

รายการอ้างอิง

ภาษาไทย

- คณะกรรมการวิชาการสาขาวิศวกรรมโยธา. เอกสารประกอบการฝึกอบรมเรื่อง การออกแบบพื้นระบบ POST-TENSIONED FLAT SLAB. วิศวกรรมสถานแห่งประเทศไทยในพระบรมราชูปถัมภ์, 2531.
- ต๋อกุล กาญจนาลัย. การออกแบบคอนกรีตอัดแรง. คณะวิศวกรรมศาสตร์ มหาวิทยาลัยเกษตรศาสตร์, 2539.
- ปณิตาน ลักคุณะประสิทธิ์. การวิเคราะห์โครงสร้าง. พิมพ์ครั้งที่ 2 , กรุงเทพมหานคร: วิศวกรรมสถานแห่งประเทศไทยในพระบรมราชูปถัมภ์, 2533.
- วัฒนชัย สมิตถากร. การวิเคราะห์โครงสร้างแผ่นพื้นท้องเรียบ ด้วยวิธีอย่างง่าย. วิทยานิพนธ์ปริญญาโทมหาบัณฑิต จุฬาลงกรณ์มหาวิทยาลัย, 2534.

ภาษาอังกฤษ

- ACI Committee 318, Building Code Requirements for Reinforced Concrete Institute, Detroit, 1989.
- Antoine,E. Naaman, Minimum Cost Versus Minimum Weight of Prestressed Slabs, Journal Struct. Div. ASCE , Vol103, ST12, Dec 1977.
- Chen H. wang. Optimum Design of Prestressed Concrete Members. Journal Struct. Div. ASCE , Vol 96, ST7, June 1970.
- Lin, T.Y., and Burns, H.Ned, Design of Prestressed Concrete Structures, John Wiley & Sons, Third Edition, 1982.
- Loov, R.E., Optimum Design of Reinforced Concrete and Prestressed Concrete, Advances in Concrete Slab Technology, First Edition, Pergamon Press Ltd., 1980.
- O.A. Bijan . Advance Design / Analysis of post - tensioned. Redwood City, California, 1993.
- Post - tensioning Institute, Post-Tensioning Manual, Post-tensioning Institute, Phoenix, Arizona, 1976.

Rajagopalan K., Minimum Cost Versus Minimum Weight of Prestressed Slabs, Journal Struct. Div. ASCE , Vol 103, ST5, May 1977.

Rozvany, G.I.N and Hampson, A.J.K. Optimum Design of Prestressed Plates. ACI Journal, Vol 60, Aug 1963.

Uri Kirsch. Optimum Design of Prestressed Plates. Journal Struct. Div. ASCE , Vol 99, ST6, June 1973.

Uri Kirsch . Optimum Structural Design , McGraw-Hill, New York, 1981.

ภาคผนวก

ภาคผนวก ก

ตัวอย่างผลลัพธ์ตามตัวอย่างที่ 1

```

=====
CHULALONGKORN UNIVERSITY 1997
DEPARTMENT OF CIVIL ENGINEERING
=====

```

```

=====
WINAI SANGHITKUL
STRUCTURAL ENGINEER
=====

```

```

=====
OPTIMUM DESIGN OF POST-TENSIONED FLAT PLATE
=====

```

DATE AND TIME OF PROGRAM EXECUTION: 17-Mar-1997 Time: 10:48:46

PROJECT TITLE: EXAMPLE1 FOR FLAT PLATE APARTMENT
SPECIFIC TITLE: DESIGN BY S.WINAI

1 - GENERAL DESIGN PARAMETERS

CONCRETE:

| | |
|-----------------------------------|------------------------------|
| STRENGTH at 28 days | 281.00 (Kg/cm ²) |
| WEIGHT | 2403.00 (Kg/m ³) |
| CREEP factor for deflections..... | 2.00 |

| | |
|--|-----------------------------|
| TENSION STRESS limit | 26.82 (Kg/cm ²) |
| TENSION STRESS Ratio (multiple of (f'c) ^{1/2}) | |
| Top of support | 1.600 |
| Bottom of span | 1.600 |

| | |
|--|------------------------------|
| COMPRESSION STRESS limit | 126.45 (Kg/cm ²) |
| COMPRESSION STRESS Ratio (multiple of (f'c)) | |
| At all locations | 0.45 |

MILD REINFORCEMENT:

| | |
|-----------------------------|-------------------------------|
| YIELD strength | 4219.00 (Kg/cm ²) |
| Minimum Concrete Cover..... | 2.50 (cm) |

POST-TENSIONING:

| | |
|--|----------------------------|
| SYSTEM | UNBONDED |
| DESIGN SYSTEM | FULLY |
| Ultimate strength of strand | 19.02 (T/cm ²) |
| Average effective stress in strand (final) | 12.00 (T/cm ²) |
| Strand area..... | 98.71 (mm ²) |
| Min CGS of tendon cover | 2.50 (cm) |
| Max tendon SPACING (multiple of member depth) .. | 8.00 |

ANALYSIS OPTIONS USED:

| | |
|--|----|
| Optimum design..... | NO |
| Two-Way Slab Structure System..... | |
| Equivalent frame formulation per ACI-318-95..... | |
| Direct Stiffness Analysis..... | |

 2 - I N P U T G E O M E T R Y
 =====

2.1 - S P A N D A T A

```

<----- SLAB ----->
SPAN  LENGTH  DEPTH  L-WIDTH  R-WIDTH
      m        m        m        m
-#-----#-----#-----#-----#-----
  1     5.17    0.165   3.04     3.04
  2     7.61    0.165   3.04     3.04
  3     5.17    0.165   3.04     3.04

```

2.2 - C O L U M N S A N D D R O P P A N E L D A T A

```

<- LOWER COLUMN ->    <- UPPER COLUMN ->
SUP   LEN     PARL  PERP   LEN     PARL  PERP
     m        m      m      m        m      m
-#-----#-----#-----#-----#-----#-----#-----#-----#-----
  1   2.61   0.305  0.355  2.61   0.305  0.355
  2   2.61   0.508  0.355  2.61   0.508  0.355
  3   2.61   0.508  0.355  2.61   0.508  0.355
  4   2.61   0.305  0.355  2.61   0.305  0.355

```

* ALL COLUMNS ARE ASSUMED FIXED AT THE FAR END

 3 - I N P U T A P P L I E D L O A D I N G
 =====

```

<-----CLASS----->
  1.DEAD LOAD
  2.LIVE LOAD
      (Uniform)    (Edge Load)
SPAN   CLASS    ( T/m)    ( T )
-#-----#-----#-----#-----#-----
  1       1       2.859
  1       2       1.192
  2       1       2.859
  2       2       1.192
  3       1       2.859
  3       2       1.192

```

NOTE: live loading is no skipped

 4 - CALCULATED SECTION PROPERTIES
 =====

4.1 AT MIDSPAN

| SPAN | AREA (m ²) | I (m ⁴) |
|------|------------------------|---------------------|
| 1 | 1.0032 | 0.00228 |
| 2 | 1.0032 | 0.00228 |
| 3 | 1.0032 | 0.00228 |

 5 - DEAD LOAD MOMENTS
 =====

| <- 5.1 SPAN MOMENTS T-m -> | | | |
|----------------------------|--------|-----------|--------|
| SPAN | M(l) | M(center) | M(r) |
| 1 | -1.77 | 3.15 | -11.03 |
| 2 | -12.89 | 7.81 | -12.89 |
| 3 | -11.03 | 3.15 | -1.77 |

NOTE: These moments are shown at center of column

| <- 5.2 COLUMN MOMENTS T-m -> | | | |
|------------------------------|---------------|---------------|-------|
| SUPP | Lower columns | Upper columns | |
| 1 | -0.87 | | -0.87 |
| 2 | -0.93 | | -0.93 |
| 3 | 0.93 | | 0.93 |
| 4 | 0.87 | | 0.87 |

 6 - LIVE LOAD MOMENTS
 =====

| <- 6.1 SPAN MOMENTS T-m -> | | | |
|----------------------------|-------|-----------|-------|
| SPAN | M(l) | M(center) | M(r) |
| 1 | -0.74 | 1.31 | -4.60 |
| 2 | -5.37 | 3.26 | -5.37 |
| 3 | -4.60 | 1.31 | -0.74 |

NOTE: These moments are shown at center of column

| <- 6.2 COLUMN MOMENTS T-m -> | | | |
|------------------------------|---------------|---------------|-------|
| SUPP | Lower columns | Upper columns | |
| 1 | -0.36 | | -0.36 |
| 2 | -0.39 | | -0.39 |
| 3 | 0.39 | | 0.39 |
| 4 | 0.36 | | 0.36 |

 7 - M O M E N T S R E D U C E D T O F A C E O F S U P P O R T
 =====

| SPAN | <- 7.1 DEAD LOAD MOMENTS -> | | | <-7.2 LIVE* LOAD MOMENTS -> | | |
|------|-----------------------------|-----------|--------|-----------------------------|-----------|-------|
| | M(l) | M(center) | M(r) | M(l) | M(center) | M(r) |
| 1 | -0.95 | 3.15 | -8.79 | -0.40 | 1.31 | -3.66 |
| 2 | -10.22 | 7.81 | -10.22 | -4.26 | 3.26 | -4.26 |
| 3 | -8.79 | 3.15 | -0.95 | -3.66 | 1.31 | -0.40 |

* Live load moments listed are maxima of support negative and span positive

8 - S U M O F D E A D A N D L I V E M O M E N T S (T-m)
 =====

Maxima of negative support and positive live load span moments with dead loading combined as indicated herein
 for serviceability checks (1.00DL + 1.00LL)

| SPAN | M(l) | M(center) | M(r) |
|------|--------|-----------|--------|
| 1 | -1.35 | 4.47 | -12.45 |
| 2 | -14.48 | 11.06 | -14.48 |
| 3 | -12.45 | 4.47 | -1.35 |

NOTE: These moments are reduced to face

9 - SELECTED POST-TENSIONING FORCES AND TENDON PROFILES

=====

| SPAN | <--- 9.1 SELECTED VALUES ---> | | | <- 9.2 CALCULATED VALUES -> | | |
|------|-------------------------------|--------------------------|--------|-----------------------------|------------------------------|------------------------------|
| | FORCE (T) | <- DISTANCE OF CGS cm -> | | | P/A (Kg/cm ²) | Wbal (T /m ²) |
| # | # | Left | Center | Right | # | # |
| 1 | 120.00 | 8.25 | 4.40 | 14.00 | 11.96 | 0.397 |
| 2 | 120.00 | 14.00 | 2.50 | 14.00 | 11.96 | 0.314 |
| 3 | 120.00 | 14.00 | 4.40 | 8.25 | 11.96 | 0.397 |

9.3 SERVICE STRESSES (Kg/cm²) (tension shown negative)

| SPAN | L E F T | | C E N T E R | | R I G H T | |
|------|---------|--------|-------------|--------|-----------|--------|
| | TOP | BOTTOM | TOP | BOTTOM | TOP | BOTTOM |
| # | # | # | # | # | # | # |
| 1 | 10.75 | 13.18 | 16.86 | 7.07 | -10.20 | 34.12 |
| 2 | -14.79 | 38.71 | 34.22 | -10.29 | -14.79 | 38.71 |
| 3 | -10.20 | 34.12 | 16.86 | 7.07 | 10.75 | 13.18 |

9.4 POST-TENSIONING BALANCED MOMENTS

| SPAN | <-- S P A N M O M E N T S T-m --> | | |
|------|-----------------------------------|-----------|------|
| | M(l) | M(center) | M(r) |
| # | # | # | # |
| 1 | 1.01 | -3.12 | 6.34 |
| 2 | 7.10 | -4.92 | 7.10 |
| 3 | 6.34 | -3.12 | 1.01 |

NOTE: These moments are reduced to face

| SUPPORT | <-- C O L U M N M O M E N T S T-m ---> | |
|---------|--|---------------|
| | Lower columns | Upper columns |
| # | # | # |
| 1 | 0.86 | 0.86 |
| 2 | 0.36 | 0.36 |
| 3 | -0.36 | -0.36 |
| 4 | -0.86 | -0.86 |

10 - FACTORED MOMENTS
=====

Calculated as (1.40D + 1.70L + 1.00 secondary moment effects)

| SPAN | 10.1 FACTORED DESIGN MOMENTS (T-m) | | |
|---------------------------|-------------------------------------|----------|---------|
| # | (left) | (center) | (right) |
| -#-----#-----#-----#----- | | | |
| 1 | -0.99 | 8.15 | -17.97 |
| 2 | -21.35 | 18.44 | -21.35 |
| 3 | -17.97 | 8.15 | -0.99 |

NOTE: These moments are reduced to face

| SUPP | 10.2 COLUMN MOMENTS (T-m) | |
|---------------------------|----------------------------|---------------|
| | Lower columns | Upper columns |
| -#-----#-----#-----#----- | | |
| 1 | -1.83 | -1.83 |
| 2 | -1.96 | -1.96 |
| 3 | 1.96 | 1.96 |
| 4 | 1.83 | 1.83 |

 11 - M I L D R E I N F O R C E M E N T R E Q U I R E M E N T S
 =====

11.1 SPECIFIC CRITERIA FOR T W O - W A Y S Y S T E M

- Minimum steel 0.00075h1
- Moment capacity > factored (design) moment

11.2 S T E E L E A C H S P A N

| SPAN # | T O P | | | B O T T O M | | |
|--------|--|--------|-------|--|--------|-------|
| | <--- cm ² /Bay Width ---> Left | Center | Right | <--- cm ² /Bay Width ---> Left | Center | Right |
| 1 | 11.60 | 0.00 | 7.91 | 0.00 | 1.90 | 0.00 |
| 2 | 10.11 | 0.00 | 10.11 | 0.00 | 5.66 | 0.00 |
| 3 | 7.91 | 0.00 | 11.60 | 0.00 | 1.90 | 0.00 |

Minimum steel all bottom (0.001Ac)...10.03 cm²

11.3 SELECTION OF R E B A R A T S U P P O R T

| SPAN # | T O P | | B O T T O M | |
|--------|--|-------------------|--|-------------------|
| | <--- Bay Width ---> cm ² | S E L E C T I O N | <--- Bay Width ---> cm ² | S E L E C T I O N |
| 1 | 11.60 | 11-DB12 mm.x1.18 | 10.03 | DB12 mm.@ 0.67 |
| 2 | 10.11 | 10-DB12 mm.x2.67 | 10.03 | DB12 mm.@ 0.67 |
| 3 | 10.11 | 10-DB12 mm.x2.67 | 10.03 | DB12 mm.@ 0.67 |
| 4 | 11.60 | 11-DB12 mm.x1.18 | 10.03 | DB12 mm.@ 0.67 |

11.4 SELECTION OF R E B A R A T M I D - S P A N

| SPAN # | B O T T O M | | T O P | |
|--------|--|-------------------|--|-------------------|
| | <--- Bay Width ---> cm ² | S E L E C T I O N | <--- Bay Width ---> cm ² | S E L E C T I O N |
| 1 | 10.03 | DB12 mm.@ 0.67 | | |
| 2 | 10.03 | DB12 mm.@ 0.67 | | |
| 3 | 10.03 | DB12 mm.@ 0.67 | | |

 12 - PUNCHING SHEAR CHECK
 =====

| SUP # | FACTORED ACTIONS | | <-- PUNCHING SHEAR STRESSES IN Kg/cm ² --> | | | | |
|-------------|------------------|---------------|---|------------------|-------------|----------------|-----------------|
| | shear T | moment T-m | due to shear | due to moment | TOTAL | allow- able | STRESS RATIO |
| -----#----- | -----#----- | -----#----- | -----#----- | -----#----- | -----#----- | -----#----- | -----#----- |
| 1 | 11.81 | 1.99 | 6.78 | 1.01 | 7.78 | 15.35 | 0.51 |
| 2 | 42.30 | 3.21 | 13.22 | 2.12 | 15.34 | 16.49 | 0.93 |
| 3 | 42.30 | 3.21 | 13.22 | 2.12 | 15.34 | 16.49 | 0.93 |
| 4 | 11.81 | 1.99 | 6.78 | 1.01 | 7.78 | 15.35 | 0.51 |

PUNCHING SHEAR CHECK SATISFACTORY

 13 - MAXIMUM SPAN DEFLECTIONS
 =====

Concrete's modulus of elasticity $E_c = 274.00 \text{ T/cm}^2$
 Creep factor $K = 2.00$
 effective-I/gross-I (due to cracking) $= 1.00$

Values in parentheses are (span/max deflection) ratios

| SPAN # | <.....DEFLECTION ARE ALL IN cm , DOWNWARD POSITIVE.....> | | | LL # | DL+PT+LL+CREEP # |
|-------------|--|-------------|------------------|-------------|---------------------|
| | DL # | DL+PT # | DL+PT+CREEP # | | |
| -----#----- | -----#----- | -----#----- | -----#----- | -----#----- | -----#----- |
| 1 | 0.11 | -0.02 | -0.04 (13191) | 0.05 | 0.01 (59437) |
| 2 | 0.69 | 0.28 | 0.70 (1080) | 0.29 | 0.99 (766) |
| 3 | 0.11 | -0.02 | -0.04 (13191) | 0.05 | 0.01 (59437) |

 14 - L O N G T E R M L O S S C A L C U L A T I O N
 =====

I N P U T P A R A M E T E R :

| | |
|---|--------------------------------|
| TYPE OF STRAND | Low Relax |
| SYSTEM OF PRESTRESSED CONCRETE..... | UNBONDED |
| ULTIMATE STRENGTH OF STRAND..... | 19020 (Kg/cm ²) |
| MODULUS OF ELASTICITY OF STRAND | 1950000 (Kg/cm ²) |
| AVERAGE COMPRESSIVE STRESS IN CONCRETE..... | 9.00 (Kg/cm ²) |
| AVERAGE INITIAL STRESS IN TENDON (after release). | 12200.00 (Kg/cm ²) |
| CONCRETE STRENGTH AT 28 DAYS..... | 281.00 (Kg/cm ²) |
| UNIT WEIGHT OF CONCRETE..... | 2403.00 (Kg/m ³) |
| ESTIMATED AGE OF CONCRETE AT STRESSING..... | 6 (Days) |
| MODULUS OF ELASTICITY OF CONCRETE AT STRESSING... | 92500 (Kg/cm ²) |
| MODULUS OF ELASTICITY OF CONCRETE AT 28 DAYS..... | 200000 (Kg/cm ²) |
| ESTIMATE OF AVERAGE RELATIVE HUMDITY..... | 80.00 (%) |
| VOLUME TO SURFACE RATIO OF MEMBER..... | 10.00 (cm) |

C A L C U L A T E D :

| | |
|------------------------------------|------------------------------|
| ELASTIC SHORTENING..... | 94.86 (Kg/cm ²) |
| SHRINKAGE..... | 191.80 (Kg/cm ²) |
| CREEP..... | 140.40 (Kg/cm ²) |
| RELAXATION..... | 163.61 (Kg/cm ²) |
| ----- | |
| TOTAL LONG TERM STRESS LOSSES..... | 590.67 (Kg/cm ²) |
| ----- | |

 15 - IMMEDIATE LOSS CALCULATIONS :
 =====

INPUT PARAMETER

COEFFICIENT OF ANGULAR FRICTION (meu)..... 0.120 (/radian)
 COEFFICIENT OF WOBBLE FRICTION (K)..... 0.0025 (/m)
 RATIO OF JACKING STRESS TO STRAND ULTIMATE STRENGTH 0.75
 ANCHORAGE SET..... 6.00 (mm)
 CROSS-SECTION AREA OF STRAND..... 0.99 (cm²)
 MODE OF STRESSING : Both End ---- RIGHT END FIRST

LEFT END STRESS ONLY

AVERAGE WEDGE SET DISTANCE..... 11.22 (m)

| PT NO. | X m | Y cm | FRICT (kg/cm ²) | WSET (kg/cm ²) | *TOTAL (kg/cm ²) | Eff STRESS (kg/cm ²) |
|--------|-------|-------|-----------------------------|----------------------------|------------------------------|----------------------------------|
| -#- | -#- | -#- | -#- | -#- | -#- | -#- |
| 1 | 0.00 | 8.25 | 0.00 | 2058.59 | 2649.27 | 11615.73 |
| 2 | 2.58 | 4.40 | 142.46 | 1584.33 | 2317.46 | 11947.54 |
| 3 | 5.17 | 14.00 | 484.76 | 1110.06 | 2185.49 | 12079.51 |
| 4 | 8.98 | 2.50 | 823.32 | 411.95 | 1825.95 | 12439.05 |
| 5 | 12.78 | 14.00 | 1161.88 | 0.00 | 1752.55 | 12512.45 |
| 6 | 15.37 | 4.40 | 1504.18 | 0.00 | 2094.85 | 12170.15 |
| 7 | 17.95 | 8.25 | 1646.64 | 0.00 | 2237.31 | 12027.69 |

 *TOTAL is TOTAL LOSS include immediate loss and long term loss

RIGHT END STRESS ONLY

AVERAGE WEDGE SET DISTANCE..... 11.22 (m)

| PT NO. | X m | Y cm | FRICT (kg/cm ²) | WSET (kg/cm ²) | *TOTAL (kg/cm ²) | Eff STRESS (kg/cm ²) |
|--------|-------|-------|-----------------------------|----------------------------|------------------------------|----------------------------------|
| -#- | -#- | -#- | -#- | -#- | -#- | -#- |
| 1 | 0.00 | 8.25 | 1646.64 | 0.00 | 2237.31 | 12027.69 |
| 2 | 2.58 | 4.40 | 1504.18 | 0.00 | 2094.85 | 12170.15 |
| 3 | 5.17 | 14.00 | 1161.88 | 0.00 | 1752.55 | 12512.45 |
| 4 | 8.98 | 2.50 | 823.32 | 411.95 | 1825.95 | 12439.05 |
| 5 | 12.78 | 14.00 | 484.76 | 1110.06 | 2185.49 | 12079.51 |
| 6 | 15.37 | 4.40 | 142.46 | 1584.33 | 2317.46 | 11947.54 |
| 7 | 17.95 | 8.25 | 0.00 | 2058.59 | 2649.27 | 11615.73 |

 *TOTAL is TOTAL LOSS include immediate loss and long term loss

 ANGULAR PROFILE AND ELONGATION

| PT NO. | X m | Y cm | L.ANGLE (rad) | R.ANGLE (rad) |
|-----------|--------|---------|------------------|------------------|
| -#- | -#- | -#- | -#- | -#- |
| 1 | 0.00 | 8.25 | 0.0000 | 0.0298 |
| 2 | 2.58 | 4.40 | 0.0298 | 0.0743 |
| 3 | 5.17 | 14.00 | 0.0743 | 0.0604 |
| 4 | 8.98 | 2.50 | 0.0604 | 0.0604 |
| 5 | 12.78 | 14.00 | 0.0604 | 0.0743 |
| 6 | 15.37 | 4.40 | 0.0743 | 0.0298 |
| 7 | 17.95 | 8.25 | 0.0298 | 0.0000 |

| | | |
|---|----------|-----------------------|
| AVERAGE INITIAL STRESS (AFTER RELEASE)..... | 12703.83 | (Kg/cm ²) |
| LONGTERM STRESS LOSSES..... | 590.67 | (Kg/cm ²) |
| FINAL AVERAGE STRESS..... | 12113.16 | (Kg/cm ²) |
| FINAL AVERAGE FORCE IN TENDON..... | 11956.90 | (Kg) |
| TOTAL ELONGATION..... | 116.94 | (mm) |

ภาคผนวก ข

ตัวอย่างผลลัพธ์ตามตัวอย่างที่ 2


```

=====
| CHULALONGKORN UNIVERSITY 1997 |
| DEPARTMENT OF CIVIL ENGINEERING |
|-----|
| WINAI SANGHITKUL |
| STRUCTURAL ENGINEER |
|-----|
| OPTIMUM DESIGN OF POST- TENSIONED FLAT PLATE |
|-----

```

DATE AND TIME OF PROGRAM EXECUTION: 17-Mar-1997 Time: 17:34:02

PROJECT TITLE: EXAMPLE 2 FOR OPTIMUM FLAT PLAT
SPECIFIC TITLE: DESIGN BY S.WINAI

1 - GENERAL DESIGN PARAMETERS

```

=====
CONCRETE:
STRENGTH at 28 days ..... 320.00 (Kg/cm^2)
WEIGHT ..... 2400.00 (Kg/m^3)
CREEP factor for deflections..... 2.00
UNIT PRICE of concrete..... 1780.00 (Baht/m^3)

TENSION STRESS limit ..... 28.62 (Kg/cm^2)
TENSION STRESS Ratio (multiple of (f'c)^1/2)
Top of support ..... 1.600
Bottom of span ..... 1.600

COMPRESSION STRESS limit ..... 144.00 (Kg/cm^2)
COMPRESSION STRESS Ratio (multiple of (f'c))
At all locations ..... 0.45

MILD REINFORCEMENT:
YIELD strength ..... 4000.00 (Kg/cm^2)
Minimum Concrete Cover..... 2.50 (cm)
UNIT PRICE of mild reinforcement..... 15.50 (Baht/Kg)

POST-TENSIONING:
SYSTEM ..... UNBONDED
DESIGN SYSTEM ..... FULLY
Ultimate strength of strand ..... 18.87 (T/cm^2)
Average effective stress in strand (final) ..... 11.55 (T/cm^2)
Strand area..... 98.71 (mm^2)
Min CGS of tendon cover ..... 3.50 (cm)
Max tendon SPACING (multiple of member depth) .. 8.00
UNIT PRICE of post-tensioned:
Strand..... 30.00 (Baht/Kg)
Stressing Anchored..... 140.00 (Baht/Set)
Fix Anchored..... 40.00 (Baht/Set)
Bar chair (spacing @1.00 m)..... 5.00 (Baht/Set)

ANALYSIS OPTIONS USED:
Optimum design..... YES
Two-Way Slab Structure System.....
Equivalent frame formulation per ACI-318-95.....
Direct Stiffness Analysis.....

```

2 - INPUT GEOMETRY

2.1 - SPAN DATA

| <----- SLAB -----> | | | | |
|---------------------------------------|--------|-------|---------|---------|
| SPAN | LENGTH | DEPTH | L-WIDTH | R-WIDTH |
| | m | m | m | m |
| -#-----#-----#-----#-----#-----#----- | | | | |
| 1 | 8.00 | 0.195 | 4.00 | 4.00 |
| 2 | 8.00 | 0.195 | 4.00 | 4.00 |
| 3 | 8.00 | 0.195 | 4.00 | 4.00 |
| 4 | 8.00 | 0.195 | 4.00 | 4.00 |

2.2 - COLUMNS AND DROP PANEL DATA

| SUP | <- LOWER COLUMN -> | | | <- UPPER COLUMN -> | | |
|---|--------------------|-------|-------|--------------------|-------|-------|
| | LEN | PARL | PERP | LEN | PARL | PERP |
| | m | m | m | m | m | m |
| -#-----#-----#-----#-----#-----#-----#----- | | | | | | |
| 1 | 3.00 | 0.800 | 0.800 | 3.00 | 0.800 | 0.800 |
| 2 | 3.00 | 0.800 | 0.800 | 3.00 | 0.800 | 0.800 |
| 3 | 3.00 | 0.800 | 0.800 | 3.00 | 0.800 | 0.800 |
| 4 | 3.00 | 0.800 | 0.800 | 3.00 | 0.800 | 0.800 |
| 5 | 3.00 | 0.800 | 0.800 | 3.00 | 0.800 | 0.800 |

* ALL COLUMNS ARE ASSUMED FIXED AT THE FAR END

3 - INPUT APPLIED LOADING

| <-----CLASS-----> | | | |
|---------------------------------|-------|---------------------|----------------------|
| 1.DEAD LOAD | | | |
| 2.LIVE LOAD | | | |
| SPAN | CLASS | (Uniform) (T/m) | (Edge Load) (T) |
| -#-----#-----#-----#-----#----- | | | |
| 1 | 1 | 5.344 | |
| 1 | 2 | 2.400 | |
| 2 | 1 | 5.344 | |
| 2 | 2 | 2.400 | |
| 3 | 1 | 5.344 | |
| 3 | 2 | 2.400 | |
| 4 | 1 | 5.344 | |
| 4 | 2 | 2.400 | |

NOTE: live loading is no skipped

 4 - CALCULATED SECTION PROPERTIES
 =====

4.1 AT MIDSPAN

| SPAN | AREA (m ²) | I (m ⁴) |
|-------------------|------------------------|---------------------|
| -#-----#-----#--- | | |
| 1 | 1.5600 | 0.00494 |
| 2 | 1.5600 | 0.00494 |
| 3 | 1.5600 | 0.00494 |
| 4 | 1.5600 | 0.00494 |

 5 - DEAD LOAD MOMENTS
 =====

| <- 5.1 SPAN MOMENTS T-m -> | | | |
|----------------------------|--------|-----------|--------|
| SPAN | M(l) | M(center) | M(r) |
| -#-----#-----#-----#--- | | | |
| 1 | -19.60 | 16.55 | -32.81 |
| 2 | -30.29 | 13.46 | -28.30 |
| 3 | -28.30 | 13.46 | -30.29 |
| 4 | -32.81 | 16.55 | -19.60 |

NOTE: These moments are shown at center of column

| <- 5.2 COLUMN MOMENTS T-m -> | | |
|------------------------------|---------------|---------------|
| SUPP | Lower columns | Upper columns |
| -#-----#-----#-----#--- | | |
| 1 | -9.59 | -9.59 |
| 2 | 1.26 | 1.26 |
| 3 | 0.00 | 0.00 |
| 4 | -1.26 | -1.26 |
| 5 | 9.59 | 9.59 |

 6 - LIVE LOAD MOMENTS
 =====

| <- 6.1 SPAN MOMENTS T-m -> | | | |
|----------------------------|--------|-----------|--------|
| SPAN | M(l) | M(center) | M(r) |
| -#-----#-----#-----#--- | | | |
| 1 | -8.80 | 7.43 | -14.73 |
| 2 | -13.60 | 6.04 | -12.71 |
| 3 | -12.71 | 6.04 | -13.60 |
| 4 | -14.73 | 7.43 | -8.80 |

NOTE: These moments are shown at center of column

| <- 6.2 COLUMN MOMENTS T-m -> | | |
|------------------------------|---------------|---------------|
| SUPP | Lower columns | Upper columns |
| -#-----#-----#-----#--- | | |
| 1 | -4.30 | -4.30 |
| 2 | 0.56 | 0.56 |
| 3 | 0.00 | 0.00 |
| 4 | -0.56 | -0.56 |
| 5 | 4.30 | 4.30 |

 7 - M O M E N T S R E D U C E D T O F A C E O F S U P P O R T
 =====

| SPAN | <- 7.1 DEAD LOAD MOMENTS -> | | | <-7.2 LIVE* LOAD MOMENTS -> | | |
|------|-----------------------------|-----------|--------|-----------------------------|-----------|--------|
| | M(l) | M(center) | M(r) | M(l) | M(center) | M(r) |
| 1 | -12.14 | 16.55 | -24.02 | -5.45 | 7.43 | -10.79 |
| 2 | -22.07 | 13.46 | -20.27 | -9.91 | 6.04 | -9.11 |
| 3 | -20.27 | 13.46 | -22.07 | -9.11 | 6.04 | -9.91 |
| 4 | -24.02 | 16.55 | -12.14 | -10.79 | 7.43 | -5.45 |

* Live load moments listed are maxima of support negative and span positive

8 - S U M O F D E A D A N D L I V E M O M E N T S (T-m)
 =====

Maxima of negative support and positive live load span moments with dead loading combined as indicated herein
 for serviceability checks (1.00DL + 1.00LL)

| SPAN | M(l) | M(center) | M(r) |
|------|--------|-----------|--------|
| 1 | -17.59 | 23.98 | -34.81 |
| 2 | -31.98 | 19.50 | -29.38 |
| 3 | -29.38 | 19.50 | -31.98 |
| 4 | -34.81 | 23.98 | -17.59 |

NOTE: These moments are reduced to face

9 - SELECTED POST-TENSIONING FORCES AND TENDON PROFILES

| SPAN | <--- 9.1 SELECTED VALUES ---> | | | <- 9.2 CALCULATED VALUES -> | | |
|------|-------------------------------|------------------------|--------|-----------------------------|------------------------------|------------------------------|
| | FORCE (T) | DISTANCE OF CGS cm --> | | | P/A (Kg/cm ²) | Wbal (T /m ²) |
| # | # | Left | Center | Right | # | # |
| 1 | 239.42 | 9.75 | 3.50 | 16.00 | 15.35 | 0.351 |
| 2 | 239.42 | 16.00 | 3.50 | 16.00 | 15.35 | 0.468 |
| 3 | 239.42 | 16.00 | 3.50 | 16.00 | 15.35 | 0.468 |
| 4 | 239.42 | 16.00 | 3.50 | 9.75 | 15.35 | 0.351 |

9.3 SERVICE STRESSES (Kg/cm²) (tension shown negative)

| SPAN | L E F T | | C E N T E R | | R I G H T | |
|------|---------|--------|-------------|--------|-----------|--------|
| | TOP | BOTTOM | TOP | BOTTOM | TOP | BOTTOM |
| # | # | # | # | # | # | # |
| 1 | -7.49 | 38.19 | 46.26 | -15.57 | -26.22 | 56.91 |
| 2 | -20.10 | 50.80 | 34.48 | -3.79 | -13.26 | 43.96 |
| 3 | -13.26 | 43.96 | 34.48 | -3.79 | -20.10 | 50.80 |
| 4 | -26.22 | 56.91 | 46.26 | -15.57 | -7.49 | 38.19 |

9.4 POST-TENSIONING BALANCED MOMENTS

| SPAN | <--- S P A N M O M E N T S T-m ---> | | |
|------|---|-----------|-------|
| | M(l) | M(center) | M(r) |
| # | # | # | # |
| 1 | 6.01 | -8.31 | 13.74 |
| 2 | 14.01 | -9.80 | 14.87 |
| 3 | 14.87 | -9.80 | 14.01 |
| 4 | 13.74 | -8.31 | 6.01 |

NOTE: These moments are reduced to face

| SUPPORT | <--- C O L U M N M O M E N T S T-m ---> | |
|---------|---|---------------|
| | Lower columns | Upper columns |
| # | # | # |
| 1 | 4.81 | 4.81 |
| 2 | 0.61 | 0.61 |
| 3 | -0.00 | -0.00 |
| 4 | -0.61 | -0.61 |
| 5 | -4.81 | -4.81 |

10 - FACTORED MOMENTS
=====

Calculated as (1.40D + 1.70L + 1.00 secondary moment effects)

| SPAN # | 10.1 FACTORED DESIGN MOMENTS (T-m) | | |
|---------------------------|-------------------------------------|----------|---------|
| | (left) | (center) | (right) |
| -#-----#-----#-----#----- | | | |
| 1 | -20.25 | 42.46 | -50.75 |
| 2 | -46.79 | 34.28 | -43.77 |
| 3 | -43.77 | 34.28 | -46.79 |
| 4 | -50.75 | 42.46 | -20.25 |

NOTE: These moments are reduced to face

| SUPP | 10.2 COLUMN MOMENTS (T-m) | |
|---------------------------|----------------------------|---------------|
| | Lower columns | Upper columns |
| -#-----#-----#-----#----- | | |
| 1 | -20.74 | -20.74 |
| 2 | 2.72 | 2.72 |
| 3 | 0.00 | 0.00 |
| 4 | -2.72 | -2.72 |
| 5 | 20.74 | 20.74 |

11 - M I L D R E I N F O R C E M E N T R E Q U I R E M E N T S

11.1 SPECIFIC CRITERIA FOR T W O - W A Y S Y S T E M

- Minimum steel for negative Moment..... 0.00075h1
- Moment capacity > factored (design) moment

11.2 S T E E L E A C H S P A N

| SPAN # | T O P | | | B O T T O M | | |
|--------|-------|--------|-------|-------------|--------|-------|
| | Left | Center | Right | Left | Center | Right |
| 1 | 16.45 | 0.00 | 24.60 | 0.00 | 15.29 | 0.00 |
| 2 | 17.50 | 0.00 | 12.10 | 0.00 | 0.00 | 0.00 |
| 3 | 12.10 | 0.00 | 17.50 | 0.00 | 0.00 | 0.00 |
| 4 | 24.60 | 0.00 | 16.45 | 0.00 | 15.29 | 0.00 |

Minimum steel all bottom (0.001Ac)...15.60 cm²

11.3 SELECTION OF R E B A R A T S U P P O R T

| SPAN # | T O P | | B O T T O M | |
|--------|-----------------|-------------------|-----------------|-------------------|
| | cm ² | S E L E C T I O N | cm ² | S E L E C T I O N |
| 1 | 16.45 | 15-DB12 mm.x2.16 | 15.60 | DB12 mm.@ 0.57 |
| 2 | 24.60 | 13-DB16 mm.x3.52 | 15.60 | DB12 mm.@ 0.57 |
| 3 | 12.10 | 12-DB12 mm.x3.52 | 15.60 | DB12 mm.@ 0.57 |
| 4 | 24.60 | 13-DB16 mm.x3.52 | 15.60 | DB12 mm.@ 0.57 |
| 5 | 16.45 | 15-DB12 mm.x2.16 | 15.60 | DB12 mm.@ 0.57 |

11.4 SELECTION OF R E B A R A T M I D - S P A N

| SPAN # | B O T T O M | | T O P | |
|--------|-----------------|-------------------|-----------------|-------------------|
| | cm ² | S E L E C T I O N | cm ² | S E L E C T I O N |
| 1 | 15.60 | DB12 mm.@ 0.57 | | |
| 2 | 15.60 | DB12 mm.@ 0.57 | | |
| 3 | 15.60 | DB12 mm.@ 0.57 | | |
| 4 | 15.60 | DB12 mm.@ 0.57 | | |

12 - PUNCHING SHEAR CHECK

| SUP # | FACTORED ACTIONS | | <-- PUNCHING SHEAR STRESSES IN Kg/cm ² --> | | | | |
|----------|------------------|---------------|---|------------------|-------|----------------|-----------------|
| | shear T | moment T-m | due to shear | due to moment | TOTAL | allow- able | STRESS RATIO |
| # | # | # | # | # | # | # | # |
| 1 | 42.67 | 32.56 | 9.47 | 6.77 | 16.24 | 16.38 | 0.99 |
| 2 | 96.60 | 6.65 | 15.17 | 1.29 | 16.46 | 18.04 | 0.91 |
| 3 | 91.41 | 0.00 | 14.35 | 0.00 | 14.35 | 18.04 | 0.80 |
| 4 | 96.60 | 6.65 | 15.17 | 1.29 | 16.46 | 18.04 | 0.91 |
| 5 | 42.67 | 32.56 | 9.47 | 6.77 | 16.24 | 16.38 | 0.99 |

PUNCHING SHEAR CHECK SATISFACTORY

13 - MAXIMUM SPAN DEFLECTIONS

Concrete's modulus of elasticity $E_c = 274.00 \text{ T/cm}^2$
 Creep factor $K = 2.00$
 effective-I/gross-I (due to cracking) $= 1.00$

Values in parentheses are (span/max deflection) ratios

| SPAN # | <.....DEFLECTION ARE ALL IN cm | | | , DOWNWARD POSITIVE.....> | |
|-----------|--------------------------------|-------|-------------|---------------------------|----------------|
| | DL | DL+PT | DL+PT+CREEP | LL | DL+PT+LL+CREEP |
| # | # | # | # | # | # |
| 1 | 0.77 | 0.39 | 1.01(795) | 0.34 | 1.35(593) |
| 2 | 0.52 | 0.12 | 0.32(2528) | 0.23 | 0.55(1459) |
| 3 | 0.52 | 0.12 | 0.32(2528) | 0.23 | 0.55(1459) |
| 4 | 0.77 | 0.39 | 1.01(795) | 0.34 | 1.35(593) |

 14 - L O N G T E R M L O S S C A L C U L A T I O N
 =====

I N P U T P A R A M E T E R :

| | |
|---|--------------------------------|
| TYPE OF STRAND | Low Relax |
| SYSTEM OF PRESTRESSED CONCRETE..... | UNBONDED |
| ULTIMATE STRENGTH OF STRAND..... | 18870 (Kg/cm ²) |
| MODULUS OF ELASTICITY OF STRAND | 1950000 (Kg/cm ²) |
| AVERAGE COMPRESSIVE STRESS IN CONCRETE..... | 16.00 (Kg/cm ²) |
| AVERAGE INITIAL STRESS IN TENDON (after release). | 12500.00 (Kg/cm ²) |
| CONCRETE STRENGTH AT 28 DAYS..... | 320.00 (Kg/cm ²) |
| UNIT WEIGHT OF CONCRETE..... | 2400.00 (Kg/m ³) |
| ESTIMATED AGE OF CONCRETE AT STRESSING..... | 5 (Days) |
| MODULUS OF ELASTICITY OF CONCRETE AT STRESSING... | 92500 (Kg/cm ²) |
| MODULUS OF ELASTICITY OF CONCRETE AT 28 DAYS..... | 200000 (Kg/cm ²) |
| ESTIMATE OF AVERAGE RELATIVE HUMDITY..... | 80.00 (%) |
| VOLUME TO SURFACE RATIO OF MEMBER..... | 10.00 (cm) |

C A L C U L A T E D :

| | |
|------------------------------------|------------------------------|
| ELASTIC SHORTENING..... | 221.35 (Kg/cm ²) |
| SHRINKAGE..... | 191.80 (Kg/cm ²) |
| CREEP..... | 327.60 (Kg/cm ²) |
| RELAXATION..... | 185.49 (Kg/cm ²) |
| ----- | |
| TOTAL LONG TERM STRESS LOSSES..... | 926.23 (Kg/cm ²) |
| ----- | |

15 - IMMEDIATE LOSS CALCULATIONS :

INPUT PARAMETER

COEFFICIENT OF ANGULAR FRICTION (meu)..... 0.120 (/radian)
 COEFFICIENT OF WOBBLE FRICTION (K)..... 0.0025 (/m)
 RATIO OF JACKING STRESS TO STRAND ULTIMATE STRENGTH 0.75
 ANCHORAGE SET..... 6.00 (mm)
 CROSS-SECTION AREA OF STRAND..... 0.99 (cm²)
 MODE OF STRESSING : Both End ---- RIGHT END FIRST

LEFT END STRESS ONLY

AVERAGE WEDGE SET DISTANCE..... 12.20 (m)

| PT NO. | X m | Y cm | FRICT (kg/cm ²) | WSET (kg/cm ²) | *TOTAL (kg/cm ²) | Eff STRESS (kg/cm ²) |
|--------|-------|-------|-----------------------------|----------------------------|------------------------------|----------------------------------|
| 1 | 0.00 | 9.75 | 0.00 | 1893.64 | 2819.88 | 11332.62 |
| 2 | 4.00 | 3.50 | 193.68 | 1272.66 | 2392.58 | 11759.92 |
| 3 | 8.00 | 16.00 | 543.11 | 651.68 | 2121.02 | 12031.48 |
| 4 | 12.00 | 3.50 | 892.54 | 30.70 | 1849.47 | 12303.03 |
| 5 | 16.00 | 16.00 | 1241.96 | 0.00 | 2168.20 | 11984.30 |
| 6 | 20.00 | 3.50 | 1591.39 | 0.00 | 2517.62 | 11634.88 |
| 7 | 24.00 | 16.00 | 1940.82 | 0.00 | 2867.05 | 11285.45 |
| 8 | 28.00 | 3.50 | 2290.24 | 0.00 | 3216.48 | 10936.02 |
| 9 | 32.00 | 9.75 | 2483.93 | 0.00 | 3410.16 | 10742.34 |

*TOTAL is TOTAL LOSS include immediate loss and long term loss

RIGHT END STRESS ONLY

AVERAGE WEDGE SET DISTANCE..... 12.20 (m)

| PT NO. | X m | Y cm | FRICT (kg/cm ²) | WSET (kg/cm ²) | *TOTAL (kg/cm ²) | Eff STRESS (kg/cm ²) |
|--------|-------|-------|-----------------------------|----------------------------|------------------------------|----------------------------------|
| 1 | 0.00 | 9.75 | 2483.93 | 0.00 | 3410.16 | 10742.34 |
| 2 | 4.00 | 3.50 | 2290.24 | 0.00 | 3216.48 | 10936.02 |
| 3 | 8.00 | 16.00 | 1940.82 | 0.00 | 2867.05 | 11285.45 |
| 4 | 12.00 | 3.50 | 1591.39 | 0.00 | 2517.62 | 11634.88 |
| 5 | 16.00 | 16.00 | 1241.96 | 0.00 | 2168.20 | 11984.30 |
| 6 | 20.00 | 3.50 | 892.54 | 30.70 | 1849.47 | 12303.03 |
| 7 | 24.00 | 16.00 | 543.11 | 651.68 | 2121.02 | 12031.48 |
| 8 | 28.00 | 3.50 | 193.68 | 1272.66 | 2392.58 | 11759.92 |
| 9 | 32.00 | 9.75 | 0.00 | 1893.64 | 2819.88 | 11332.62 |

*TOTAL is TOTAL LOSS include immediate loss and long term loss

 ANGULAR PROFILE AND ELONGATION

| PT NO. | X m | Y cm | L.ANGLE (rad) | R.ANGLE (rad) |
|-----------|--------|---------|------------------|------------------|
| 1 | 0.00 | 9.75 | 0.0000 | 0.0315 |
| 2 | 4.00 | 3.50 | 0.0315 | 0.0625 |
| 3 | 8.00 | 16.00 | 0.0625 | 0.0625 |
| 4 | 12.00 | 3.50 | 0.0625 | 0.0625 |
| 5 | 16.00 | 16.00 | 0.0625 | 0.0625 |
| 6 | 20.00 | 3.50 | 0.0625 | 0.0625 |
| 7 | 24.00 | 16.00 | 0.0625 | 0.0625 |
| 8 | 28.00 | 3.50 | 0.0625 | 0.0315 |
| 9 | 32.00 | 9.75 | 0.0315 | 0.0000 |

| | |
|---|--------------------------------|
| AVERAGE INITIAL STRESS (AFTER RELEASE)..... | 12482.91 (Kg/cm ²) |
| LONGTERM STRESS LOSSES..... | 926.23 (Kg/cm ²) |
| FINAL AVERAGE STRESS..... | 11556.67 (Kg/cm ²) |
| FINAL AVERAGE FORCE IN TENDON..... | 11407.59 (Kg) |
| TOTAL ELONGATION..... | 204.85 (mm) |

ภาคผนวก ค

ตัวอย่างผลลัพธ์ตามตัวอย่างที่ 3

```

=====
CHULALONGKORN UNIVERSITY 1997
DEPARTMENT OF CIVIL ENGINEERING

```

```

-----
WINAI SANGHITKUL
STRUCTURAL ENGINEER
-----

```

```

=====
OPTIMUM DESIGN OF POST-TENSIONED FLAT PLATE
=====

```

DATE AND TIME OF PROGRAM EXECUTION: 17-Mar-1997 Time: 17:50:16

PROJECT TITLE: EXAMPLE 3 FOR OPTIMUM FLAT PLAT
SPECIFIC TITLE: DESIGN BY S.WINAI

1 - GENERAL DESIGN PARAMETERS

```

=====
CONCRETE:
STRENGTH at 28 days ..... 320.00 (Kg/cm^2)
WEIGHT ..... 2400.00 (Kg/m^3)
CREEP factor for deflections..... 2.00
UNIT PRICE of concrete..... 1780.00 (Baht/m^3)

TENSION STRESS limit ..... 28.62 (Kg/cm^2)
TENSION STRESS Ratio (multiple of (f'c)^1/2)
Top of support ..... 1.600
Bottom of span ..... 1.600

COMPRESSION STRESS limit ..... 144.00 (Kg/cm^2)
COMPRESSION STRESS Ratio (multiple of (f'c))
At all locations ..... 0.45

MILD REINFORCEMENT:
YIELD strength ..... 4000.00 (Kg/cm^2)
Minimum Concrete Cover..... 2.50 (cm)
UNIT PRICE of mild reinforcement..... 15.50 (Baht/Kg)

POST-TENSIONING:
SYSTEM ..... BONDED
DESIGN SYSTEM ..... FULLY
Ultimate strength of strand ..... 18.87 (T/cm^2)
Average effective stress in strand (final) ..... 11.40 (T/cm^2)
Strand area..... 98.71 (mm^2)
Min CGS of tendon cover ..... 4.20 (cm)
Max tendon SPACING (multiple of member depth) .. 8.00
UNIT PRICE of post-tensioned:
Strand..... 25.00 (Baht/Kg)
Stressing Anchored..... 170.00 (Baht/Set)
Fix Anchored..... 65.00 (Baht/Set)
Bar chair (spacing @1.00 m)..... 7.00 (Baht/Set)
Flat duct (Corrugate)..... 30.00 (Baht/m)
Grouting..... 10.00 (Baht/m)

ANALYSIS OPTIONS USED:
Optimum design..... YES
Two-Way Slab Structure System.....
Equivalent frame formulation per ACI-318-95.....

```

2 - INPUT GEOMETRY
 =====

2.1 - SPAN DATA

| <----- SLAB -----> | | | | |
|---------------------------------|--------|-------|---------|---------|
| SPAN | LENGTH | DEPTH | L-WIDTH | R-WIDTH |
| | m | m | m | m |
| -#-----#-----#-----#-----#----- | | | | |
| 1 | 8.00 | 0.200 | 4.00 | 4.00 |
| 2 | 8.00 | 0.200 | 4.00 | 4.00 |
| 3 | 8.00 | 0.200 | 4.00 | 4.00 |
| 4 | 8.00 | 0.200 | 4.00 | 4.00 |

2.2 - COLUMNS AND DROP PANEL DATA

| SUP | <- LOWER COLUMN -> | | | <- UPPER COLUMN -> | | |
|---|--------------------|-------|-------|--------------------|-------|-------|
| | LEN | PARL | PERP | LEN | PARL | PERP |
| | m | m | m | m | m | m |
| -#-----#-----#-----#-----#-----#-----#----- | | | | | | |
| 1 | 3.00 | 0.800 | 0.800 | 3.00 | 0.800 | 0.800 |
| 2 | 3.00 | 0.800 | 0.800 | 3.00 | 0.800 | 0.800 |
| 3 | 3.00 | 0.800 | 0.800 | 3.00 | 0.800 | 0.800 |
| 4 | 3.00 | 0.800 | 0.800 | 3.00 | 0.800 | 0.800 |
| 5 | 3.00 | 0.800 | 0.800 | 3.00 | 0.800 | 0.800 |

* ALL COLUMNS ARE ASSUMED FIXED AT THE FAR END

 3 - INPUT APPLIED LOADING
 =====

| <----CLASS----> | | | |
|---------------------------|-------|---------------------|----------------------|
| 1.DEAD LOAD | | | |
| 2.LIVE LOAD | | | |
| SPAN | CLASS | (Uniform) (T/m) | (Edge Load) (T) |
| -#-----#-----#-----#----- | | | |
| 1 | 1 | 5.440 | |
| 1 | 2 | 2.400 | |
| 2 | 1 | 5.440 | |
| 2 | 2 | 2.400 | |
| 3 | 1 | 5.440 | |
| 3 | 2 | 2.400 | |
| 4 | 1 | 5.440 | |
| 4 | 2 | 2.400 | |

NOTE: live loading is no skipped

 4 - CALCULATED SECTION PROPERTIES
 =====

4.1 AT MIDSPAN

| SPAN | AREA (m ²) | I (m ⁴) |
|------------------|------------------------|---------------------|
| -#-----#-----#-- | | |
| 1 | 1.6000 | 0.00533 |
| 2 | 1.6000 | 0.00533 |
| 3 | 1.6000 | 0.00533 |
| 4 | 1.6000 | 0.00533 |

 =====
 5 - DEAD LOAD MOMENTS
 =====

| <- 5.1 SPAN MOMENTS T-m -> | | | |
|----------------------------|--------|-----------|--------|
| SPAN | M(l) | M(center) | M(r) |
| -#-----#-----#-----#-- | | | |
| 1 | -19.90 | 16.86 | -33.41 |
| 2 | -30.85 | 13.70 | -28.80 |
| 3 | -28.80 | 13.70 | -30.85 |
| 4 | -33.41 | 16.86 | -19.90 |

NOTE: These moments are shown at center of column

| <- 5.2 COLUMN MOMENTS T-m -> | | |
|------------------------------|---------------|---------------|
| SUPP | Lower columns | Upper columns |
| -#-----#-----#-----#-- | | |
| 1 | -9.73 | -9.73 |
| 2 | 1.28 | 1.28 |
| 3 | -0.00 | -0.00 |
| 4 | -1.28 | -1.28 |
| 5 | 9.73 | 9.73 |

 =====
 6 - LIVE LOAD MOMENTS
 =====

| <- 6.1 SPAN MOMENTS T-m -> | | | |
|----------------------------|--------|-----------|--------|
| SPAN | M(l) | M(center) | M(r) |
| -#-----#-----#-----#-- | | | |
| 1 | -8.78 | 7.44 | -14.74 |
| 2 | -13.61 | 6.04 | -12.71 |
| 3 | -12.71 | 6.04 | -13.61 |
| 4 | -14.74 | 7.44 | -8.78 |

NOTE: These moments are shown at center of column

| <- 6.2 COLUMN MOMENTS T-m -> | | |
|------------------------------|---------------|---------------|
| SUPP | Lower columns | Upper columns |
| -#-----#-----#-----#-- | | |
| 1 | -4.29 | -4.29 |
| 2 | 0.57 | 0.57 |
| 3 | 0.00 | 0.00 |
| 4 | -0.57 | -0.57 |
| 5 | 4.29 | 4.29 |

 7 - M O M E N T S R E D U C E D T O F A C E O F S U P P O R T
 =====

| SPAN | <- 7.1 DEAD LOAD MOMENTS -> | | | <-7.2 LIVE* LOAD MOMENTS -> | | |
|------|-----------------------------|-----------|--------|-----------------------------|-----------|--------|
| | M(l) | M(center) | M(r) | M(l) | M(center) | M(r) |
| 1 | -12.31 | 16.86 | -24.47 | -5.43 | 7.44 | -10.79 |
| 2 | -22.48 | 13.70 | -20.63 | -9.92 | 6.04 | -9.10 |
| 3 | -20.63 | 13.70 | -22.48 | -9.10 | 6.04 | -9.92 |
| 4 | -24.47 | 16.86 | -12.31 | -10.79 | 7.44 | -5.43 |

* Live load moments listed are maxima of support negative and span positive

8 - S U M O F D E A D A N D L I V E M O M E N T S (T-m)
 =====

Maxima of negative support and positive live load span moments with dead loading combined as indicated herein
 for serviceability checks (1.00DL + 1.00LL)

| SPAN | M(l) | M(center) | M(r) |
|------|--------|-----------|--------|
| 1 | -17.74 | 24.30 | -35.26 |
| 2 | -32.39 | 19.74 | -29.74 |
| 3 | -29.74 | 19.74 | -32.39 |
| 4 | -35.26 | 24.30 | -17.74 |

NOTE: These moments are reduced to face

9 - SELECTED POST-TENSIONING FORCES AND TENDON PROFILES

| SPAN | <---- 9.1 SELECTED VALUES ----> | | | | <- 9.2 CALCULATED VALUES -> | |
|------|---------------------------------|--------------------------|--------|-------|------------------------------|------------------------------|
| | FORCE (T) | <- DISTANCE OF CGS cm -> | | | P/A (Kg/cm ²) | Wbal (T /m ²) |
| # | # | Left | Center | Right | # | # |
| 1 | 270.00 | 10.00 | 4.20 | 15.80 | 16.88 | 0.367 |
| 2 | 270.00 | 15.80 | 4.20 | 15.80 | 16.88 | 0.489 |
| 3 | 270.00 | 15.80 | 4.20 | 15.80 | 16.88 | 0.489 |
| 4 | 270.00 | 15.80 | 4.20 | 10.00 | 16.88 | 0.367 |

9.3 SERVICE STRESSES (Kg/cm²) (tension shown negative)

| SPAN | L E F T | | C E N T E R | | R I G H T | |
|------|---------|--------|-------------|--------|-----------|--------|
| | TOP | BOTTOM | TOP | BOTTOM | TOP | BOTTOM |
| # | # | # | # | # | # | # |
| 1 | -4.64 | 38.39 | 46.13 | -12.38 | -22.26 | 56.01 |
| 2 | -16.37 | 50.12 | 34.65 | -0.90 | -9.70 | 43.45 |
| 3 | -9.70 | 43.45 | 34.65 | -0.90 | -16.37 | 50.12 |
| 4 | -22.26 | 56.01 | 46.13 | -12.38 | -4.64 | 38.39 |

9.4 POST-TENSIONING BALANCED MOMENTS

| SPAN | <-- S P A N M O M E N T S T-m --> | | |
|------|-----------------------------------|-----------|-------|
| | M(l) | M(center) | M(r) |
| # | # | # | # |
| 1 | 6.26 | -8.70 | 14.39 |
| 2 | 14.66 | -10.26 | 15.57 |
| 3 | 15.57 | -10.26 | 14.66 |
| 4 | 14.39 | -8.70 | 6.26 |

NOTE: These moments are reduced to face

| SUPPORT | <-- C O L U M N M O M E N T S T-m ----> | |
|---------|---|---------------|
| | Lower columns | Upper columns |
| # | # | # |
| 1 | 5.02 | 5.02 |
| 2 | 0.63 | 0.63 |
| 3 | 0.00 | 0.00 |
| 4 | -0.63 | -0.63 |
| 5 | -5.02 | -5.02 |

10 - FACTORED MOMENTS
=====

Calculated as (1.40D + 1.70L + 1.00 secondary moment effects)

| SPAN # | 10.1 FACTORED DESIGN MOMENTS (T-m) (left) | (center) | (right) |
|---------------------------|---|----------|---------|
| -#-----#-----#-----#----- | | | |
| 1 | -20.20 | 43.21 | -51.33 |
| 2 | -47.33 | 34.85 | -44.27 |
| 3 | -44.27 | 34.85 | -47.33 |
| 4 | -51.33 | 43.21 | -20.20 |

NOTE: These moments are reduced to face

| SUPP | 10.2 COLUMN MOMENTS (T-m) Lower columns | Upper columns |
|---------------------------|---|---------------|
| -#-----#-----#-----#----- | | |
| 1 | -20.93 | -20.93 |
| 2 | 2.76 | 2.76 |
| 3 | 0.00 | 0.00 |
| 4 | -2.76 | -2.76 |
| 5 | 20.93 | 20.93 |

 11 - M I L D R E I N F O R C E M E N T R E Q U I R E M E N T S
 =====

11.1 SPECIFIC CRITERIA FOR T W O - W A Y S Y S T E M

- Minimum steel for negative Moment..... 0.00075hl
- Moment capacity > factored (design) moment

11.2 S T E E L E A C H S P A N

| SPAN # | T O P | | | B O T T O M | | |
|--------|---|--------|-------|---|--------|-------|
| | <--- cm ² /Bay Width ---> Left | Center | Right | <--- cm ² /Bay Width ---> Left | Center | Right |
| 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Minimum steel all bottom (0.001Ac)...16.00 cm²

11.3 SELECTION OF R E B A R A T S U P P O R T

| SPAN # | T O P | | B O T T O M | |
|--------|-------------------------------------|-------------------|-------------------------------------|-------------------|
| | <--- Bay Width ---> cm ² | S E L E C T I O N | <--- Bay Width ---> cm ² | S E L E C T I O N |
| 1 | | | 16.00 | DB12 mm.@ 0.53 |
| 2 | | | 16.00 | DB12 mm.@ 0.53 |
| 3 | | | 16.00 | DB12 mm.@ 0.53 |
| 4 | | | 16.00 | DB12 mm.@ 0.53 |
| 5 | | | 16.00 | DB12 mm.@ 0.53 |

11.4 SELECTION OF R E B A R A T M I D - S P A N

| SPAN # | B O T T O M | | T O P | |
|--------|-------------------------------------|-------------------|-------------------------------------|-------------------|
| | <--- Bay Width ---> cm ² | S E L E C T I O N | <--- Bay Width ---> cm ² | S E L E C T I O N |
| 1 | 16.00 | DB12 mm.@ 0.53 | | |
| 2 | 16.00 | DB12 mm.@ 0.53 | | |
| 3 | 16.00 | DB12 mm.@ 0.53 | | |
| 4 | 16.00 | DB12 mm.@ 0.53 | | |

 12 - P U N C H I N G S H E A R C H E C K
 =====

| SUP # | FACTORED ACTIONS | | <-- PUNCHING SHEAR STRESSES IN Kg/cm ² --> | | | | allow- able | STRESS RATIO |
|----------|------------------|---------------|---|------------------|-------|-------|----------------|-----------------|
| | shear T | moment T-m | due to shear | due to moment | TOTAL | | | |
| -#- | -#- | -#- | -#- | -#- | -#- | -#- | -#- | -#- |
| 1 | 43.15 | 32.52 | 9.48 | 6.65 | 16.13 | 16.38 | 0.98 | |
| 2 | 97.75 | 6.77 | 15.19 | 1.30 | 16.48 | 18.43 | 0.89 | |
| 3 | 92.47 | 0.00 | 14.37 | 0.00 | 14.37 | 18.43 | 0.78 | |
| 4 | 97.75 | 6.77 | 15.19 | 1.30 | 16.48 | 18.43 | 0.89 | |
| 5 | 43.15 | 32.52 | 9.48 | 6.65 | 16.13 | 16.38 | 0.98 | |

PUNCHING SHEAR CHECK SATISFACTORY

 13 - M A X I M U M S P A N D E F L E C T I O N S
 =====

Concrete's modulus of elasticity $E_c = 274.00 \text{ T/cm}^2$
 Creep factor $K = 2.00$
 effective-I/gross-I (due to cracking) $= 1.00$

Values in parentheses are (span/max deflection) ratios

| SPAN # | <.....DEFLECTION ARE ALL IN cm | | | , DOWNWARD POSITIVE.....> | |
|-----------|--------------------------------|-------|--------------|---------------------------|----------------|
| | DL | DL+PT | DL+PT+CREEP | LL | DL+PT+LL+CREEP |
| -#- | -#- | -#- | -#- | -#- | -#- |
| 1 | 0.72 | 0.36 | 0.93 (864) | 0.32 | 1.25 (642) |
| 2 | 0.49 | 0.11 | 0.27 (2945) | 0.21 | 0.49 (1645) |
| 3 | 0.49 | 0.11 | 0.27 (2945) | 0.21 | 0.49 (1645) |
| 4 | 0.72 | 0.36 | 0.93 (864) | 0.32 | 1.25 (642) |

14 - L O N G T E R M L O S S C A L C U L A T I O N

=====

I N P U T P A R A M E T E R :

| | |
|---|--------------------------------|
| TYPE OF STRAND | Low Relax |
| SYSTEM OF PRESTRESSED CONCRETE..... | BONDED |
| ULTIMATE STRENGTH OF STRAND..... | 18870 (Kg/cm ²) |
| MODULUS OF ELASTICITY OF STRAND | 1950000 (Kg/cm ²) |
| AVERAGE COMPRESSIVE STRESS IN CONCRETE..... | 16.00 (Kg/cm ²) |
| AVERAGE INITIAL STRESS IN TENDON (after release). | 12000.00 (Kg/cm ²) |
| CONCRETE STRENGTH AT 28 DAYS..... | 320.00 (Kg/cm ²) |
| UNIT WEIGHT OF CONCRETE..... | 2400.00 (Kg/m ³) |
| ESTIMATED AGE OF CONCRETE AT STRESSING..... | 6 (Days) |
| MODULUS OF ELASTICITY OF CONCRETE AT STRESSING... | 92500 (Kg/cm ²) |
| MODULUS OF ELASTICITY OF CONCRETE AT 28 DAYS..... | 200000 (Kg/cm ²) |
| ESTIMATE OF AVERAGE RELATIVE HUMDITY..... | 80.00 (%) |
| VOLUME TO SURFACE RATIO OF MEMBER..... | 10.00 (cm) |

C A L C U L A T E D :

| | |
|------------------------------------|------------------------------|
| ELASTIC SHORTENING..... | 118.05 (Kg/cm ²) |
| SHRINKAGE..... | 191.80 (Kg/cm ²) |
| CREEP..... | 124.80 (Kg/cm ²) |
| RELAXATION..... | 169.72 (Kg/cm ²) |
| ----- | |
| TOTAL LONG TERM STRESS LOSSES..... | 604.37 (Kg/cm ²) |
| ----- | |

 15 - IMMEDIATE LOSS CALCULATIONS :
 =====

INPUT PARAMETER

COEFFICIENT OF ANGULAR FRICTION (meu)..... 0.200 (/radian)
 COEFFICIENT OF WOBBLE FRICTION (K)..... 0.0030 (/m)
 RATIO OF JACKING STRESS TO STRAND ULTIMATE STRENGTH 0.75
 ANCHORAGE SET..... 6.00 (mm)
 CROSS-SECTION AREA OF STRAND..... 0.99 (cm²)
 MODE OF STRESSING : Both End ---- RIGHT END FIRST

LEFT END STRESS ONLY

AVERAGE WEDGE SET DISTANCE..... 10.37 (m)

| PT NO. | X m | Y cm | FRICT (kg/cm ²) | WSET (kg/cm ²) | *TOTAL (kg/cm ²) | Eff STRESS (kg/cm ²) |
|--------|-------|-------|-----------------------------|----------------------------|------------------------------|----------------------------------|
| -#- | -#- | -#- | -#- | -#- | -#- | -#- |
| 1 | 0.00 | 10.00 | 0.00 | 2227.30 | 2831.67 | 11320.83 |
| 2 | 4.00 | 4.20 | 249.69 | 1368.21 | 2222.26 | 11930.24 |
| 3 | 8.00 | 15.80 | 739.19 | 509.11 | 1852.67 | 12299.83 |
| 4 | 12.00 | 4.20 | 1228.69 | 0.00 | 1833.06 | 12319.44 |
| 5 | 16.00 | 15.80 | 1718.19 | 0.00 | 2322.56 | 11829.94 |
| 6 | 20.00 | 4.20 | 2207.69 | 0.00 | 2812.07 | 11340.43 |
| 7 | 24.00 | 15.80 | 2697.20 | 0.00 | 3301.57 | 10850.93 |
| 8 | 28.00 | 4.20 | 3186.70 | 0.00 | 3791.07 | 10361.43 |
| 9 | 32.00 | 10.00 | 3436.38 | 0.00 | 4040.76 | 10111.74 |

 *TOTAL is TOTAL LOSS include immediate loss and long term loss

RIGHT END STRESS ONLY

AVERAGE WEDGE SET DISTANCE..... 10.37 (m)

| PT NO. | X m | Y cm | FRICT (kg/cm ²) | WSET (kg/cm ²) | *TOTAL (kg/cm ²) | Eff STRESS (kg/cm ²) |
|--------|-------|-------|-----------------------------|----------------------------|------------------------------|----------------------------------|
| -#- | -#- | -#- | -#- | -#- | -#- | -#- |
| 1 | 0.00 | 10.00 | 3436.38 | 0.00 | 4040.76 | 10111.74 |
| 2 | 4.00 | 4.20 | 3186.70 | 0.00 | 3791.07 | 10361.43 |
| 3 | 8.00 | 15.80 | 2697.20 | 0.00 | 3301.57 | 10850.93 |
| 4 | 12.00 | 4.20 | 2207.69 | 0.00 | 2812.07 | 11340.43 |
| 5 | 16.00 | 15.80 | 1718.19 | 0.00 | 2322.56 | 11829.94 |
| 6 | 20.00 | 4.20 | 1228.69 | 0.00 | 1833.06 | 12319.44 |
| 7 | 24.00 | 15.80 | 739.19 | 509.11 | 1852.67 | 12299.83 |
| 8 | 28.00 | 4.20 | 249.69 | 1368.21 | 2222.26 | 11930.24 |
| 9 | 32.00 | 10.00 | 0.00 | 2227.30 | 2831.67 | 11320.83 |

 *TOTAL is TOTAL LOSS include immediate loss and long term loss

ANGULAR PROFILE AND ELONGATION

| PT NO. | X m | Y cm | L.ANGLE (rad) | R.ANGLE (rad) |
|-----------|--------|---------|------------------|------------------|
| -#- | -#- | -#- | -#- | -#- |
| 1 | 0.00 | 10.00 | 0.0000 | 0.0290 |
| 2 | 4.00 | 4.20 | 0.0290 | 0.0580 |
| 3 | 8.00 | 15.80 | 0.0580 | 0.0580 |
| 4 | 12.00 | 4.20 | 0.0580 | 0.0580 |
| 5 | 16.00 | 15.80 | 0.0580 | 0.0580 |
| 6 | 20.00 | 4.20 | 0.0580 | 0.0580 |
| 7 | 24.00 | 15.80 | 0.0580 | 0.0580 |
| 8 | 28.00 | 4.20 | 0.0580 | 0.0290 |
| 9 | 32.00 | 10.00 | 0.0290 | 0.0000 |

| | |
|---|--------------------------------|
| AVERAGE INITIAL STRESS (AFTER RELEASE)..... | 11978.24 (Kg/cm ²) |
| LONGTERM STRESS LOSSES..... | 604.37 (Kg/cm ²) |
| FINAL AVERAGE STRESS..... | 11373.87 (Kg/cm ²) |
| FINAL AVERAGE FORCE IN TENDON..... | 11227.14 (Kg) |
| TOTAL ELONGATION..... | 196.57 (mm) |

ประวัติผู้เขียน

นาย วินัย สंहิตกุล เกิดเมื่อวันที่ 21 ตุลาคม พ.ศ. 2508 ที่จังหวัด กรุงเทพมหานคร สำเร็จการศึกษาวิศวกรรมบัณฑิตจากภาควิชาวิศวกรรมโยธา คณะวิศวกรรมศาสตร์ มหาวิทยาลัย เชียงใหม่ ในปีการศึกษา 2533 และเข้าศึกษาหลักสูตรวิศวกรรมศาสตรมหาบัณฑิต ภาควิชา วิศวกรรมโยธา คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย เมื่อปีการศึกษา 2536

