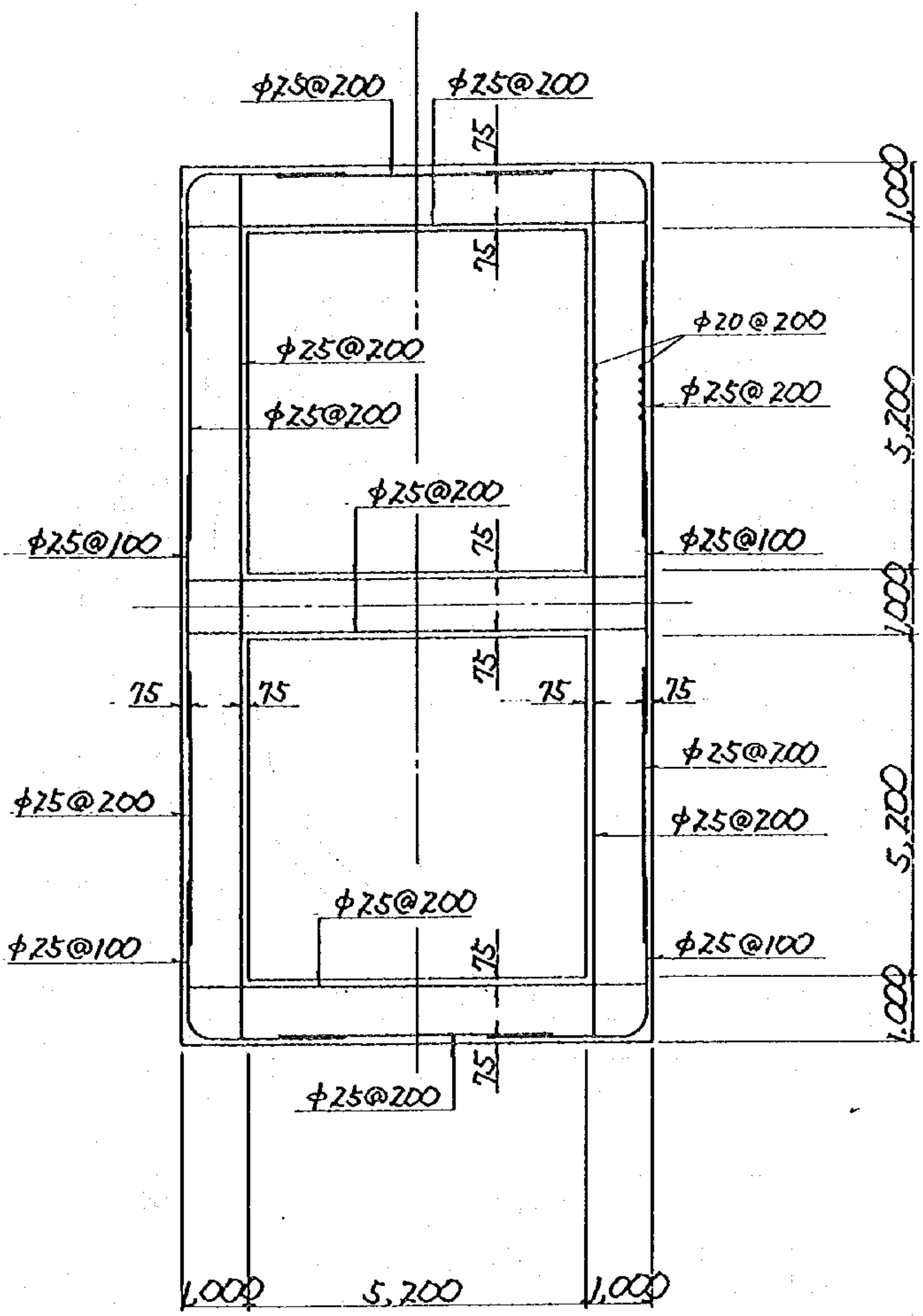


INLET SHAFT, SECTION A - A

CONGUILLO INLET STRUCTURE

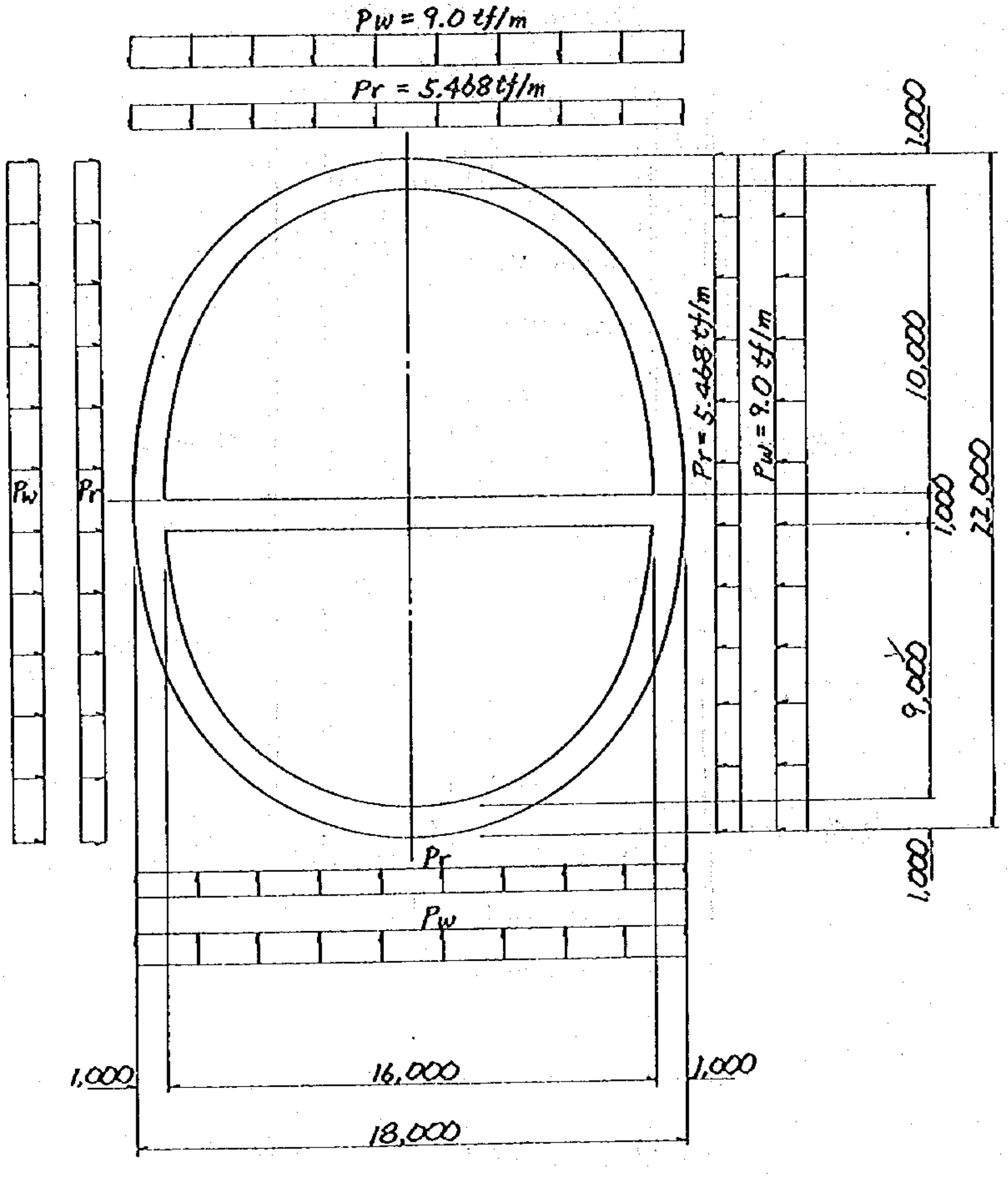


CONGUILLO SHAFT
-55.62
-55.62
111.2
115.44
111.2
MOMENT DIAGRAM
Z
Y
CONGS260
FRAME
OUTPUT M33
LOAD 1
MIN < 36>
-.1154E+03
AT 1.03
MAX < 6>
.1154E+03
AT 1.03
SAP90



INLET SHAFT, SECTION A – A

CONGUILLO INLET STRUCTURE

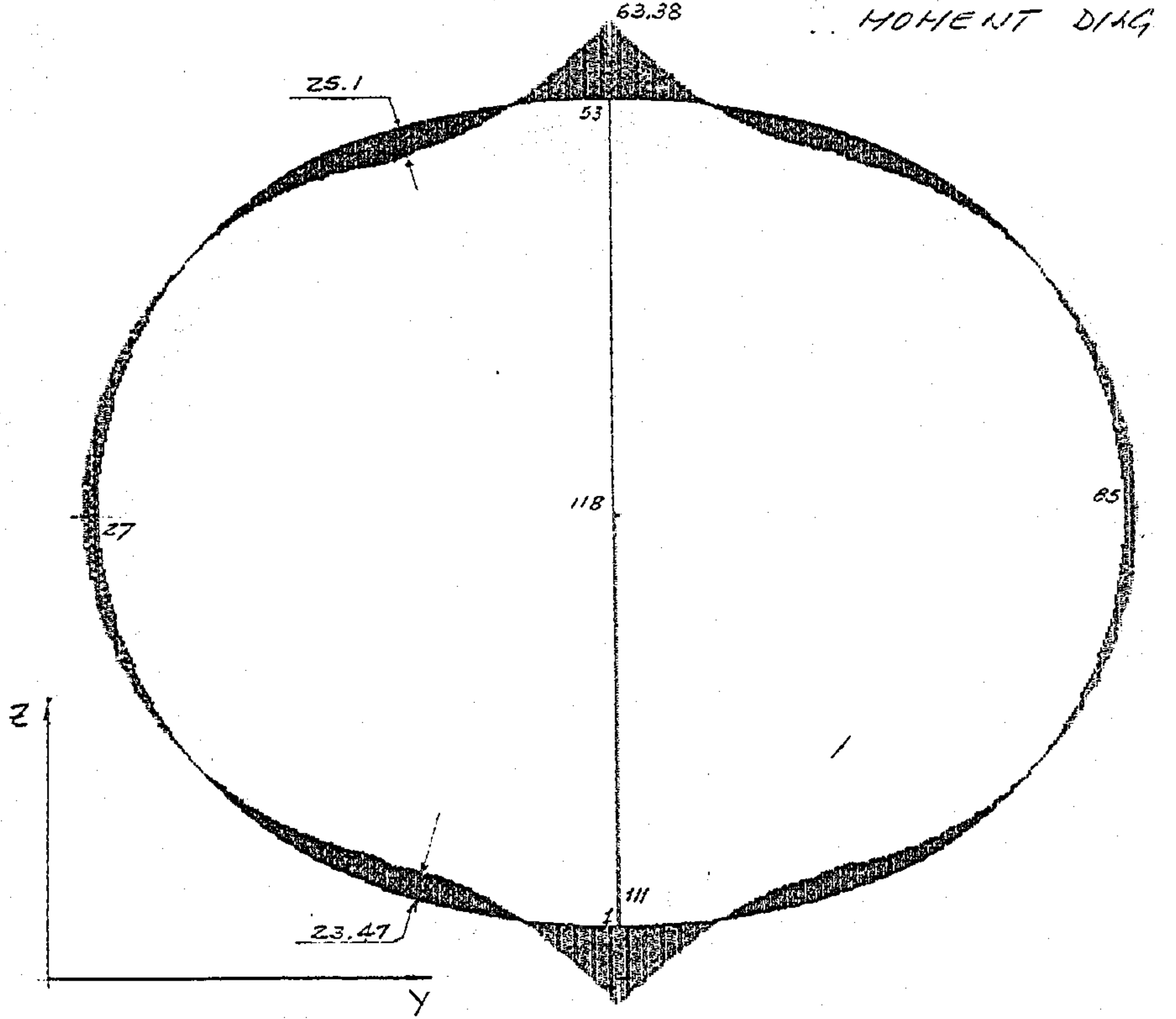


INLET SHAFT, SECTION B - B

CONGUILLO INLET STRUCTURE

CONGUILLO SHAFT SECTION B - B

.. MOMENT DIAG



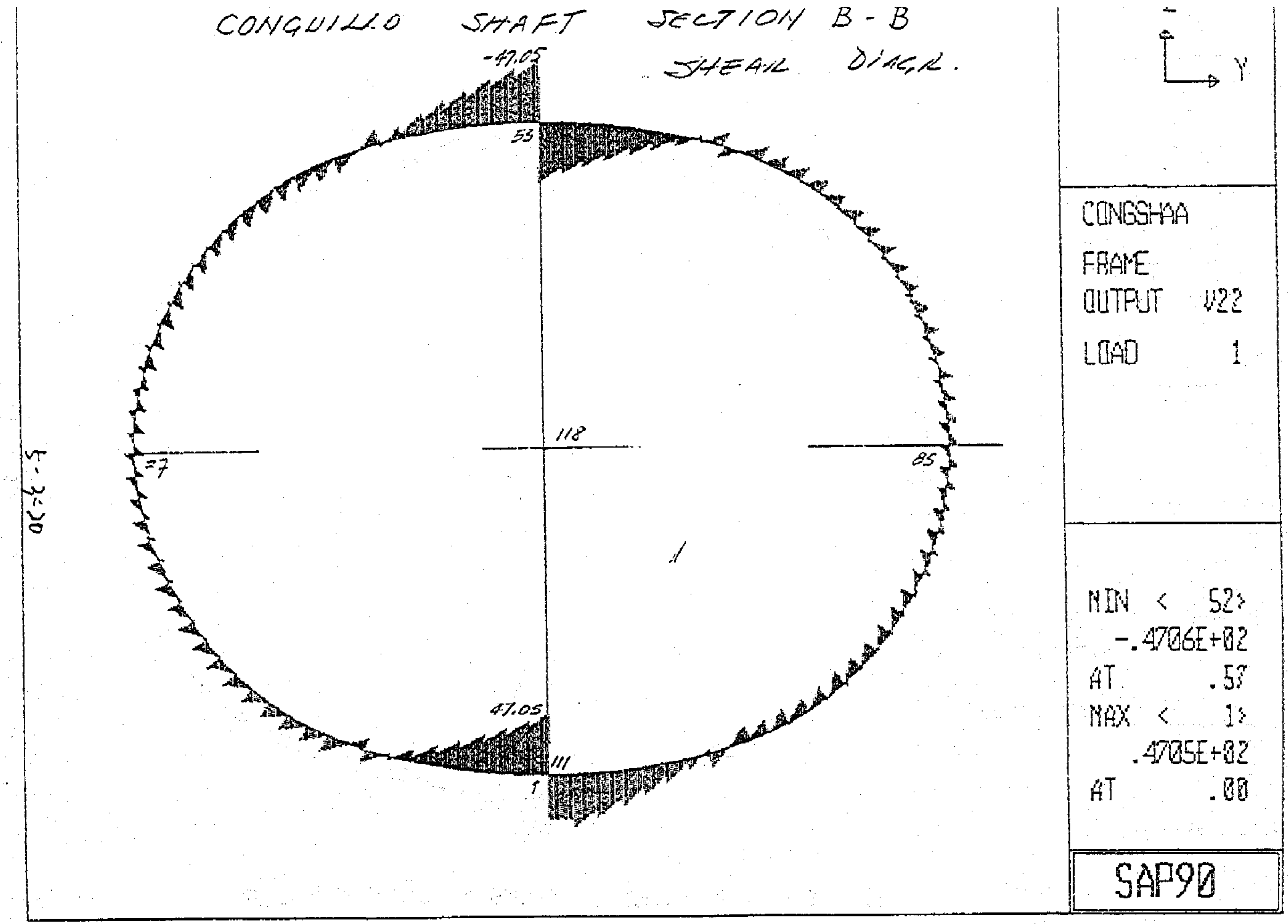
Z
Y

CONGSHAA
FRAME
OUTPUT M33
LOAD 1

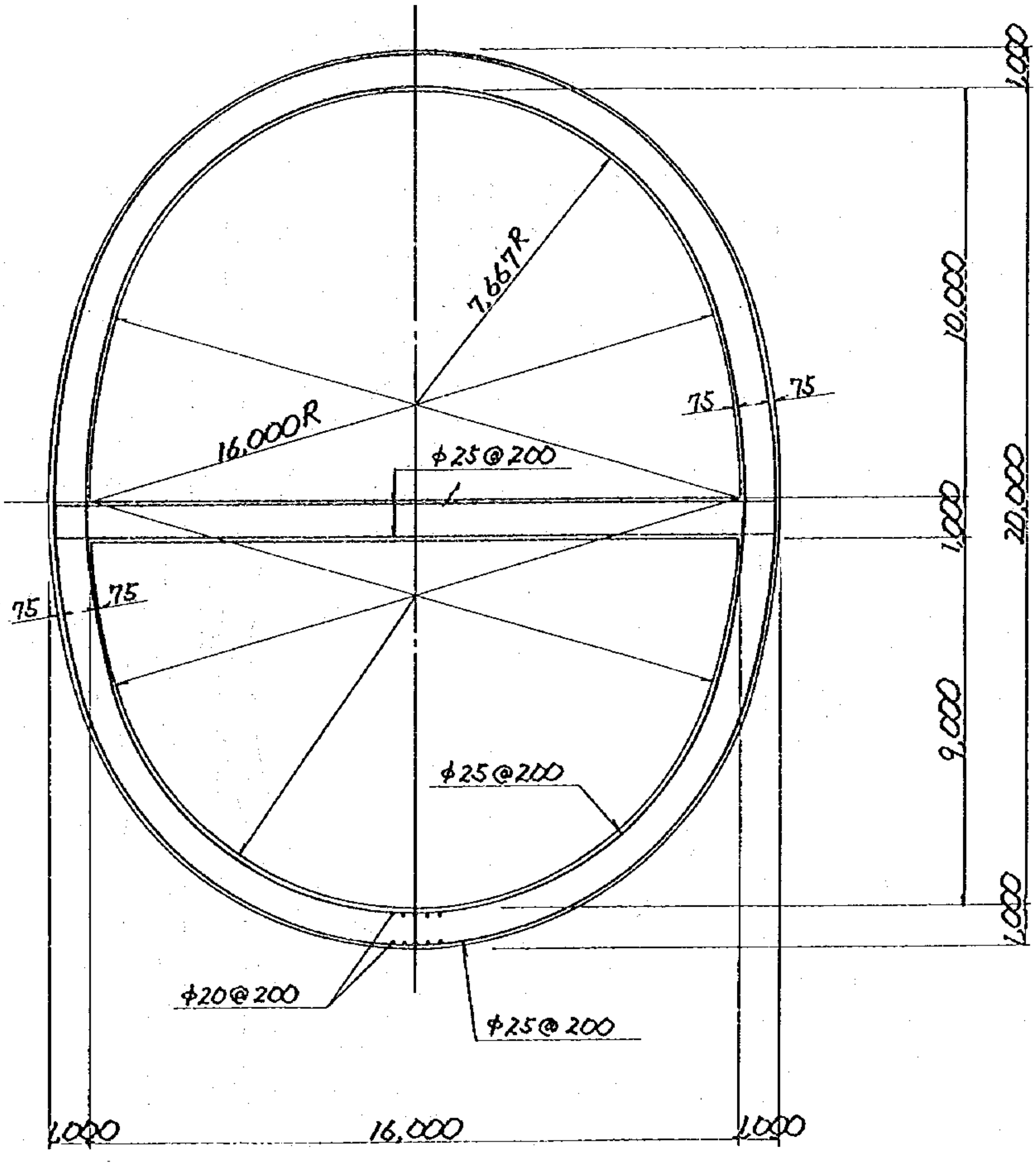
MIN < 52>
-.6443E+02
AT .57
MAX < 45>
.2540E+02
AT .16

SAP90

5-3-19



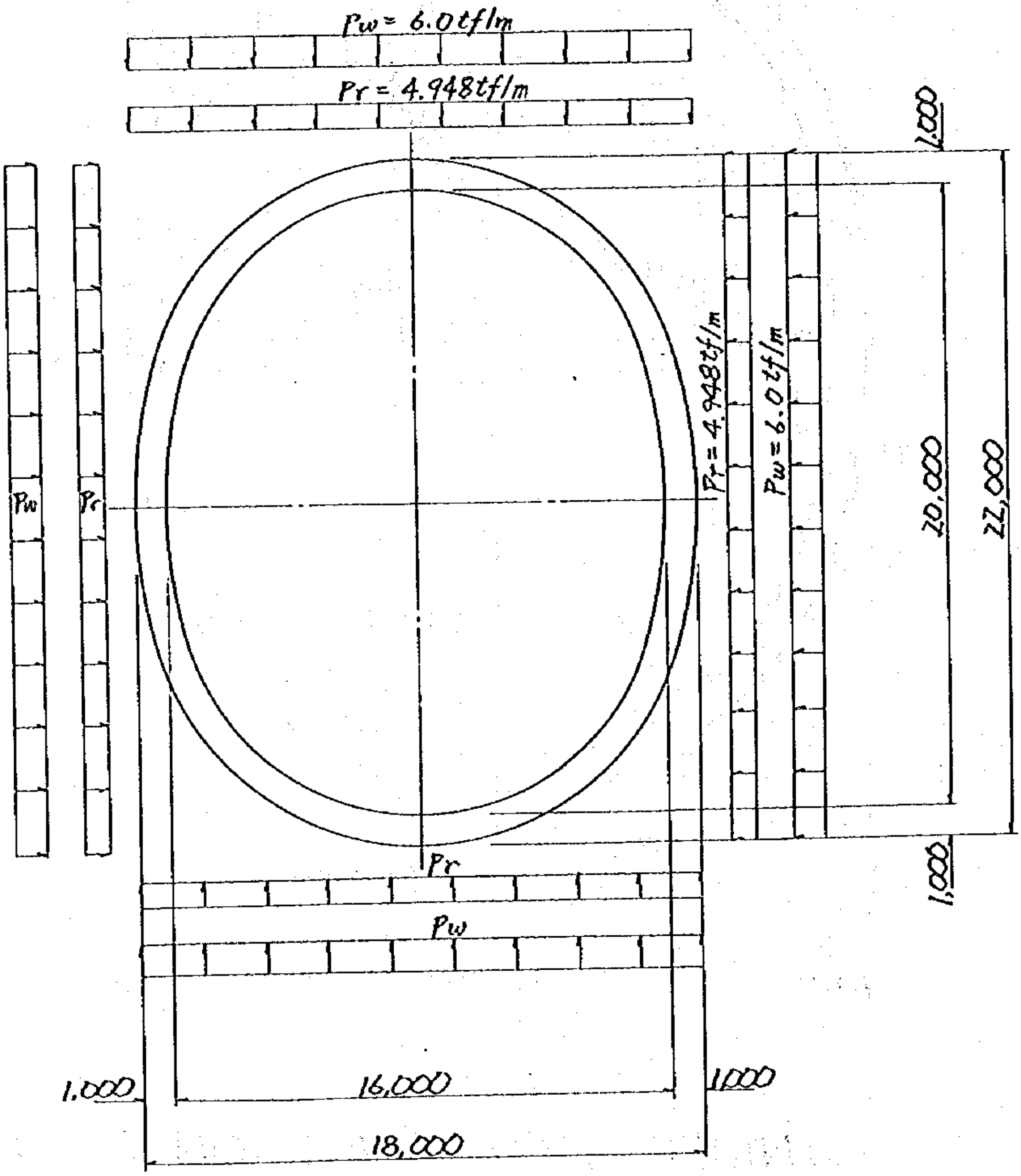
CONGUILLO SHAFT SECTION B - B
SHEAR DIAGR.
-47.05
53
118
27
85
47.05
111
1
5-3-90
Y
CONGSHAA
FRAME
OUTPUT V22
LOAD 1
MIN < 52>
-.4706E+02
AT .57
MAX < 1>
.4705E+02
AT .00
SAP90



INLET SHAFT, SECTION B - B

CONGUILLO INLET STRUCTURE

5・3-21

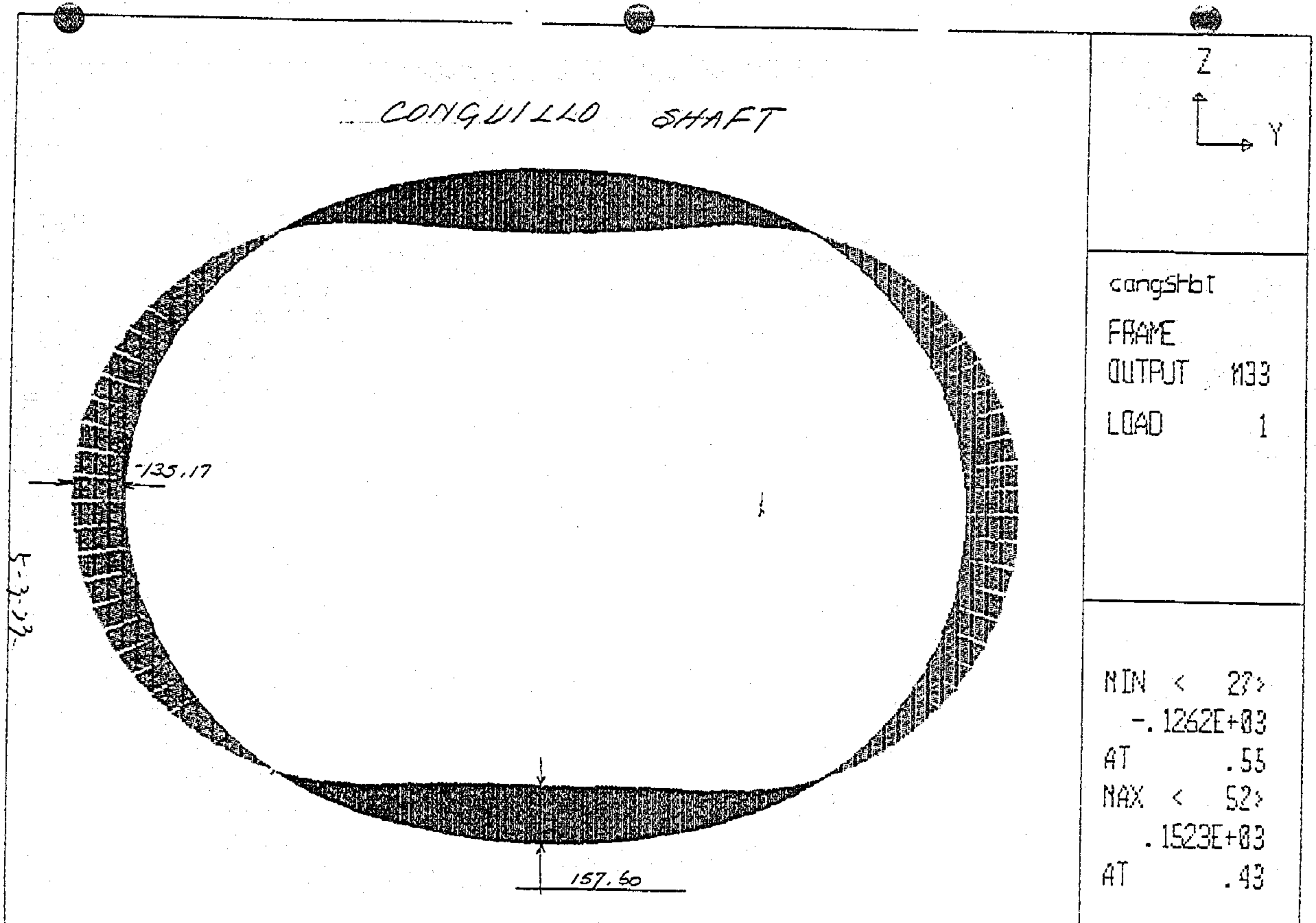


INLET SHAFT, SECTION C - C

CONGUILLO INLET STRUCTURE

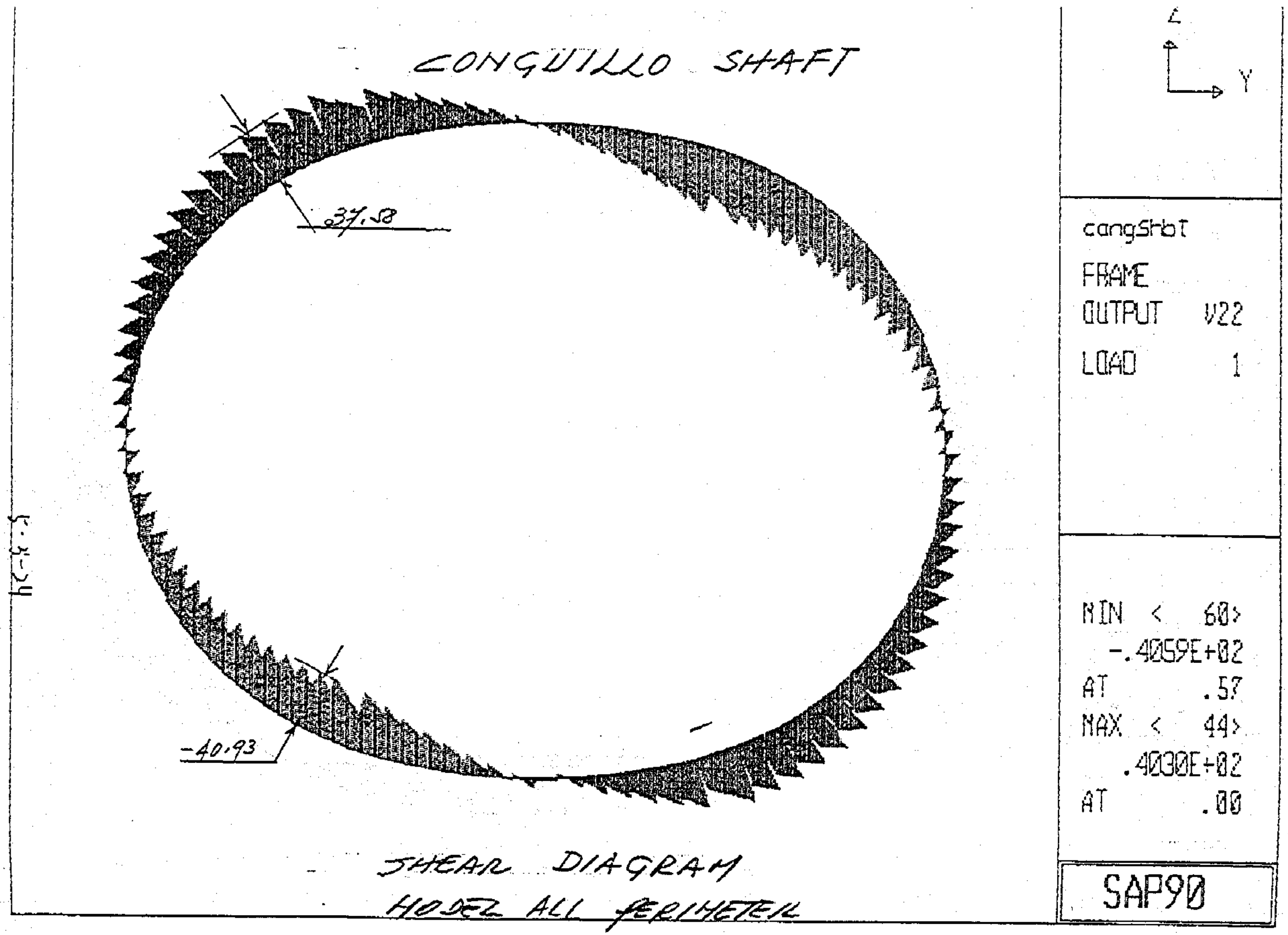
5-3-72

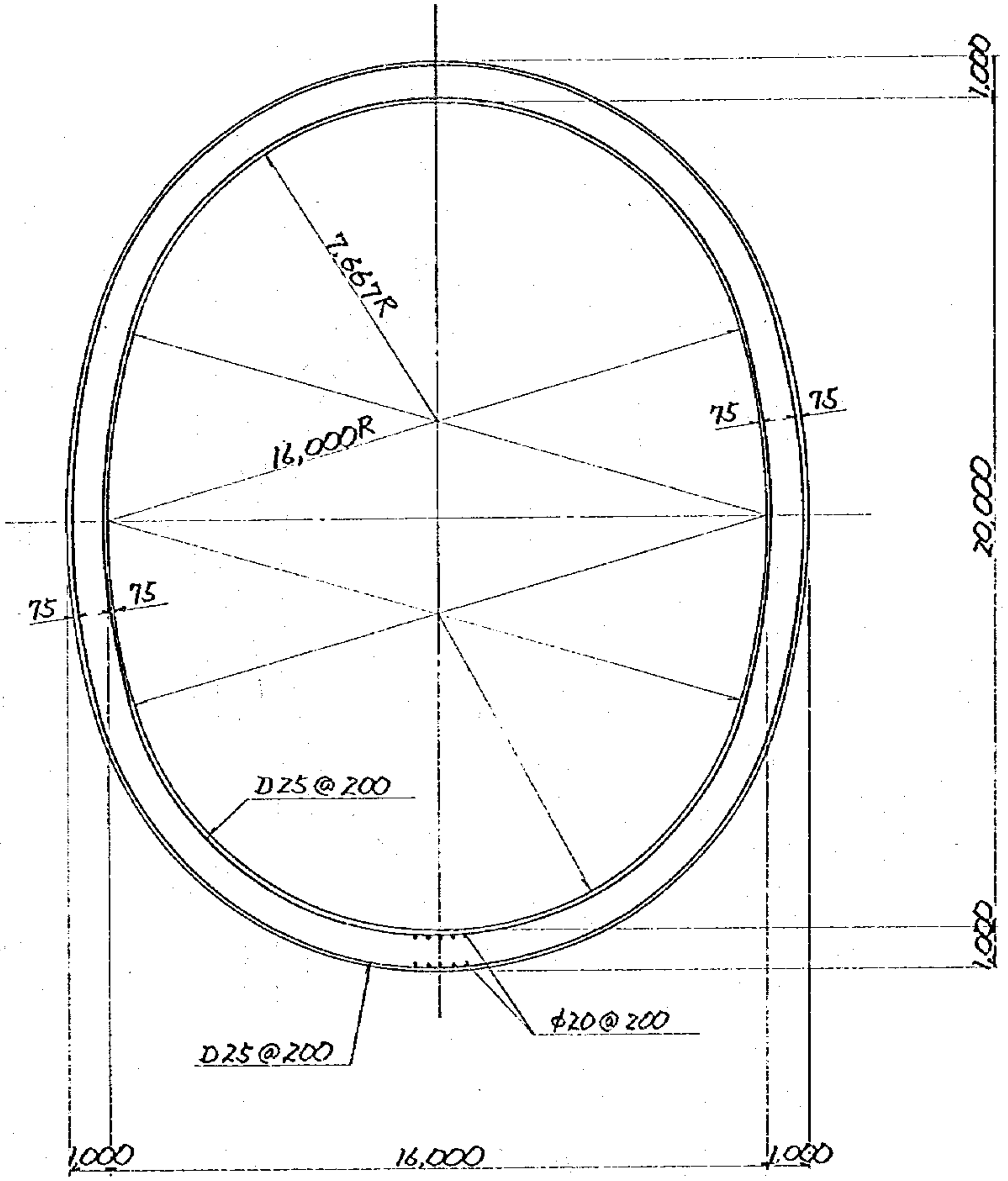
CONGUILLO SHAFT



MOMENT DIAGRAM

MODEL ALL PERIMETER

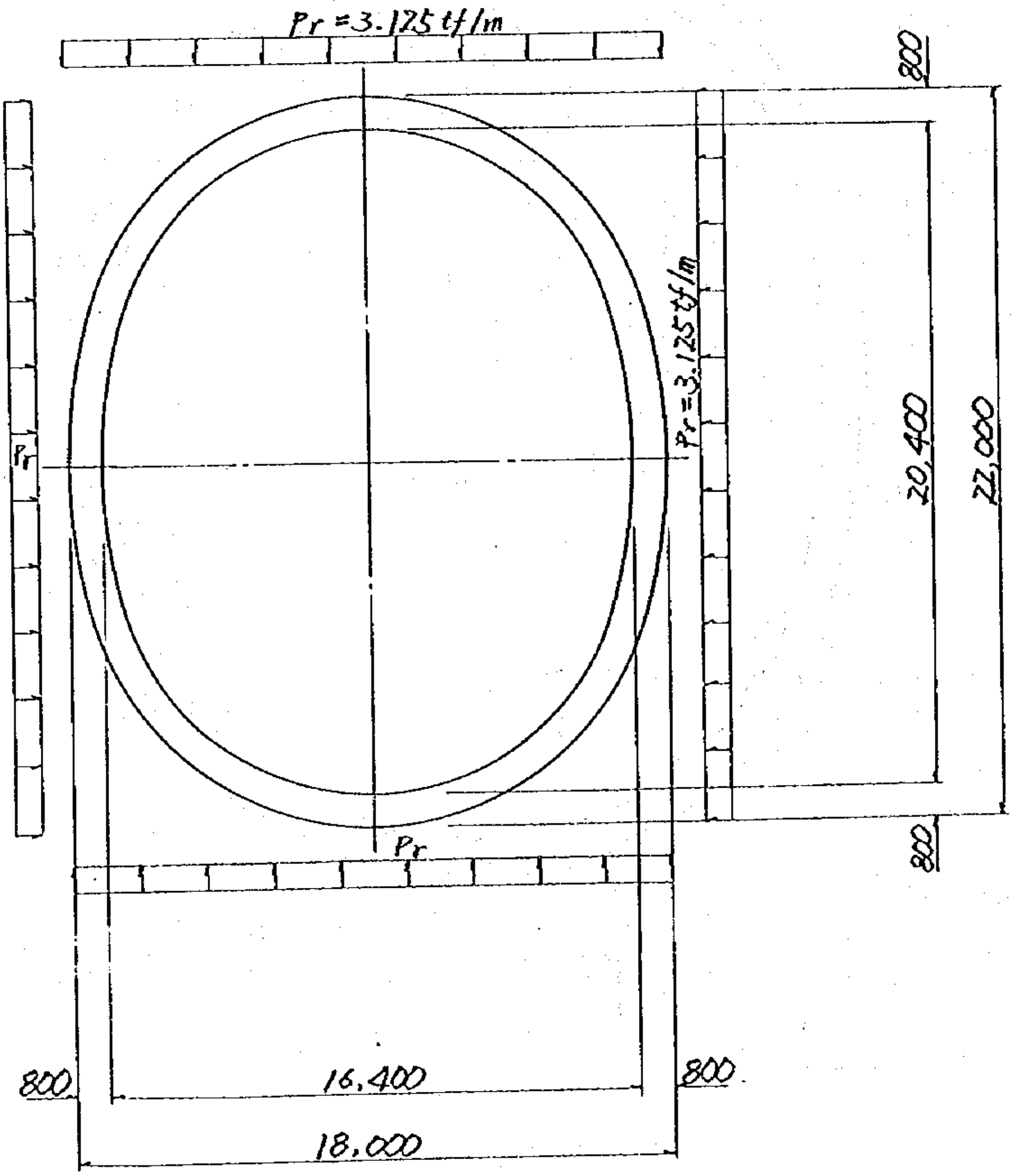

CONGUILLO SHAFT
Z
Y
37.58
-40.93
SHEAR DIAGRAM
MODEL ALL PERIMETER
cangShbT
FRAME
OUTPUT V22
LOAD 1
MIN < 60>
-.4059E+02
AT .57
MAX < 44>
.4030E+02
AT .00
SAP90
5-3-24



INLET SHAFT, SECTION C - C

CONGUILLO INLET STRUCTURE

5·3-75

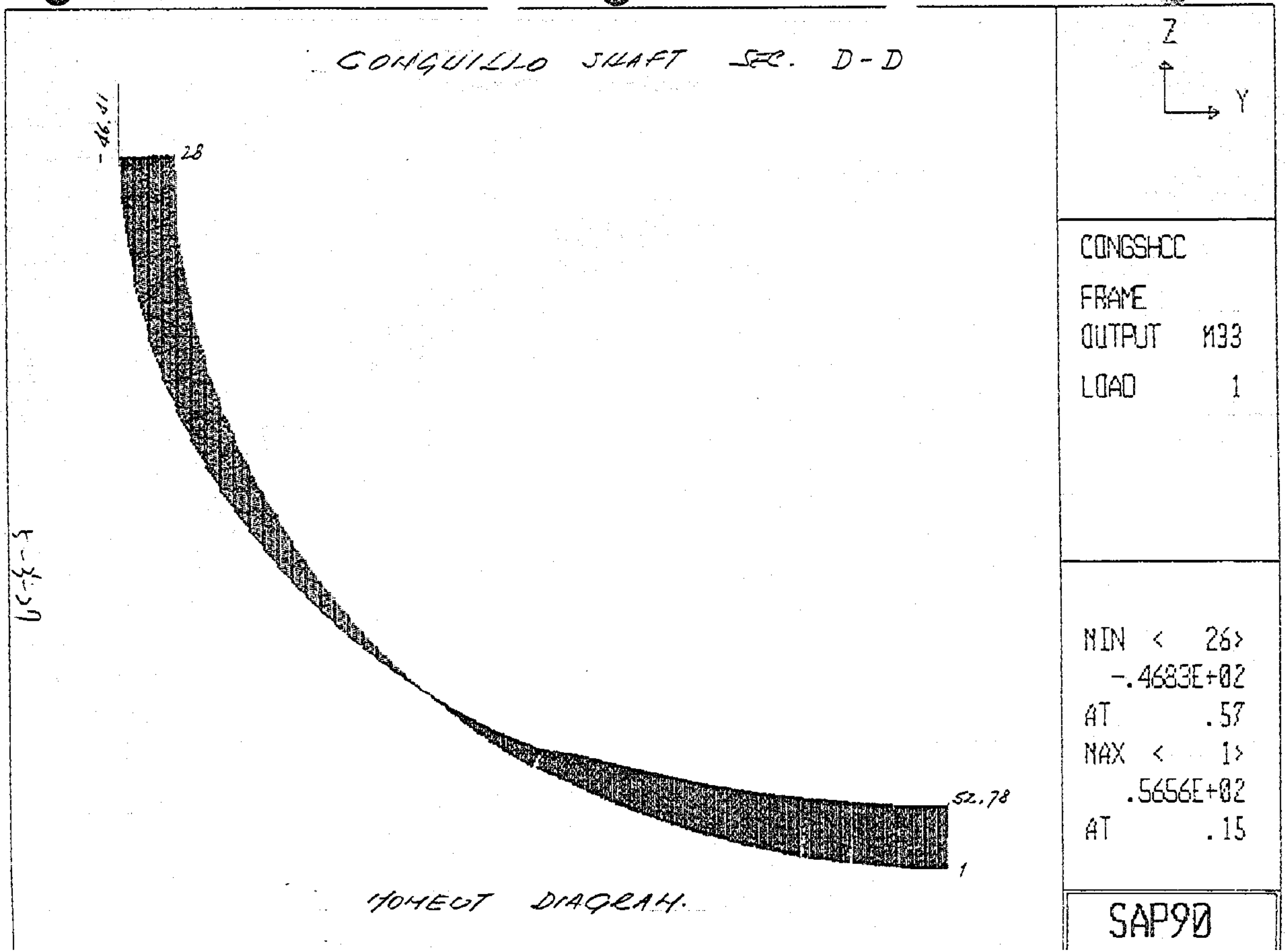


INLET SHAFT, SECTION D - D

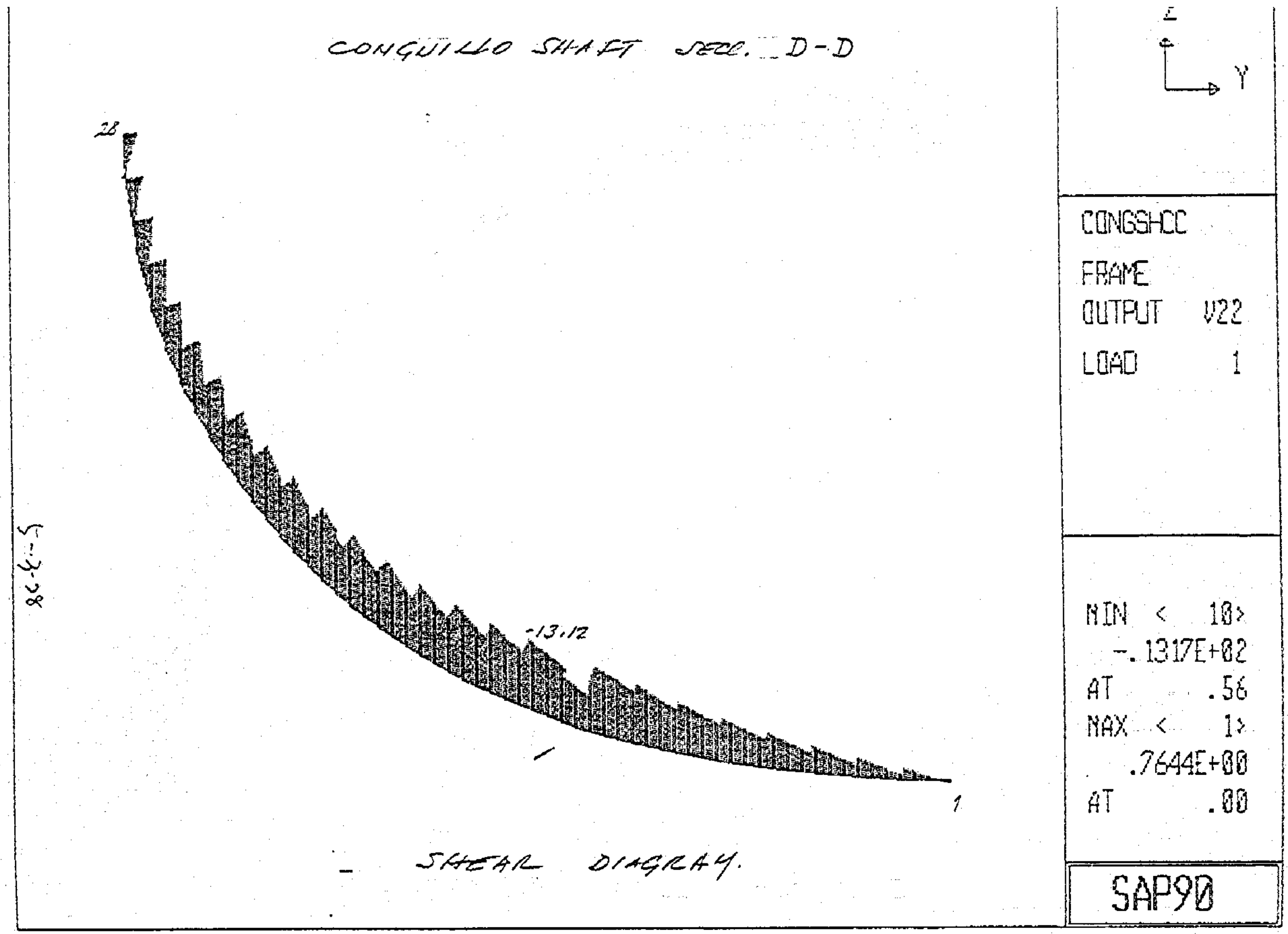
CONGUILLO INLET STRUCTURE

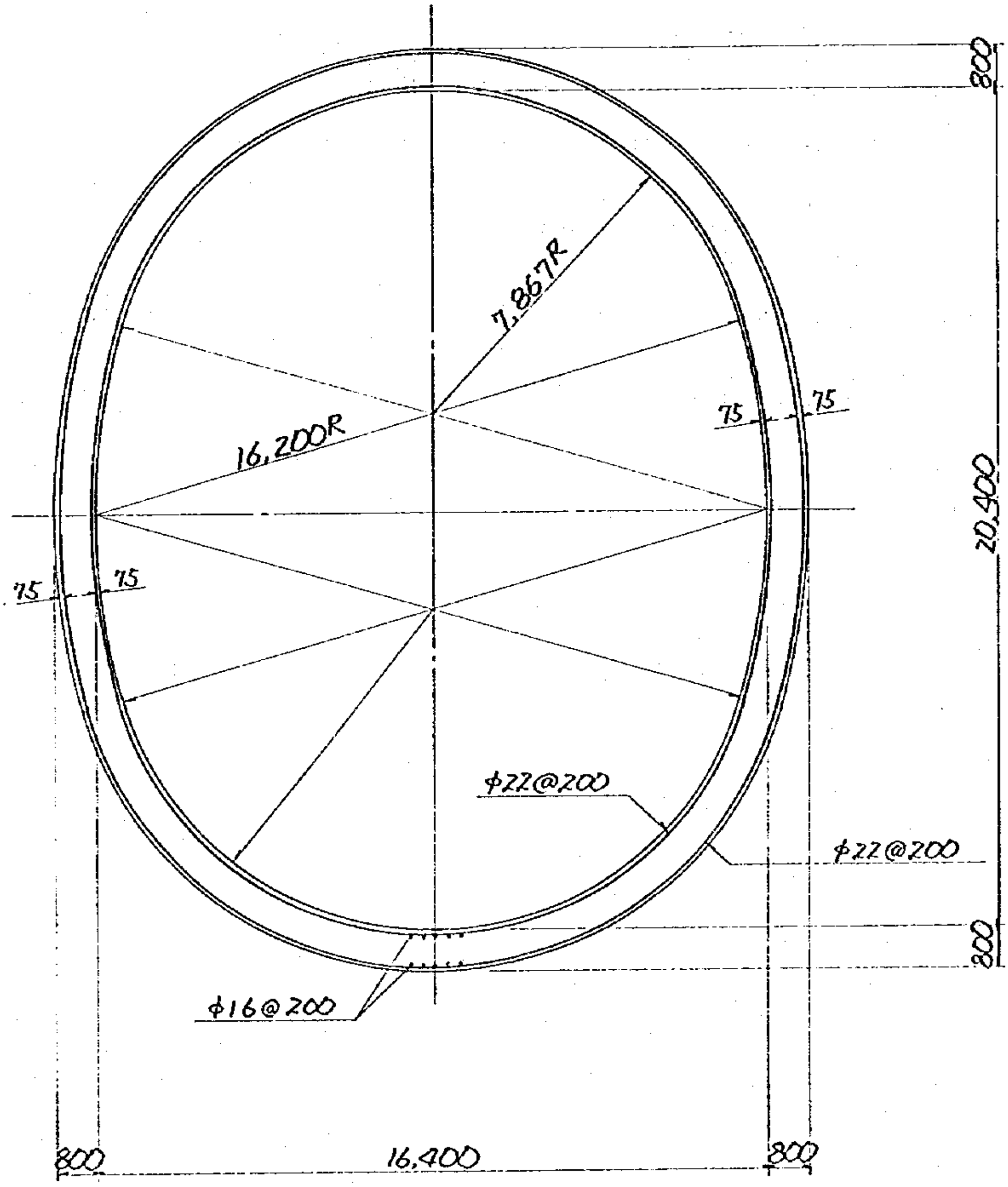
5-3-26

CONGUILLO SHAFT SEC. D-D



MOMENT DIAGRAM.


CONGUILLO SHAFT SECC. D-D
Z
Y
28
-13.12
1
SHEAR DIAGRAM.
5-3-98
CONGSHCC
FRAME
OUTPUT V22
LOAD 1
MIN < 10>
-.1317E+02
AT .56
MAX < 1>
.7644E+00
AT .00
SAP90



INLET SHAFT, SECTION D - D

CONGUILLO INLET STRUCTURE

5-3-29

(C) Inlet Transition

Case 1 : During construction

1) Dead weight of lining concrete

Wc = 0.8 x 2.4 = 1.92 tf/m

2) Vertical bedrock pressure, water pressure and backfill grout pressure

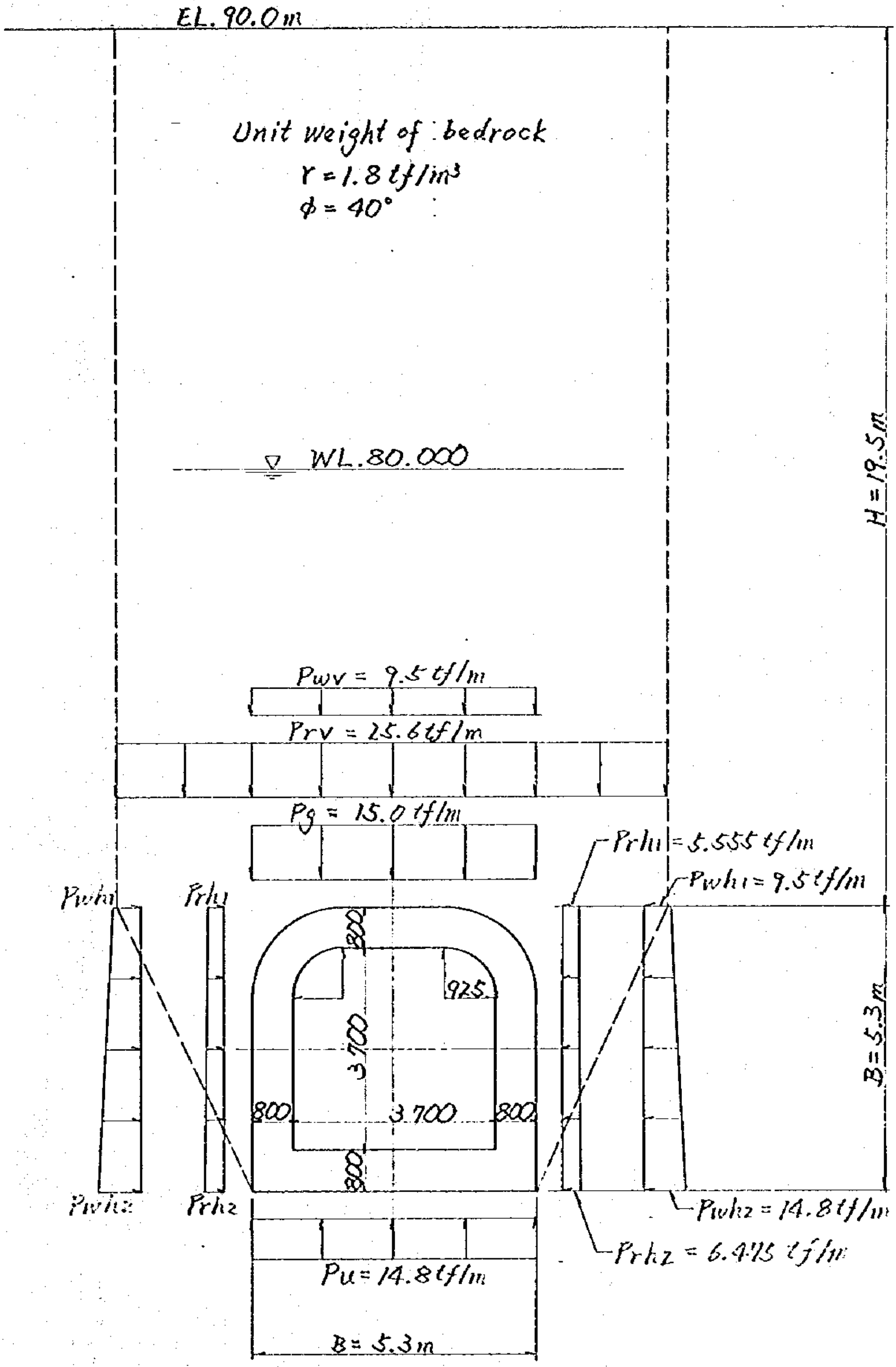
Pr = 1.8 x 10.0 + (1.8 -1.0) x 9.5 = 25.6 tf/m
Pw = 1.0 x (El.80.0 - El.70.5) = 9.5 tf/m
Pg= 15.0 tf/m

3) Lateral water pressure

Pw1 = 1.0 x 9.5 = 9.5 tf/m
Pw2 = 1.0 x 14.8 = 14.8 tf/m

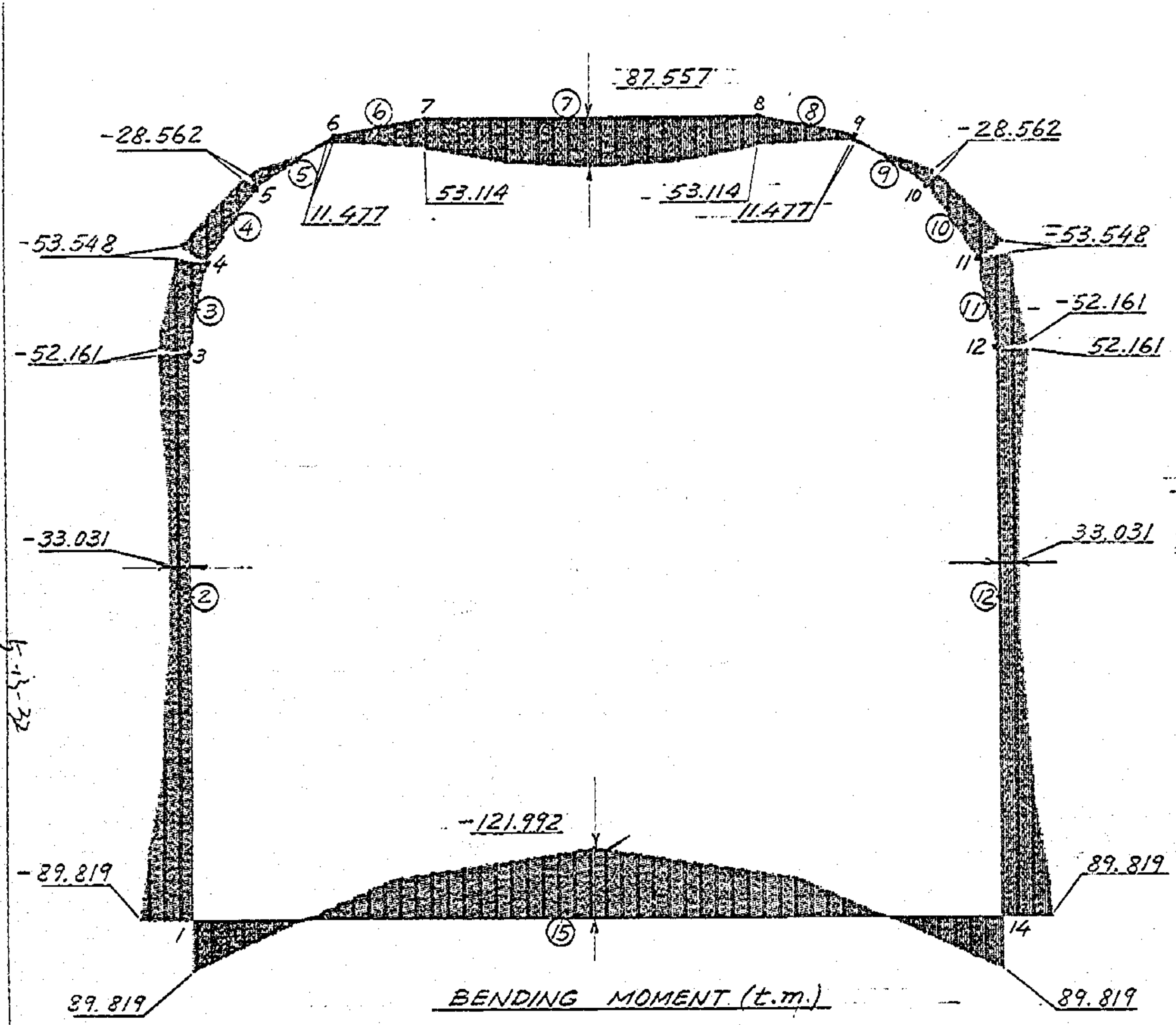
4) Uplift pressure

Pu = 1.0 x 14.8 = 14.8 tf/m



CONGUILLO INLET (TRANSITION)

DAULE-PERIPA ~ LA ESPERANZA TUNNEL



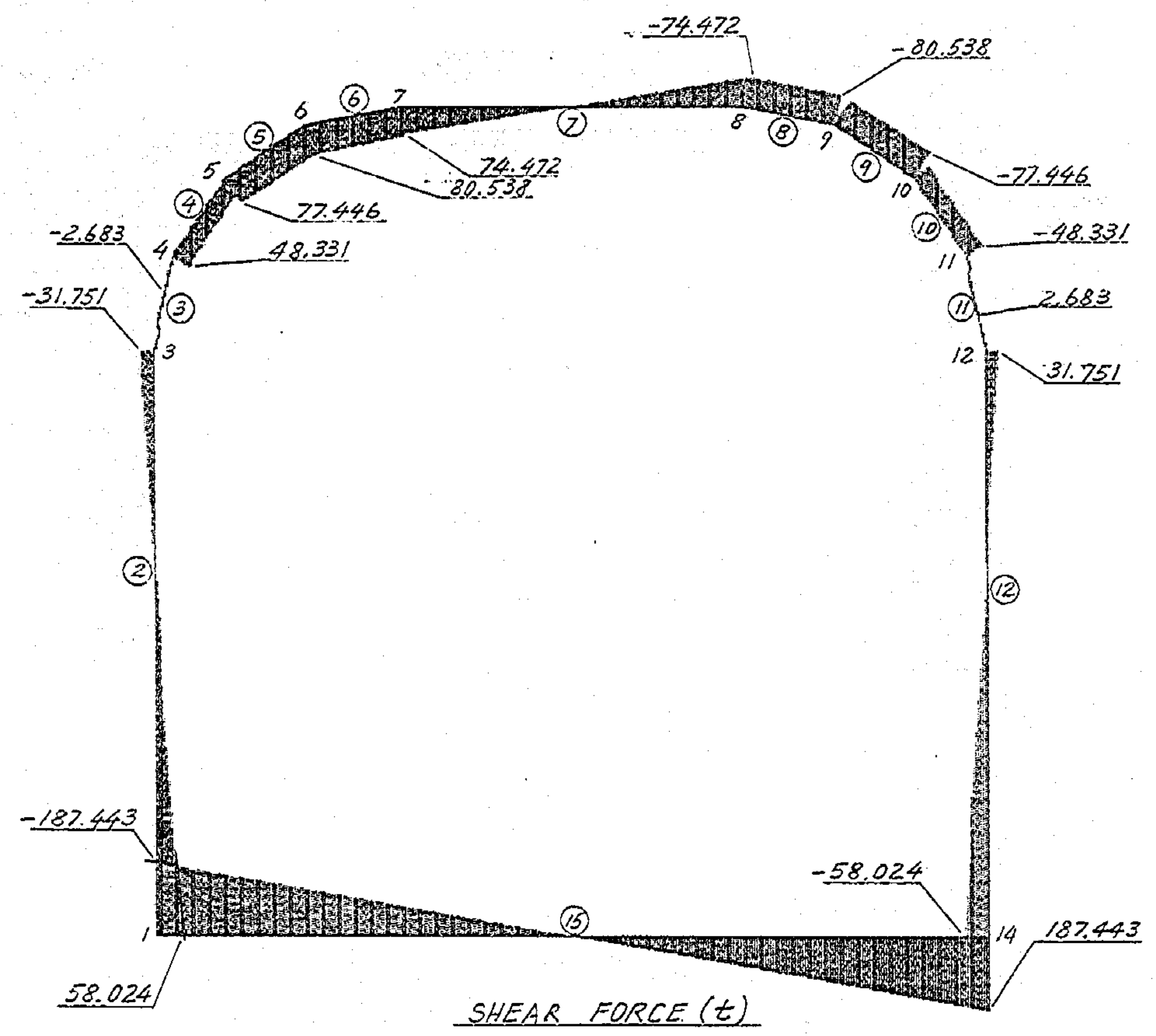
BENDING MOMENT (t.m.)

DAULEPE
FRAME
OUTPUT M33
LOAD 1

CASE 2
DURING CONSTRUCTION

MIN < 15>
-.1220E+03
AT 2.24
MAX < 13>
.8986E+02
AT .00

SAP90



DAULEPE
FRAME
OUTPUT V22
LOAD 1

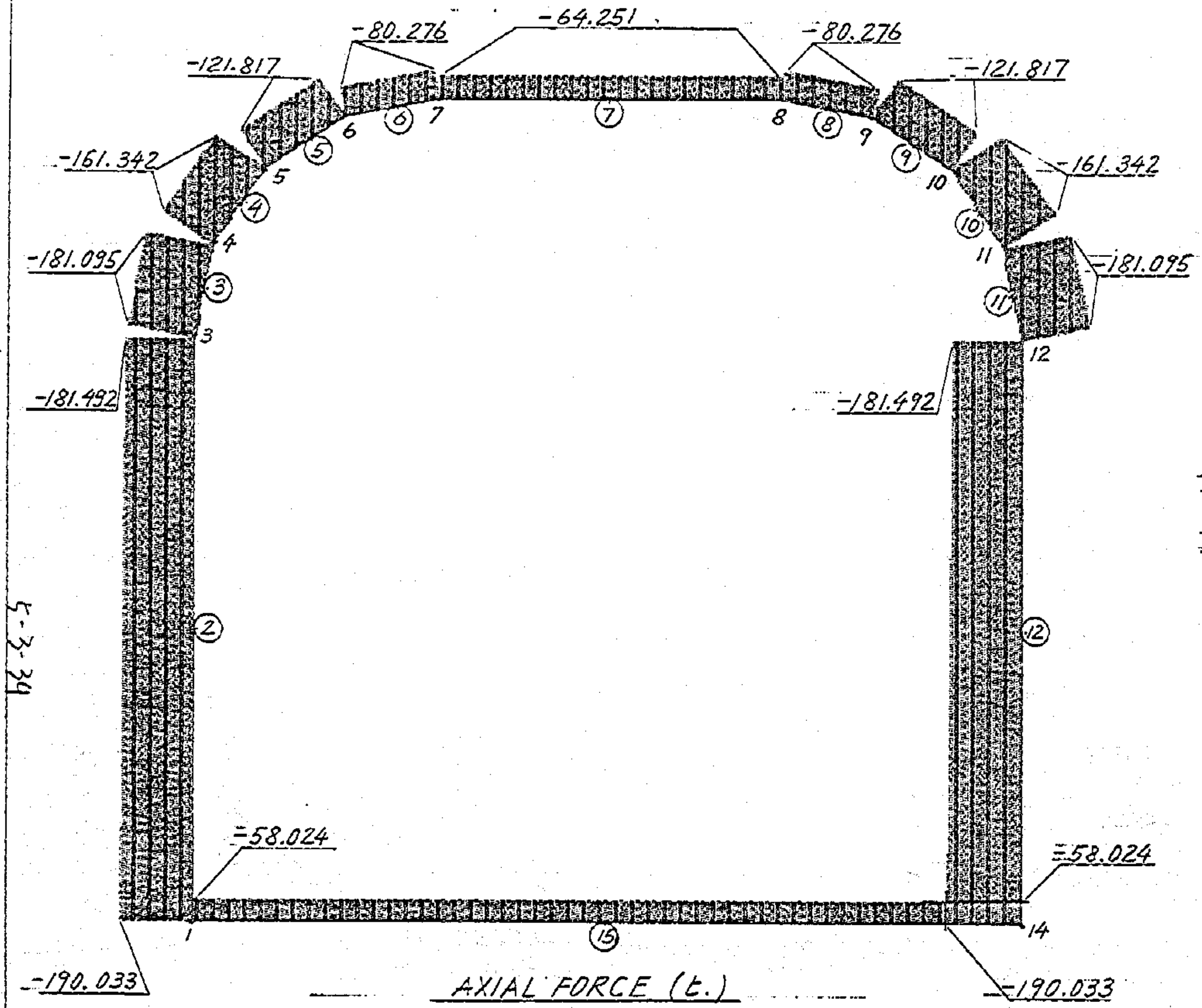
CASE 2

DURING CONSTRUCTION

MIN < 15>
-.1874E+03
AT .00
MAX < 14>
.1875E+03
AT .00

SAP90

5. 3-33



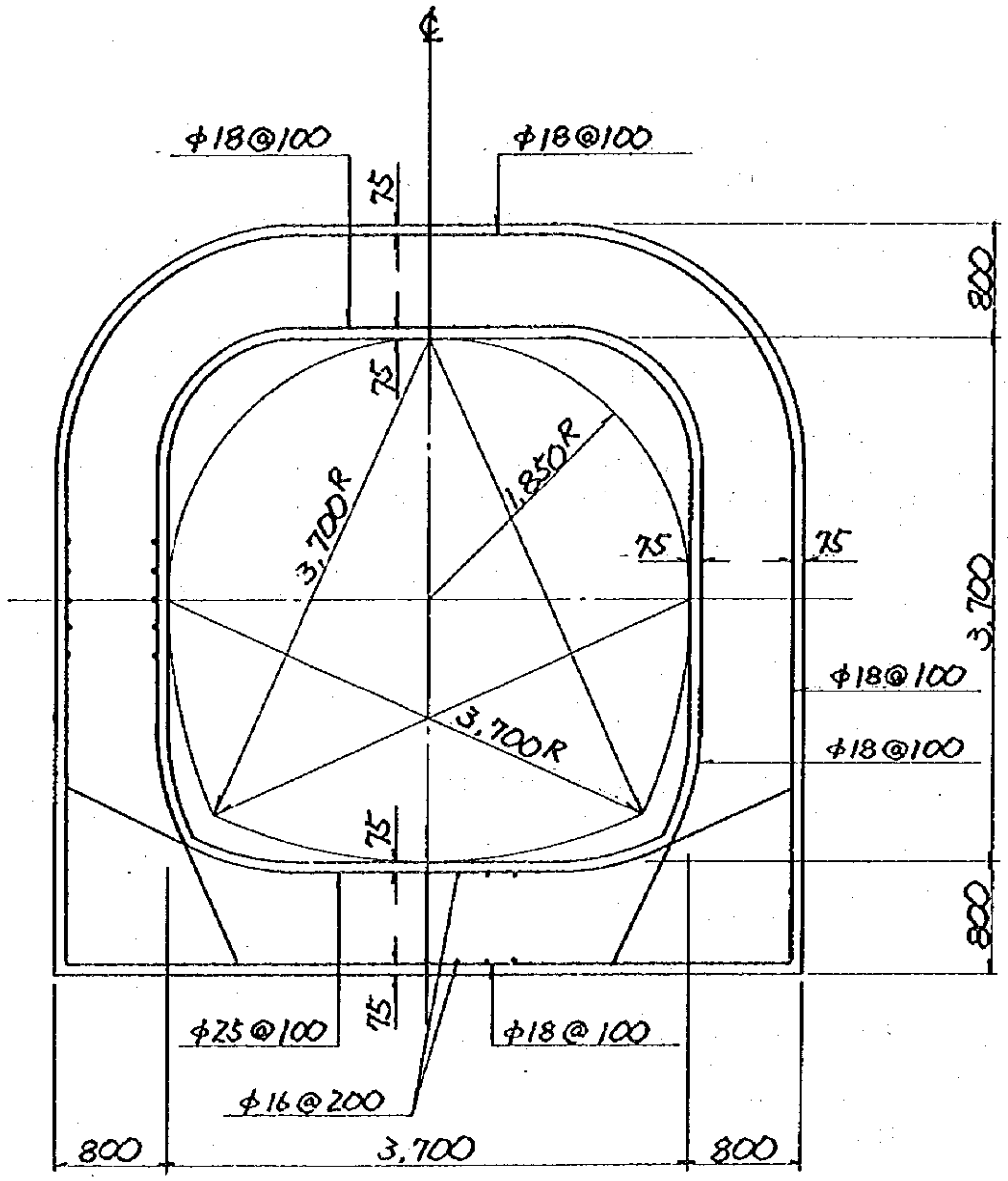
AXIAL FORCE (t.)

DAULEPE
FRAME
OUTPUT P
LOAD 1

CASE 2
DURING CONSTRUCTION

MIN < 1>
-.1901E+03
AT .00
MAX < 14>
-.5805E+02
AT .00

SAP90



CONGUILLO INLET (TRANSITION)

DAULE - PERIPA ~ LA ESPERANZA TUNNEL

5-3-35

(2) Membrilo Outlet

(A) Transition

Case 1 : After construction

1) Dead weight of lining concrete

Wc = 0.5 x 2.4 = 1.2 tf/m

2) Vertical bedrock pressure

Pr = 1.7 x 5.3 = 9.01 tf/m

3) Lateral bedrock pressure and water pressure

Ka = tan2(45 - 35/2) = 0.271
Prh1 = 0.271 x 1.7 x 5.3 = 2.442 tf/m
Prh2 = 0.271 x 1.7 x 5.3 + 0.271 x (1.7 -1.0) x 4.7 = 3.333 tf/m
Pw = 1.0 x 4.4 = 4.4 tf/m

4) Uplift pressure

Pu = 1.0 x 4.4 = 4.4 tf/m

5) Foudation reaction

Pf = (9.01 x 4.7 + 20.079)/4.7 - 4.4 = 8.882 tf/m

Case 2 : During construction

1) Dead weight of lining concrete

Wc = 0.5 x 2.4 = 1.2 tf/m

2) Vertical bedrock pressure and backfill grout pressure

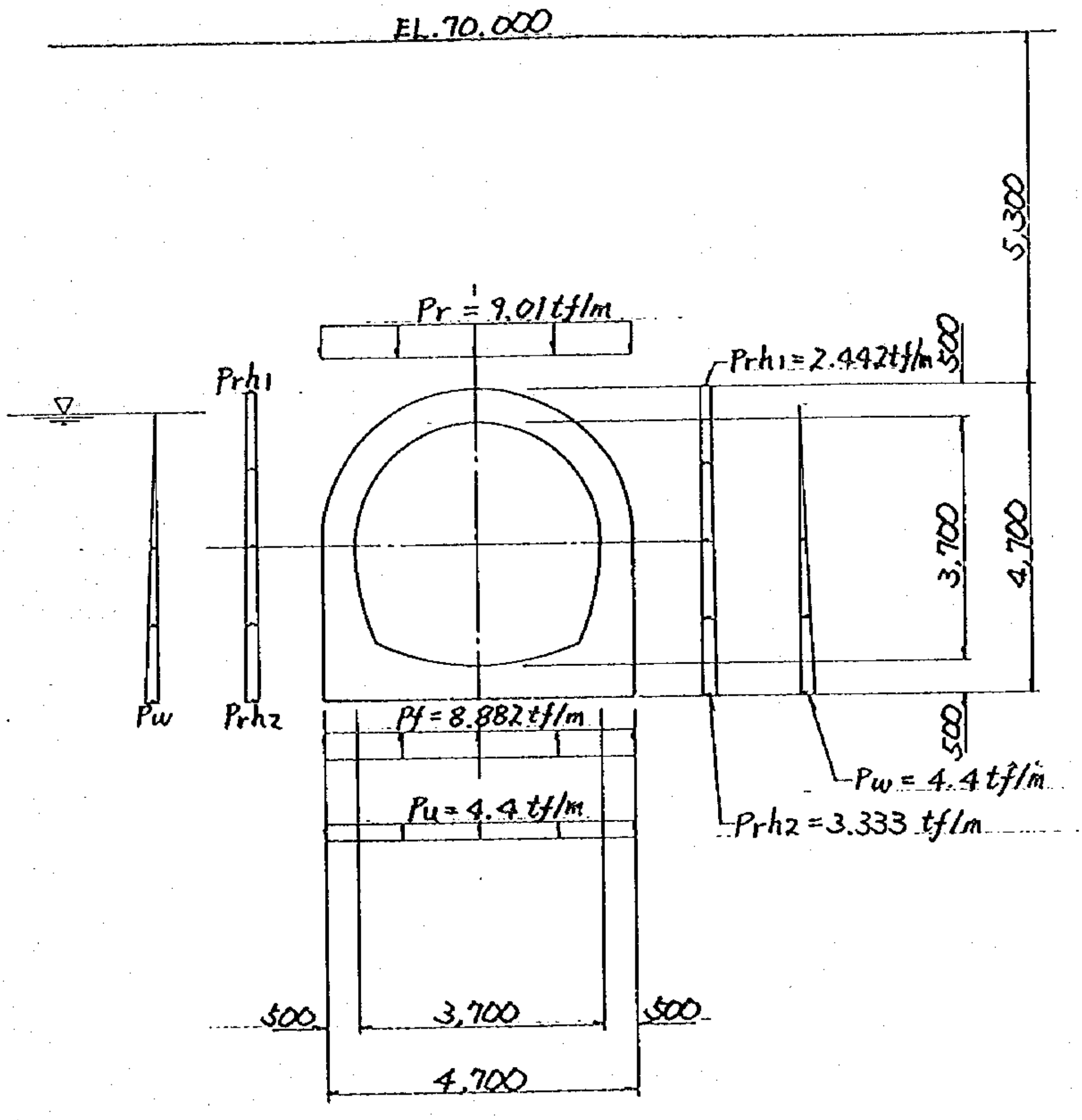
Pr = 1.7 x 5.3 = 9.01 tf/m
Pg = 15.0 tf/m

3) Lateral bedrock pressure

Ka = tan2(45 - 35/2) = 0.271
Prh1 = 0.271 x 1.7 x 5.3 = 2.442 tf/m
Prh2 = 0.271 x 1.7 x 10.0 = 4.607 tf/m

4) Foudation reaction

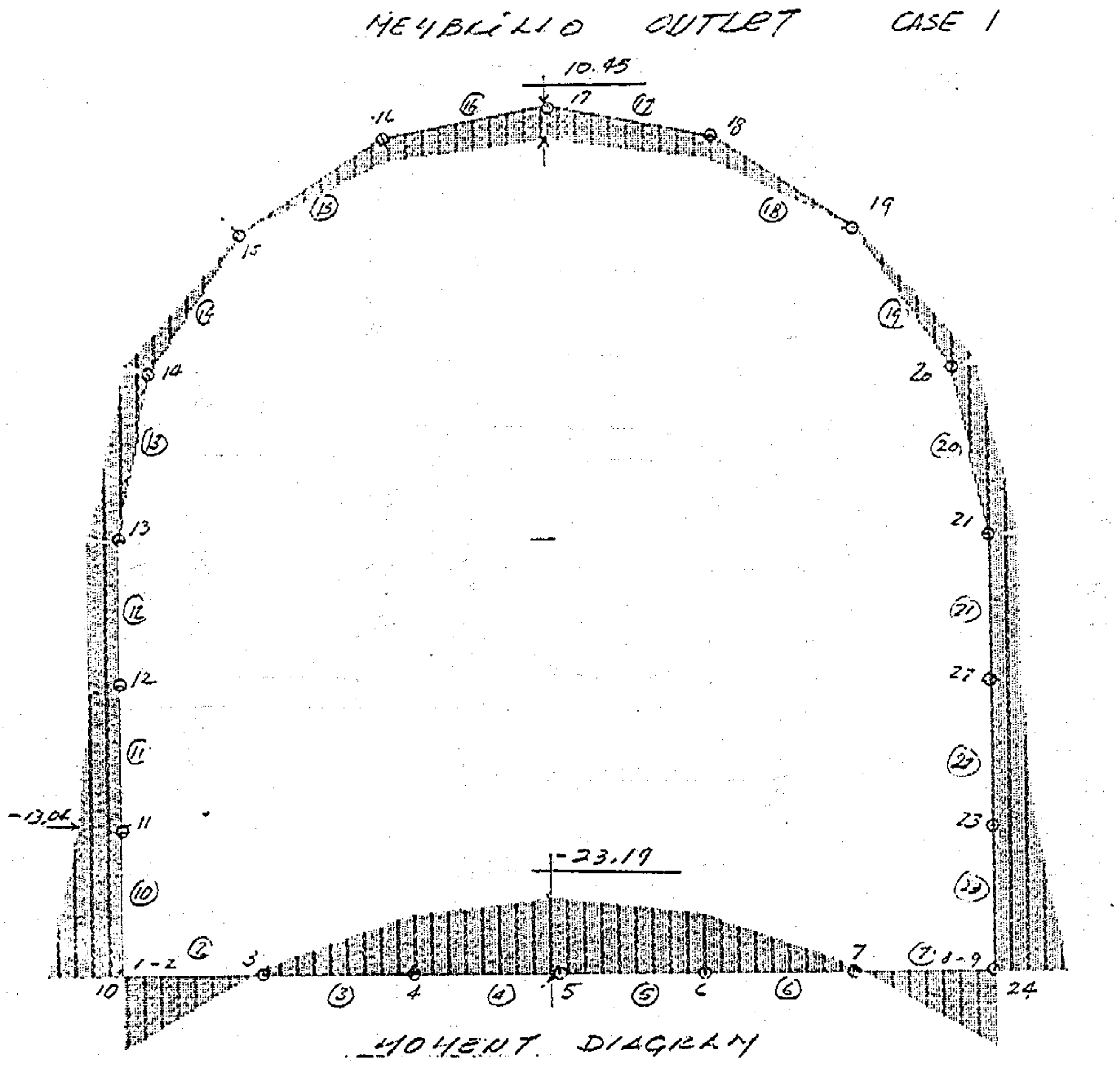
Pf = (9.01 x 4.7 + 15.0 x 4.7 + 20.079)/4.7 = 28.282 tf/m



MEMBRILLO OUTLET (TRANSITION), CASE 1

DAULE-PERIPA ~ LA ESPERANZA TUNNEL

5・3-37

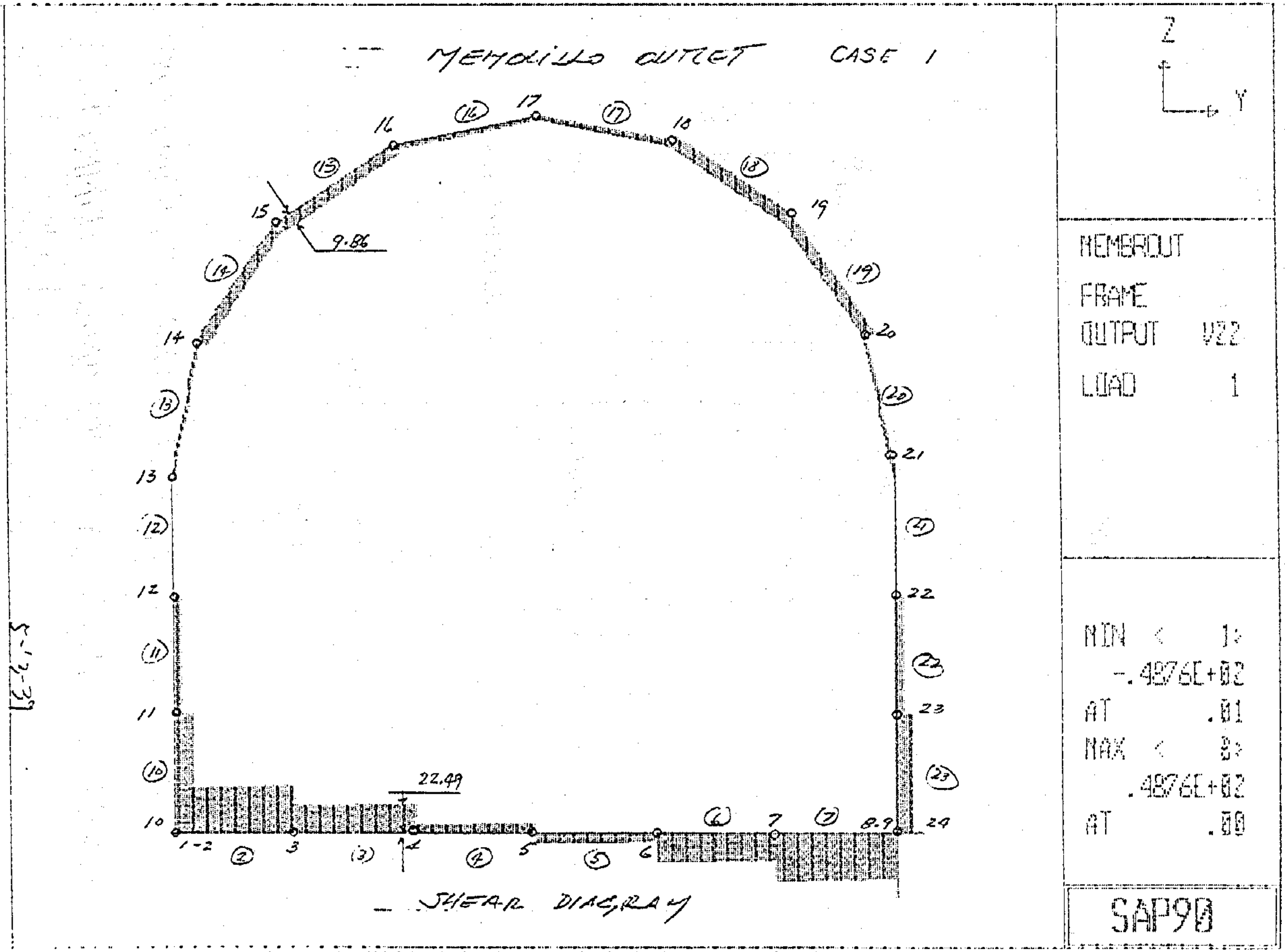


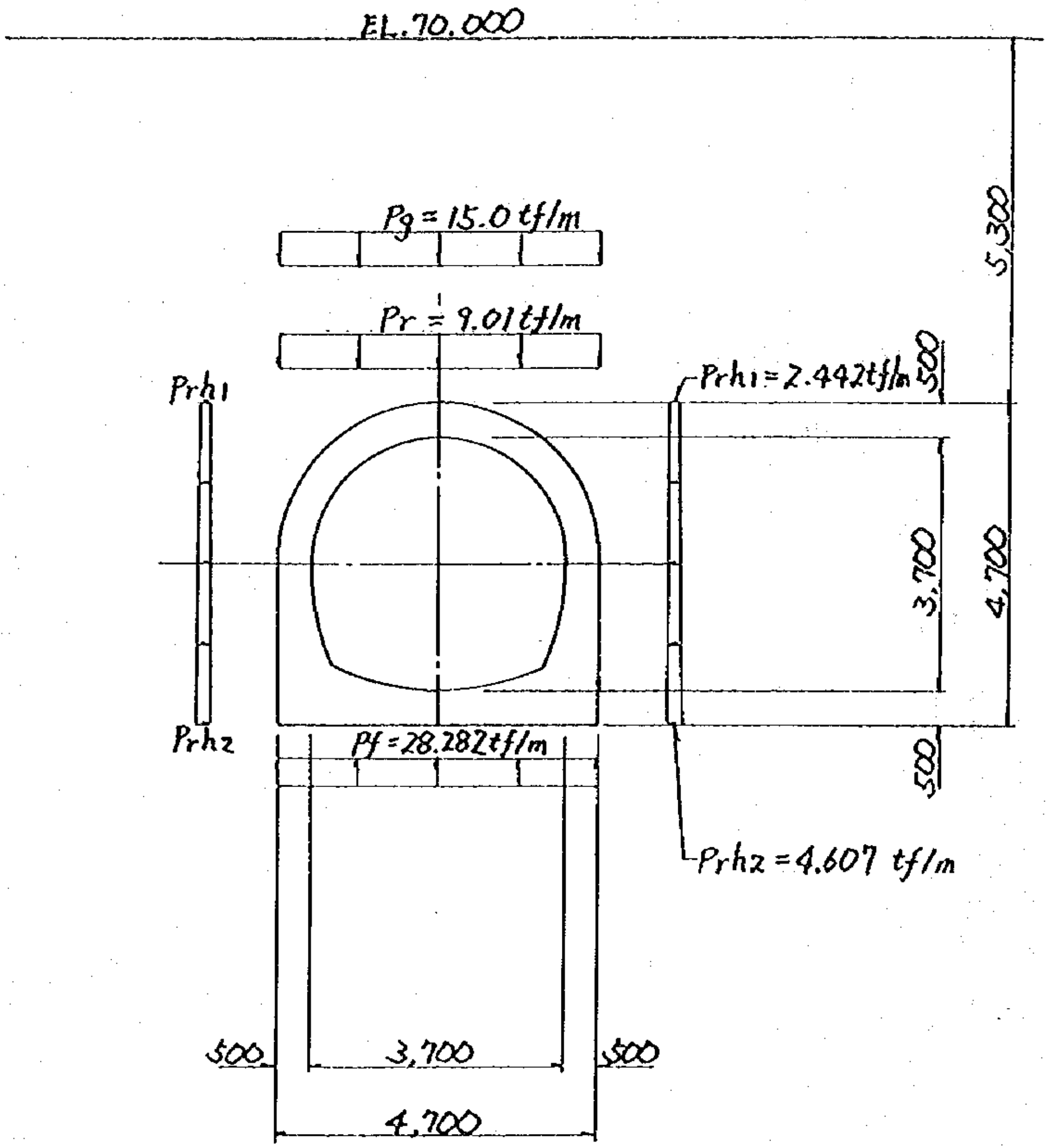
Z
Y

NEMBROUT
FRAME
OUTPUT M33
LOAD 1

MIN < 4>
-.2319E+02
AT .70
MAX < 1>
.2244E+02
AT .00

SAP90

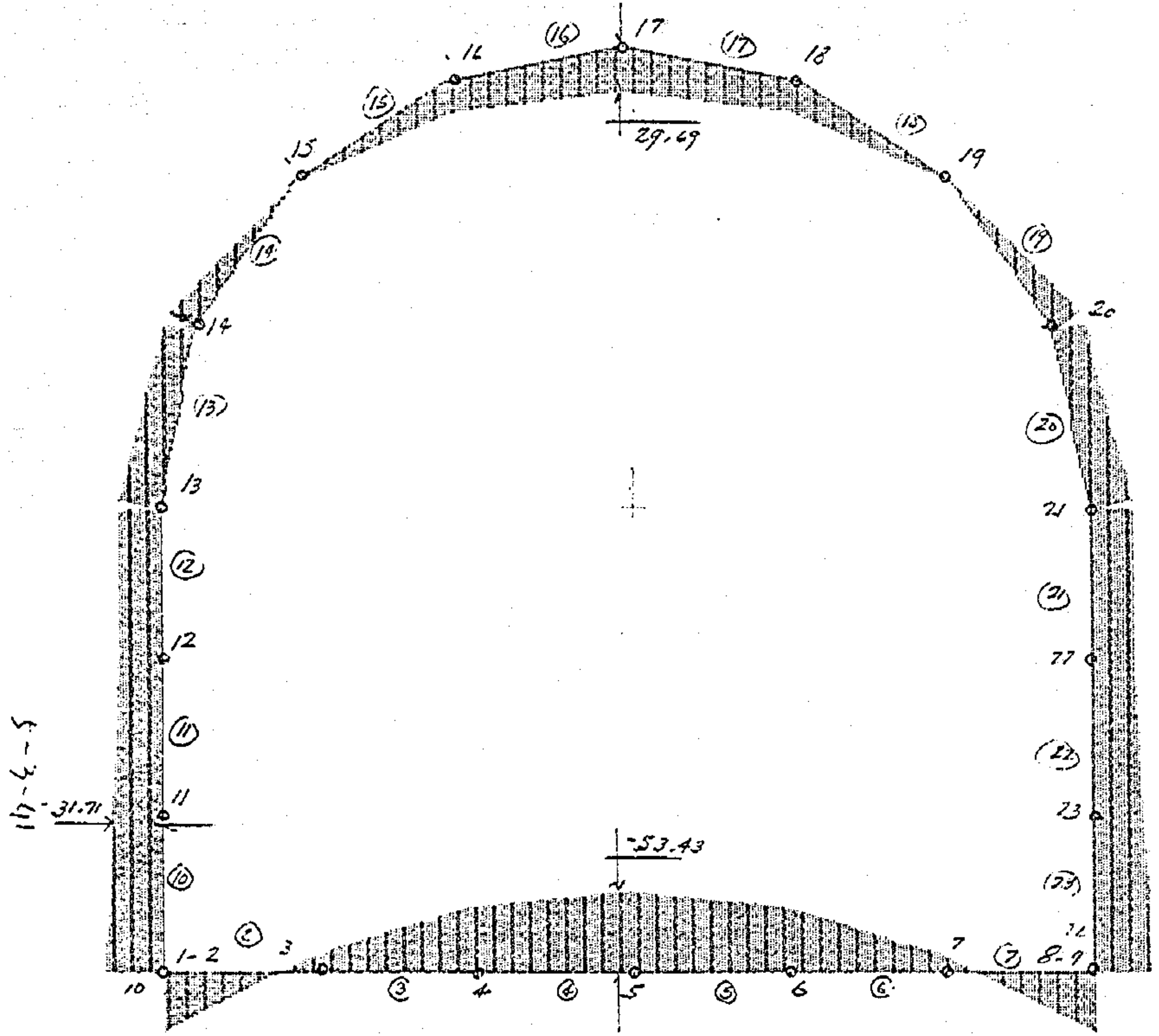

MEMORILLO OUTLET CASE 1
Z
Y
MEMBROUT
FRAME
OUTPUT V22
LOAD 1
MIN < 1>
-.4876E+02
AT .01
MAX < 8>
.4876E+02
AT .00
SAP90
9.86
22.49
- SHEAR DIAGRAM
5-'3-39



MEMBRILLO OUTLET (TRANSITION), CASE 2

DAULE - PERIPA ~ LA ESPERANZA TUNNEL

MEMBRILLO OUTLET CASE 2



MOMENT DIAGRAM

MEMBROU2

FRAME

OUTPUT M33

LOAD 1

MIN (4)

-.5343E+02

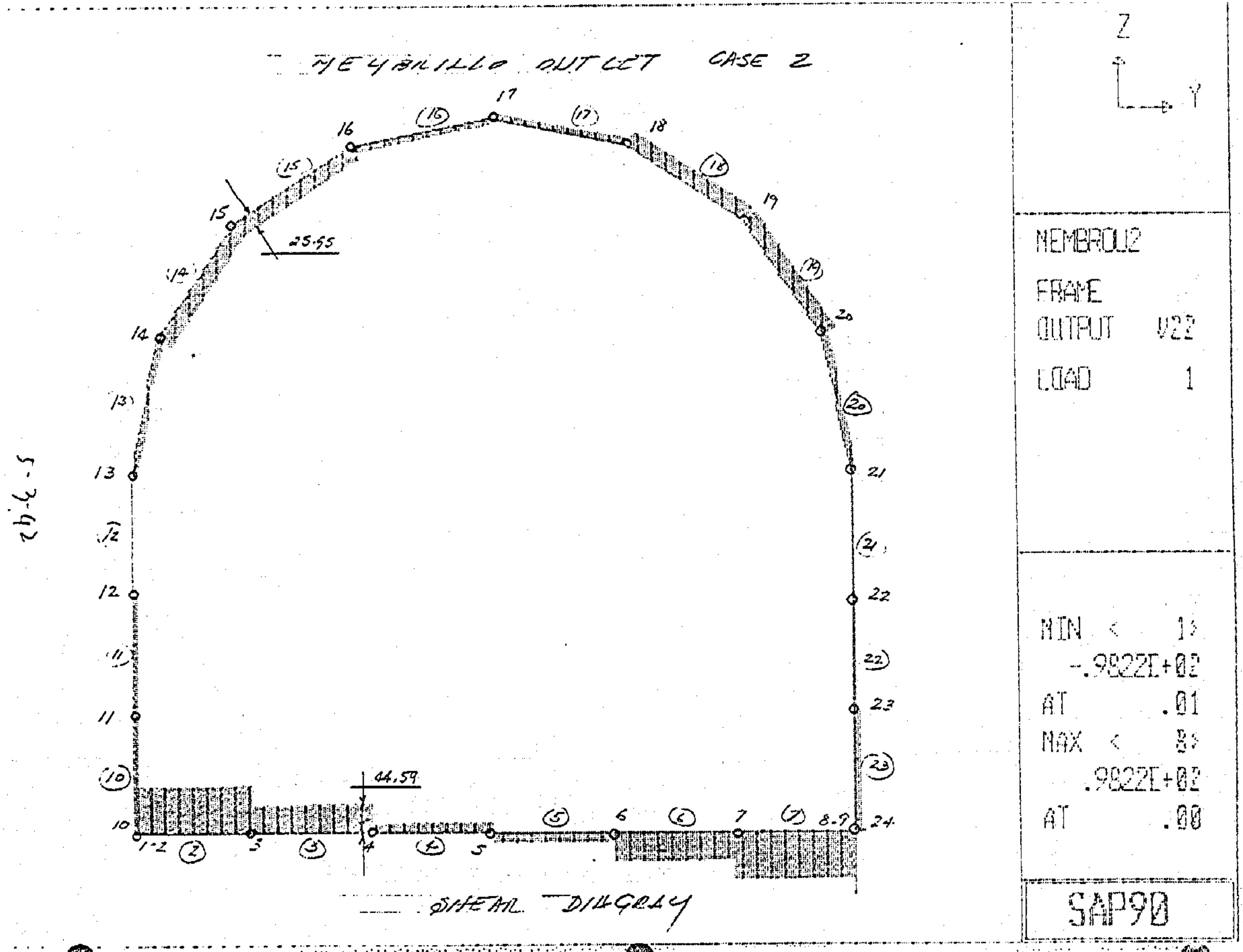
AT .70

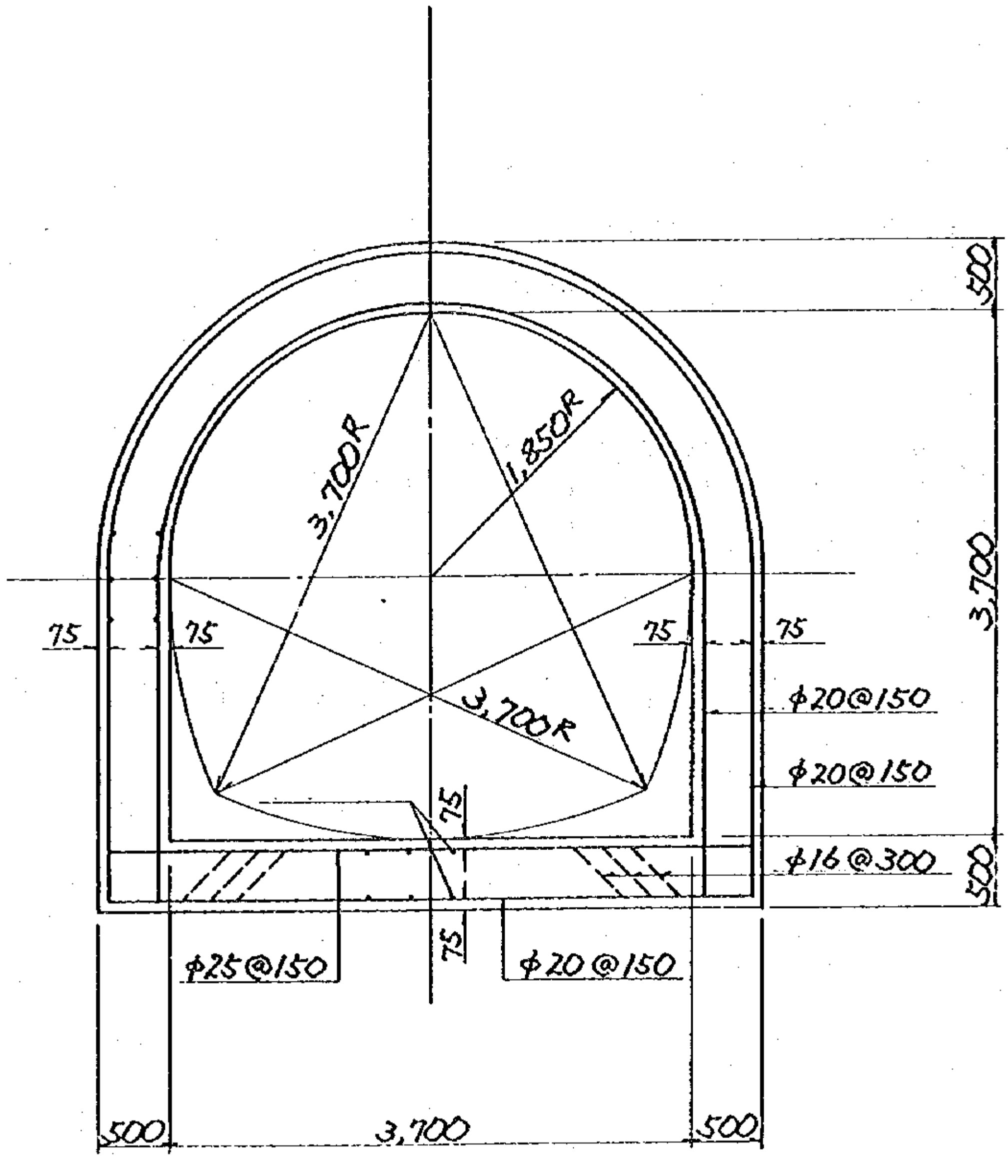
MAX (1)

.3874E+02

AT .00

SAP90


MEYBRILLO OUTLET CASE 2
25.55
44.59
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
1-2 3 4 5 6 7 8.9
SHEAR DIAGRAM
5-3-42
Z
Y
MEMBROU2
FRAME
OUTPUT V22
LOAD 1
MIN < 1>
-.9822E+02
AT .01
MAX < 8>
.9822E+02
AT .00
SAP90



MEMBRILLO OUTLET (TRANSITION)

DAULE-PERIPA ~ LA ESPERANZA TUNNEL 5-3-4

(3) Caña Dulce Inlet

(A) Culvert

Case 1 : Normal Condition

1) Dead weight of box culvert

Wc1 = 0.50 x 2.4 = 1.20 tf/m
Wc2 = 0.50 x 2.4 = 1.20 tf/m
Wc3 = 0.55 x 2.4 = 1.32 tf/m

2) Vertical earth pressure and water pressure

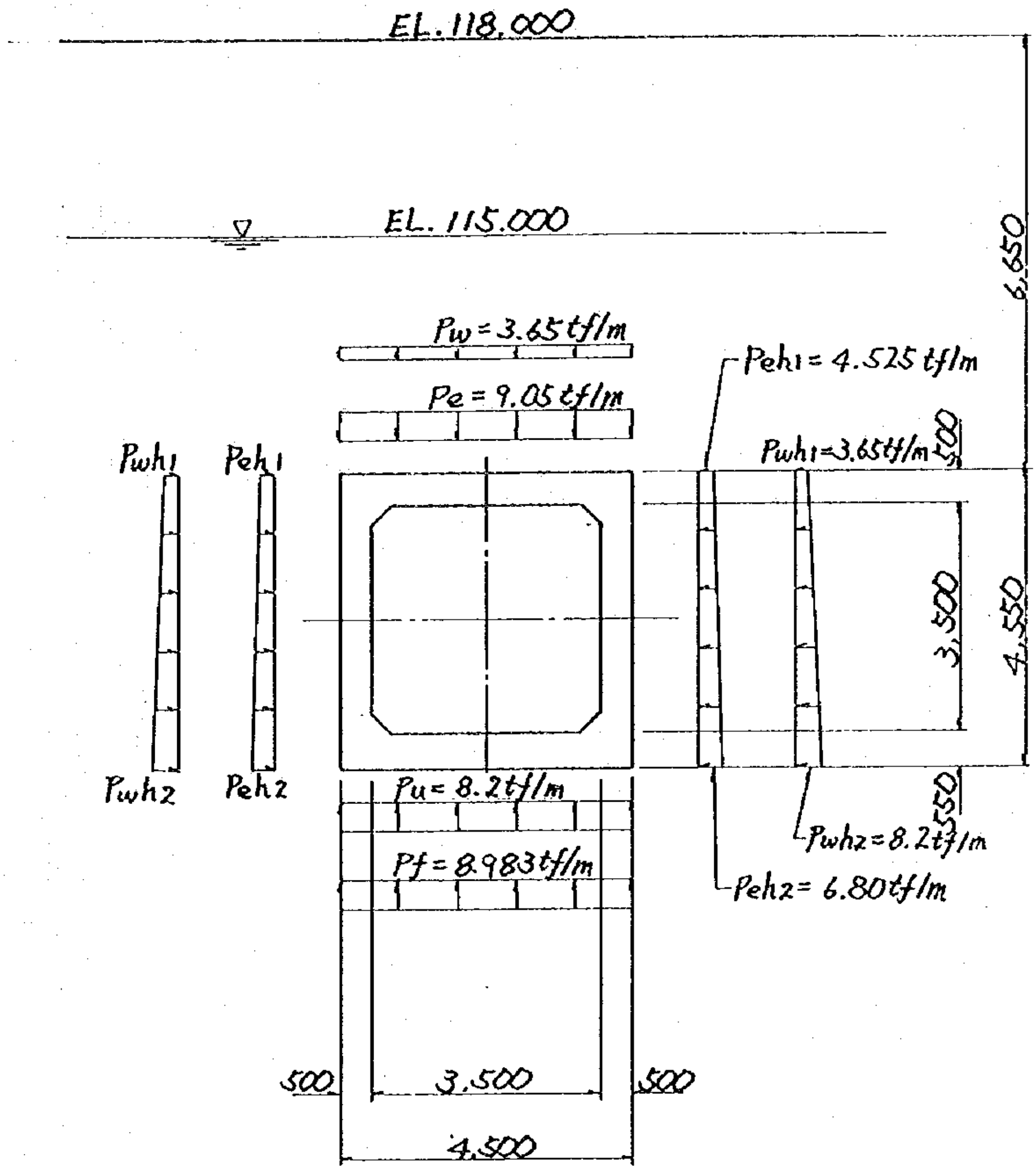
Pe = 1.8 x 3.0 + (2.0 -1.0) x 3.65 = 9.05 tf/m
Pw = 1.0 x 3.65 = 3.65 tf/m

3) Lateral earth pressure and water pressure

Peh1 = 0.5 x 1.8 x 3.0 + 0.5 x (2.0 - 1.0) x 3.65 = 4.525 tf/m
Peh2 = 0.5 x 1.8 x 3.0 + 0.5 x (2.0 - 1.0) x 8.2 = 6.80 tf/m
Pwh1 = 1.0 x 3.65 = 3.65 tf/m
Pwh2 = 1.0 x 8.2 = 8.2 tf/m

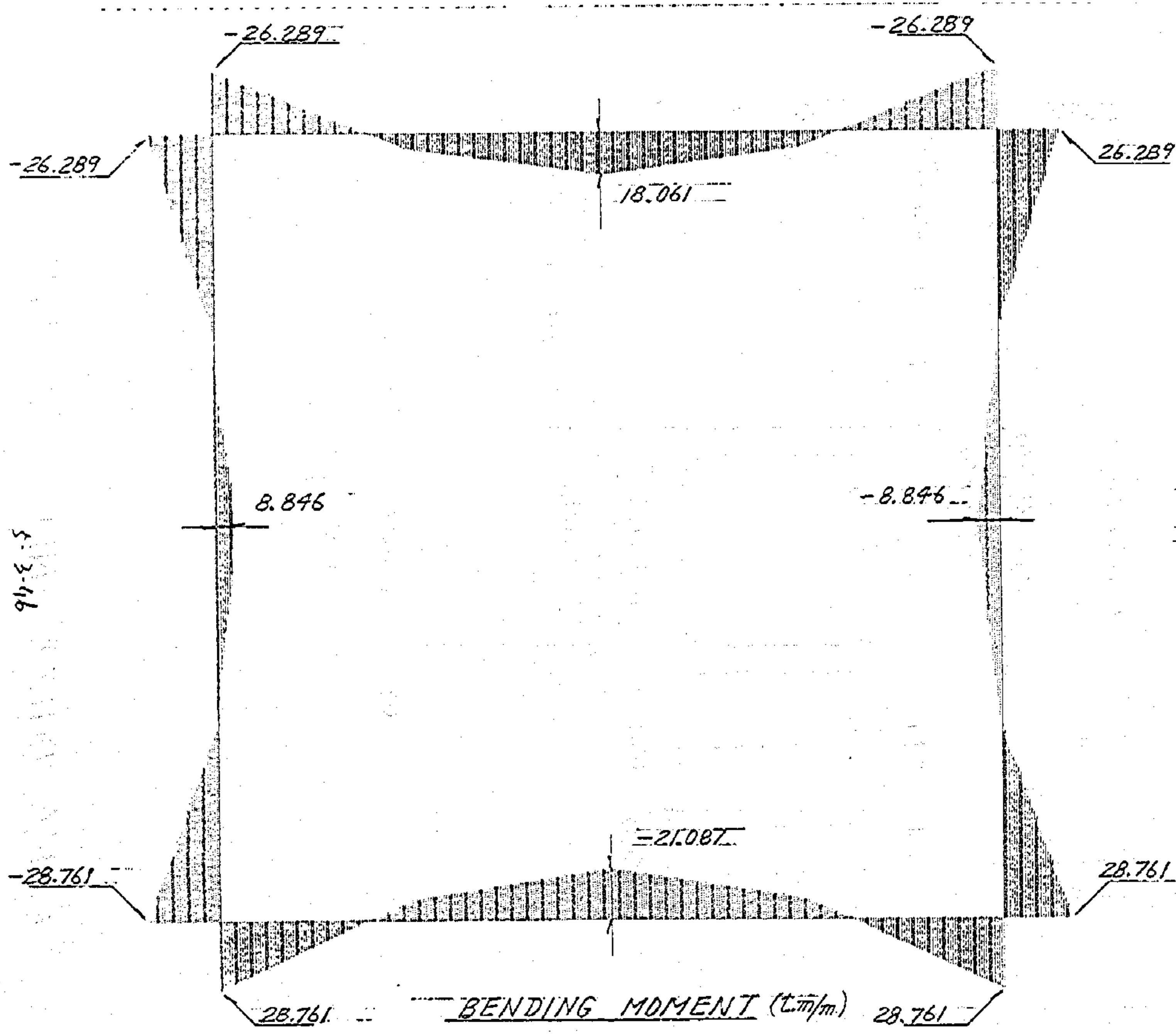
4) Uplift pressure and foundation reaction

Pu = 1.0 x 8.20 = 8.20 tf/m
Pf = (9.05 x 4.5 + 3.65 x 4.5 + (4.55 x 4.5 - 3.5 x 3.5 + 0.3 x 0.3 x 2) x 2.4) /4.5 - 8.20 = 8.983 tf/m



CANA DULCE INLET CULVERT

5 · 3 · 05

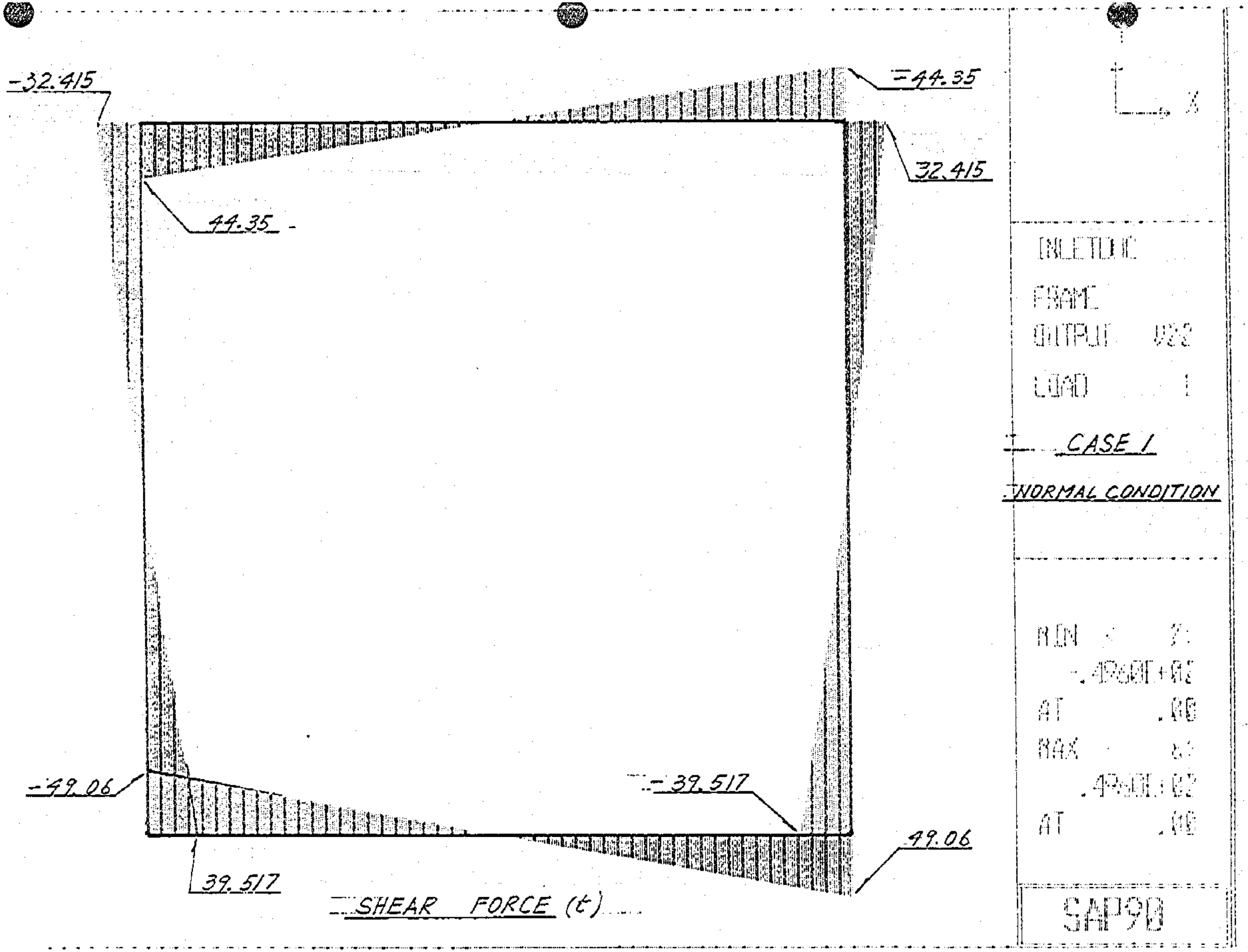


INLETDIC
FRAME
OUTPUT 103
LOAD 1

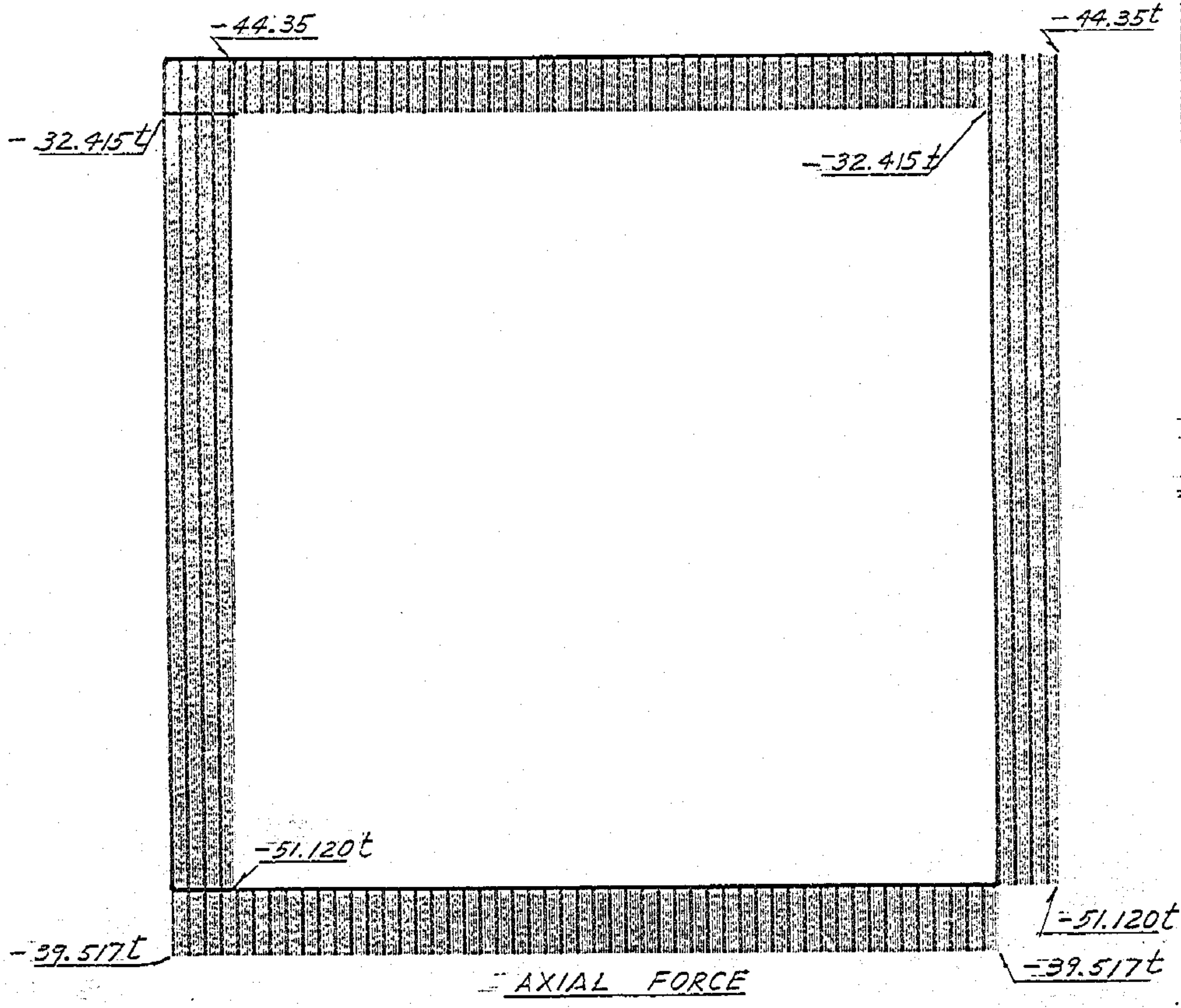
CASE 1
NORMAL CONDITION

MOM < 1>
-.2876E+02
AT .00
MAX < 1>
.2876E+02
AT .00

SAP90


-32.415
44.35
-44.35
32.415
-49.06
39.517
-39.517
49.06
SHEAR FORCE (t)
INLETDUC
FRAME
OUTPUT V22
LOAD 1
CASE I
NORMAL CONDITION
MIN
-.4960E+02
AT .00
MAX
.4960E+02
AT .00
SAP90

5.13.(1)



FRAME

OUTPUT F

LOAD 1

CASE I

NORMAL CONDITION

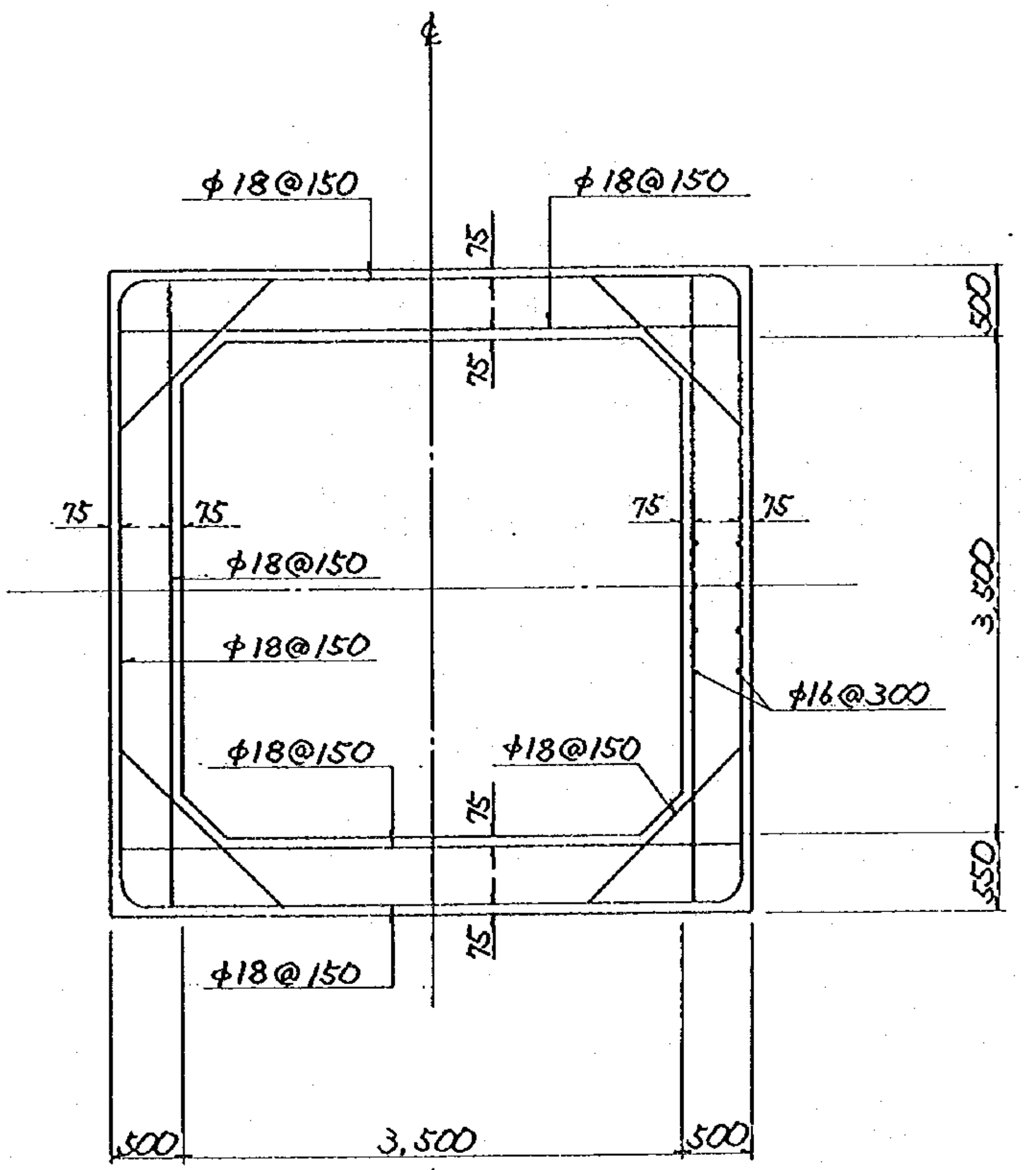
MIN

AT .00

MAX

AT 4.00

SAP90



Note;
φ18 means diameter of deformed bar.

CANA DULCE INLET CULVERT

5-3-49

Cana Dulce Inlet Tunnel

(B) Inlet Tunnel

Case 1 : After construction

1) Dead weight of lining concrete

Wc = 0.5 x 2.4 = 1.2 tf/m

2) Vertical bedrock pressure and water pressure

Pr = 2.0 x 6.3 + (2.0 - 1.0) x 3.7 = 16.3 tf/m
Pw = 1.0 x (El.115.0 - El.111.3) = 3.7 tf/m

3) Lateral bedrock pressure and water pressure

Ka = tan2(45 - 40/2) = 0.217
Prh1 = 0.217 x 2.0 x 6.3 + 0.217 x (2.0 - 1.0) x 3.7 = 3.537 tf/m
Prh2 = 0.217 x 2.0 x 6.3 + 0.217 x (2.0 - 1.0) x 8.2 = 4.514 tf/m
Pwh1 = 1.0 x 3.7 = 3.7 tf/m
Pwh2 = 1.0 x 8.2 = 8.2 tf/m

4) Uplift pressure and foundation reaction

Pu = 1.0 x 8.2 = 8.2 tf/m
Pf = (3.7 x 4.5 + (4.5 x 2.25 - 3.14 x 4.5 x 4.5 / 8) + 16.3 x 4.5 + 19.003)
/4.5-8.2 = 16.506 tf/m

Case 2 : During construction

1) Dead weight of lining concrete

Wc = 0.5 x 2.4 = 1.2 tf/m

2) Vertical bedrock pressure and backfill grout pressure

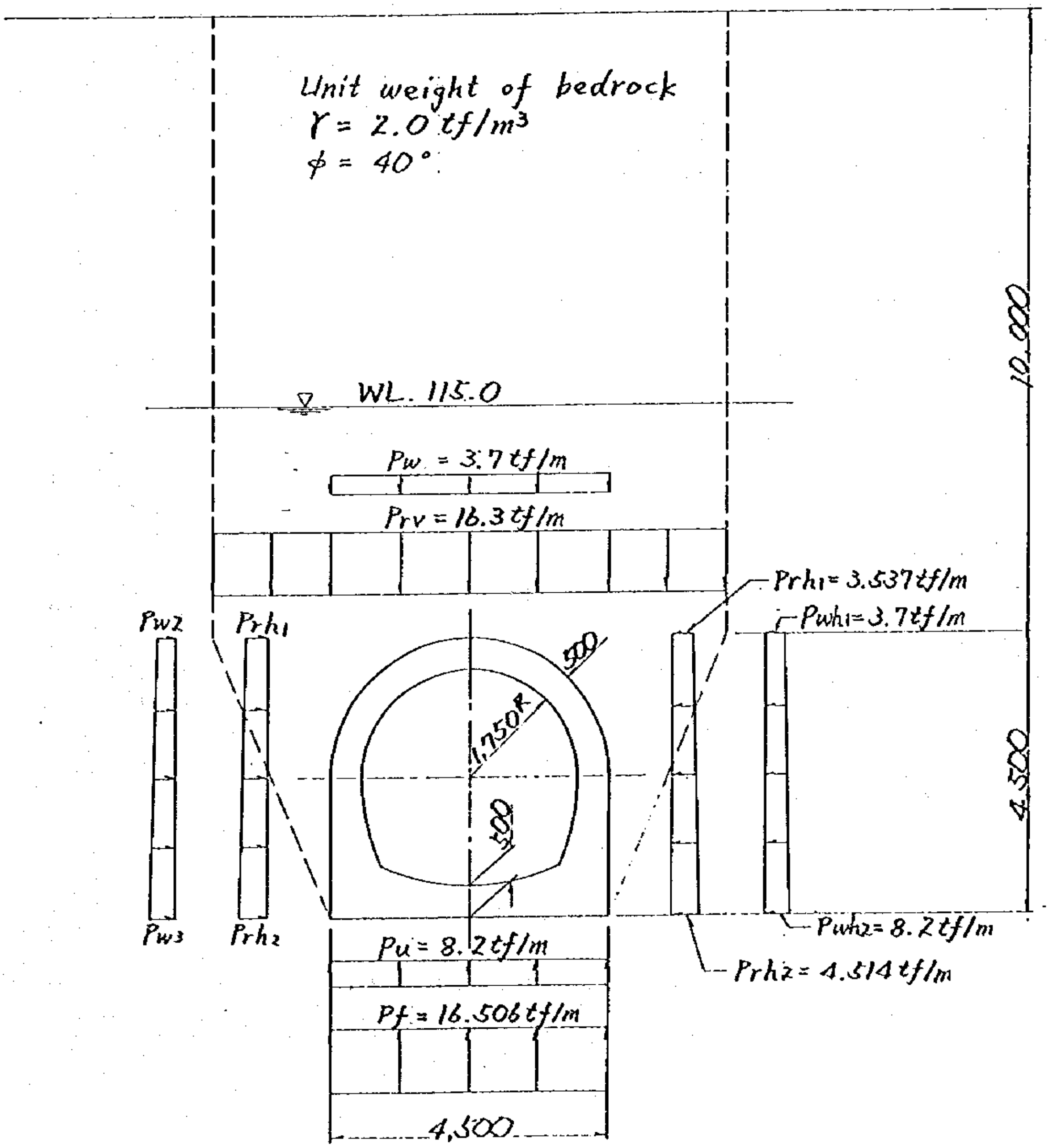
Pr = 2.0 x 10.0 = 20.0 tf/m
Pg = 15.0 tf/m

3) Lateral bedrock pressure and water pressure

Ka = tan2(45 - 40/2) = 0.217
Prh1 = 0.217 x 2.0 x 10.0 = 4.34 tf/m
Prh2 = 0.217 x 2.0 x 12.25 + 0.217 x (2.0 - 1.0) x 2.25 = 5.805 tf/m
Pw = 1.0 x 2.25 = 2.25 tf/m

4) Uplift pressure and foundation reaction

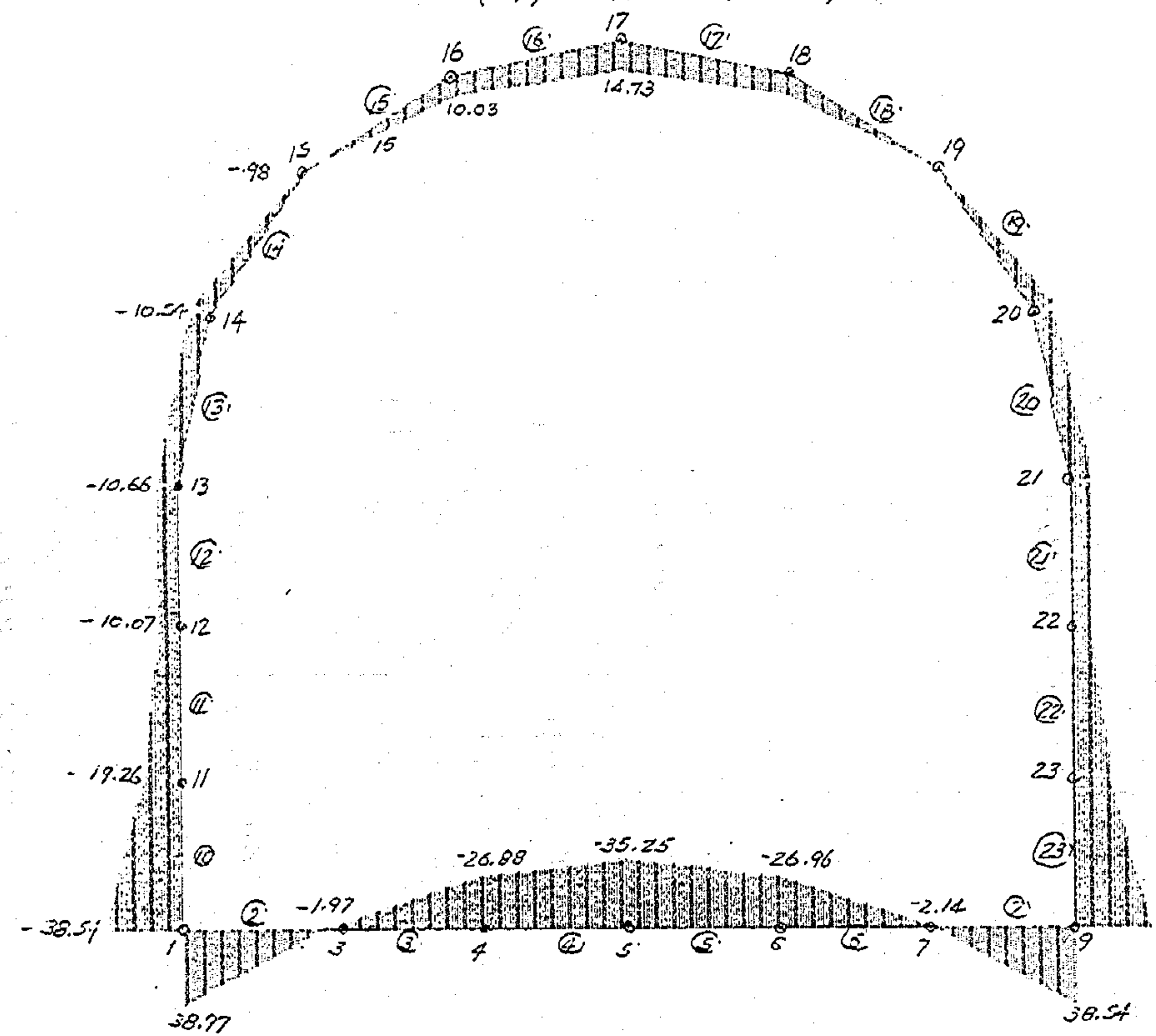
Pu = 1.0 x 2.25 = 2.25 tf/m
Pf = (20.0 x 4.5 + 15.0 x 4.5 + 19.003)/4.5 - 2.25 = 36.973 tf/m



CANA DULCE INLET, CASE 1

LA ESPERANZA ~ POZA HONDA TUNNEL

CAÑA DULCE INLET CAS. 1
(MOMENT DIAGRAM)

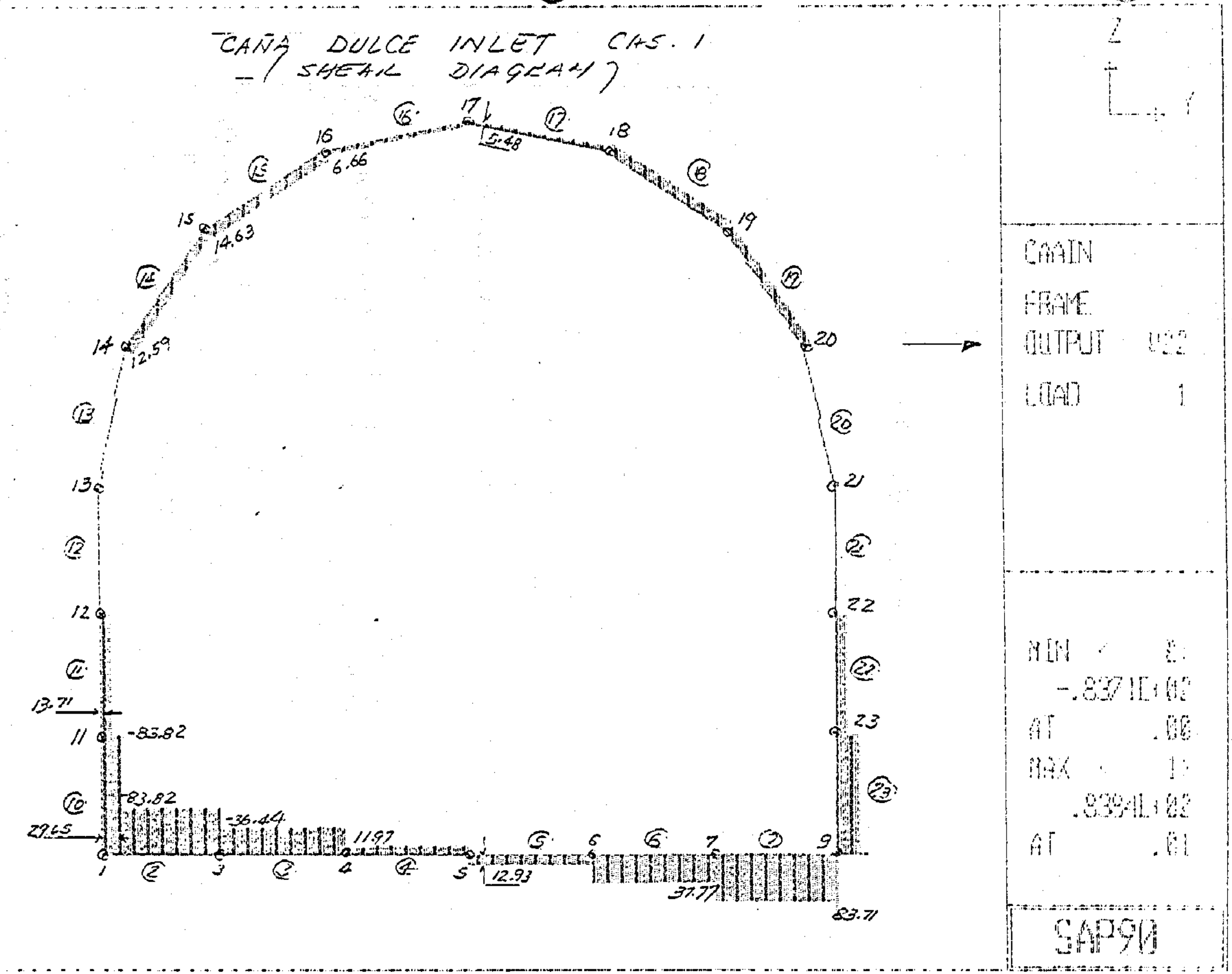


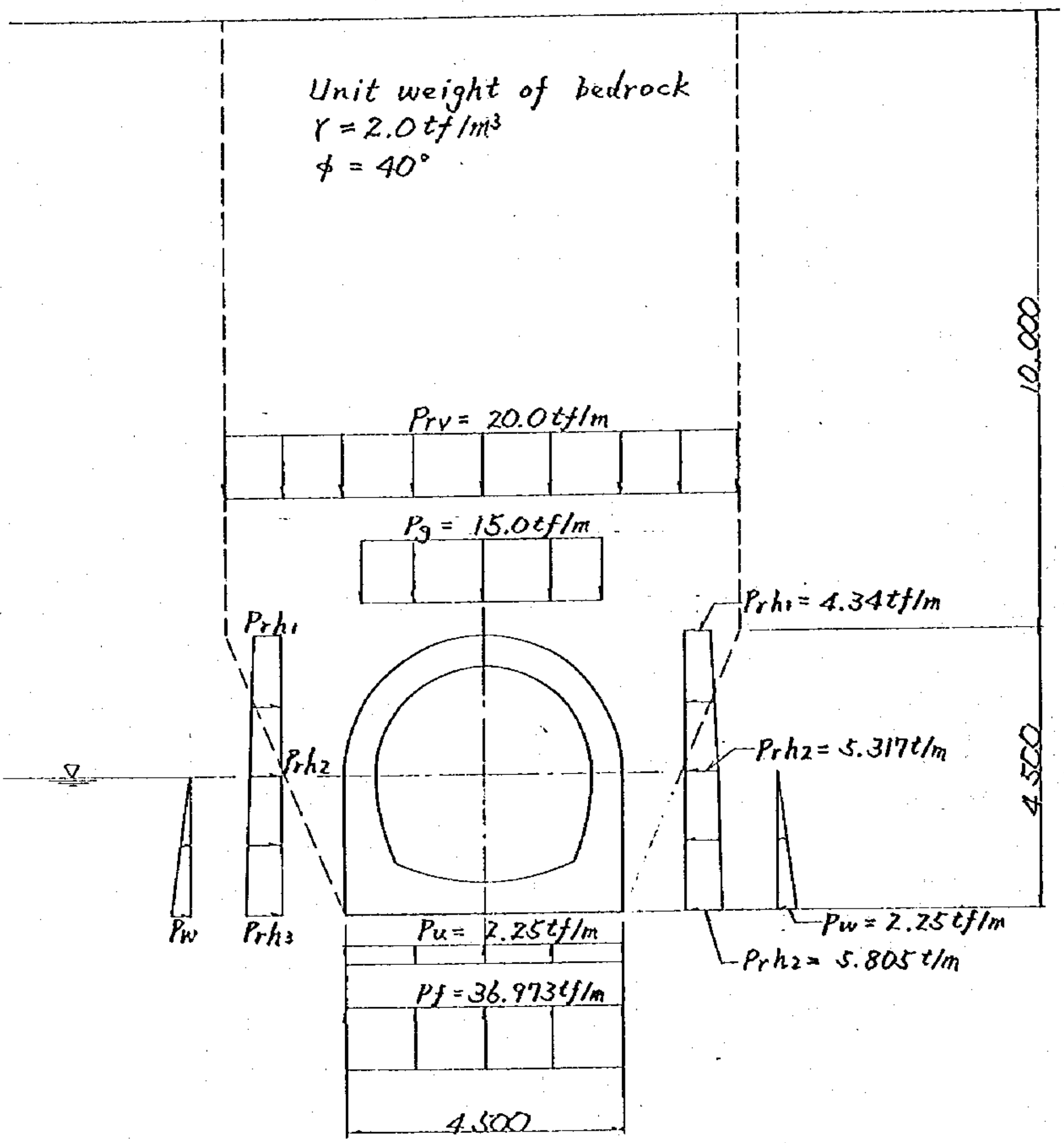
CAADN
FRAME
OUTPUT M33
LOAD 1

MIN 1
-.3998E+02
AT .00
MAX 9
.3998E+02
AT .00

SAP90

5-3-92

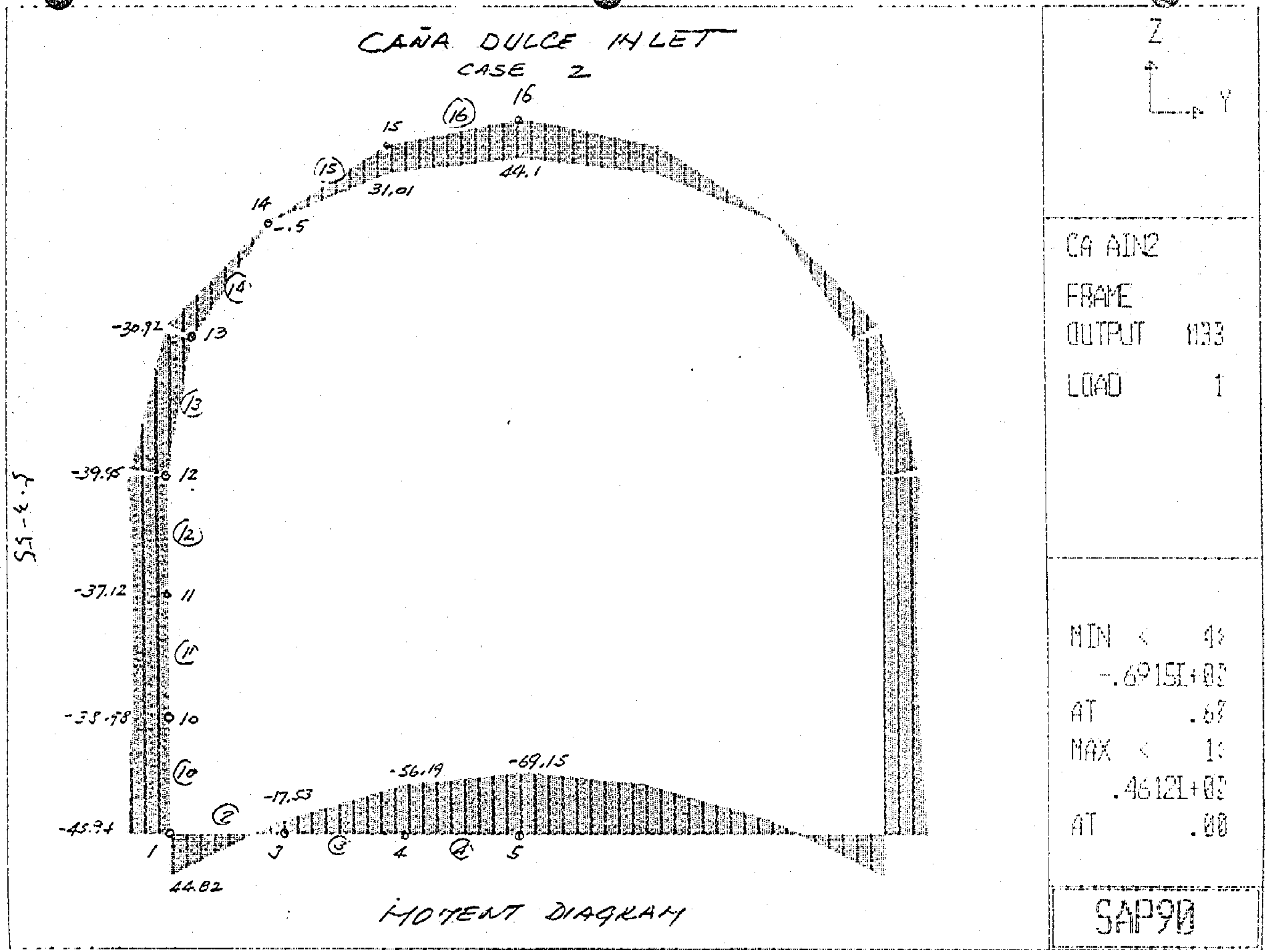

CAÑA DULCE INLET CAS. 1
-(SHEAR DIAGRAM)
5.48
6.66
14.63
12.59
13.71
-83.82
83.82
-36.44
11.97
29.65
12.93
37.77
83.71
CAAIN
FRAME
OUTPUT V22
LOAD 1
MIN 8:
-.8371E+02
AT .00
MAX 1:
.8394E+02
AT .01
SAP90

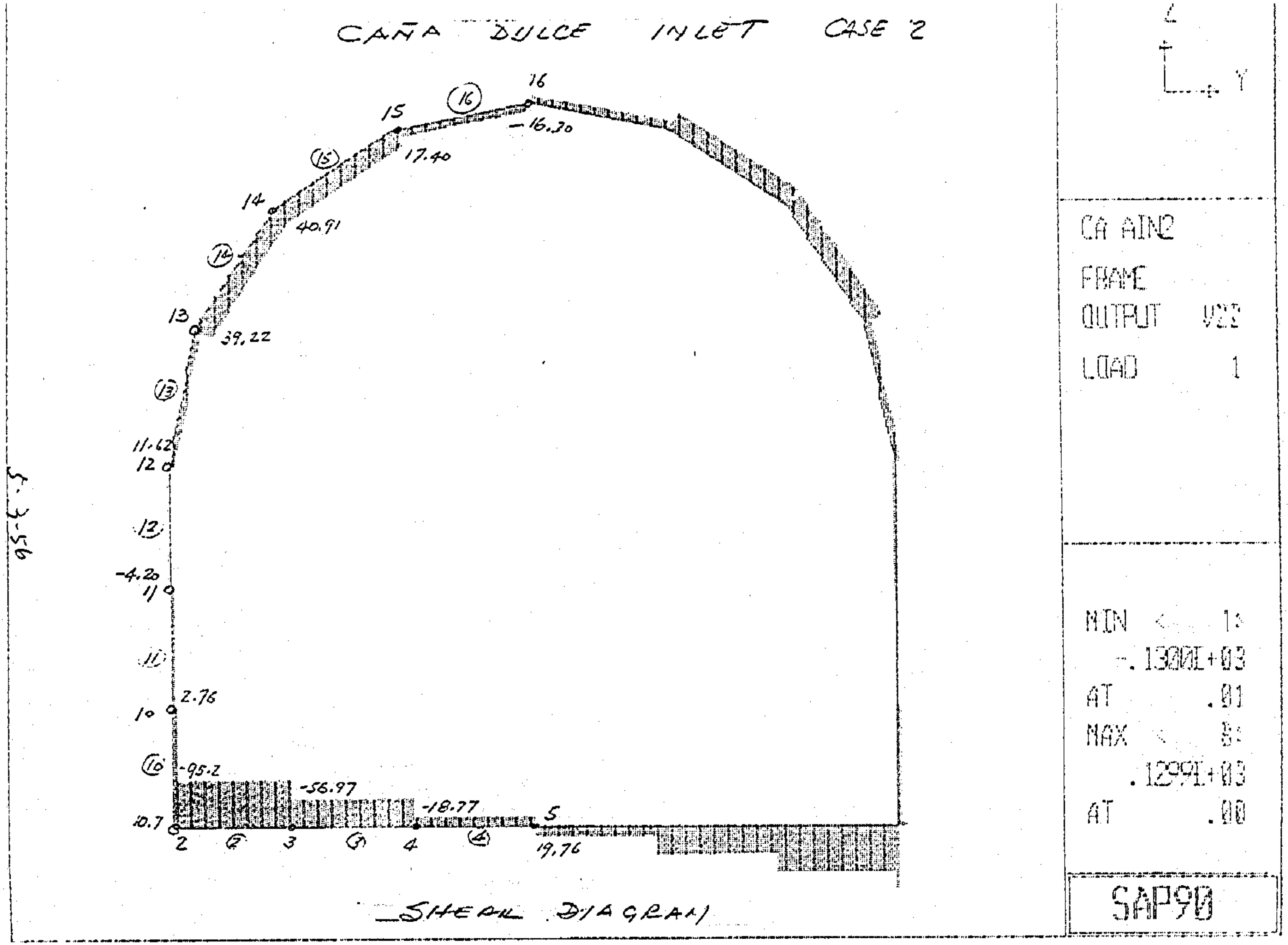


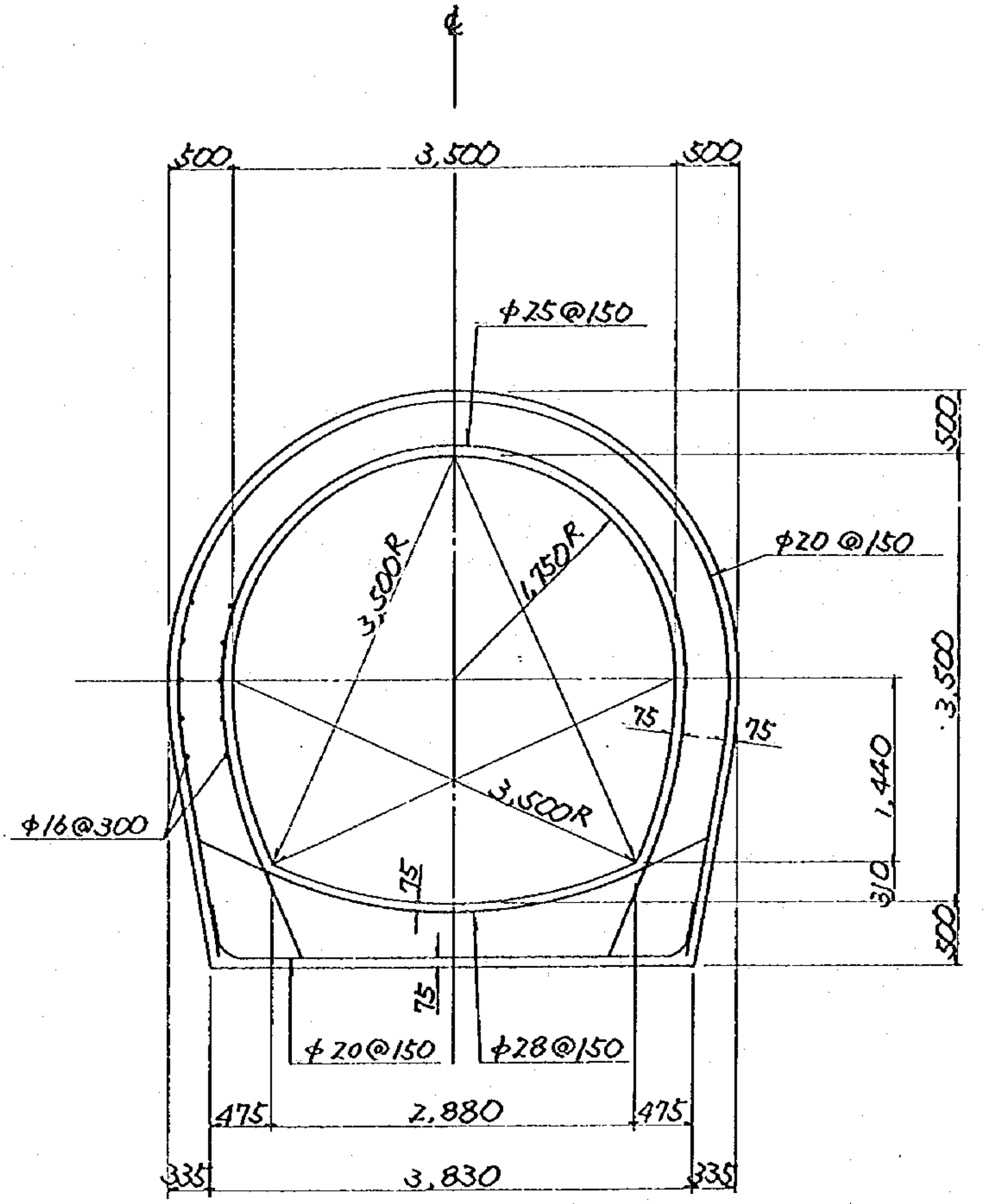
CANA DULCE INLET, CASE 2

LA ESPERANZA ~ POZA HONDA TUNNEL

5-3-3


CAÑA DULCE INLET
CASE 2
16
15
14
13
12
11
10
1
3
4
5
44.1
31,01
-.5
-30.92
-39.56
-37.12
-35.98
-45.94
44.82
-17.53
-56.19
-69.15
MOMENT DIAGRAM
5-3-55
Z
Y
CA AIN2
FRAME
OUTPUT M33
LOAD 1
MIN <
AT
MAX <
AT .00
SAP90


CAÑA DULCE INLET CASE 2
16
15
14
13
12
11
10
2
3
4
5
-16.30
17.40
40.91
39.22
11.62
-4.20
2.76
-95.2
10.7
-56.97
-18.77
19.76
SHEAR DIAGRAM
5-3-56
Z
Y
CA AIN2
FRAME
OUTPUT V22
LOAD 1
MIN
-.1300E+03
AT .01
MAX
.1299E+03
AT .00
SAP90



CANA DULCE INLET

LA ESPERANZA ~ POZA HONDA TUNNEL

5-3-57

(4) Los Cuyuyes Outlet

Case 1 : After construction

1) Dead weight of lining concrete

Wc = 0.5 x 2.4 = 1.2 tf/m

2) Vertical bedrock pressure

Pr = 1.8 x 11.0 = 19.8 tf/m

3) Lateral bedrock pressure and water pressure

Ka = tan2(45 - 35/2) = 0.271
Prh1 = 0.271 x 1.8 x 11.0 = 5.366 tf/m
Prh2 = 0.271 x 1.8 x 11.0 + 0.271 x (1.8 - 1.0) x 4.5 = 6.341 tf/m
Pw = 1.0 x 4.2 = 4.2 tf/m

4) Uplift pressure and foundation reaction

Pu = 1.0 x 4.2 = 4.2 tf/m
Pf = (19.8 x 4.5 + 19.003)/4.5 - 4.2 = 19.823 tf/m

Case 2 : During construction

1) Dead weight of lining concrete

Wc = 0.5 x 2.4 = 1.2 tf/m

2) Vertical bedrock pressure and backfill grout pressure

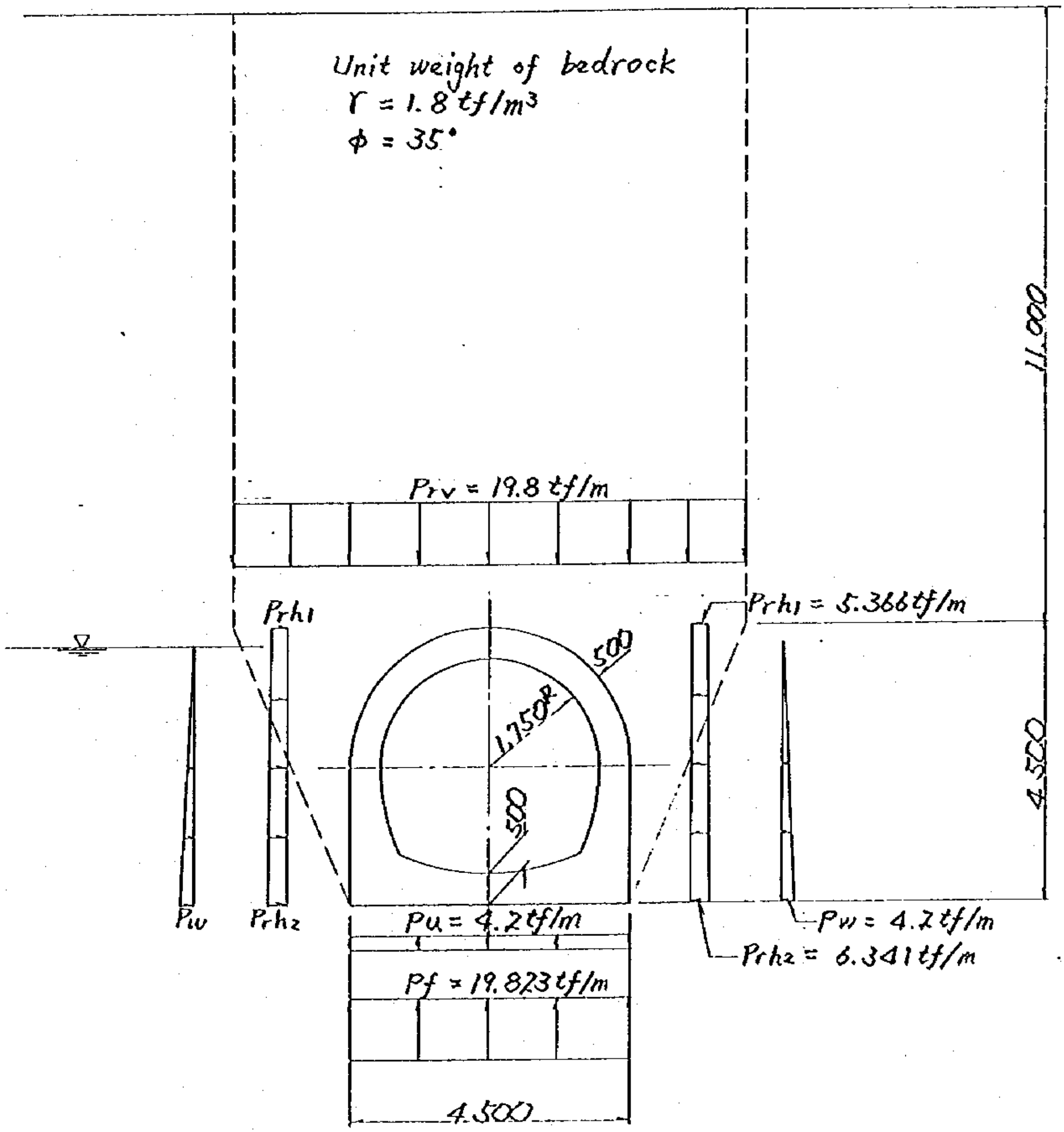
Pr = 1.8 x 11.0 = 19.8 tf/m
Pg = 15.0 tf/m

3) Lateral bedrock pressure

Ka = tan2(45 - 35/2) = 0.271
Prh1 = 0.271 x 1.8 x 11.0 = 5.366 tf/m
Prh2 = 0.271 x 1.8 x 15.5 = 7.561 tf/m

4) Foundation reaction

Pf = (19.8 x 4.5 + 15.0 x 4.5 + 19.003)/4.5 = 39.023 tf/m

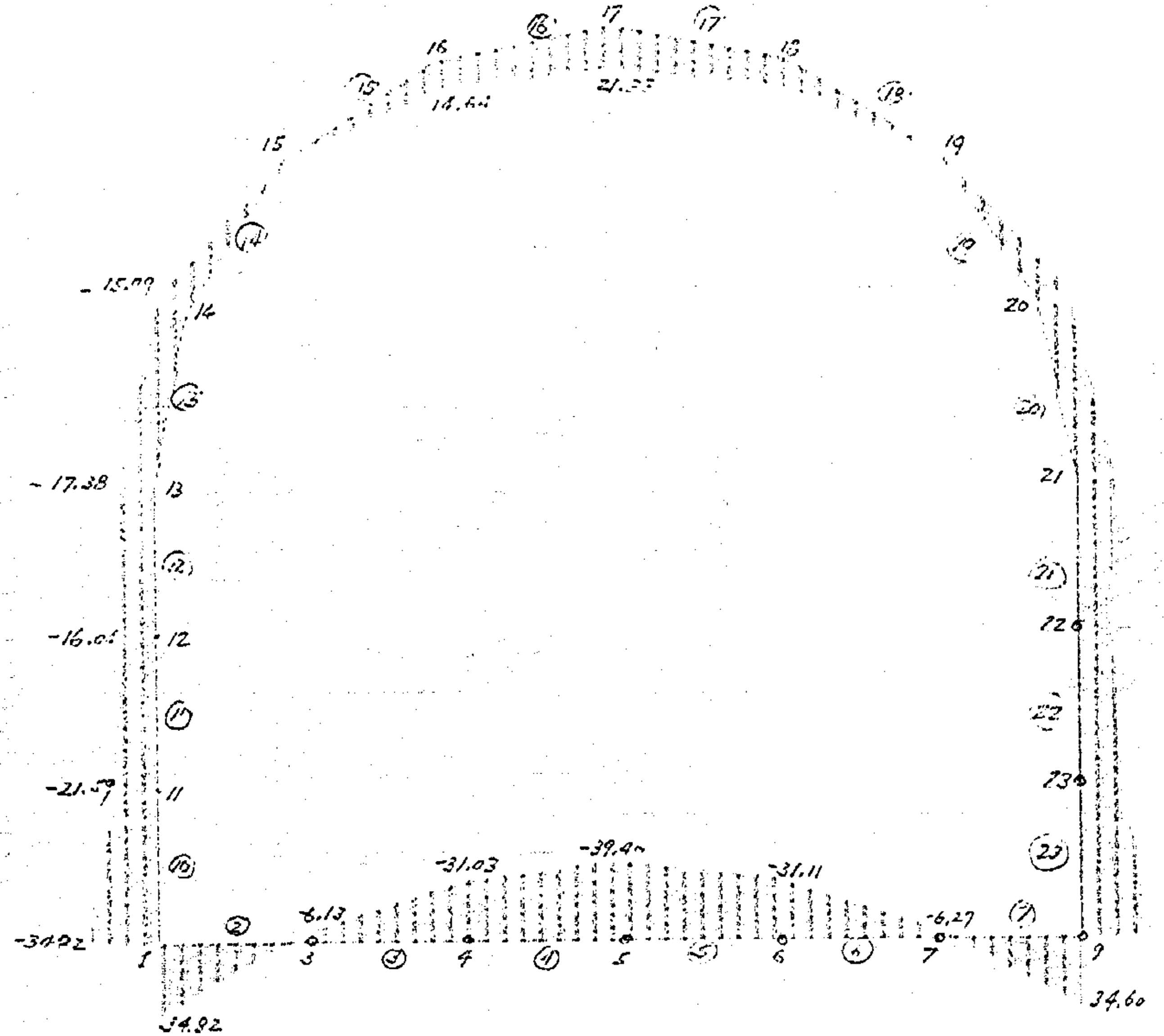


LOS CUYUYES OUTLET, CASE 1

LA ESPERANZA ~ POZA HONDA TUNNEL

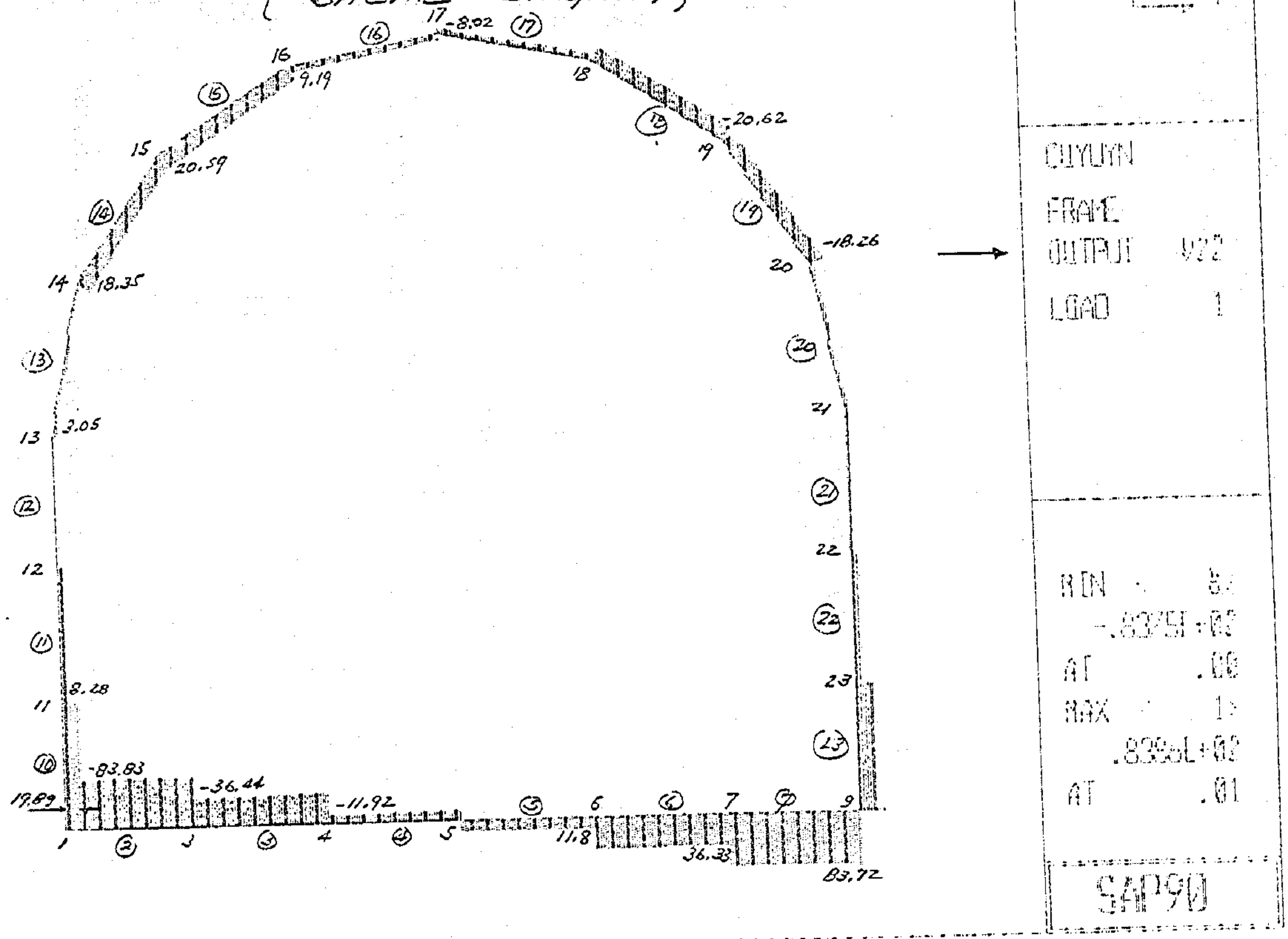
LAS CUYUYES OUTLET ...

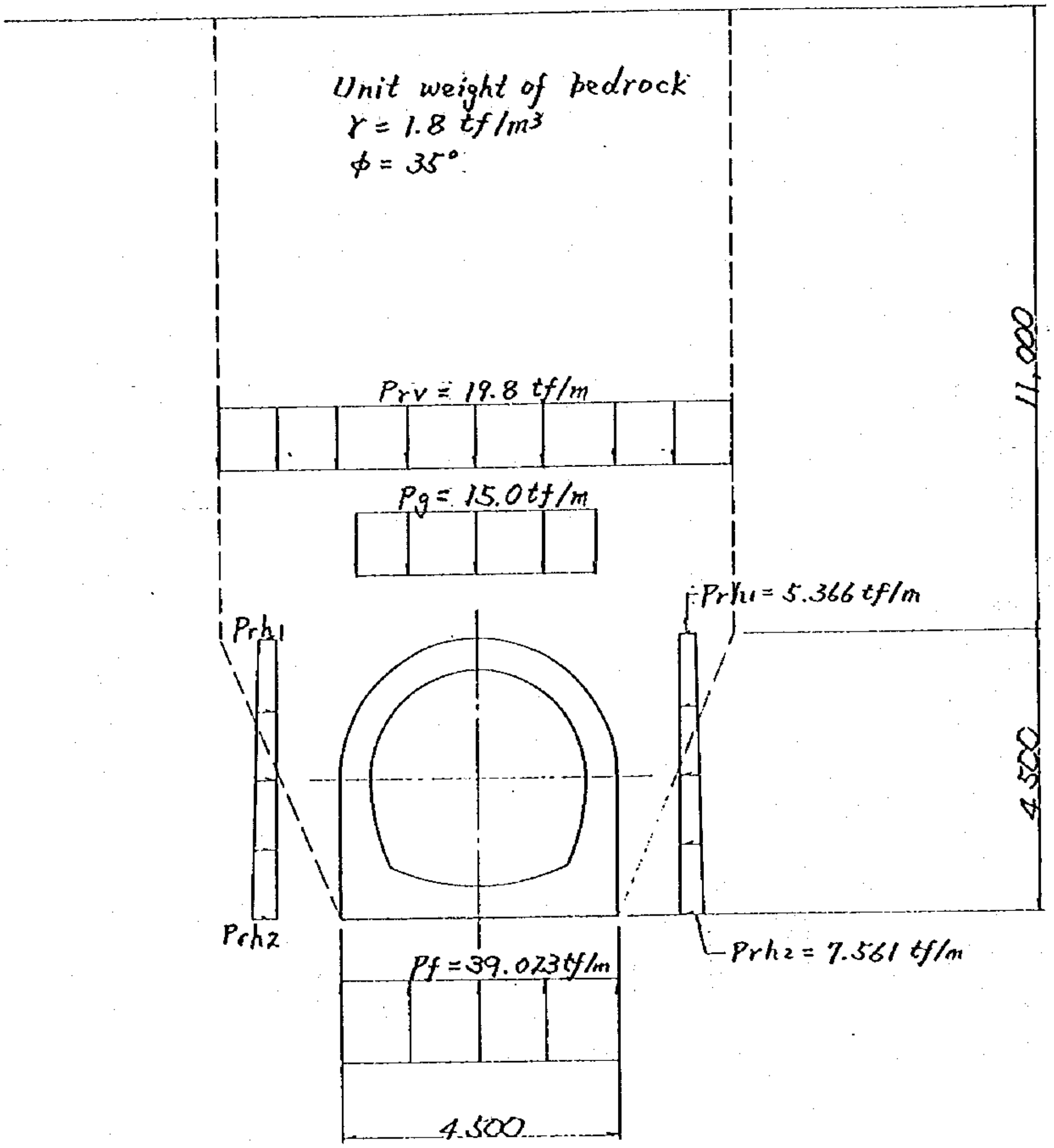
MOMENT ...



5-3-60

LOS CUYUYES OUTLET CAS. 1
(SHEAR DIAGRAM)

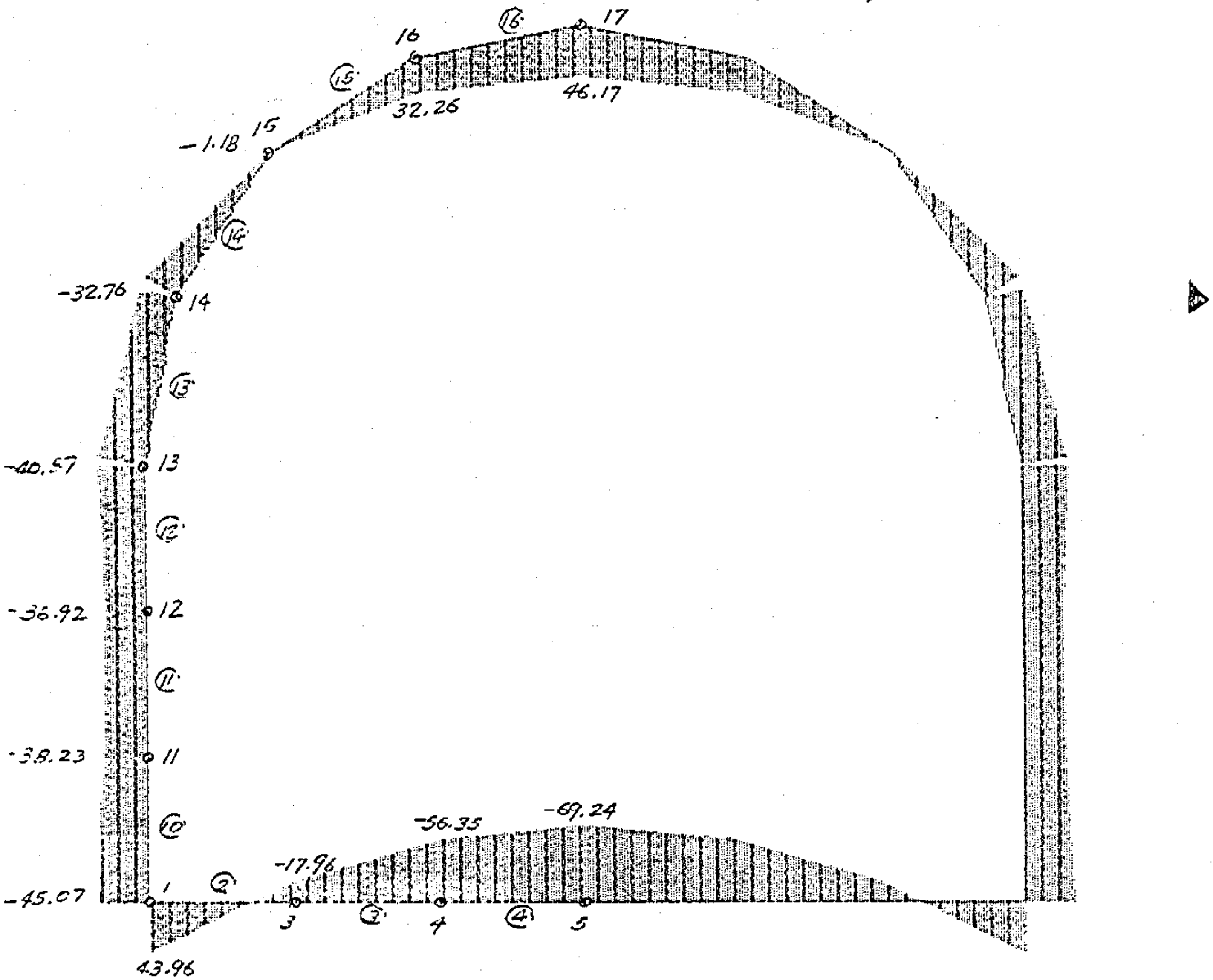




LOS CUYUYES OUTLET, CASE 2

LA ESPERANZA ~ POZA HONDA TUNNEL

LOS CUYUYES OUTLET (CAS. 2)
(MOMENT DIAGRAM)

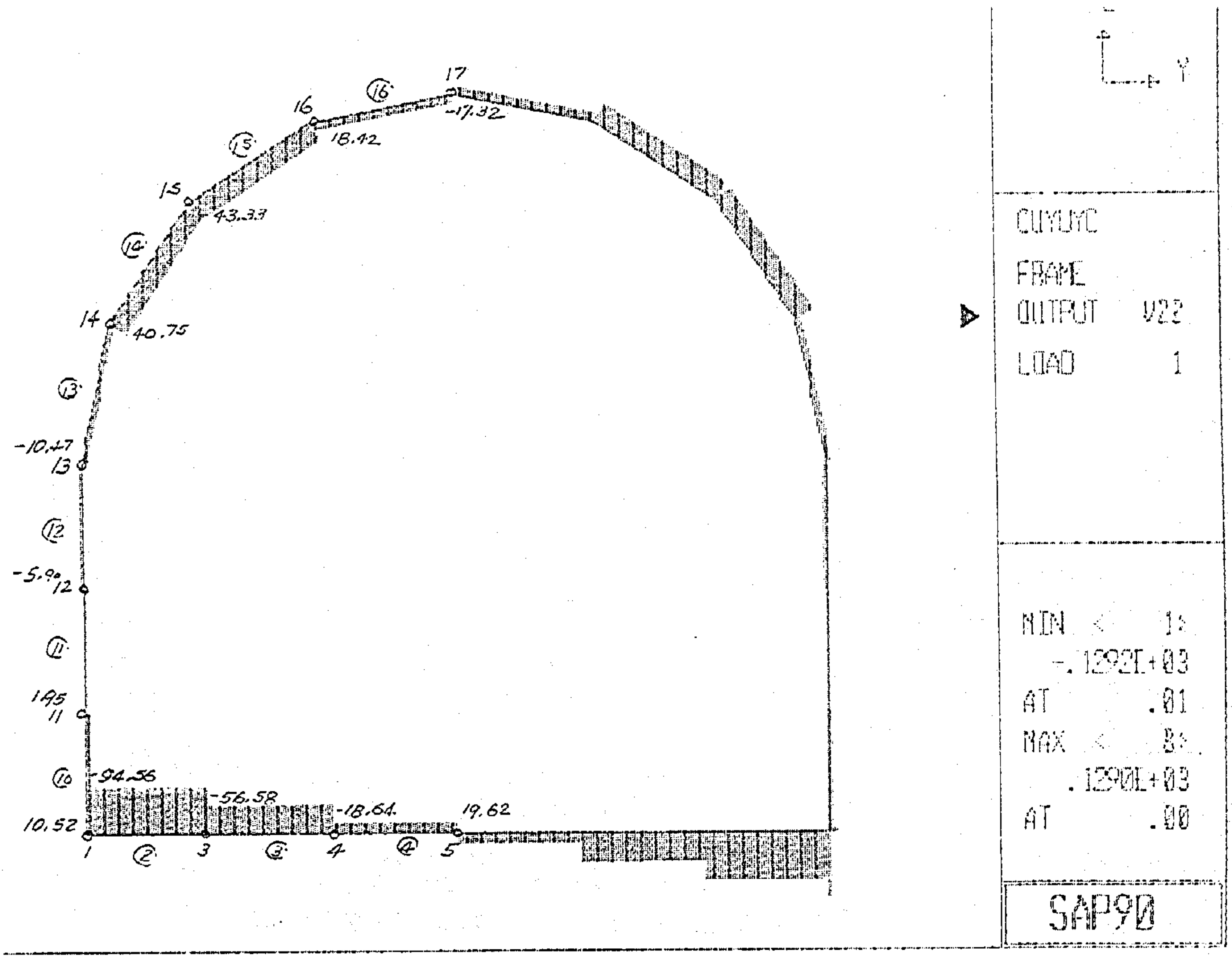


CUYUYC
FRAME
OUTPUT M33
LOAD 1

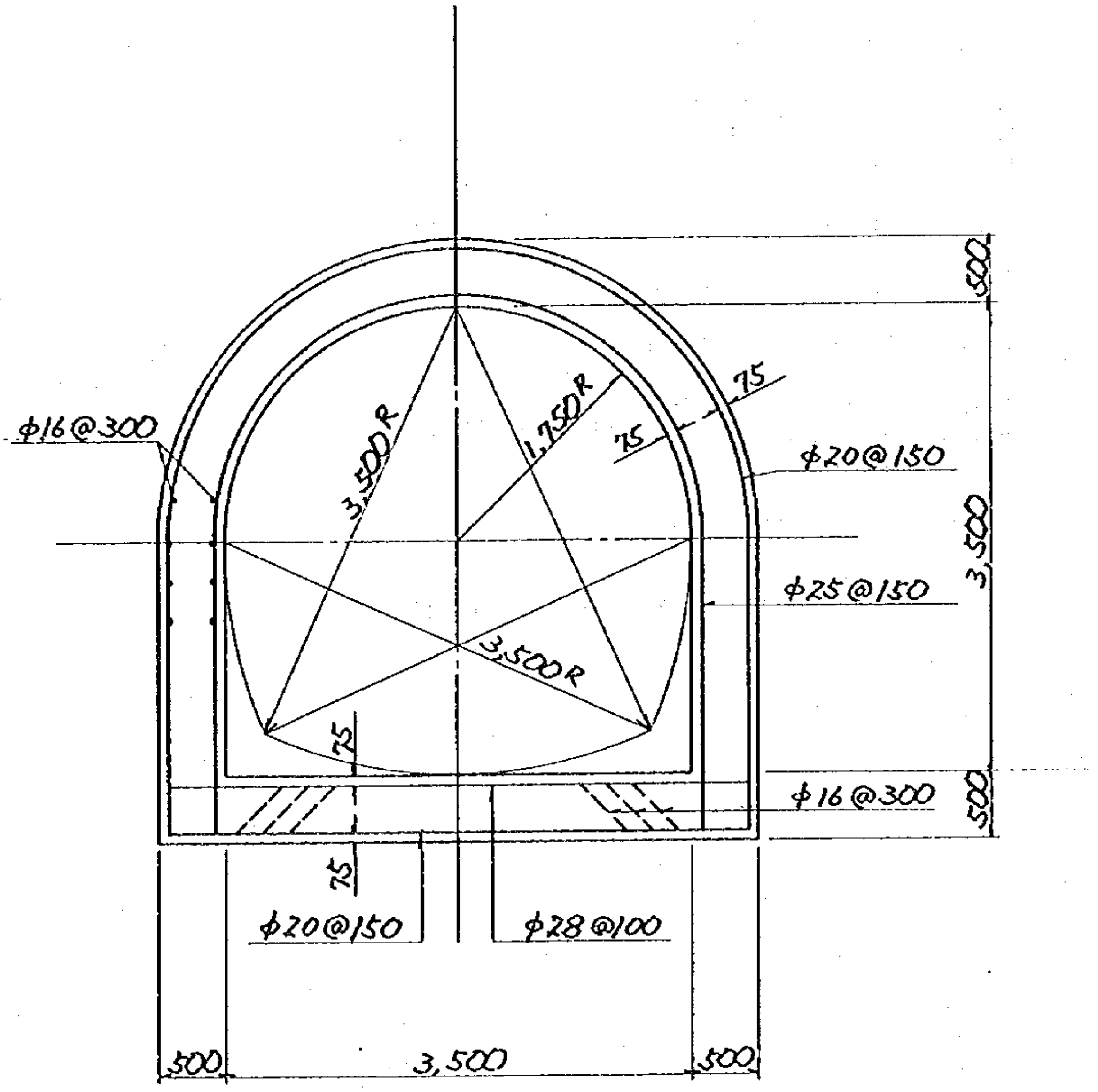
MIN < 4>
-.6924E+02
AT .67
MAX < 16>
.4617E+02
AT .78

SAP90

5-3-67



17
16
15
14
13
12
11
10
1
2
3
4
5
-17.32
18.42
43.33
40.75
-10.47
-5.90
1.95
10.52
-94.56
-56.58
-18.64
19.62
CUYUYC
FRAME
OUTPUT V22
LOAD 1
MIN < 1>
-.1292E+03
AT .01
MAX < 8>
.1290E+03
AT .00
SAP90



LOS CUYUYES OUTLET

LA ESPERANZA ~ POZA HONDA TUNNEL

s 3-15

(5) Poza Honda Inlet

(A) Inlet Culvert

Case 1 : Normal Condition

1) Dead weight of box culvert

Wc1 = 0.50 x 2.4 = 1.20 tf/m
Wc2 = 0.50 x 2.4 = 1.20 tf/m
Wc3 = 0.50x 2.4 = 1.20 tf/m

2) Vertical earth pressure

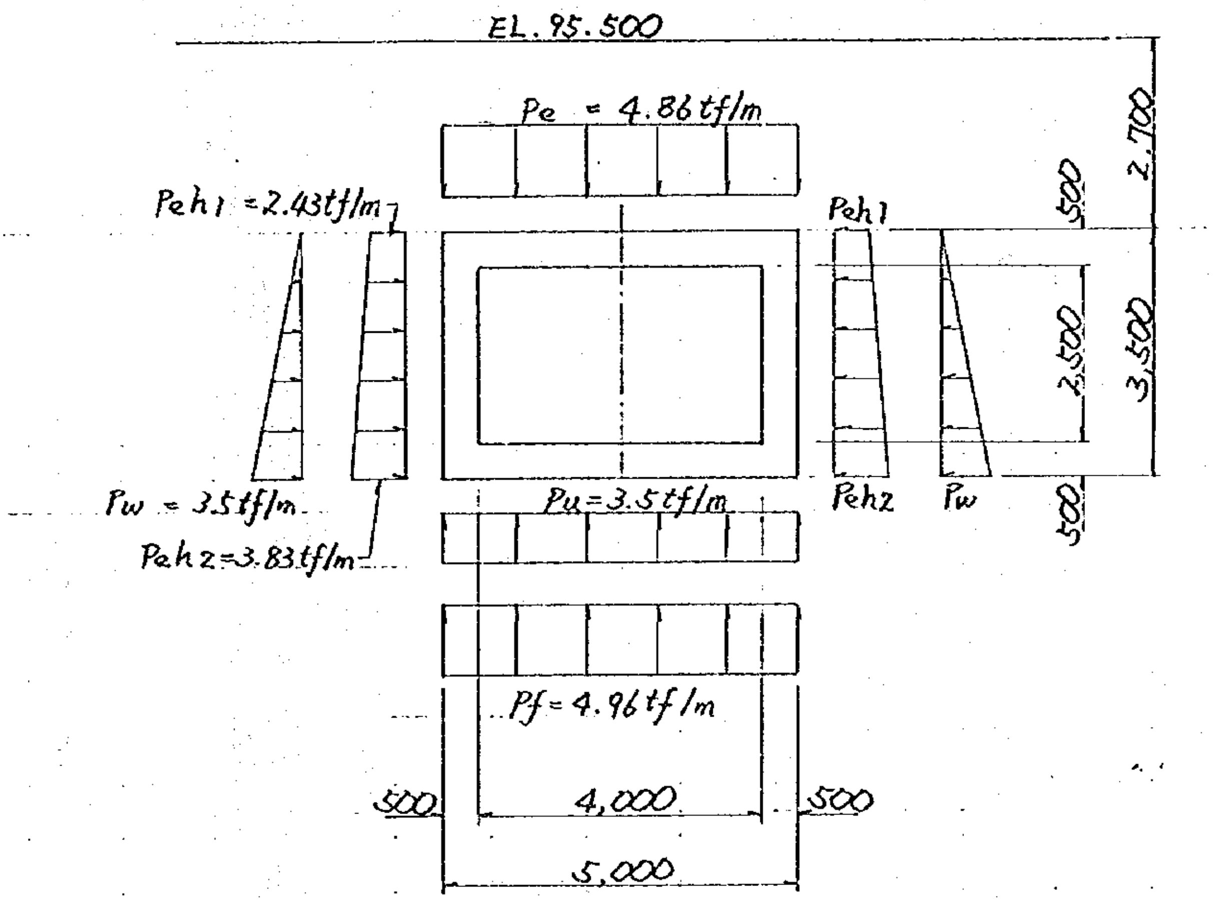
Pe = 1.8 x 2.7 = 4.86 tf/m

3) Lateral earth pressure and water pressure

Peh1 = 0.5 x 1.8 x 2.7 = 2.43 tf/m
Peh2 = 0.5 x 1.8 x 2.7 + 0.5 x (1.8 - 1.0) x 3.5 = 3.83 tf/m
Pw = 1.0 x 3.5 = 3.5 tf/m

4) Uplift pressure and foundation reaction

Pu = 1.0 x 3.5 = 3.5 tf/m
Pf = (1.2 x 5.0 + 1.2 x 2.5 x 2 + 1.2 x 5.0 + 4.86 x 5.0)/5.0 - 3.5
= 4.96 tf/m

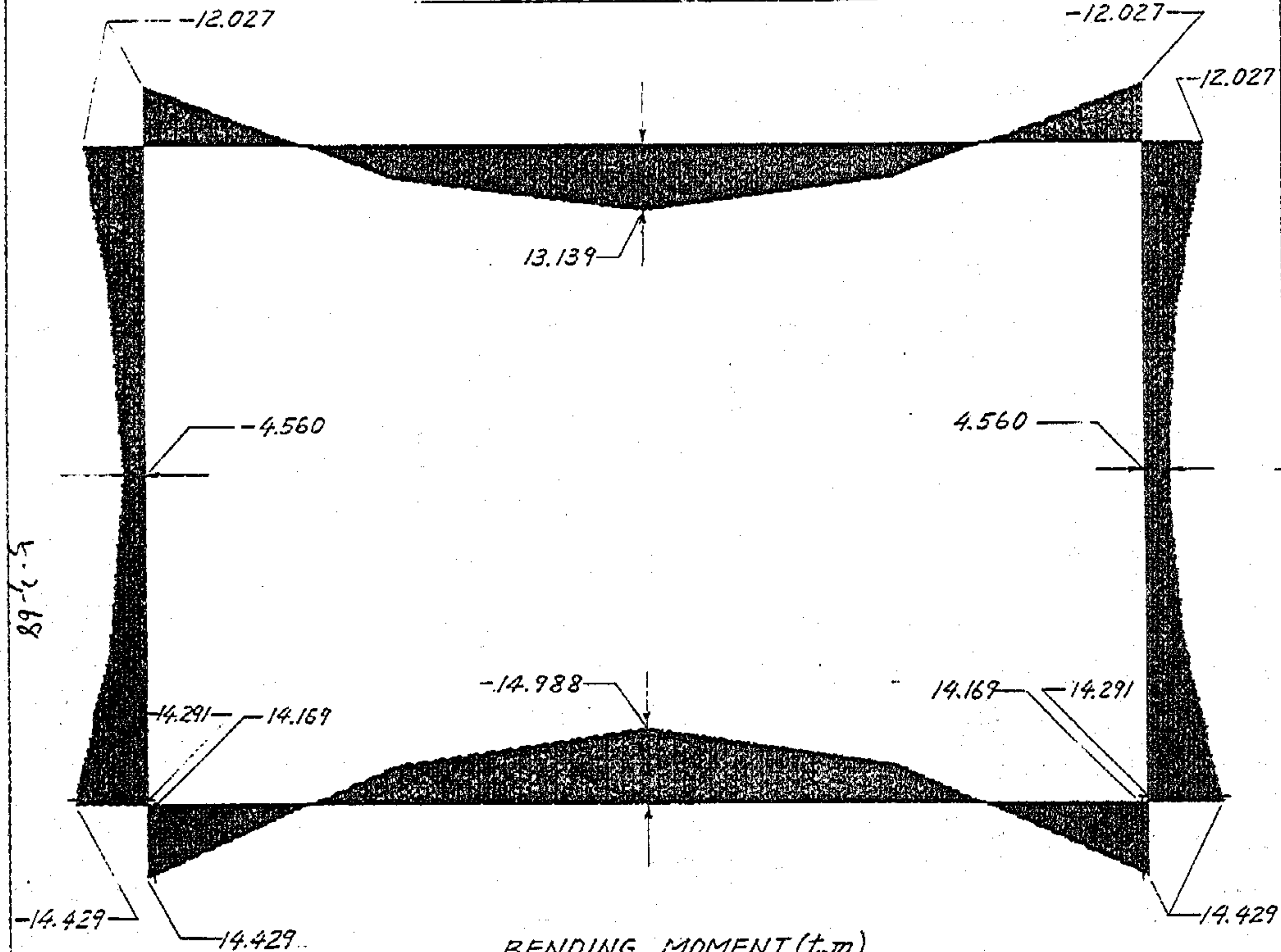


INLET CULVERT

POZA HONDA INLET STRUCTURE

5-3-67

POZA HONDA INLET CULVERT



BENDING MOMENT (t.m)

PHCULVERT

FRAME

OUTPUT M33

LOAD 1

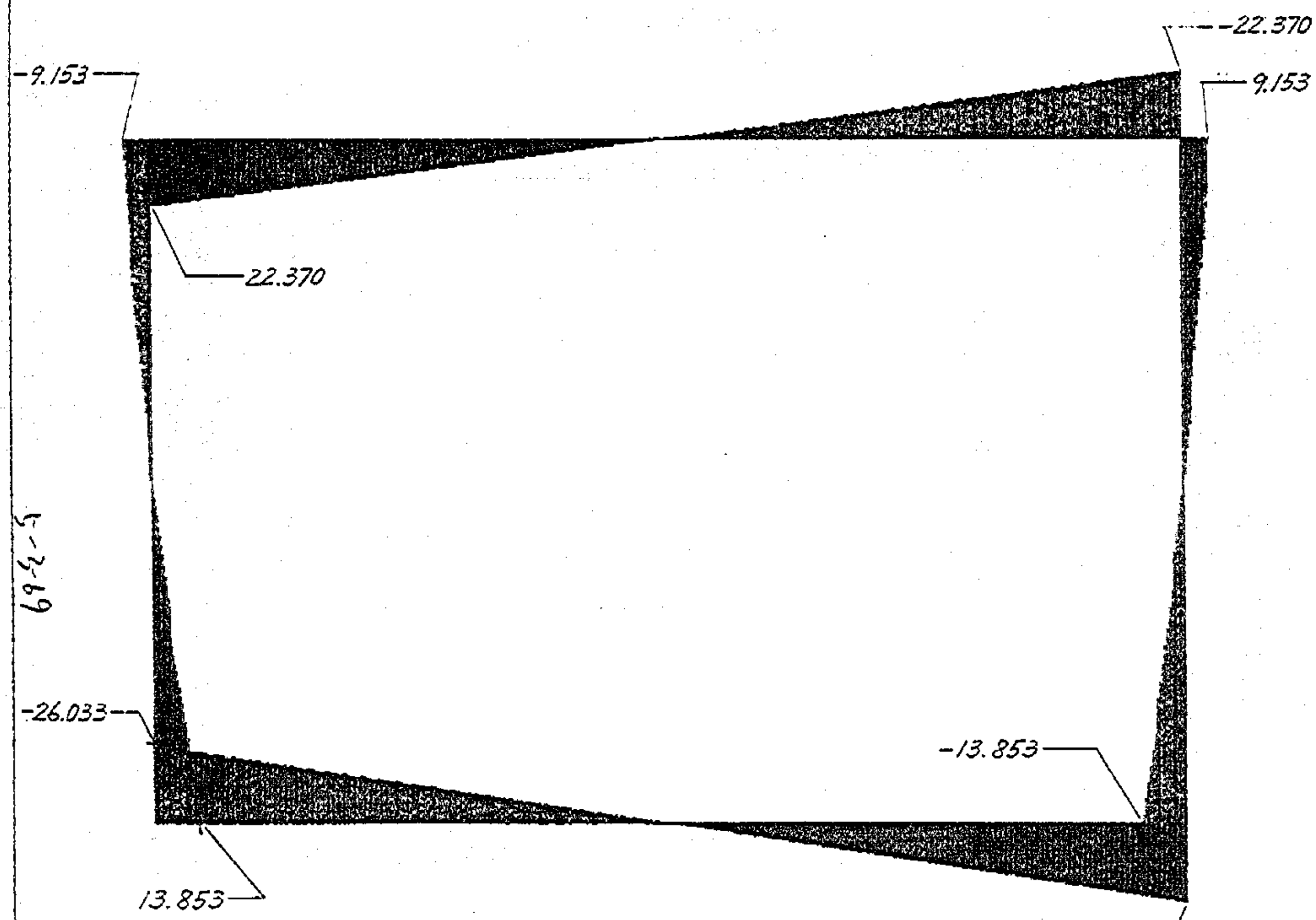
FACTORED LOADS

MIN < 7>
-.1499E+02
AT 2.24
MAX < 5>
.1443E+02
AT .00

SAP90

5-2-68

POZA HONDA INLET CULVERT



SHEAR FORCE (t.)

5-3-69

PHCULVERT

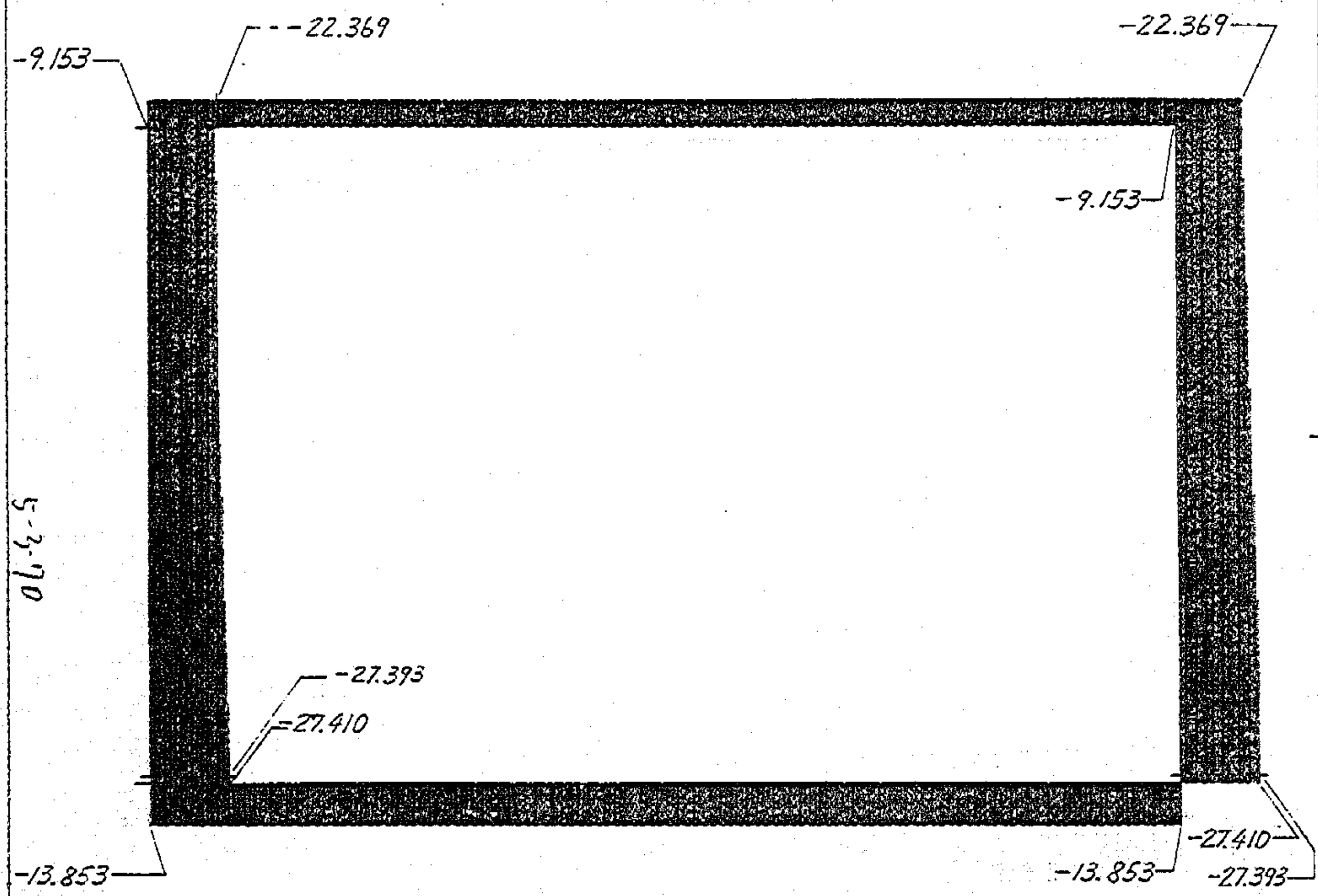
FRAME
OUTPUT V22
LOAD 1

FACTORED LOADS

MIN < 7>
-.2603E+02
AT .00
MAX < 6>
.2603E+02
AT .00

SAP90

POZA HONDA INLET CULVERT



AXIAL FORCE (t)

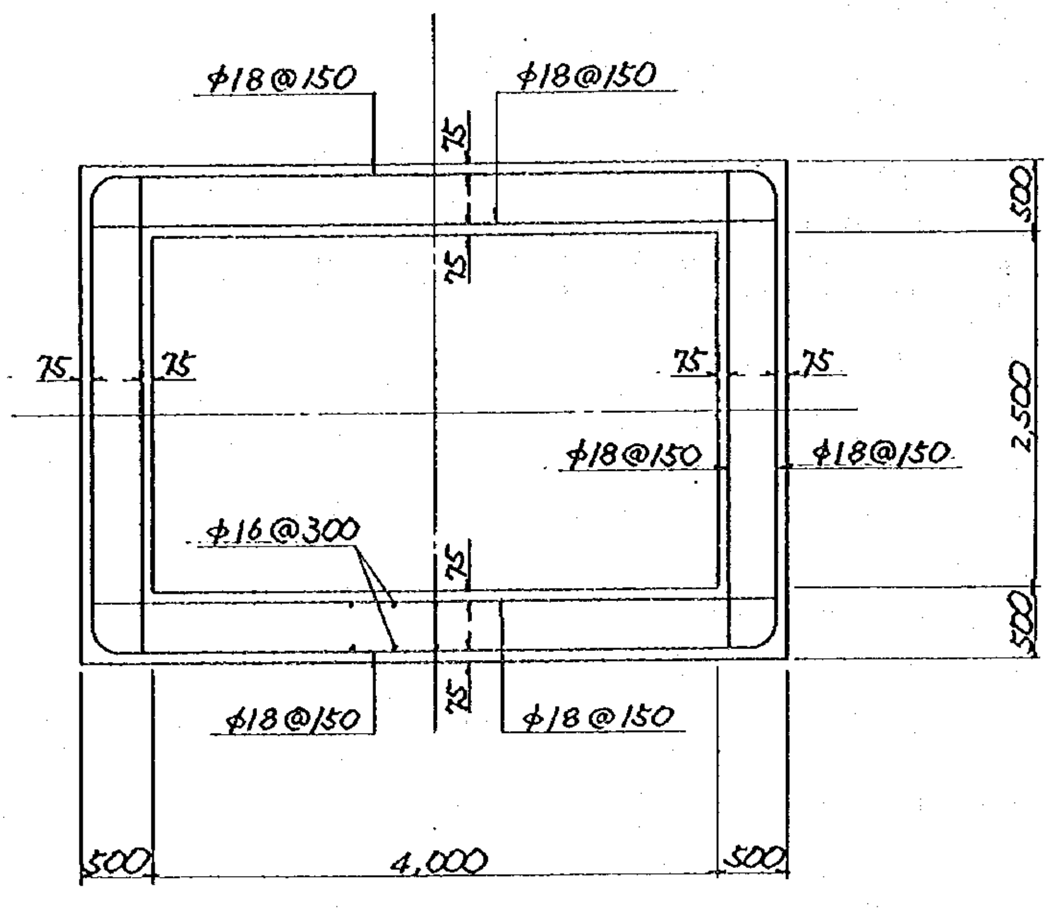
PHCULVERT
FRAME
OUTPUT P
LOAD 1

FACTORED LOADS

MIN < 1>
-.2741E+02
AT .00
MAX < 3>
-.9153E+01
AT .00

SAP90

5-3-70



INLET CULVERT

POZA HONDA INLET STRUCTURE

5·3·71

(B) Tunnel Inlet

Case 1 : After construction

1) Dead weight of lining concrete

Wc = 0.5 x 2.4 = 1.2 tf/m

2) Vertical bedrock pressure and water pressure

Pr = 1.8 x 10.3 + (1.8 - 1.0) x 8.95 = 25.7 tf/m
Pw = 1.0 x (El.102.0 - El.93.05) = 8.95 tf/m

3) Lateral bedrock pressure and water pressure

Ka = tan2(45 - 30/2) = 0.333
Prh1 = 0.333 x 1.8 x 10.3 + 0.333 x (1.8 - 1.0) x 8.95 = 8.558 tf/m
Prh2 = 0.333 x 1.8 x 10.3 + 0.333 x (1.8 - 1.0) x 12.45 = 9.49 tf/m
Pwh1 = 1.0 x 8.95 = 8.95 tf/m
Pwh2 = 1.0 x 12.45 = 12.45 tf/m

4) Uplift pressure and foundation reaction

Pu = 1.0 x 12.45 tf/m
Pf = (8.95 x 3.5 + 25.7 x 3.5 + 14.616)/3.5 - 12.45 = 26.376 tf/m

Case 2 : During construction

1) Dead weight of lining concrete

Wc = 0.5 x 2.4 = 1.2 tf/m

2) Vertical bedrock pressure and backfill grout pressure

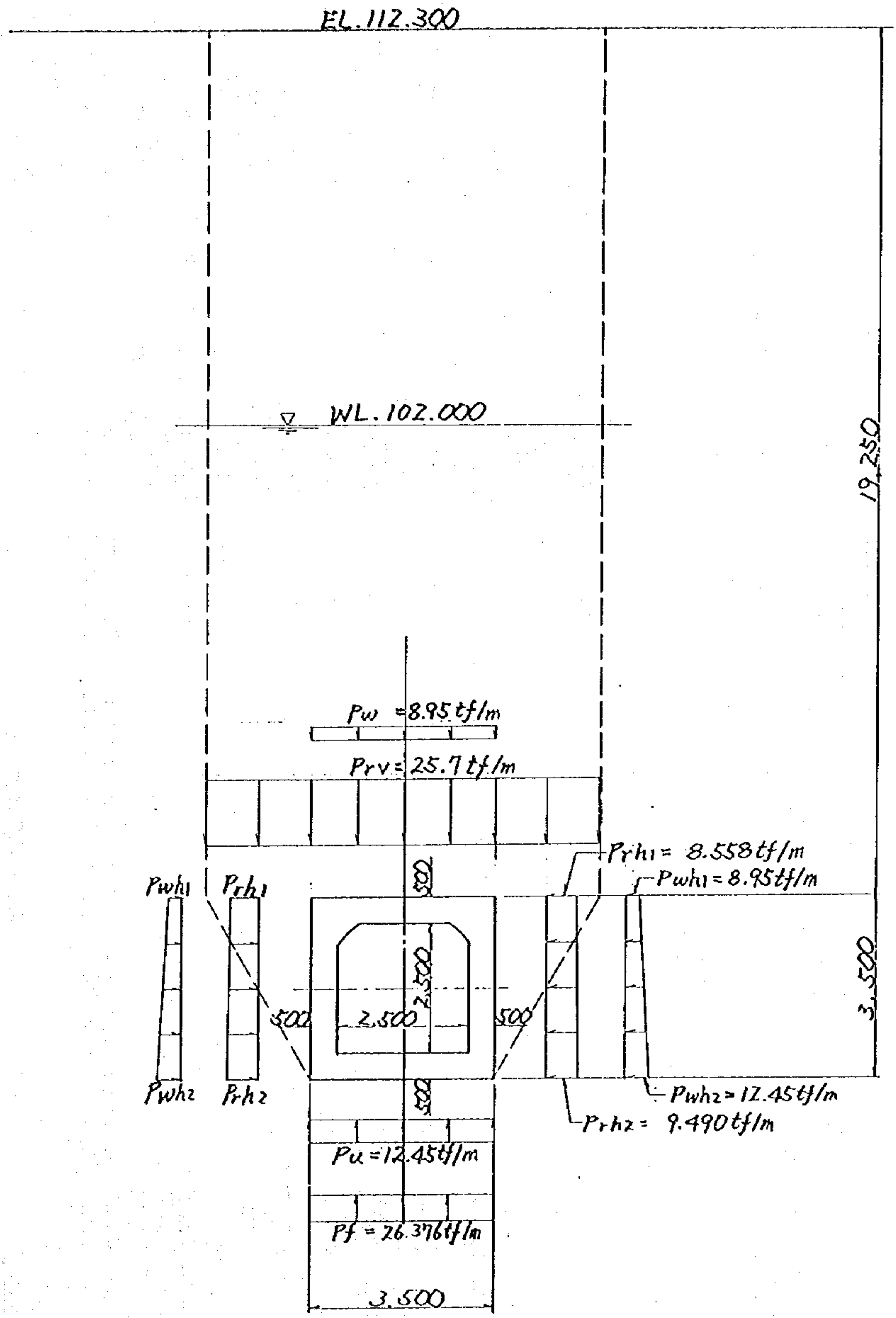
Pr = 1.8 x 19.25 = 34.65 tf/m
Pg = 15.0 tf/m

3) Lateral bedrock pressure and water pressure

Ka = tan2(45 - 30/2) = 0.333
Prh1 = 0.333 x 1.8 x 19.25 = 11.538 tf/m
Prh2 = 0.333 x 1.8 x 19.25 + 0.333 x (1.8 - 1.0) x 3.5 = 12.47 tf/m
Pw = 1.0 x 3.5 = 3.5 tf/m

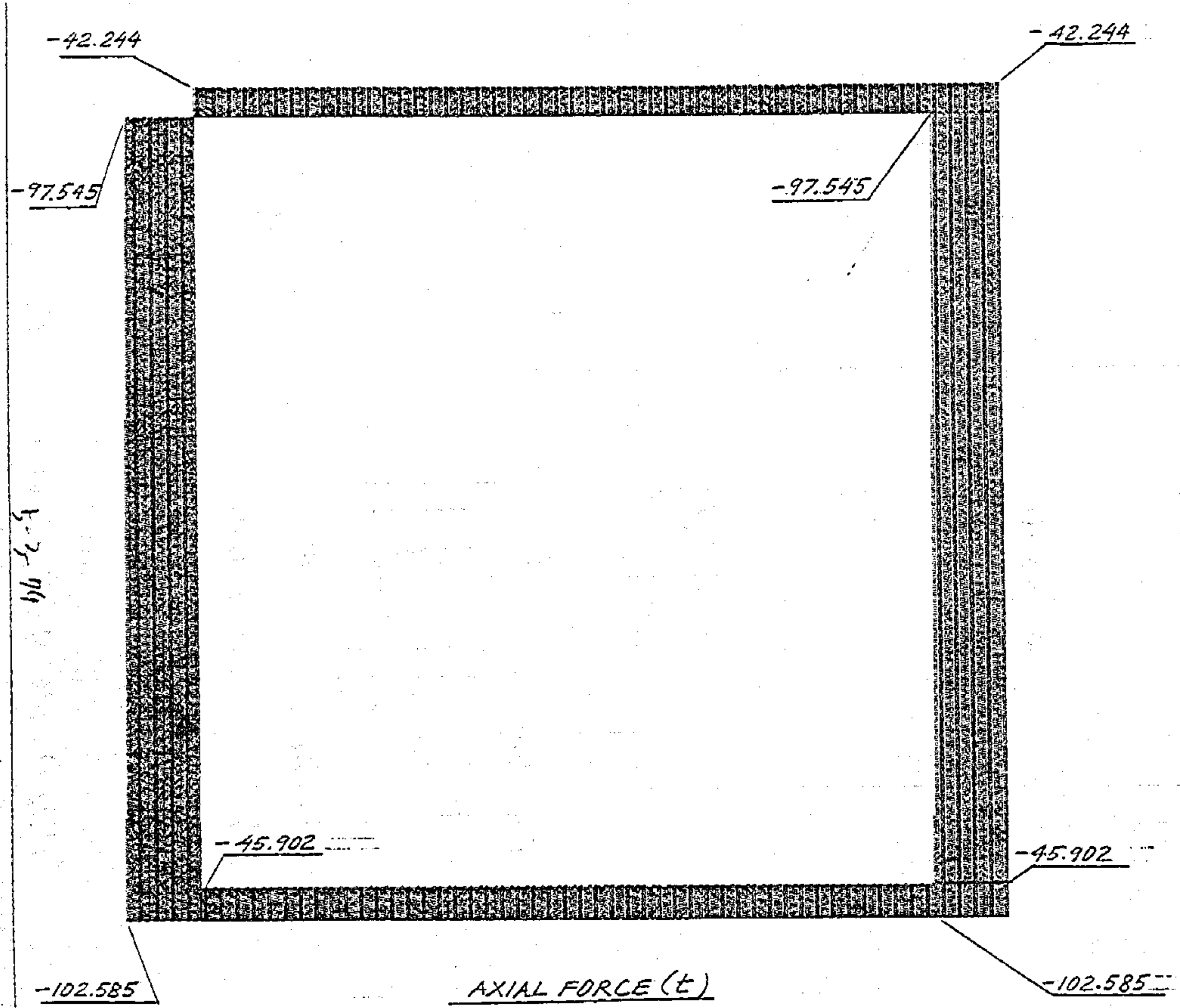
4) Uplift pressure and foundation reaction

Pu = 1.0 x 3.5 = 3.5 tf/m
Pf = (34.65 x 3.5 + 15.0 x 3.5 + 14.616)/3.5 - 3.5 = 50.326 tf/m



POZA HONDA INLET, CASE 1

POZA HONDA ~ MANCHA GRANDE TUNNEL 5-3-73

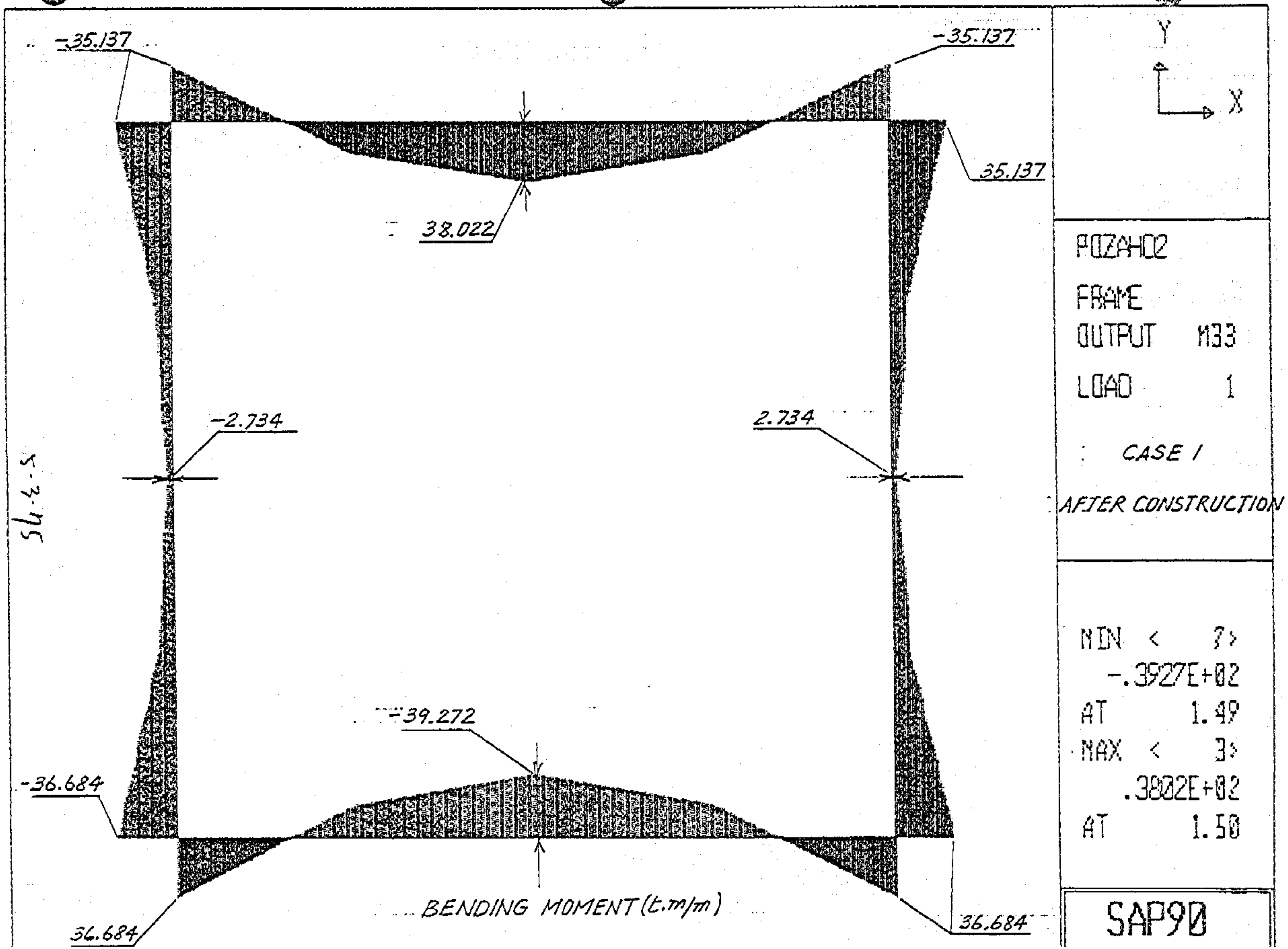


AXIAL FORCE (t)

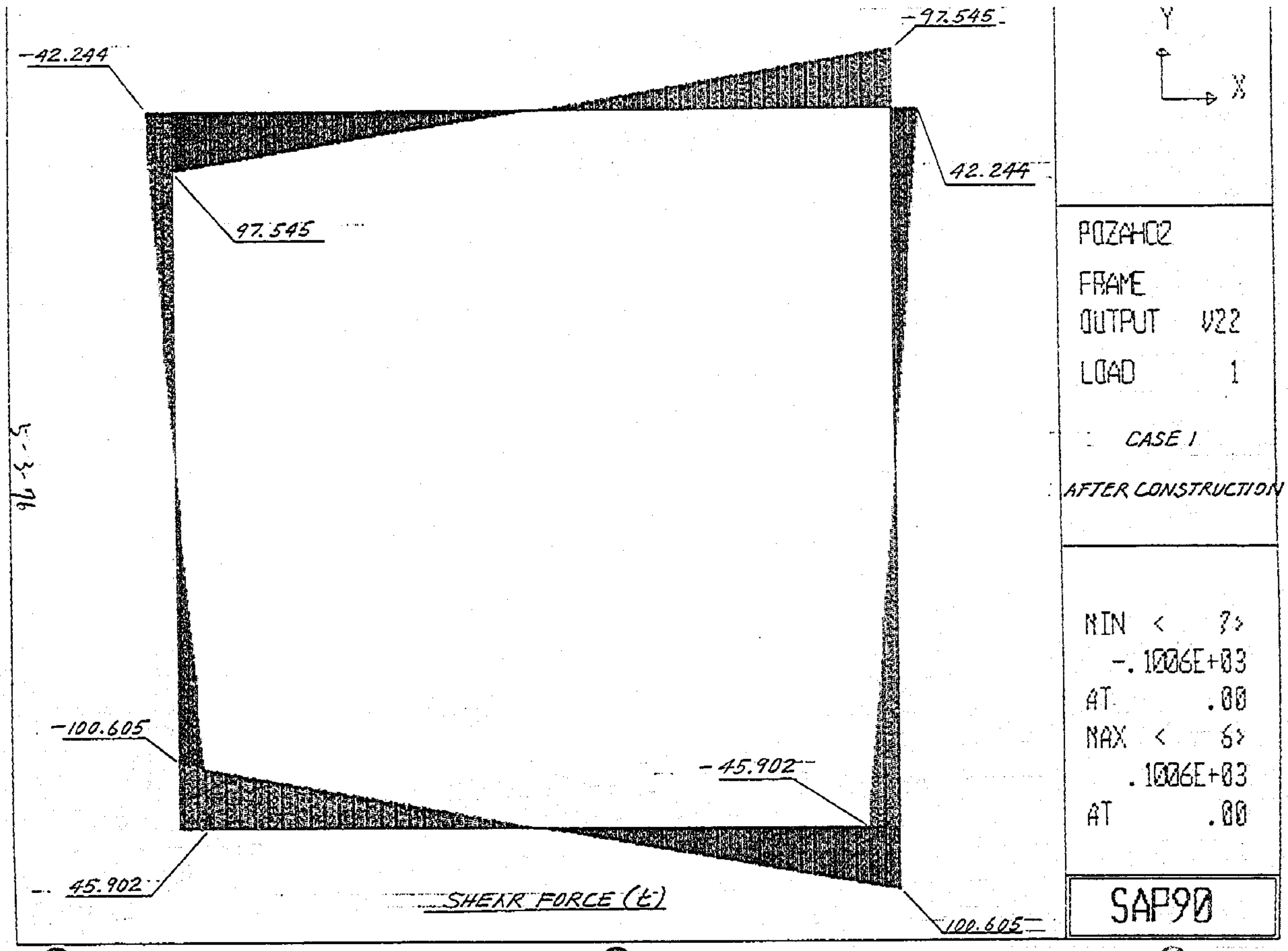
POZAHO2
FRAME
OUTPUT P
LOAD 1
: CASE I
AFTER CONSTRUCTION

MIN < 1>
-.1026E+03
AT .00
MAX < 3>
-.4224E+02
AT .00

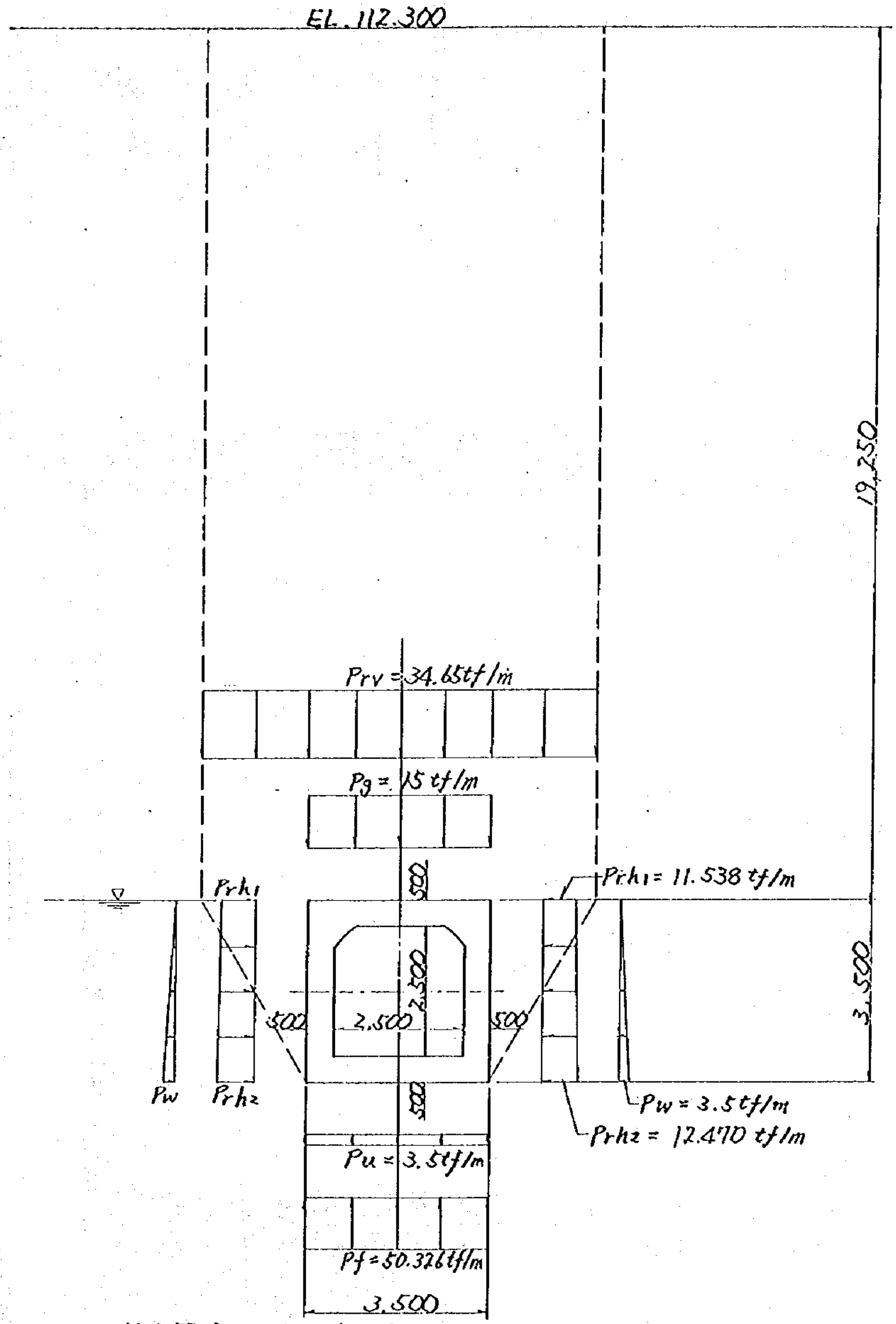
SAP90


-35.137
-35.137
35.137
38.022
-2.734
2.734
-39.272
-36.684
36.684
36.684
BENDING MOMENT (t.m/m)
Y
X
POZAHO2
FRAME
OUTPUT M33
LOAD 1
CASE I
AFTER CONSTRUCTION
MIN < 7>
-.3927E+02
AT 1.49
MAX < 3>
.3802E+02
AT 1.50
SAP90

5-3-75

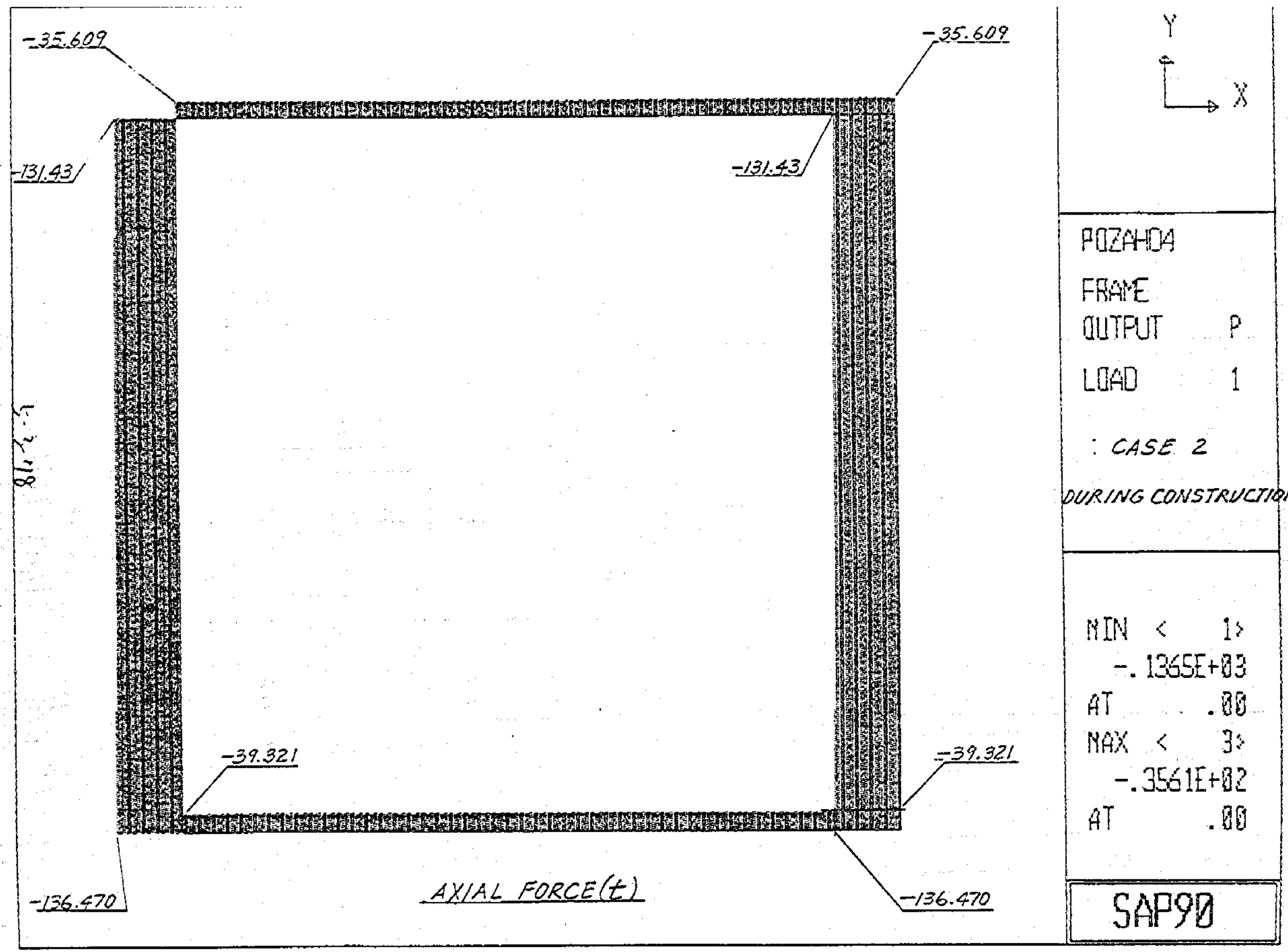

-97.545
-42.244
42.244
97.545
-100.605
-45.902
45.902
100.605
SHEAR FORCE (t)
Y
X
POZAHO2
FRAME
OUTPUT V22
LOAD 1
CASE I
AFTER CONSTRUCTION
MIN < 7>
-.1006E+03
AT .00
MAX < 6>
.1006E+03
AT .00
SAP90

5-3-76

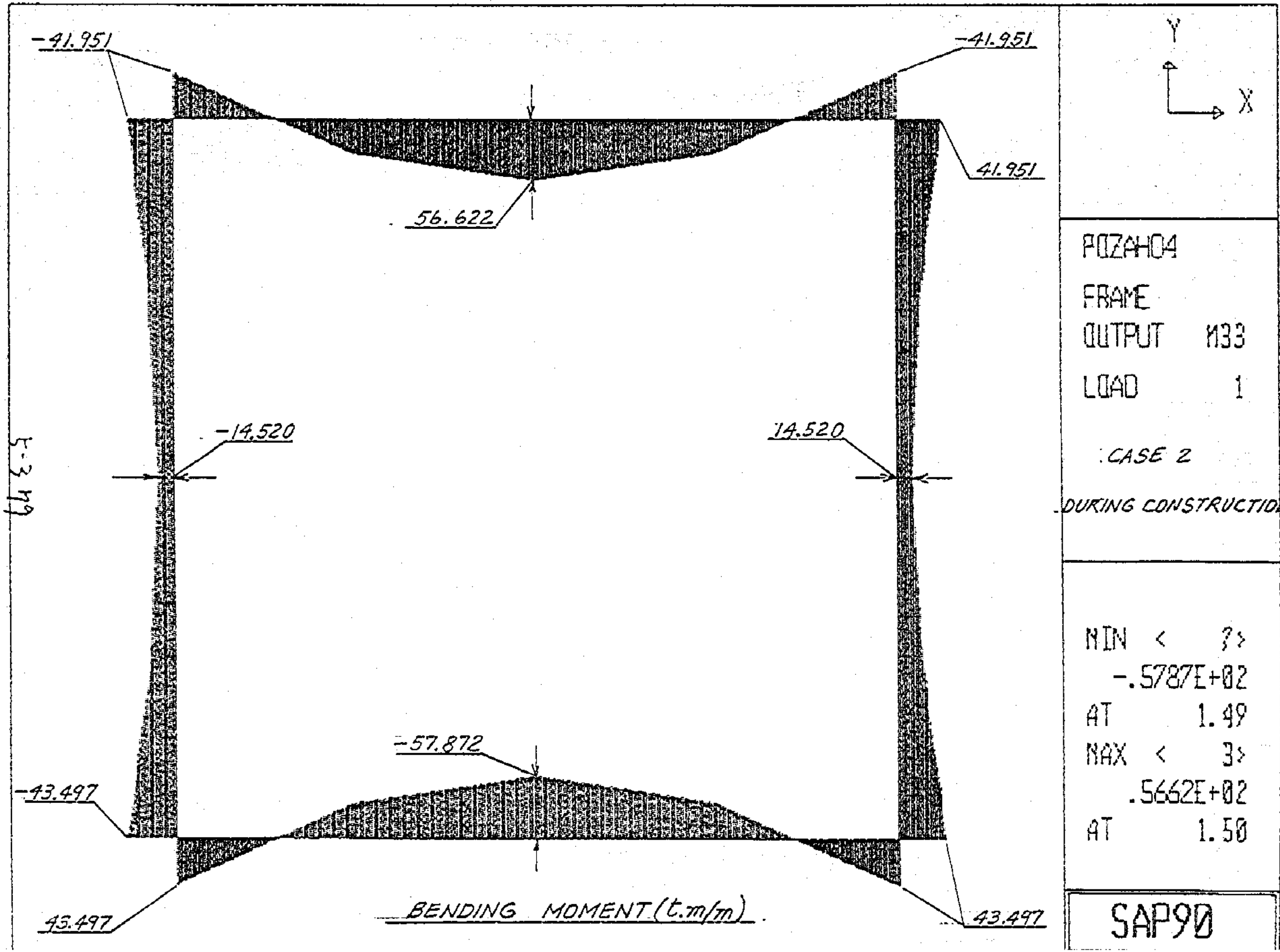


POZA HONDA INLET, CASE 2

POZA HONDA ~ MANCHA GRANDE TUNNEL

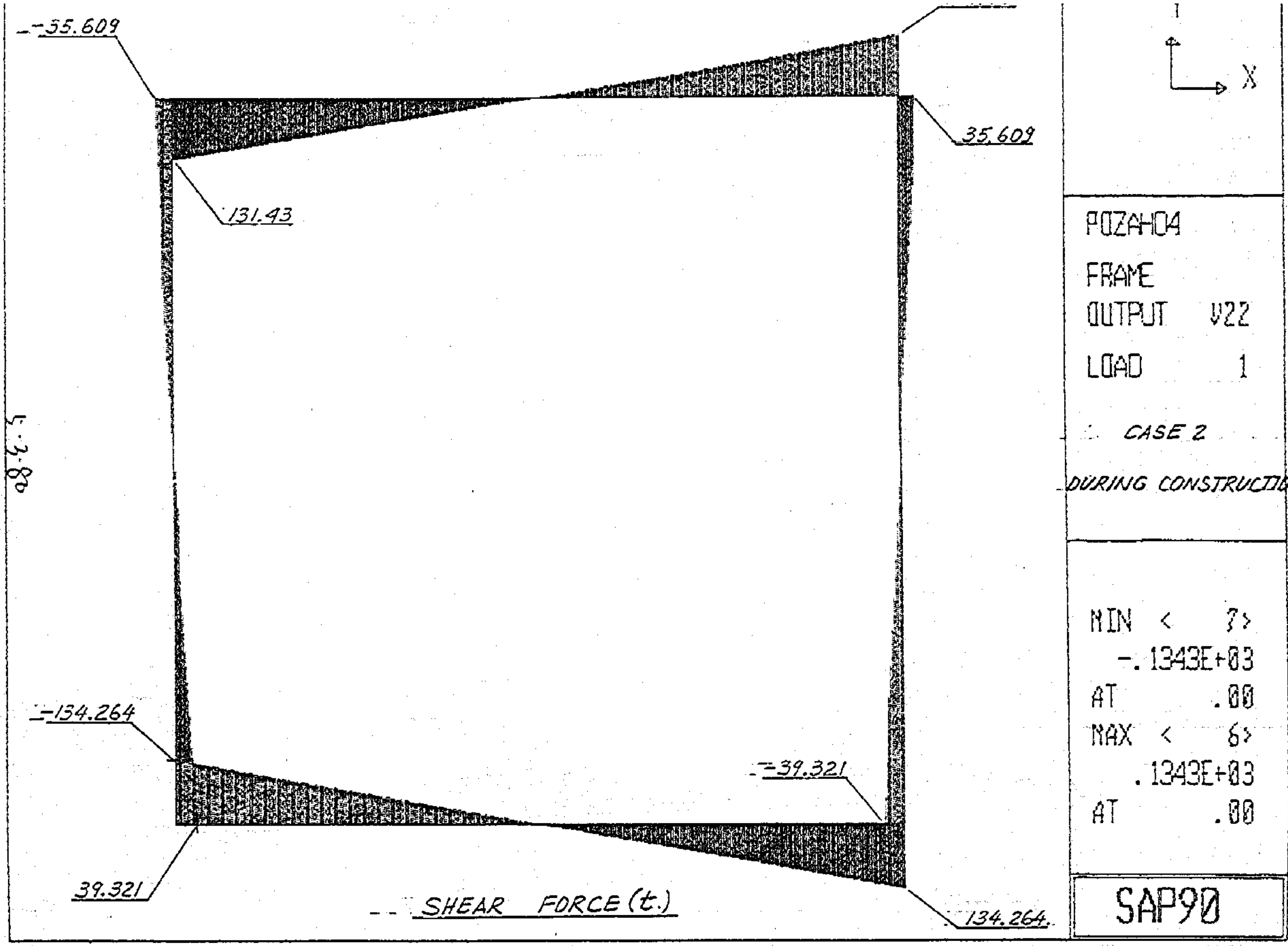


-35.609
-35.609
-131.43
-131.43
-39.321
-39.321
-136.470
-136.470
AXIAL FORCE(t)
Y
X
POZAHO4
FRAME
OUTPUT P
LOAD 1
: CASE 2
DURING CONSTRUCTION
MIN < 1>
-.1365E+03
AT .00
MAX < 3>
-.3561E+02
AT .00
SAP90

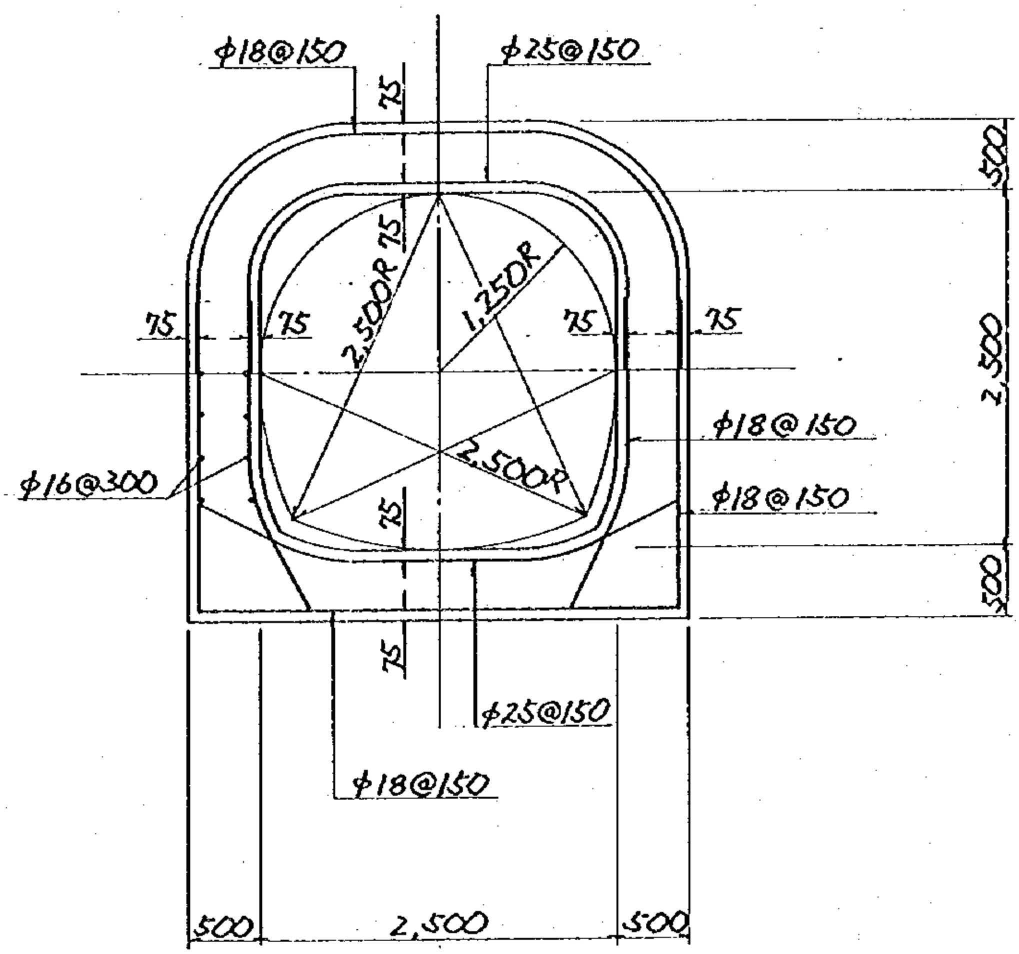


BENDING MOMENT (t.m/m)

5-3 79



-35.609
35.609
131.43
-134.264
-39.321
39.321
134.264
5.3.80
SHEAR FORCE (t.)
I
X
POZAHO4
FRAME
OUTPUT V22
LOAD 1
CASE 2
DURING CONSTRUCTION
MIN < 7>
-.1343E+03
AT .00
MAX < 6>
.1343E+03
AT .00
SAP90



POZA HONDA INLET (TRANSITION)

POZA HONDA - MANCHA GRANDE TUNNEL

5-3-81

(C) Inlet Shaft

Inlet Shaft, Section A - A

Case 1 : After construction

1) Lateral water pressure

Pw = 1.0 x (El.102.0 - El.83.45) = 18.55 tf/m

2) Lateral bedrock pressure

Ka = tan2(45 - 30/2) = 0.333
Pr = 0.333 x (1.8 - 1.0) x 5.35 = 1.43 tf/m

Inlet Shaft, Section B - B

Case 1 : After construction

1) Lateral water pressure

Pw = 1.0 x (El.102.0 - El.94.0) = 8.0 tf/m

2) Lateral bedrock pressure

Ka = tan2(45 - 30/2) = 0.333
Pr = 0.333 x 1.8 x 10.3 + 0.333 x (1.8 - 1.0) x 8.0 = 8.305 tf/m

Inlet Shaft, Section C - C

Case 1 : After construction

1) Lateral water pressure

Pw = 1.0 x (El.102.0 - El.96.5) = 5.5 tf/m

2) Lateral bedrock pressure

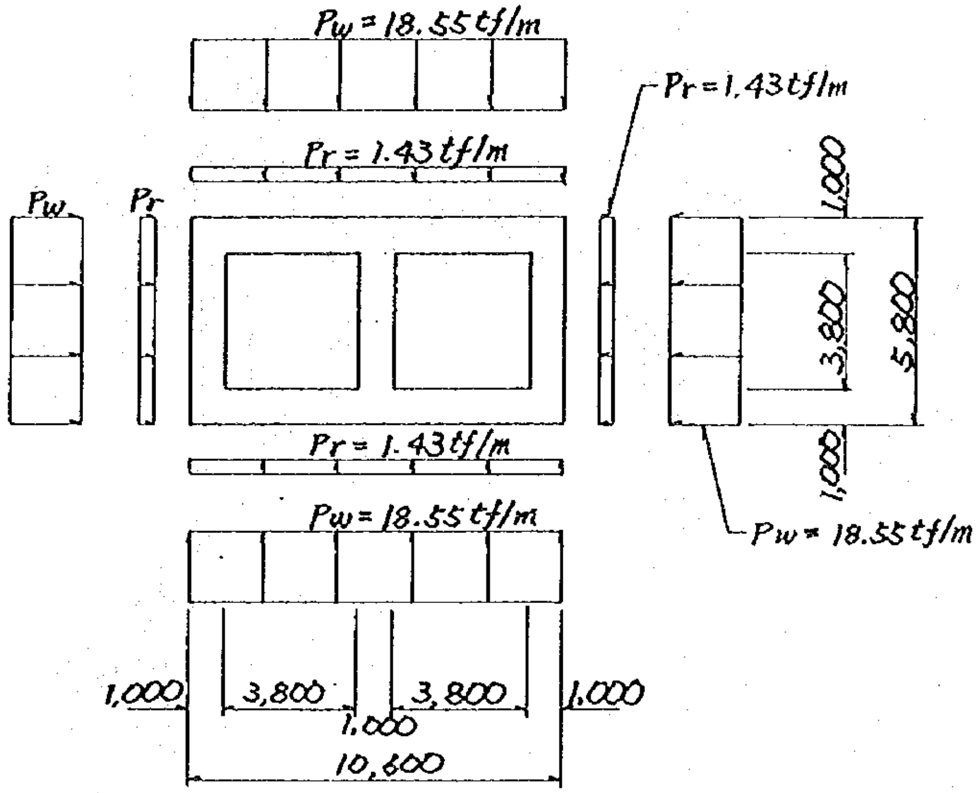
Ka = tan2(45 - 30/2) = 0.333
Pr = 0.333 x 1.8 x 10.3 + 0.333 x (1.8 - 1.0) x 5.5 = 7.639 tf/m

Inlet Shaft, Section D - D

Case 1 : After construction

1) Lateral bedrock pressure

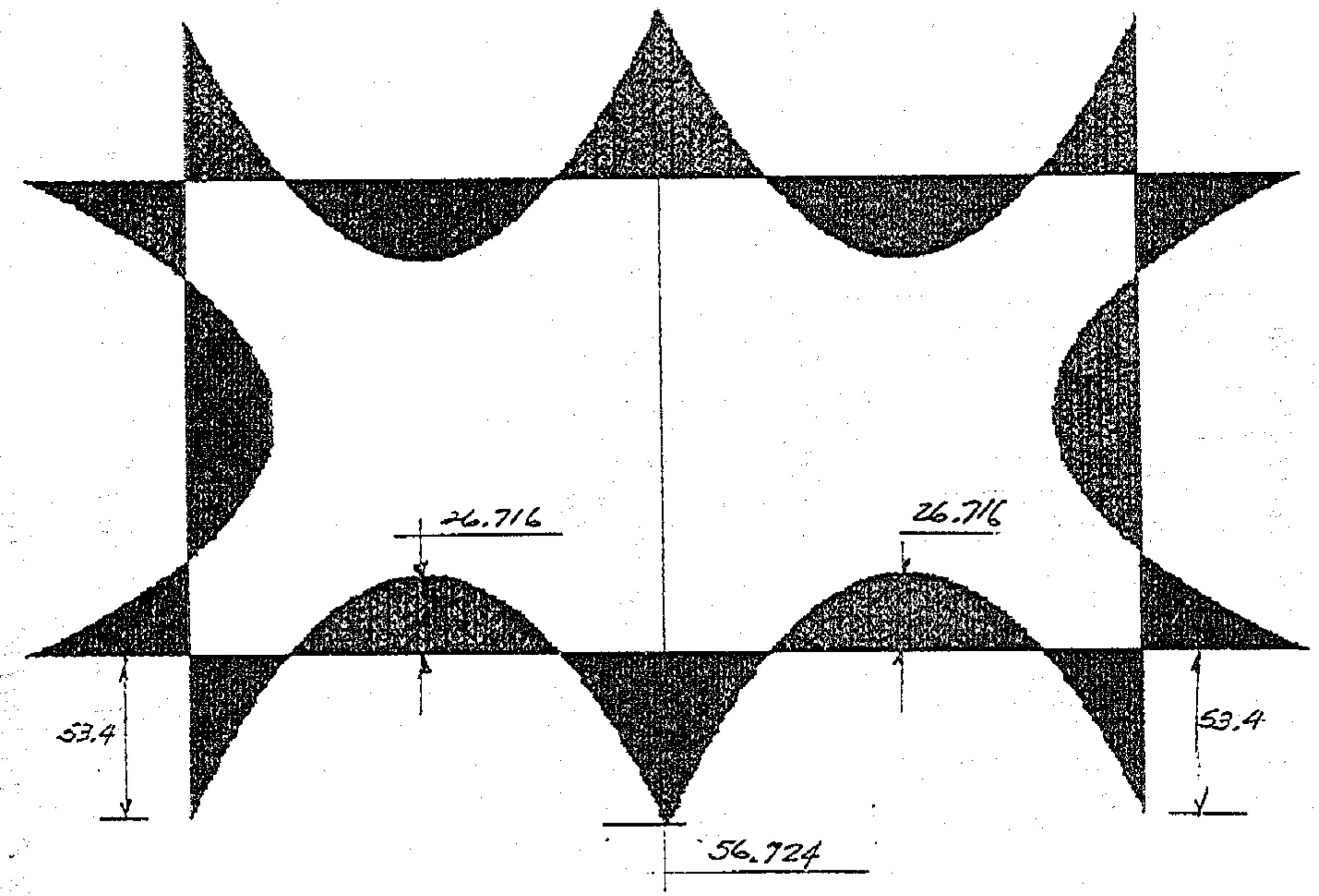
Ka = tan2(45 - 30/2) = 0.333
Pr = 0.333 x 1.8 x 8.0 = 4.975 tf/m



INLET SHAFT, SECTION A - A

POZA HONDA INLET STRUCTURE 5·3·83

POZA HONDA SHIFT



MOMENT DIAGRAM

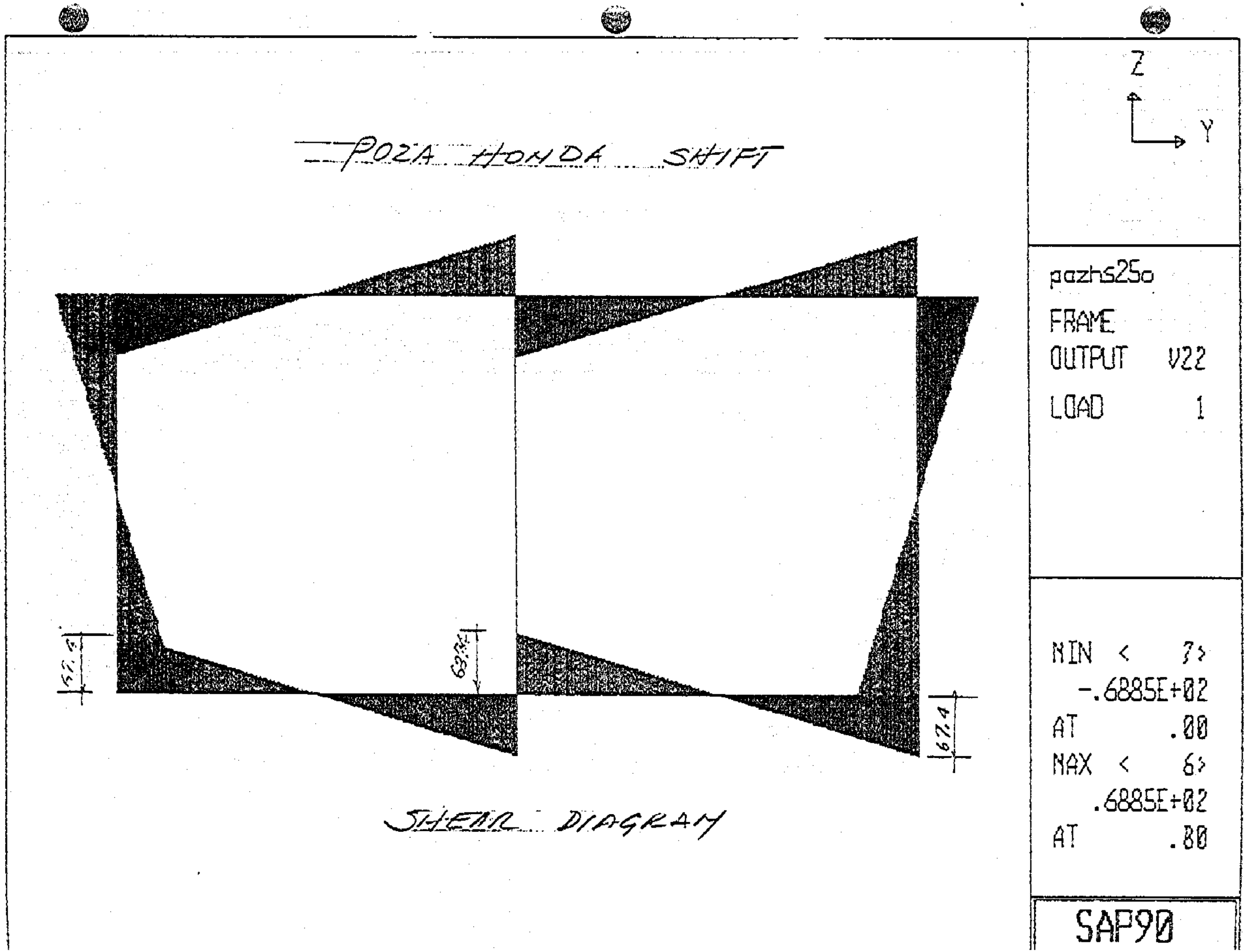
Z
Y

POZHS250
FRAME
OUTPUT M33
LOAD 1

MIN < 36>
-.5672E+02
AT .80
MAX < 6>
.5672E+02
AT .80

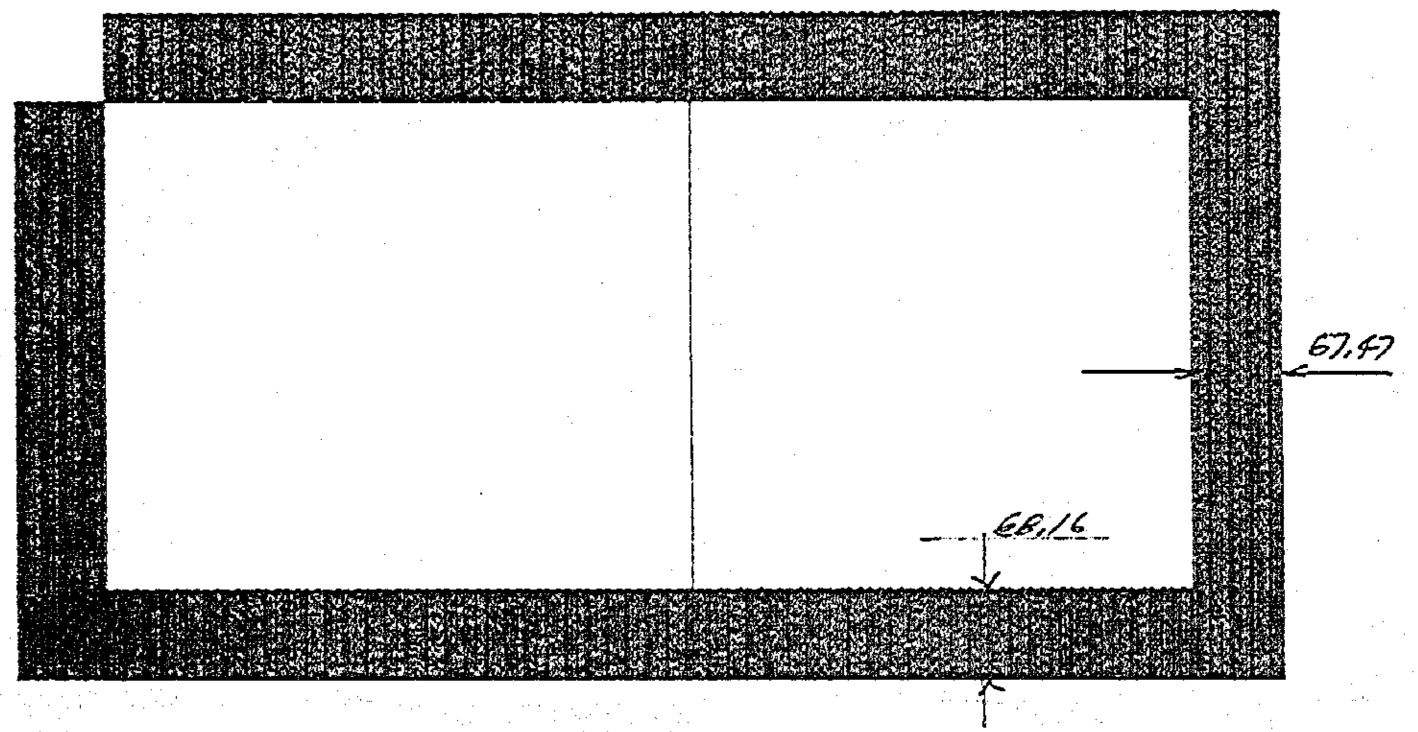
SAP90

5-3.84


POZA HONDA SHIFT
67.4
63.4
67.4
SHEAR DIAGRAM
Z
Y
pazhs25o
FRAME
OUTPUT V22
LOAD 1
MIN < 7>
-.6885E+02
AT .00
MAX < 6>
.6885E+02
AT .80
SAP90

58 / 5

— POZA HONDA SHIFT



— AXIAL FORCE

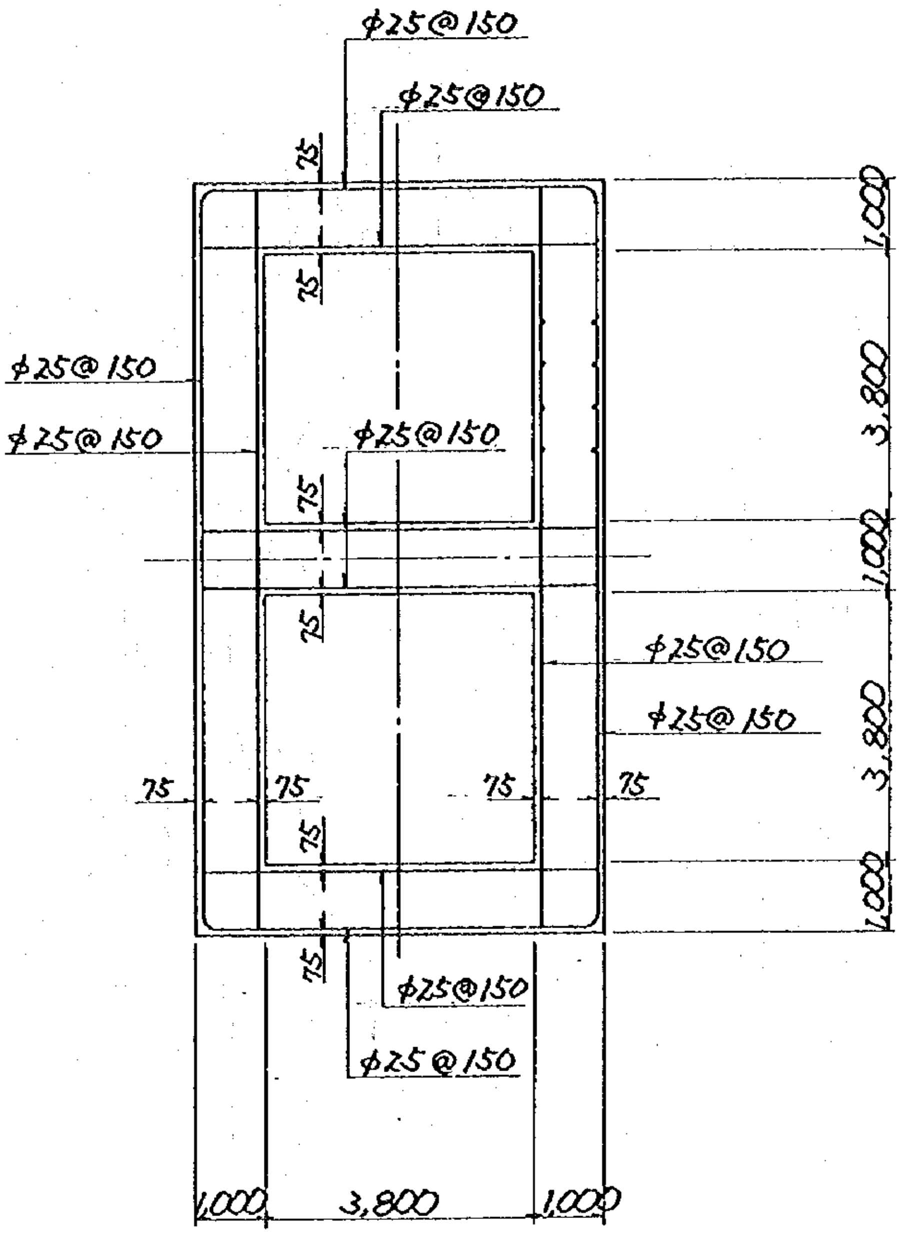
Z
Y

pazhs25o
FRAME
OUTPUT P
LOAD 1

MIN < 1>
-.6816E+02
AT .00
MAX < 14>
-.1392E-27
AT .00

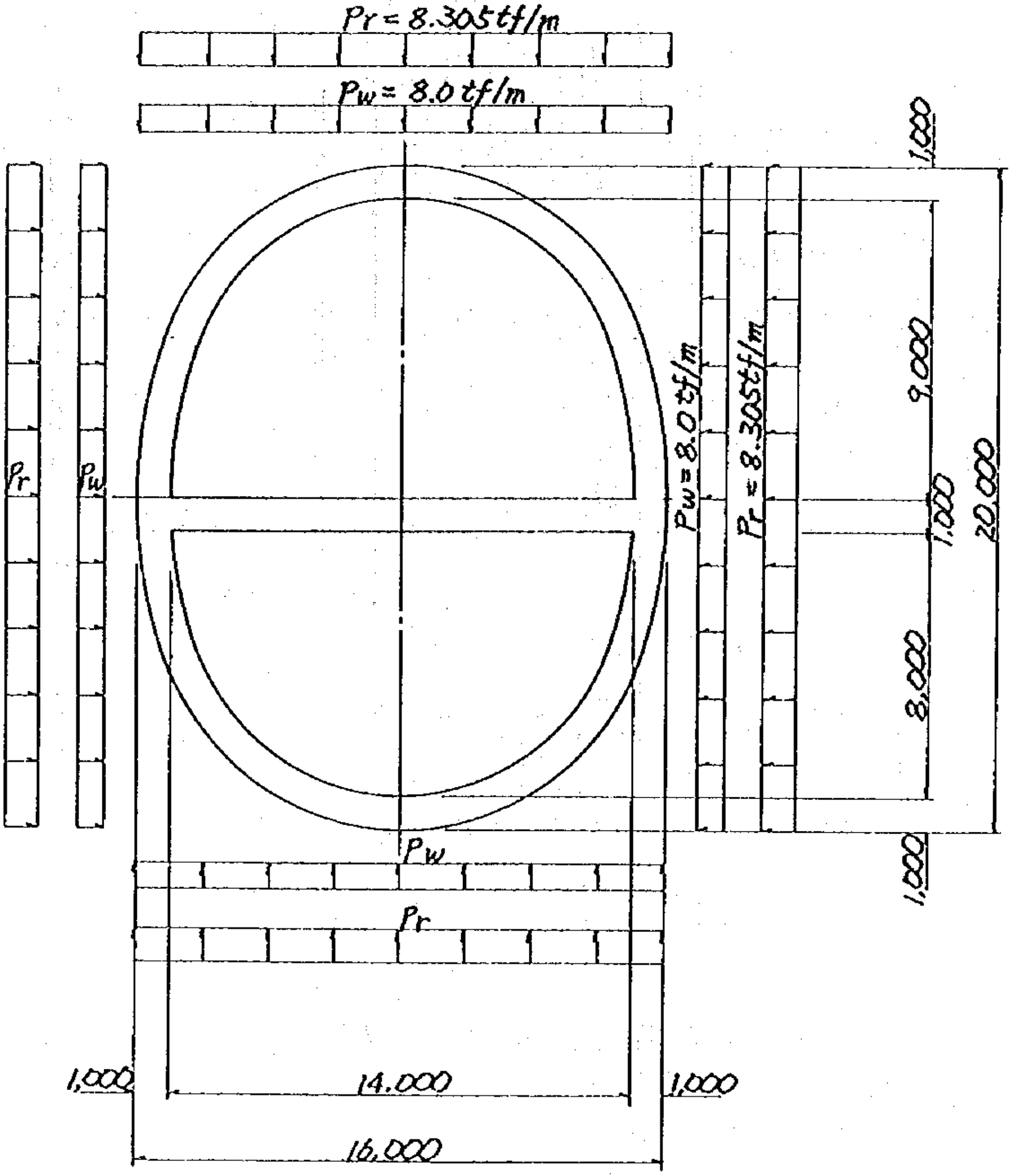
SAP90

5.3.98



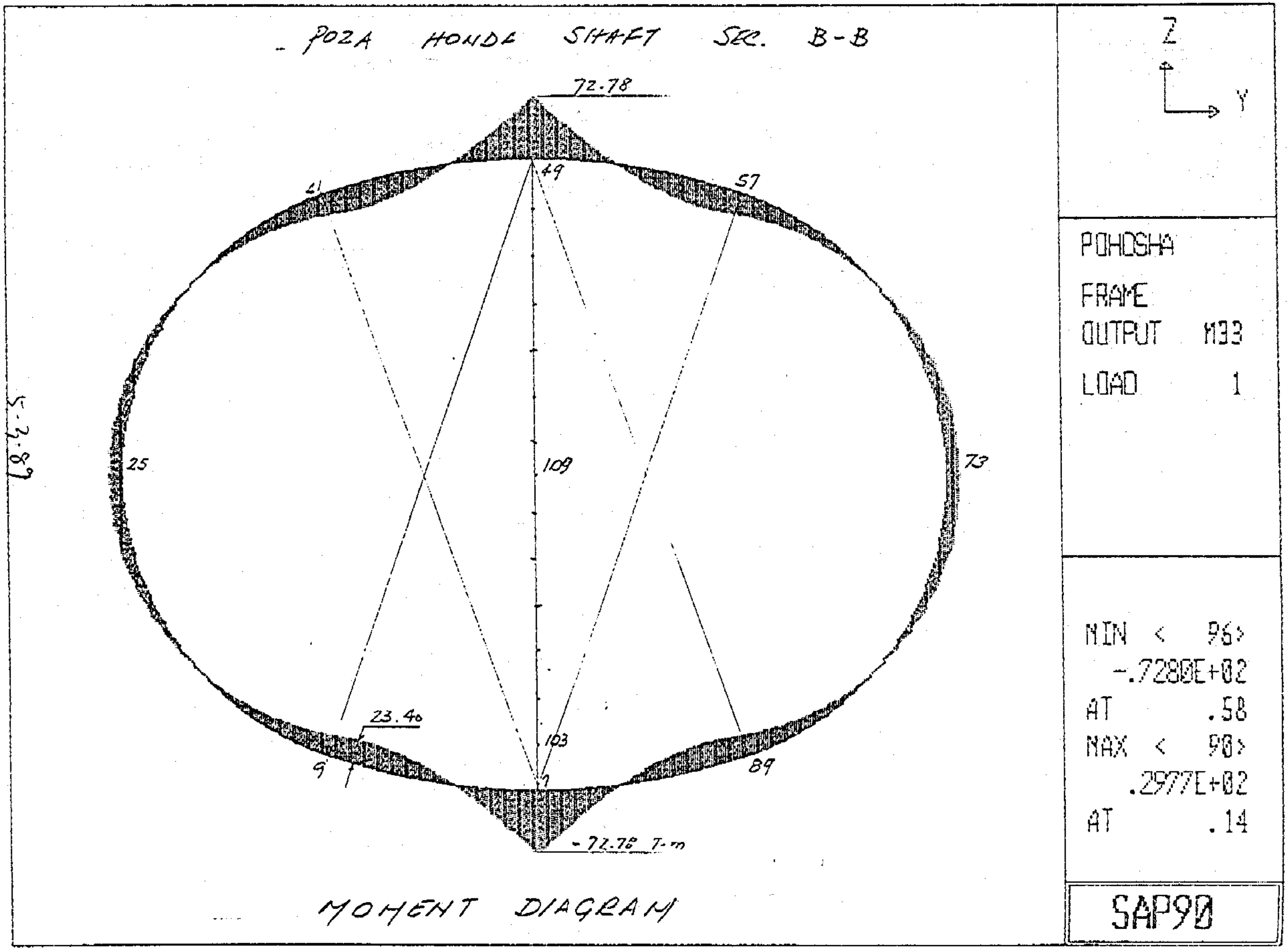
INLET SHAFT, SECTION A - A

POZA HONDA INLET STRUCTURE 5-3-87

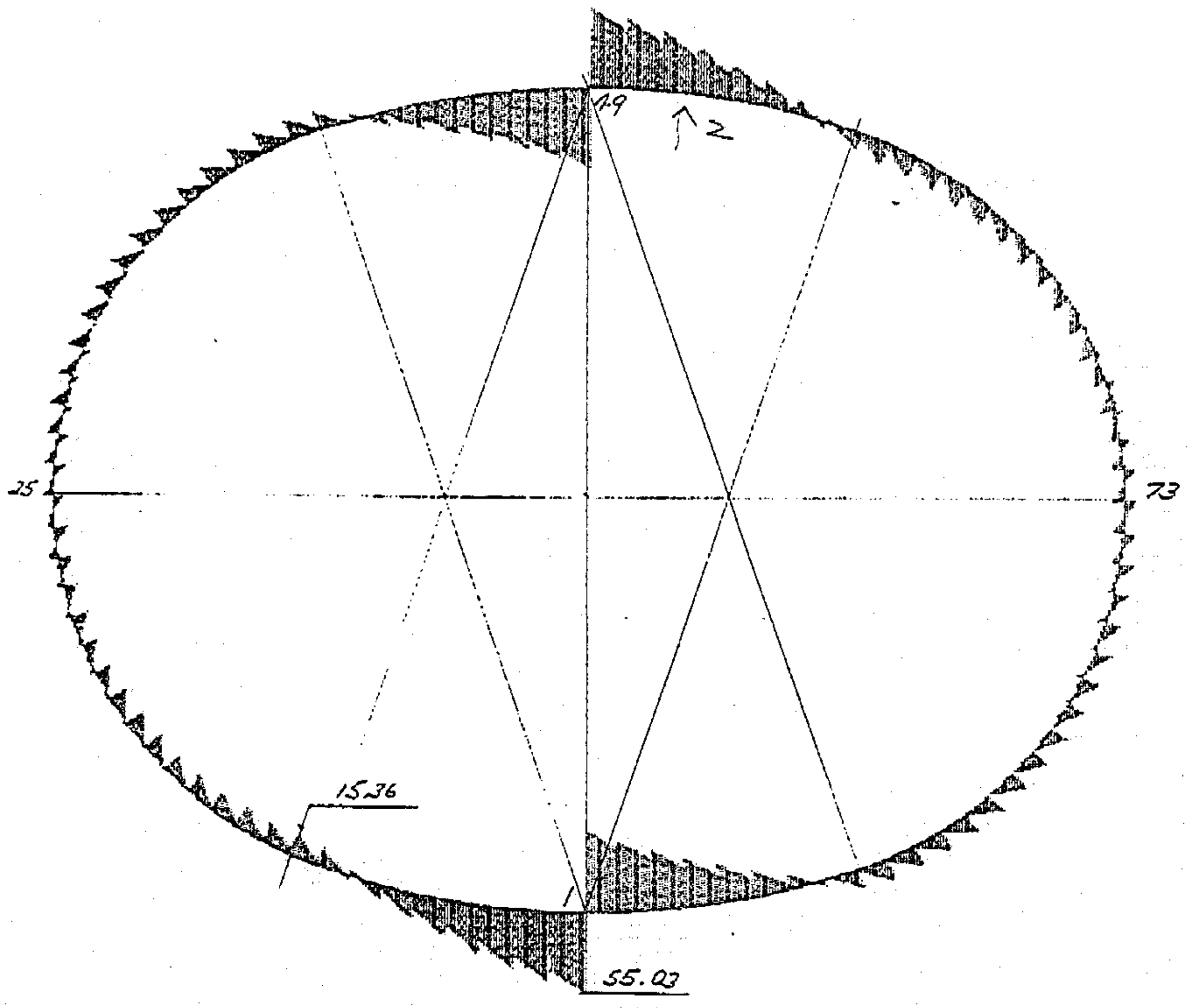


INLET SHAFT, SECTION B - B

POZA HONDA INLET STRUCTURE 5-3-88


- POZA HONDA SHAFT SEC. B-B
72.78
49
41
57
25
109
73
23.40
103
9
1
89
-72.78 T-m
MOMENT DIAGRAM
5-3-89
Z
Y
POHDSHA
FRAME
OUTPUT M33
LOAD 1
MIN < 96>
-.7280E+02
AT .58
MAX < 90>
.2977E+02
AT .14
SAP90

POZA HONDA SHAFT SEC. B-B



SHEAR DIAGRAM

5.7.90

POHOSHA

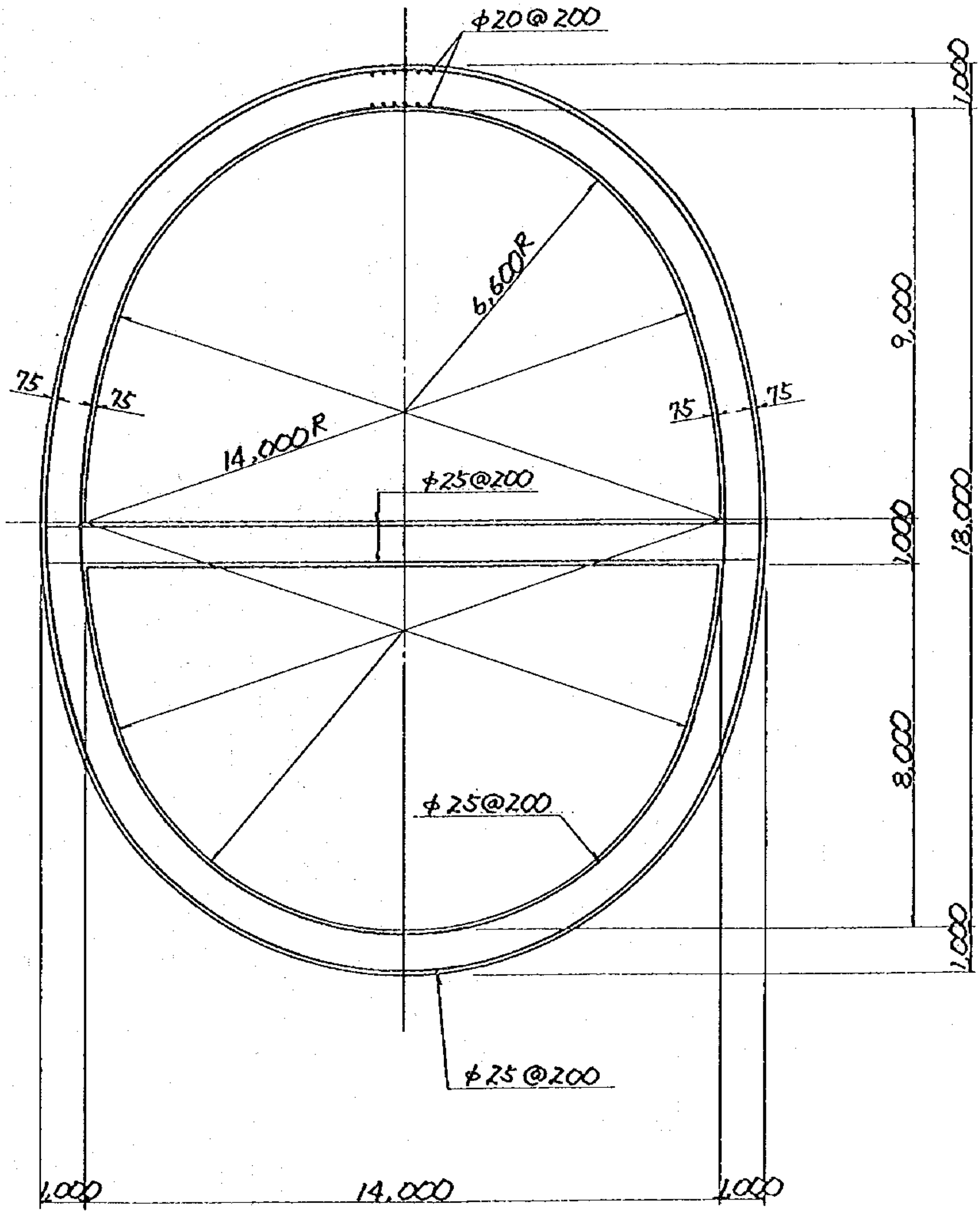
FRAME

OUTPUT V22

LOAD 1

MIN < 96>
-.5513E+02
AT .58
MAX < 49>
.5504E+02
AT .00

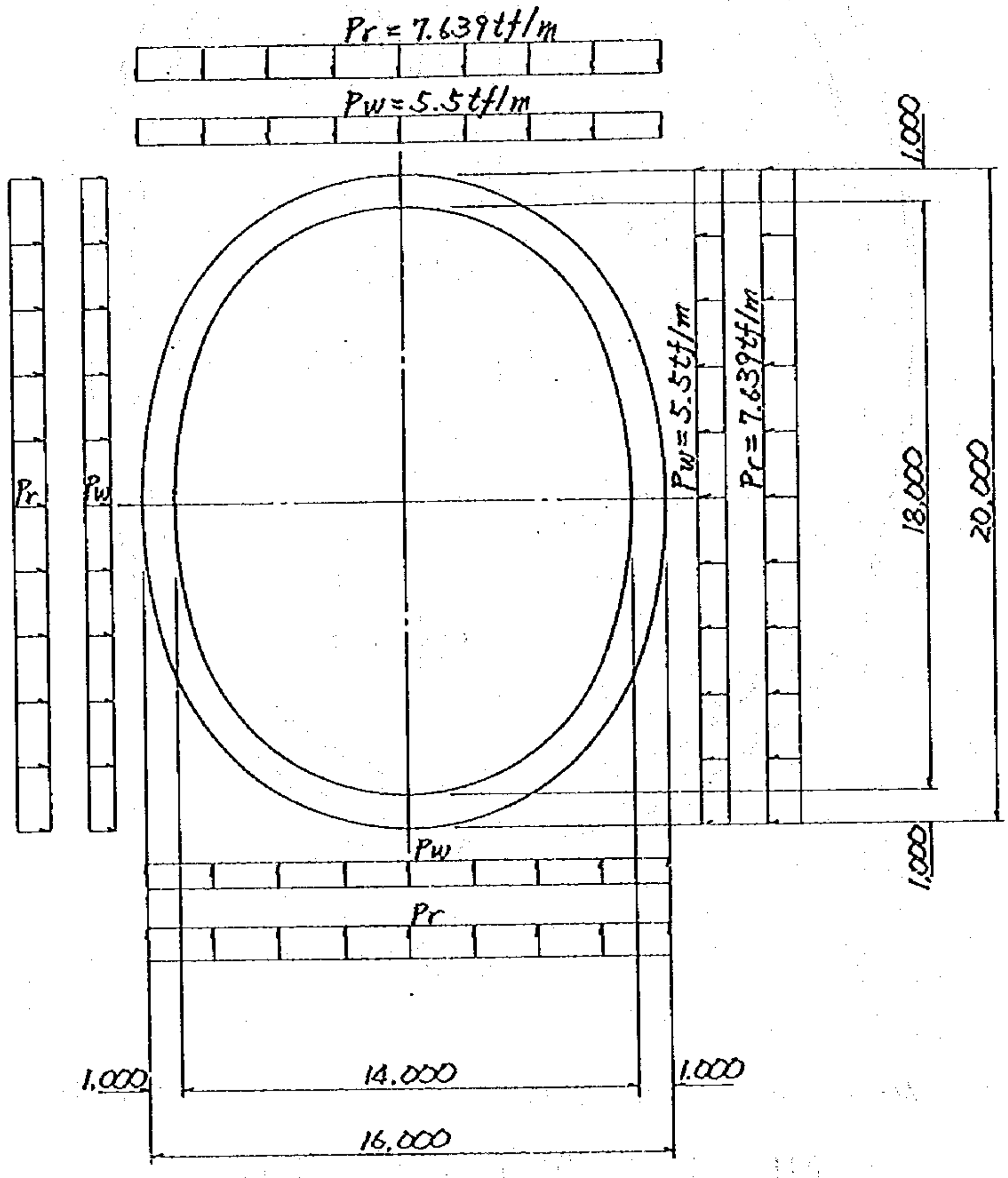
SAP90



INLET SHAFT, SECTION B - B

POZA HONDA INLET STRUCTURE

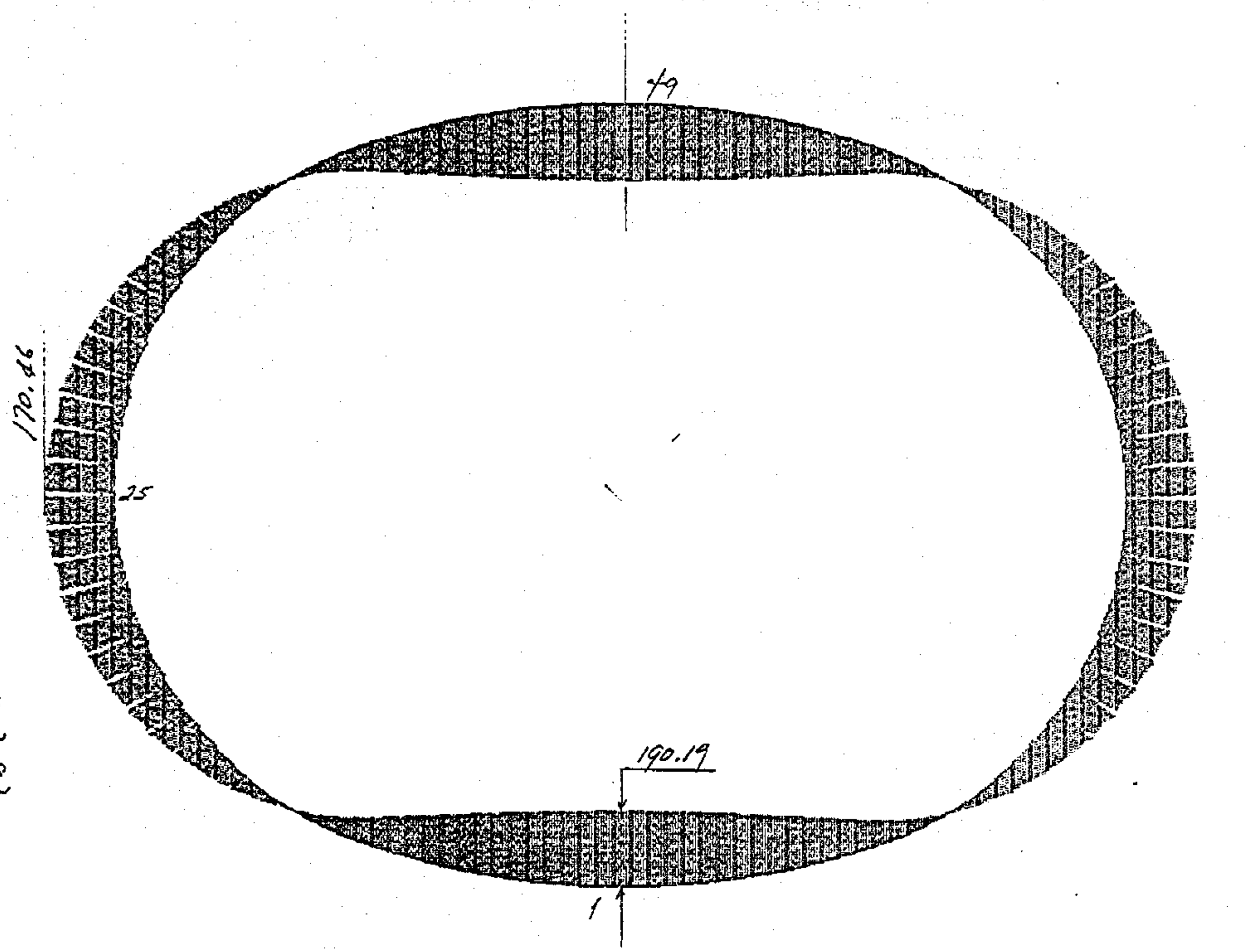
5·3·91



INLET SHAFT, SECTION C - C

POZA HONDA INLET STRUCTURE 5·3·95

POZA HOUDA SHAFT SEC. C-C



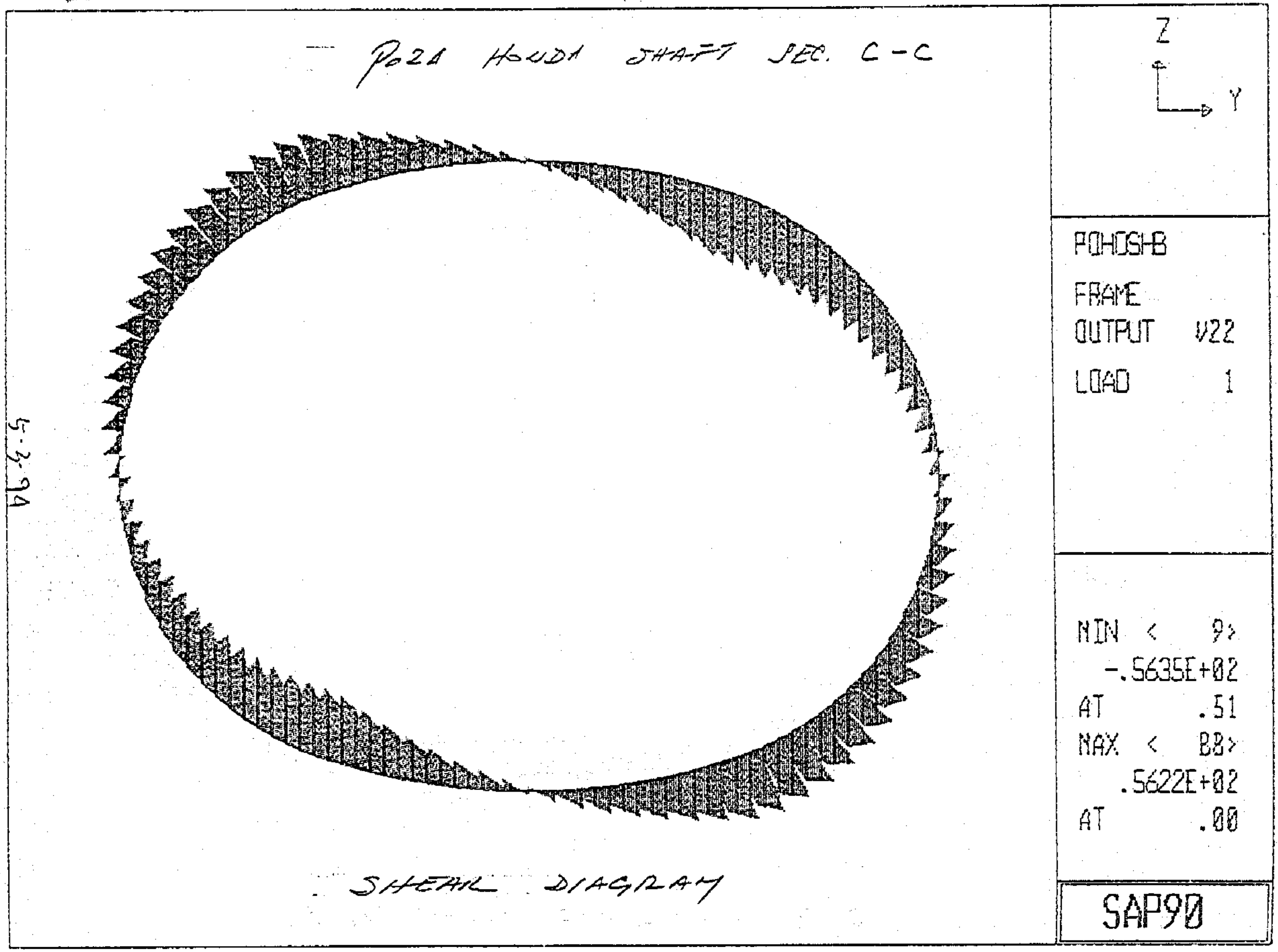
MOMENT DIAGRAM

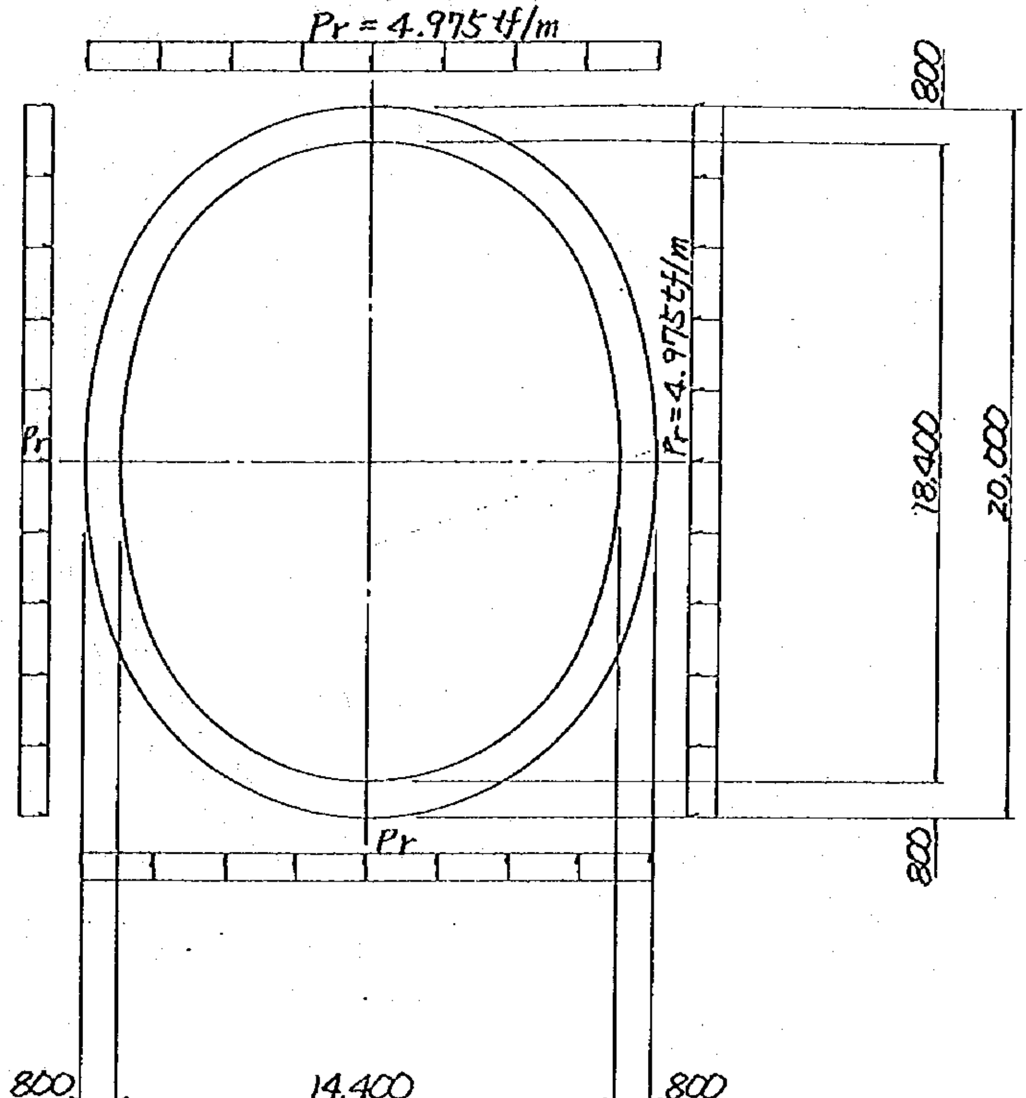
5-3-93

POHOSHB
FRAME
OUTPUT M33
LOAD 1

MIN < 72>
-.1705E+03
AT .51
MAX < 48>
.1904E+03
AT .43

SAP90

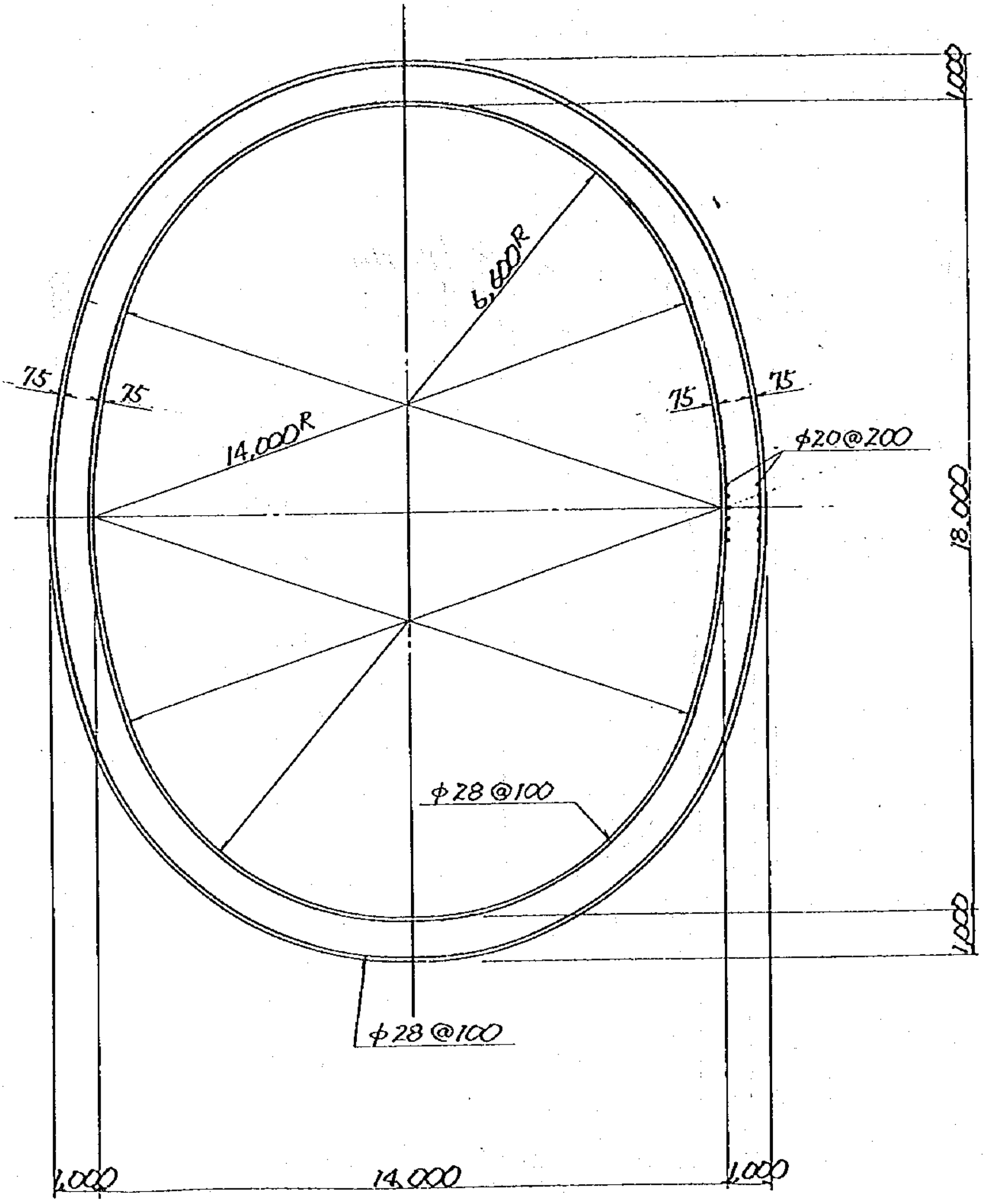

Po2A Houda Shaft Sec. C-C
Z
Y
POHOSHB
FRAME
OUTPUT V22
LOAD 1
MIN < 9>
-.5635E+02
AT .51
MAX < 88>
.5622E+02
AT .00
SAP90
SHEAR DIAGRAM
5-3-94



INLET SHAFT, SECTION D - D

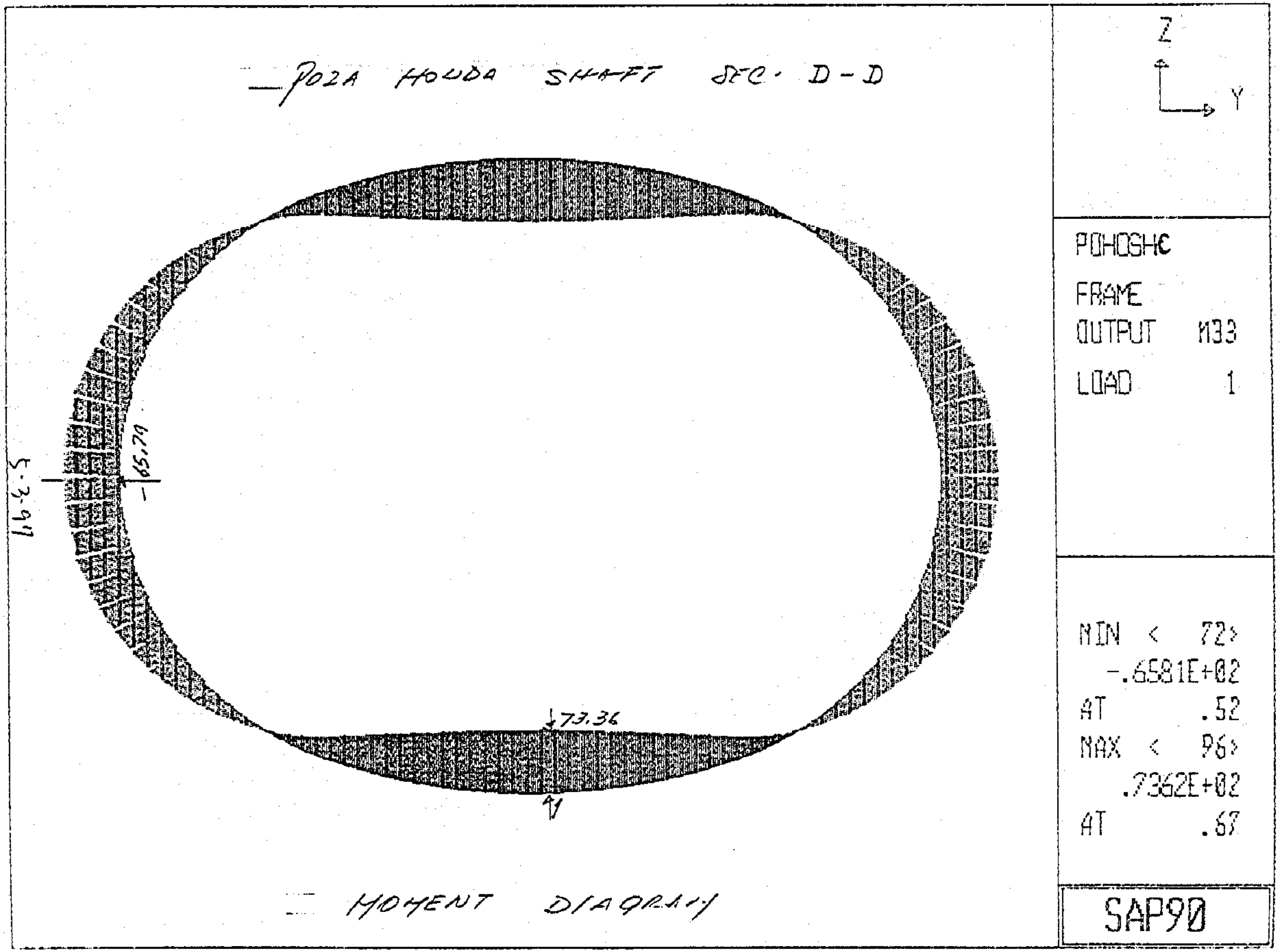
POZA HONDA INLET STRUCTURE

5-3-95

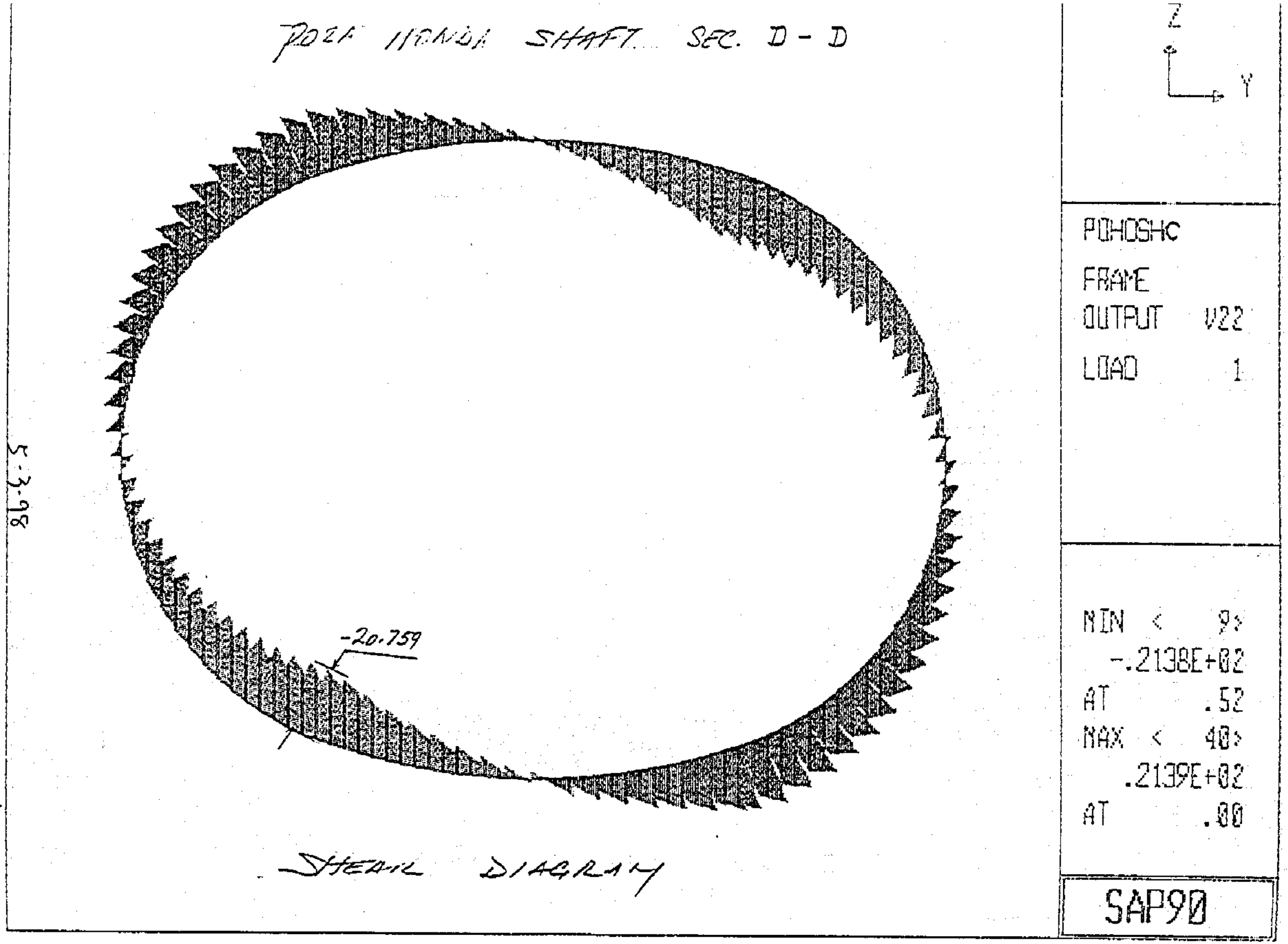


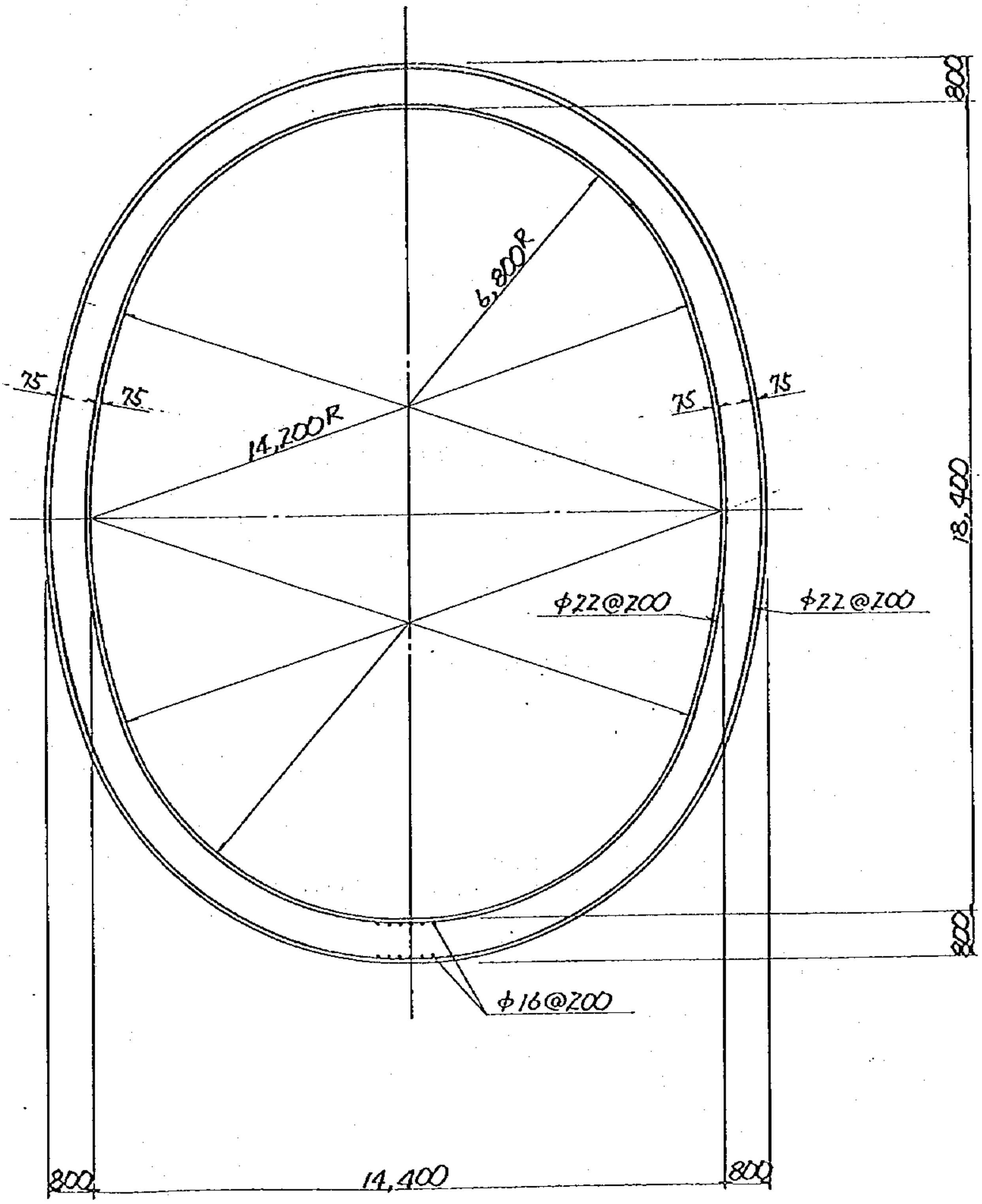
INLET SHAFT, SECTION C - C

POZA HONDA INLET STRUCTURE



— POZA HONDA SHAFT SEC. D - D
-65.79
73.36
5-3-97
Z
Y
POHOSHC
FRAME
OUTPUT M33
LOAD 1
MIN < 72>
-.6581E+02
AT .52
MAX < 96>
.7362E+02
AT .67
SAP90
— MOMENT DIAGRAM


POZA HONDA SHAFT SEC. D - D
Z
Y
-20.759
SHEAR DIAGRAM
5-3-98
POHOSHC
FRAME
OUTPUT V22
LOAD 1
MIN < 9>
-.2138E+02
AT .52
MAX < 40>
.2139E+02
AT .00
SAP90



INLET SHAFT. SECTION D - D

POZA HONDA INLET STRUCTURE

5·3·99

(D) Inlet Tunnel

Case 1 : After Construction

1) Dead weight of lining concrete

Wc = 0.50 x 2.4 = 1.20 tf/m

2) Vertical bedrock pressure

Pr = 2.0 x 18.3 + (2.0 - 1.0) x 1.2 = 37.8 tf/m

3) Lateral bedrock pressure

Ka = tan2(45 - 30/2) = 0.333
Prh1 = 0.333 x 2.0 x 18.3 + 0.333 x (2.0 - 1.0) x 1.2 = 12.587 tf/m tf/m
Prh2 = 0.333 x 2.0 x 18.3 + 0.333 x (2.0 - 1.0) x 4.7 = 13.753 tf/m

Case 2 : During Construction

1) Dead weight of lining concrete

Wc = 0.50 x 2.4 = 1.20 tf/m

2) Vertical bedrock pressure and backfill grout pressure

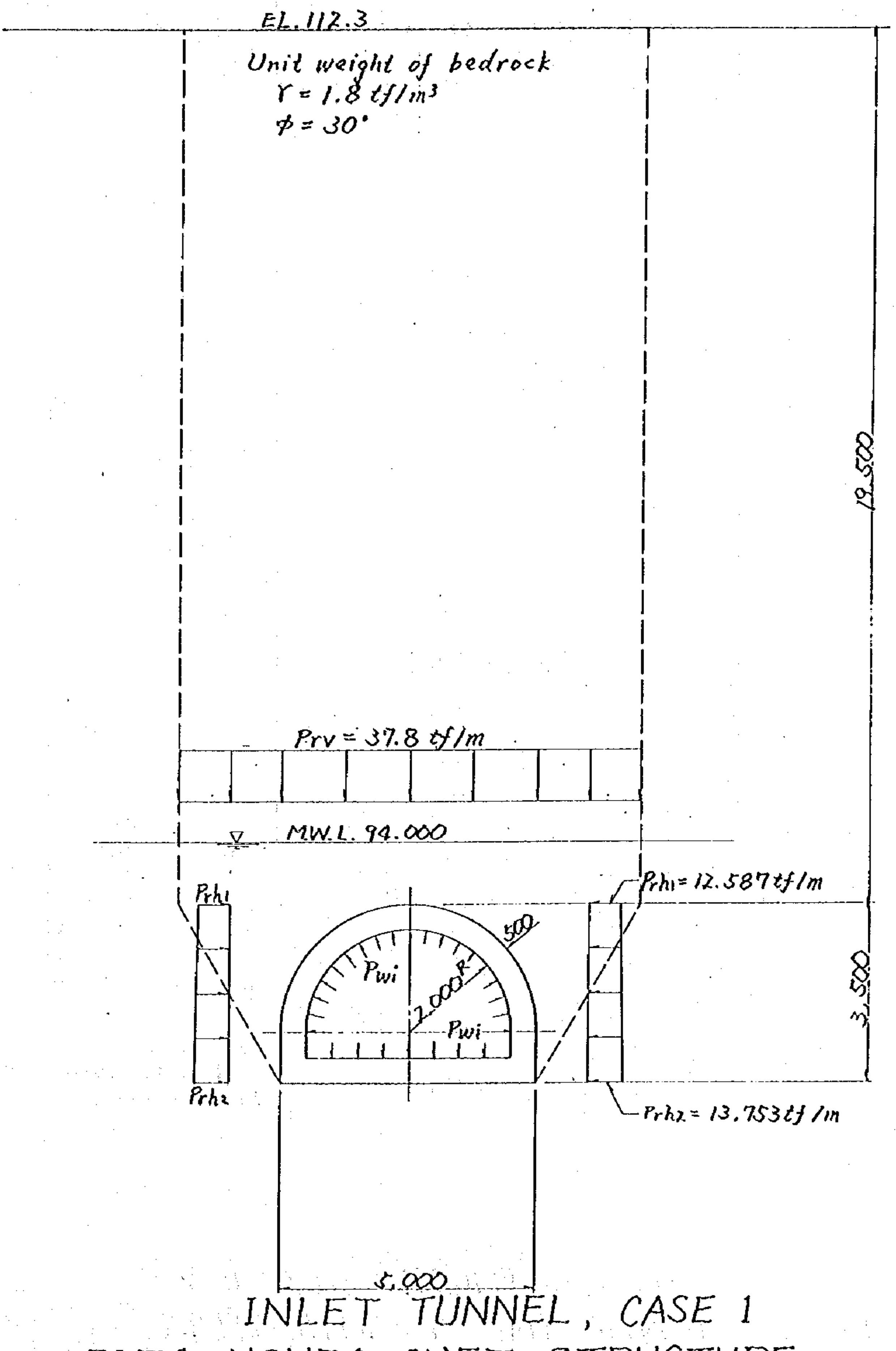
Pr = 2.0 x 19.5 = 39.0 tf/m
Pg = 15.0 tf/m

3) Lateral bedrock pressure water pressure

Ka = tan2(45 - 30/2) = 0.333
Prh1 = 0.333 x 2.0 x 19.5 = 12.987 tf/m tf/m
Prh2 = 0.333 x 2.0 x 19.5 + 0.333 x (2.0 - 1.0) x 3.5 = 14.153 tf/m
Pw = 1.0 x 3.5 = 3.5 tf/m

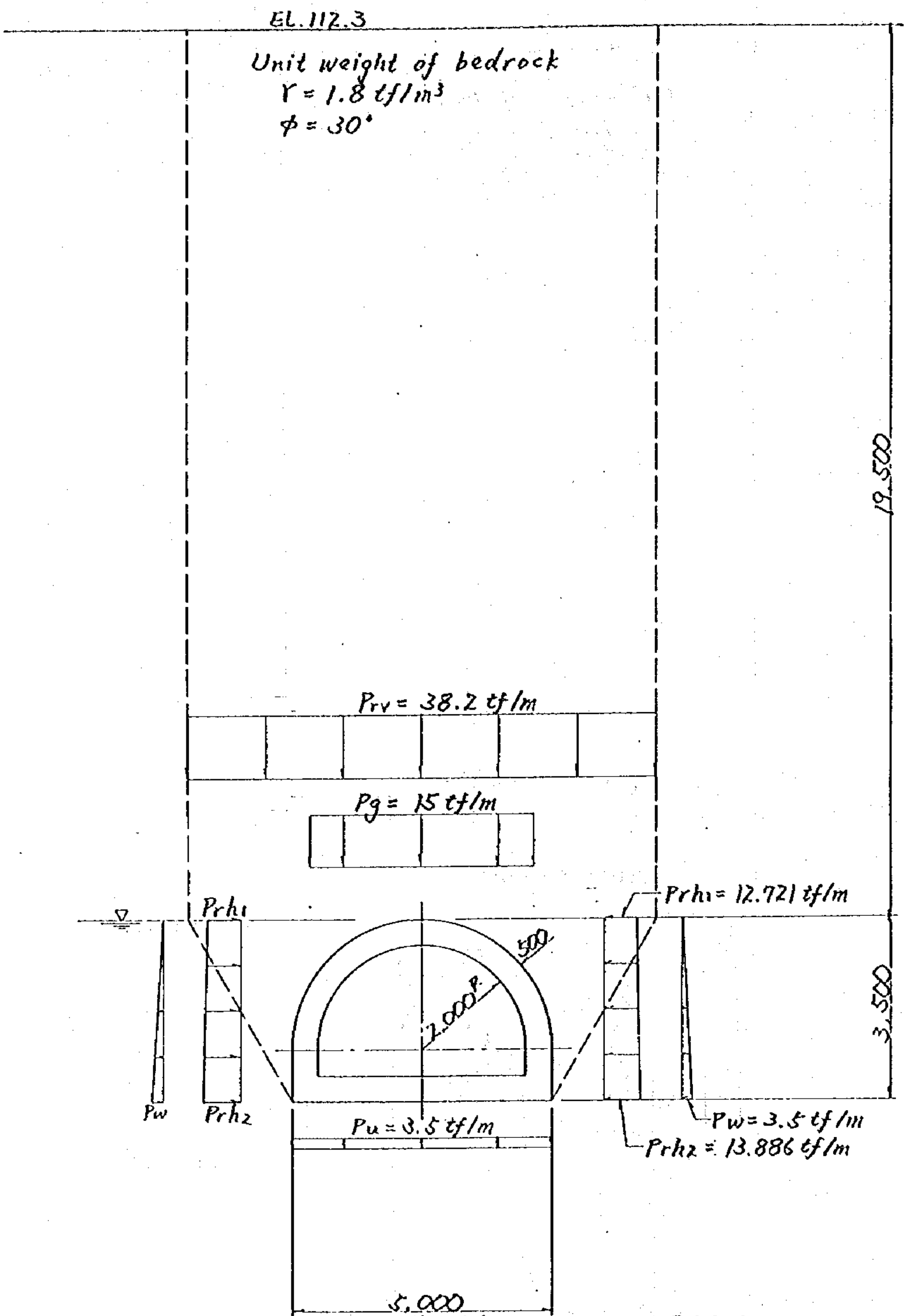
4) Uplift pressure

Pu = 1.0 x 3.5 = 3.5 tf/m



INLET TUNNEL, CASE 1

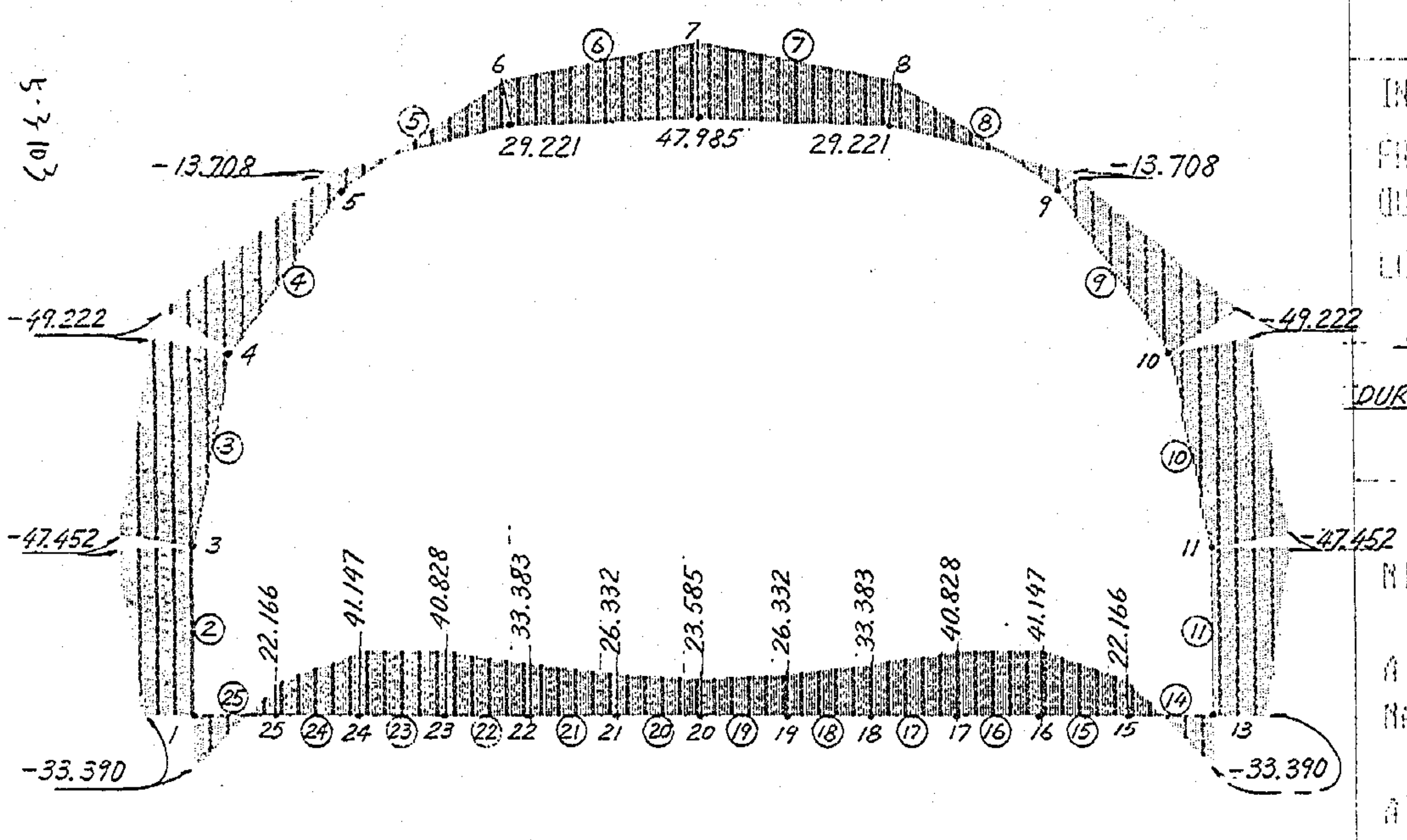
POZA HONDA INET STRUCTURE



INLET TUNNEL, CASE 2

POZA HONDA INLET STRUCTURE

5-3 103



BENDING: MOMENT (t.m/m)

FRAME

OUTPUT 103

LOAD 1

CASE 2

DURING CONSTRUCTION

MIN

-.4922

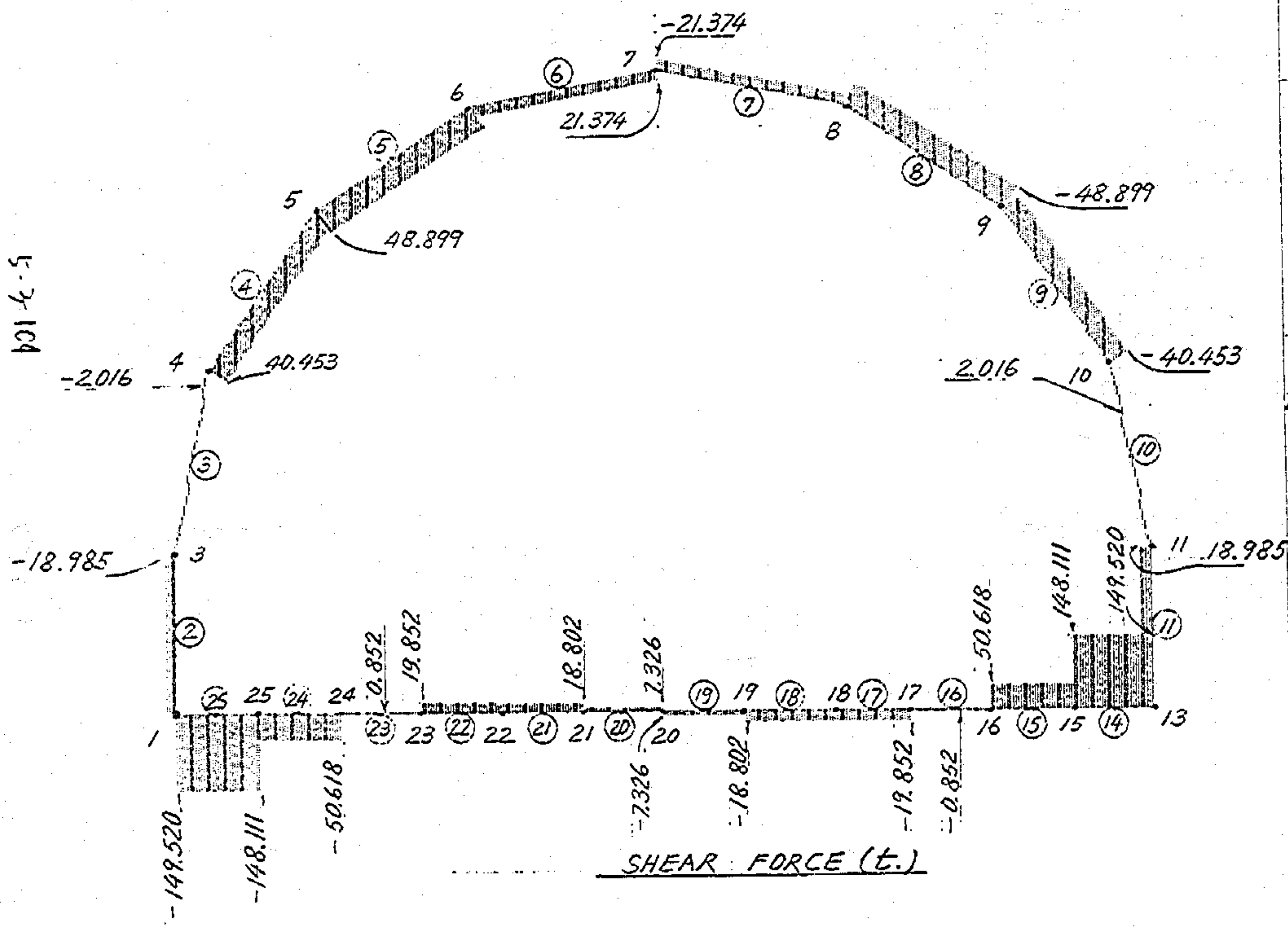
AT

MAX

.4798

AT

SAP90



SHEAR FORCE (t.)

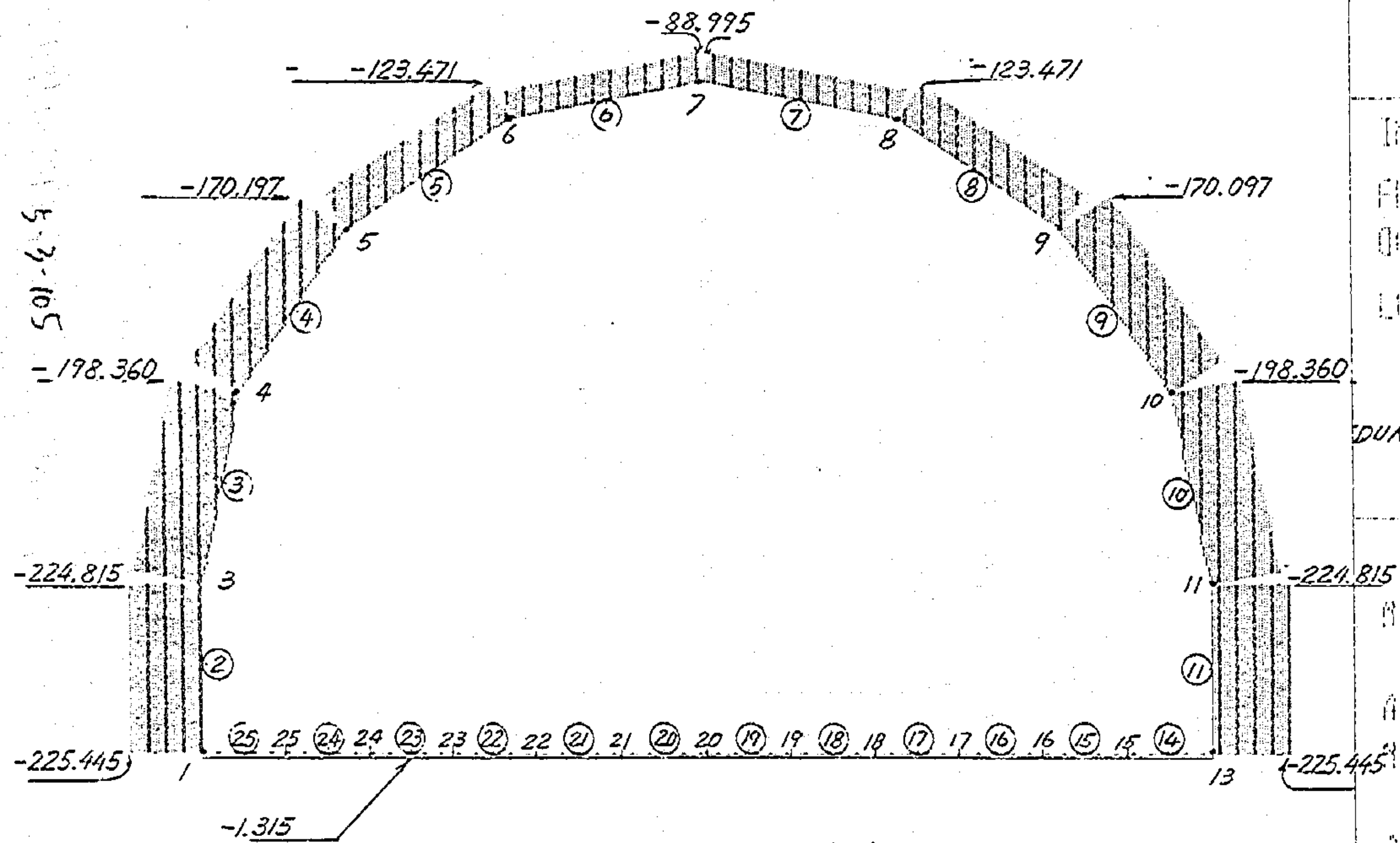
INLETH01
FRAME
OUTPUT V23
LOAD 1

CASE 2
DURING CONSTRUCTION

MIN < 26>
-.1495E+03
AT .00
MAX < 13>
.1495E+03
AT .00

SAP90

5-3-104



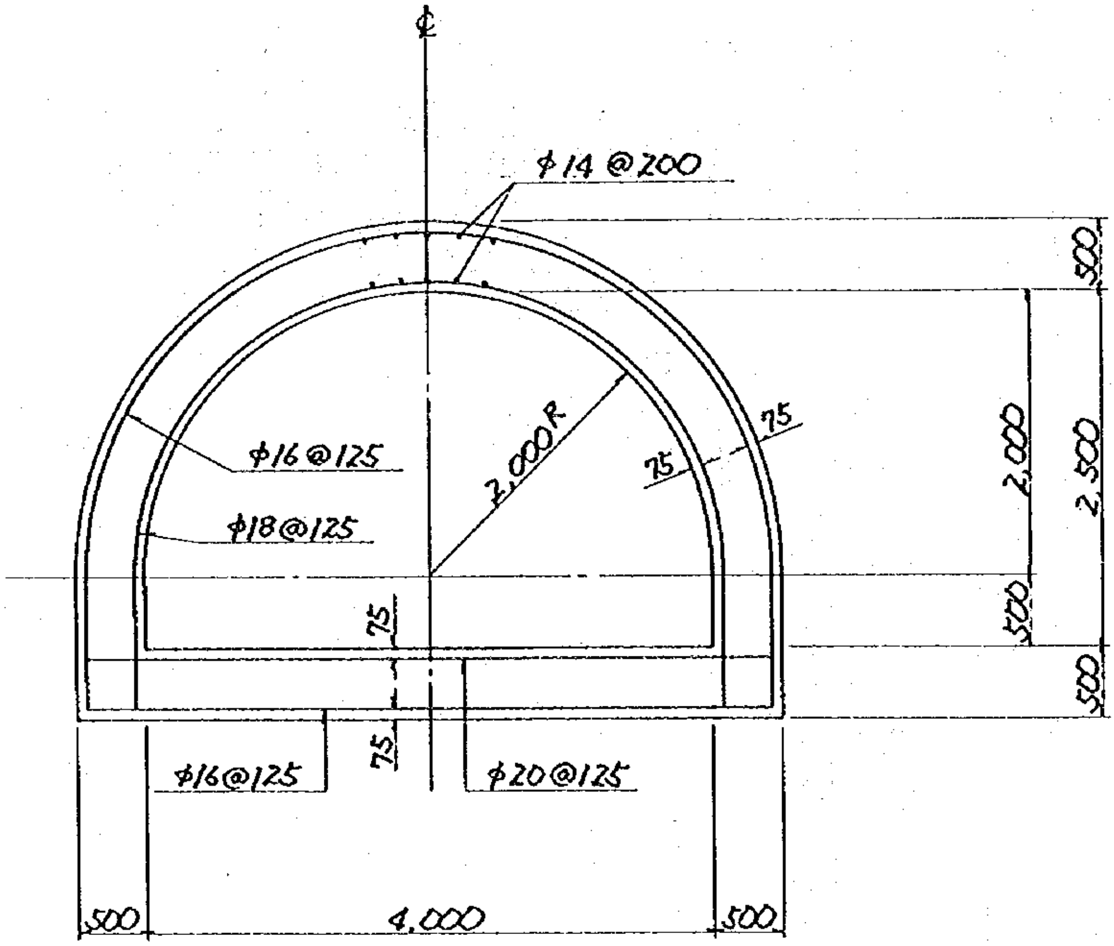
AXIAL FORCE (t.)

INLETHOL
FRAME
OUTPUT P
LOAD 1

CASE 2
DURING CONSTRUCTION

MIN < 1:
-.2254E+03
AT .00
MAX < 13:
.0000E+00
AT .00

SAP90



INLET TUNNEL

POZA HONDA INLET STRUCTURE

5-3-106

(6) Mancha Grande Outlet

Case 1 : After construction

1) Dead weight of lining concrete

$Wc = 0.5 \times 2.4 = 1.2$ tf/m

2) Vertical bedrock pressure

$Pr = 2.0 \times 12.0 = 24.0$ tf/m

3) Lateral bedrock pressure and water pressure

$Ka = \tan2(45 - 30/2) = 0.333$
$Prh1 = 0.333 \times 2.0 \times 12.0 = 7.992$ tf/m
$Prh2 = 0.333 \times 2.0 \times 12.0 + 0.333 \times (2.0 - 1.8) \times 3.5 = 9.158$ tf/m
$Pw = 1.0 \times 3.266 = 3.266$ tf/m

4) Uplift pressure and foundation reaction

$Pu = 1.0 \times 3.266 = 3.266$ tf/m
$Pf = (24.0 \times 3.5 + 13.805)/3.5 - 3.266 = 24.678$ tf/m

Case 2 : During construction

1) Dead weight of lining concrete

$Wc = 0.5 \times 2.4 = 1.2$ tf/m

2) Vertical bedrock pressure and backfill grout pressure

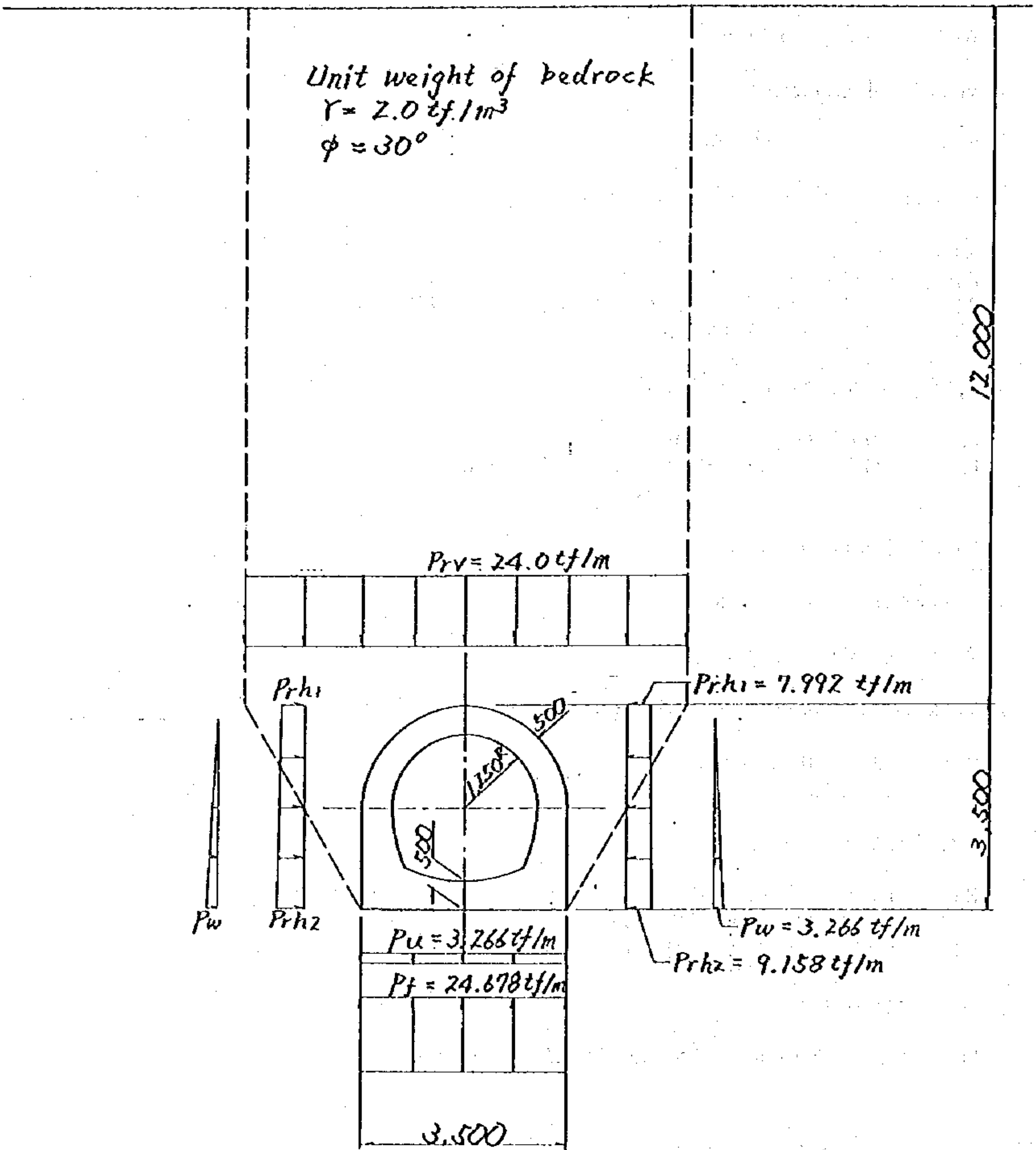
$Pr = 2.0 \times 12.0 = 24.0$ tf/m
$Pg = 15.0$ tf/m

3) Lateral bedrock pressure

$Ka = \tan2(45 - 30/2) = 0.333$
$Prh1 = 0.333 \times 2.0 \times 12.0 = 7.992$ tf/m
$Prh2 = 0.333 \times 2.0 \times 15.5 = 10.323$ tf/m

4) Foundation reaction

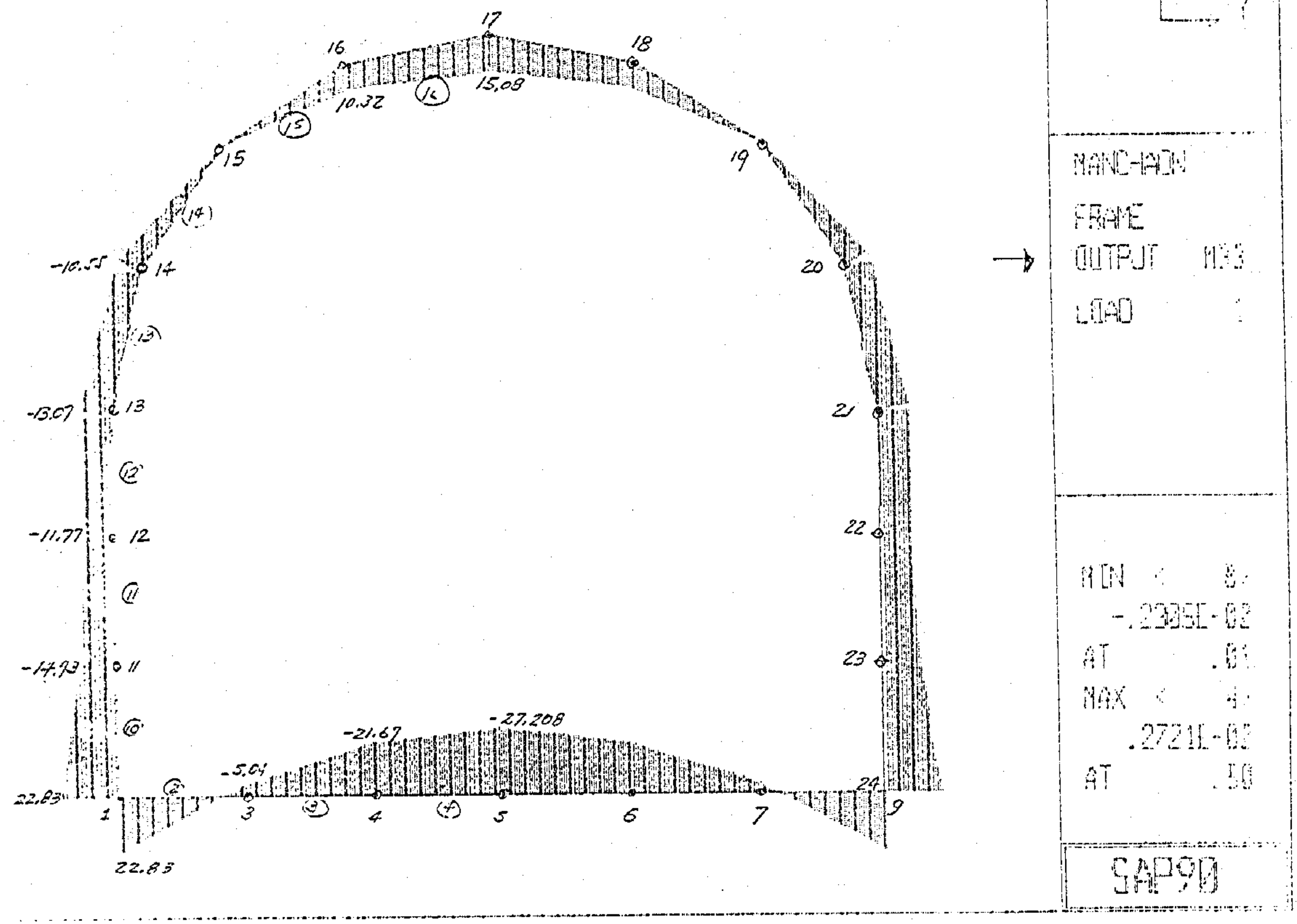
$Pf = (24.0 \times 3.5 + 15.0 \times 3.5 + 13.805)/3.5 = 42.944$ tf/m



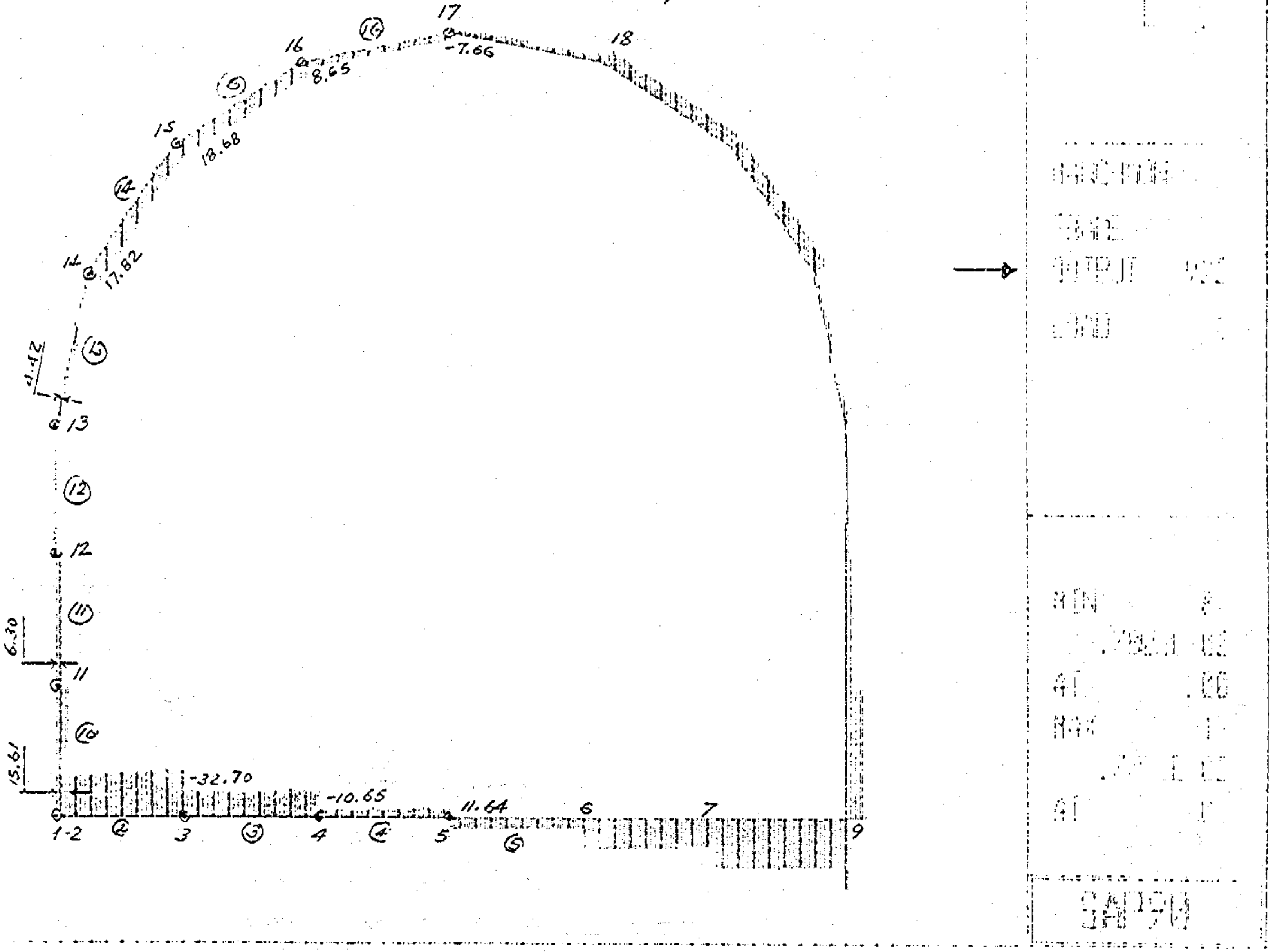
MANCHA GRANDE OUTLET, CASE 1

POZA HONDA ~ MANCHA GRANDE TUNNEL 5-3-108

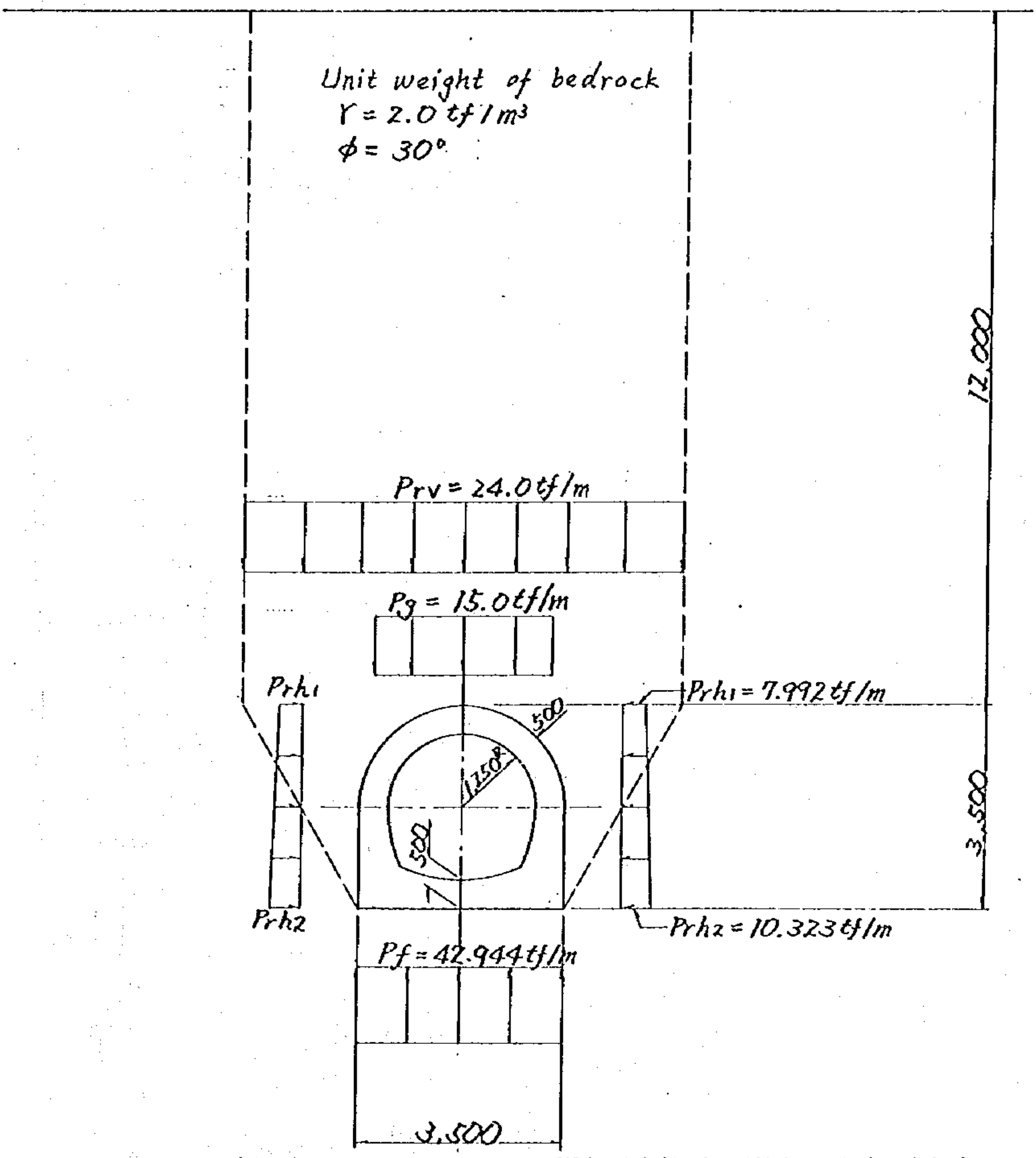
MANCHA GRANDE OUTLET CAS. 1
(MOMENT DIAGRAM)



MANCHA GRANDE OUTLET CAS. I
(SHEAR DIAGRAM)



1.3/110

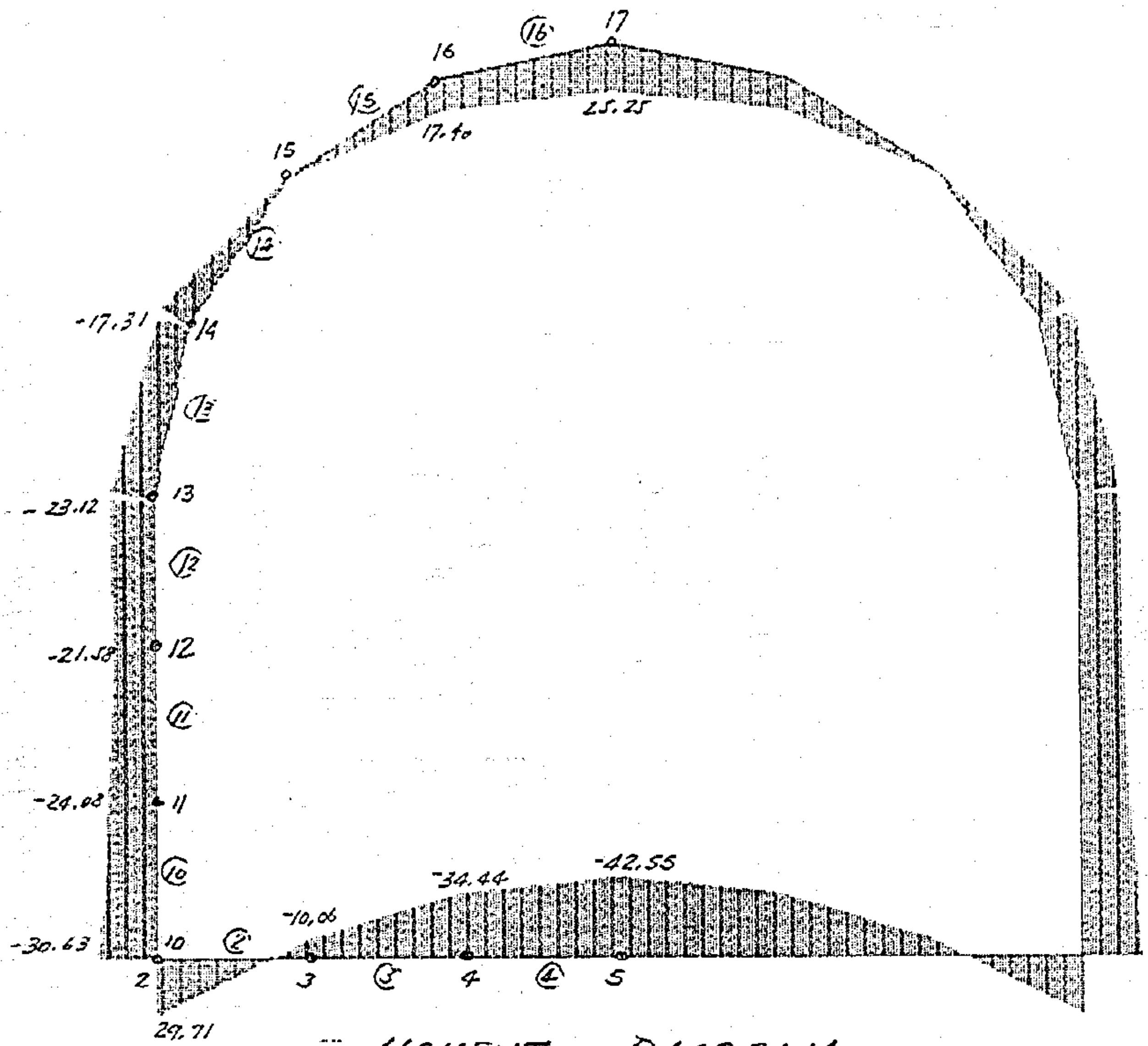


MANCHA GRANDE OUTLET, CASE 2

POZA HONDA ~ MANCHA GRANDE TUNNEL

5.3.11

MANCHA GRANDE OUTLET
CASE 2



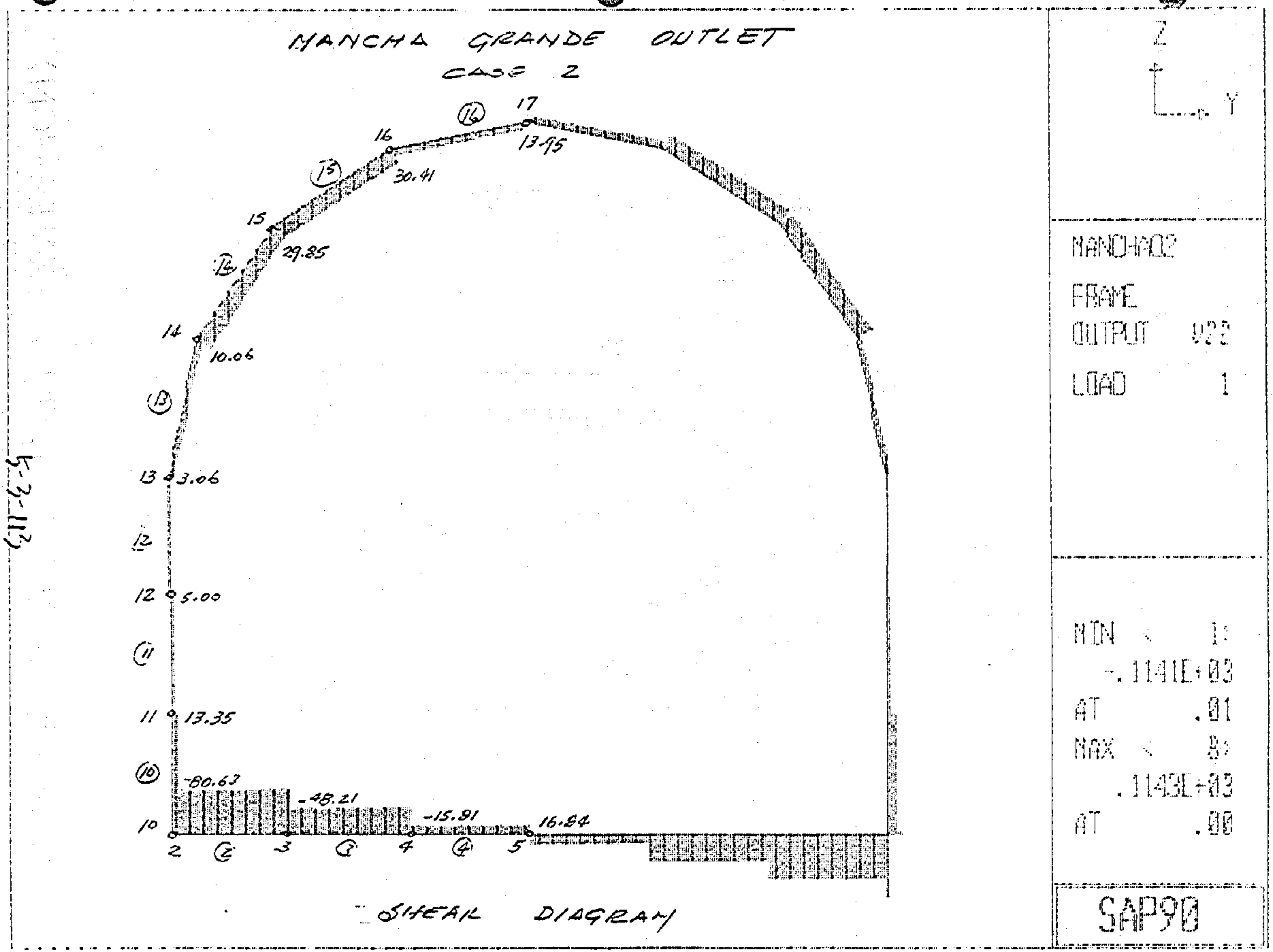
MOMENT DIAGRAM

MANCHA02
FRAME
OUTPUT M33
LOAD 1

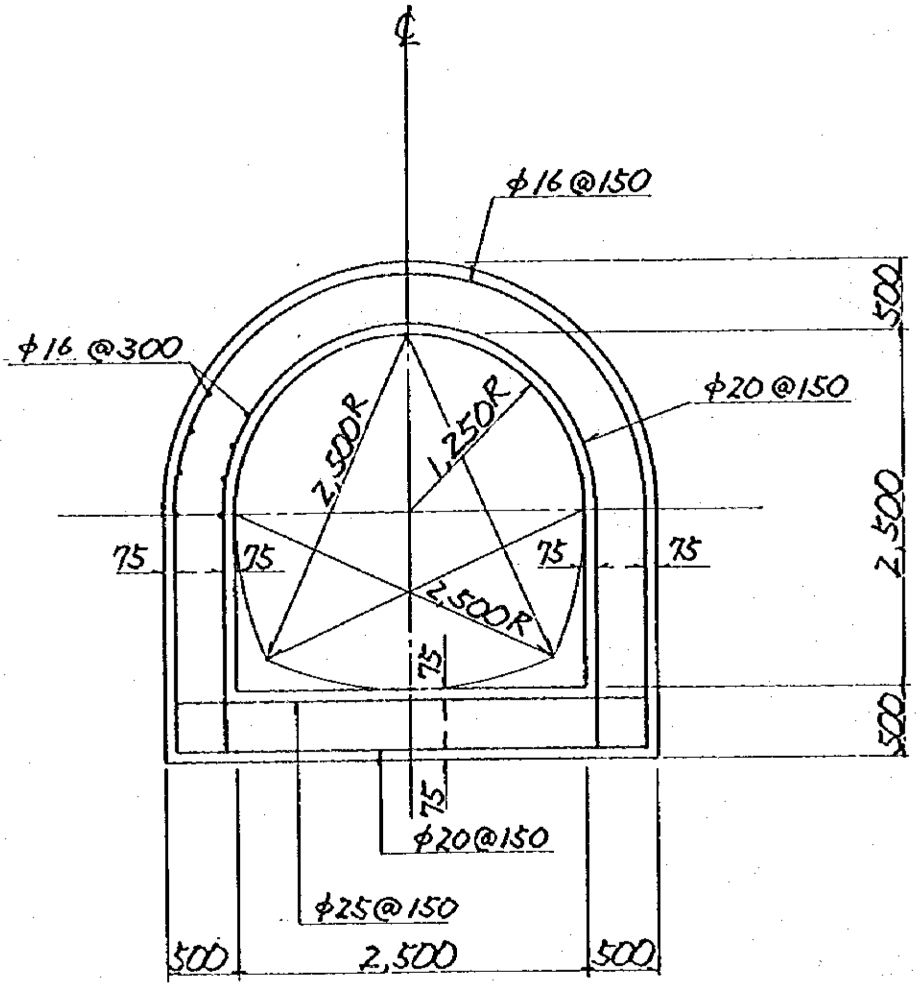
MIN < 4>
-.4256E+02
AT .50
MAX < 8>
.3114E+02
AT .01

SAP90

5.75 112



MANCHA GRANDE OUTLET
CASE 2
17
13.95
16
30.41
15
29.85
14
10.06
13
3.06
12
5.00
11
13.35
10
-80.63
-48.21
-15.91
16.84
2
3
4
5
SHEAR DIAGRAM
Z
Y
MANCHA02
FRAME
OUTPUT V22
LOAD 1
MIN
-.1141E+03
AT .01
MAX
.1143E+03
AT .00
SAP90



MANCHA GRANDE OUTLET (TRANSITION)

POZA HONDA ~ MANCHA GRANDE TUNNEL