FINITE ELEMENT ANALYSIS
IN
DESIGN OF
STEEL-CONCRETE-STEEL SANDWICH
AND
REINFORCED CONCRETE SECTIONS
BY

Anis J Helou, BCE, M.Sc, Ph.D February 2010

CHAPTER 3 COMPUTER SOFTWARE

3.1 INTRODUCTION

ANALYSIS software was developed to solve Structural and Civil Engineering designs by implementing the Finite Element Analysis formulations presented in this study. Many original solutions were incorporated in this work, and colossal efforts and many years of intensive research were spent in the development of this software.

3.2 SCOPE OF PROGRAM

A brief description of the most prominent capabilities of ANALYSIS software is given here below

1. Determination of the buoyancy of immersed sections.
2. Determination by the finite element analysis method of nodal internal forces and displacements of elastic structures that are idealized as an assemblage of discrete beam-column elements, supported by self-equilibrating external forces and pressures. The formulation incorporates deformations due to bending, shear and axial forces, the non-linear influence of axial forces on bending and equivalent nodal force vectors corresponding to trapezoidal loading, uniformly distributed loading and linear thermal gradients across elements. Elastic sub-grade foundation elements are incorporated in the analysis of foundation structures.
3. Plotting the nodal internal moment and shear diagrams.
4. Design of shear connectors for double skin composite (DSC) to resist compression plate buckling, interface shearing forces and to act as transverse shear reinforcement.
5 Determination of ultimate moment of resistance of DSC sections subject to bending and axial forces.
6. Design for shear reinforcement of RC beam-column elements.
7. Determination of ultimate moment resistance of reinforced concrete (RC) sections subject to bending and axial forces.
8. Display and or print literature, axes, input data forms, and sections' details.
9. Provide a drafting board for plotting of figures and cross-sections.

3.3 FORMULATION

The program has been originally developed as a general-purpose program to perform all the calculations implied by the finite element formulation. The analysis can be applied to any plane assemblage of discrete beam column elements. The program determines the internal forces (axial, bending and transverse shear) acting within the plane of the cross-section, which is idealized as an assemblage of discrete beam - column, finite elements (see Figure 5.2). The analysis incorporates deformations due to bending, axial and transverse shearing forces, the non-linear influence of axial forces on bending, equivalent nodal force vectors corresponding to trapezoidal and uniformly distributed load, and linear thermal gradients across elements [5]. The program also incorporates elastic foundation elements to model the effect of inter-granular soil pressures beneath the foundations and designs RC and DSC elements. The design of RC elements is based on ACI Code. The design of DSC elements is based on Euro Code and on research in the School of Engineering, UWCC.

The program has been validated, by comparing the numerical results for a carefully chosen range of problems, with available analytical solutions.

3.4 OPTIONS OFFERED BY ANALYSIS SOFTWARE

1. The use of mouse or soft keys menu to control program execution during the entire performance in DOS environment
2. Graphical I/O capability is added to create dialogs and widgets for effective graphical user interfaces to control program execution during the entire performance in Windows environment.
3. Determination of nodal displacements, internal forces and moments
4. Designing double skin composite elements
5. Designing reinforced concrete elements
6. Checking the design of double skin composite elements against ACI Code

3.5 INPUT OF DATA

ANALYSIS Program displays on the screen at proper intervals all the input data forms that are then filled by the user with the required information. Corrections of the data input can be made at all times, and printing the input data forms is an available option. For demonstration, the data of the selected example is entered by DEMO program on behalf of the user.

3.6 PROGRAMMING LANGUAGE

The programming language of the present development is HP BASIC for Windows and HP BASIC PLUS. ANALYSIS program can run under DOS 5.0 or above and under Windows 95+ environments.

3.7 SYSTEM REQUIREMENTS

A 386/486/Pentium class processor or better is required. A processor with built-in numeric processor (486, Pentium) or an external numeric coprocessor (387SX, 387DX, 487) is strongly recommended. Eight megabytes of free RAM are recommended. If memory is inadequate, the program displays the free available memory and gives proper advice. The program will run with a monochrome, 16-colour, 256-colour or 24-bit display driver, but a 256-colour display driver is recommended. COLOR MAP functions only with 256-color display driver. The program can send screen dumps to any graphic printer supported by Windows. Plotters must be HPGL or PostScript compatible.

3.8 ENVIRONMENT

ANALYSIS runs in DOS and Windows as follows

1. DOS version –
   It runs in MS-DOS version 5.0 or above. Microsoft mouse software must be installed on your computer before running the program.
2) Windows version-
   a. Windows 3.1x - Add Microsoft WIN32S to the system.
   b. Windows 95+

3.9 THE DEMONSTRATION PROGRAM

To demonstrate the performance of ANALYSIS, a DEMO program that presents the various features and capabilities of the software has been developed. It solves the same example presented in Fig 5.1.

Although the intended use of the master program is for much more complicated problems, this example was carefully selected simple to allow checking the computer output by hand calculations. The DEMO diskette is easy to run and pleasant to watch.

3.10 RUNNING THE DEMO PROGRAM

Before running the Demo program, make sure that the computer complies with the limitations stated under SYSTEM REQUIREMENTS and ENVIRONMENT mentioned above. After that is done, insert the Demo diskette in drive A, keep it inserted during the entire performance of the program, and strictly heed the instructions displayed on the screen by the DEMO program. DEMO.ZIP has been uploaded unto Supremelogic Ltd website. Those wishing to download it may click on the following URL link. After extracting all its files, click on START_DEMO.BAT file to start the program execution. Thenceforth follow carefully the instructions as they are displayed on the screen.

If Windows version is used, invoke DEMO.EXE by the File Manager. The Demo program runs for 1 hour then quits and returns control to Windows.

If MS-DOS version is used, type A:\>demo then press [ENTER]. The Demo program runs for 1/2 hour then quits and returns control to DOS drive A.

To re-run either Demo program repeat the relevant steps explained above.

CHAPTER 4 EXAMPLES OF PROGRAM APPLICATION

4.1 INTRODUCTION

Two examples, a single bore DSC immersed tube tunnel and a continuous RC frame are chosen for the application of the program. Printing of the input data forms is provided by ANALYSIS software to assist the users entering the input data into the program memory.

4.2 DOUBLE SKIN COMPOSITE TUBE TUNNEL SECTION

4.2.1 Ultimate limit state bending and axial force

Determination of the ultimate bending resistance of a double skin composite section, is based on the following assumptions

a) Strain in the concrete is assumed to be proportional to the distance from the neutral axis (Fig 4.1 c). The maximum strain in the extreme fibre, at ultimate load, is assumed to be equal to 0.003.
b) Tensile strength of the concrete is neglected.
c) At ultimate load, concrete stress is not proportional to strain, and a rectangular compressive concrete stress distribution may be assumed (Fig 4.1 b).
d) The designed compressive axial force P_U, is assumed to act at the centroid of the transformed un-cracked section (Fig 4.1 b).
e) Stress in the compression steel plate f_{SC}, is limited by the material yield stress f_Y, slip yielding of the compressive plate connectors and plate buckling. Hence for compression plate yielding [6,7]

$$f_{SC} \leq f_Y \qquad (4.1)$$

For slip yielding of the compressive plate connectors

$$f_{SC} \leq \frac{n_C P_{RK}}{bt_C \gamma_V} \qquad (4.2)$$

In which, n_C is the number of compression plate connectors effective in resisting the longitudinal shear force between the compression plate and concrete (number of studs between points of zero and maximum moment), P_{RK} is the characteristic shear resistance of the stud connectors and γ_V is a partial material safety factor, taken as 1.25.

For plate buckling

$$f_{SC} \leq \frac{\pi^2 E_S t_C{}^2}{4.5 S_C{}^2} \qquad (4.3)$$

Where, b, t_C, and E_S are the width, thickness and Young's modulus of compression plate and S_C is the longitudinal spacing of compression plate connectors

f) Stress in the tensile steel plate f_{St}, is limited by the material yield stress f_Y and slip yielding of the tension plate connectors. Hence for tension plate yielding

$$f_{St} \leq f_Y \tag{4.4}$$

for slip yielding

$$f_{St} \leq \frac{n_t P_{RK}}{b t_t \gamma_{Vt}} \tag{4.5}$$

In which, n_t is the number of tension plate connectors effective in resisting the tensile forces (number of studs between points of zero and maximum moment), and γ_{Vt} is a partial material safety factor based on actual tests [6.11], taken as 1.6 for concrete in tension zones. When f_{St} is compressive, equations (4.1), (4.2) and (4.3) should be applied instead of equations (4.4) and (4.5), for the determination of the allowable tension plate stress.

The ultimate design resistance of a double skin composite section, subjected to bending and axial force, may now be determined as follows:

Considering the equilibrium of axial forces (see Fig 4.1 b) gives

$$P_U = F_{SC} + F_C + F_{St} \tag{4.6}$$

Taking moments about the line of action of F_{St} gives

$$M_U + P_U e' = F_{SC} Z' + F_C Z \tag{4.7}$$

In equations (4.6) and (4.7)

$$F_{SC} = \frac{f_{SC} b t_C}{\gamma_a} \tag{4.8}$$

$$F_C = \frac{f_{CK} b x}{\gamma_C} \tag{4.9}$$

$$F_{St} = \frac{f_{St} b t_t}{\gamma_a} \tag{4.10}$$

From the geometry of Fig 4.1 we may derive the following:

$$e' = \frac{1}{2}\frac{(d+t_t+t_C\}^2+(n-1)\left[t_t^{\,2}+t_C\{2(d+t_t)+t_C\ \}\right]}{d+n(t_t+t_C)} - \frac{t_t}{2} \qquad (4.11)$$

$$Z = d + \frac{t_t - x}{2} \qquad (4.12)$$

$$Z' = d + \frac{t_t + t_C}{2} \qquad (4.13)$$

In which n is steel/concrete modular ratio γ_a and γ_c are the partial material safety factors of steel plate and of concrete. All other terms in equations (4.6) to (4.13) are defined in Fig 4.1

From the geometry of Fig 4.1 c, the tension plate strain ε_{st} and the compressive strain ε_{sc} are given by

$$\varepsilon_{st} = \frac{d + \frac{t}{2} - c}{c}\ \varepsilon_c \qquad (4.14)$$

$$\varepsilon_{sc} = \frac{c + \frac{t_c}{2}}{c}\ \varepsilon_c \qquad (4.15)$$

where ε_C is the strain in the extreme concrete fibre, taken equal to 0.003 at ultimate load. Hence,

$$f_{St} = \varepsilon_{st} E_S = \frac{d + \frac{t_t}{2} - c}{c}\ \varepsilon_c E_S \qquad (4.16)$$

$$f_{SC} = \varepsilon_{sc} E_S = \frac{c + \frac{t_C}{2}}{2}\ \varepsilon_c E_S \qquad (4.17)$$

in which f_{St} is the lowest value given by equations (4.4) to (4.17) and f_{SC} is the lowest value given by equations (4.1), (4.2) and (4.3).

Solving equations (4.6) to (4.17) can be best achieved by plotting interaction diagrams (Figures 5) by computers. The ultimate moment of resistance of the section, corresponding to a particular value of P_U, can then be read directly from the plotted interaction diagram. If desired, these equations can be also solved by hand as follows:

a) Assume a value of c = d/2 and take x = 0.90 c

b) Solve for f_{St} and f_{SC} (equations (4.16) and (4.17)). Note that f_{St} and f_{SC} are limited by equations (4.1) to (4.5).

c) Determine F_{SC}, F_C, and F_{St} and P_U. If P_U is equal, or close enough, to the external compressive force, determine M_U. Otherwise adjust c and repeat steps (a) to (c).

4.2.2 Diagonal tension in concrete

Consider an element of concrete (Figure 4.2 (a)), which is acted upon by transverse shear stress τ and axial compressive stress σ_x. Under combined action of τ and σ_x, the concrete is assumed to fail by diagonal tension, caused by tensile stress σ_t (Figure 4.2 (b)). The magnitude and direction of the tensile stress can be deduced from Mohr's circle. Stresses σ_x and τ produce a minor principal stress σ_t on a plane inclined at an angle β to the line of action of τ.

From the geometry of the Mohr's circle we may write the following

$$\sigma_t = \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + \tau^2} - \frac{\sigma_x}{2} \tag{4.18}$$

If τ.is the shear stress causing diagonal tension failure, then σ_t is equal to the ultimate tensile strength of the concrete f_{Ct}. Hence the ultimate shear strength of the concrete is given by

$$\tau = \sqrt{f_{Ct}^2 + \sigma_x f_{Ct}} \tag{4.19}$$

The value of σ_x should be determined approximately and conservatively from the equation

$$\sigma_x = \frac{P_U}{A_C} \tag{4.20}$$

Where P_U is the axial compressive force and A_C is the area of the uncracked transformed composite section (Figure 4.3), given by

$$A_C = b\{n(t_c + t_t) + d\} \tag{4.21}$$

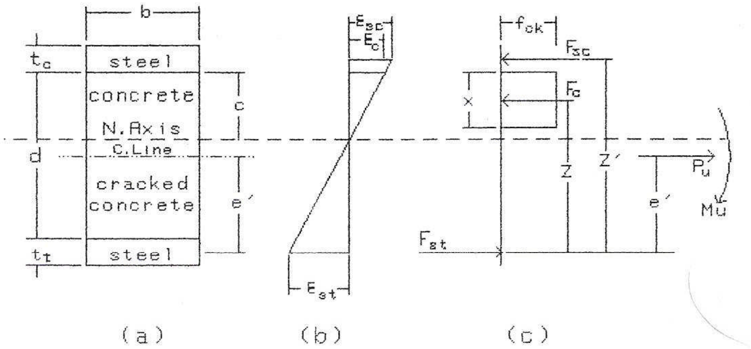


Fig 4.1 DSC element subjected to axial force and bending a) cross-section b) strain diagram c) stress block diagram

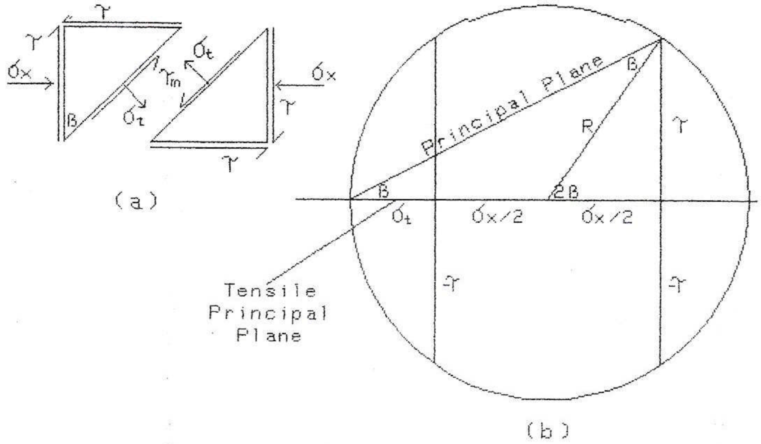


Fig. 4.2 Combined shear and axial compression
a) shear and normal stresses
b) Mohr's circle

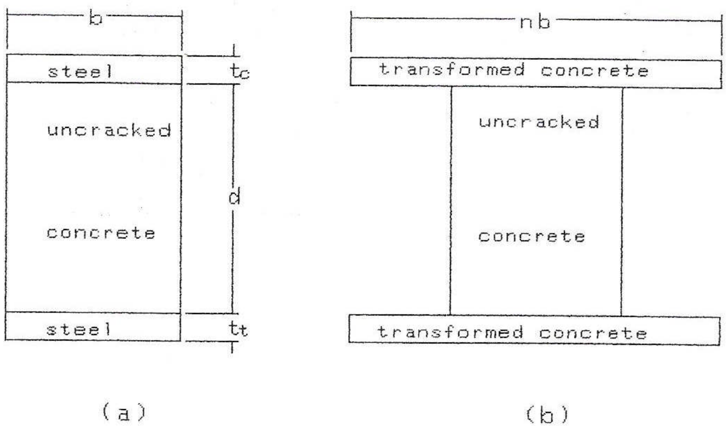


Fig 4.3 Composite section representation a) typical section b) transformed uncracked section

4.2.3 Buoyancy

Figure 4.1 shows the assumed tunnel cross-section, with the exterior, interior and ballast surfaces defined by suitable elements and nodes. The origin of the global co-ordinates is taken at node 1 so that all nodal co-ordinates are positive. Information contained in Fig 4.1 was used to complete input data forms 1 to 3. Computer output is given in Fig 1 and in Table form.

4.2.4 Finite element representation

Figure 4.2 shows the finite element representation of the tunnel cross-section. Information contained in Figure 4.2, was used to fill input data forms 1 to 3. Computer output is given in Fig 1 and in Table forms

4.2.5 Loading

Figure 4.3 shows the assumed trapezoidal and concentrated loading and external and internal temperature loading acting on the cross-section. The information contained in Figure 4.3 and the material properties in Table 6 were used to complete the data input data forms 6 to 9. Since the section is supported by elastic foundations there are no assumed fixed boundary conditions, whence input data Table 10 was ignored.

4.2.6 Shear connection

The material properties, the specified steel plates' thickness and the concrete depth are filled in input data forms 11 and 12.

4.2.7 Computer output

After running the program the information of the section was entered into the computer memory, then Tables 4 to 14 were displayed on the screen and printed. Since no boundary nodes were considered, Table 10 did not appear. The deformed section is plotted in Fig 2. Note that elements 1, 2 and 3 are not shown, as deformed. This is due to the fact that in the finite elements analysis method, the element's internal forces, moments and displacements are represented by their equivalence at the element's nodes. Therefore, extrapolating displacements or internal forces at locations other than the element's nodes may not be correct. If it is desired to show displacements or internal forces at any other position, nodes should be created at those positions. Nevertheless, the program plots shear and moment diagrams for selected elements but displays a warning message on screen into this effect. Fig 4 plots stress and strain diagrams of DSC cross-section and Fig 5 plots interaction diagrams of ultimate moment resistance versus axial forces.

4.4 RUNNING THE PROGRAM

Printing the output Tables and dumping the Figures are available options during the first and subsequent runs of the program. Since most of the input and output data is recorded automatically in binary data files, printing Tables and dumping Figures may, at the discretion of the user, be postponed to a subsequent run.

4.4.1 Buoyancy

The data input in forms 1 to 3 was entered into the computer memory during the first run. The computer output is shown in Tables 1 to 3, which are also recorded as binary data files on the mass storage media.

4.4.2 Finite element analysis

The input data forms, 4 to 8 were entered into the computer memory during the first run. The computer output is shown in Tables 4 to 11 and Figures 2 and 3. Tables 4 to 10 are recorded as binary data files. Table 11 is computed each time the subroutine is executed.

4.4.3 Design of shear connection

The input data forms, 10 and 11 were entered into the computer memory during the first run. The computer output is shown in Tables 13 and 14. Table 13 is recorded as binary data file and Table 14 is computed each time the program is executed.

4.4.5 Design for ultimate moment and axial force

The data in form 12 and the internal bending moment and axial compressive force in output Table 11 (node 1 element 1) were entered into the computer memory. The computer output is shown in Fig 5. Since no binary data file is created, dumping of the graphics, if required, should be performed during each run.

Composite Section
Buoyancy data input

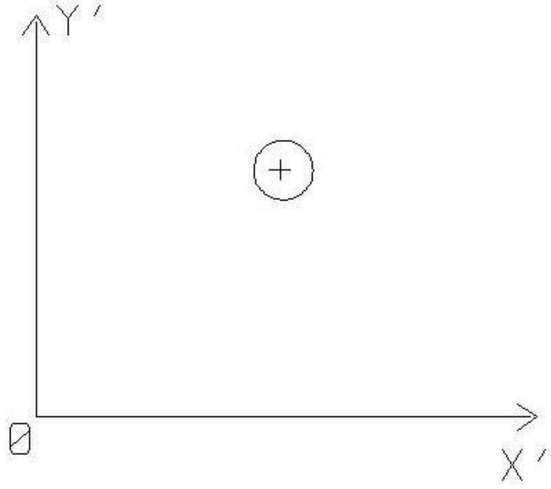


Fig 2.7 Global axes for the geometry of cross-sections and finite element representation

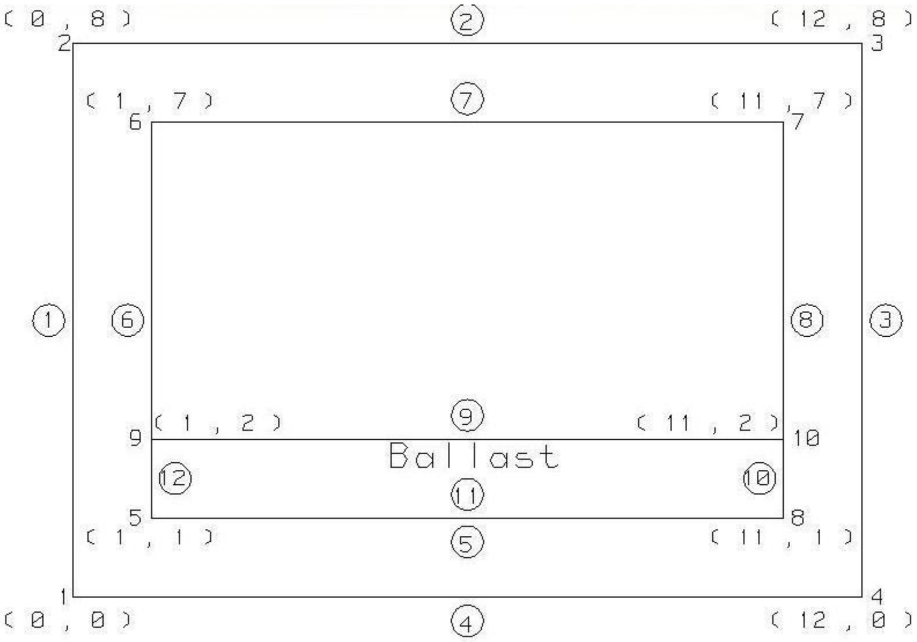


Fig 4.1 Global co-ordinates of tunnel cross-section

INPUT DATA FORM 1 - BUOYANCY

Surface elements

Divide the exterior, interior and ballast surfaces of the cross-section into suitable elements and nodes for buoyancy calculations

The entire cross-section should be placed in the first quadrant of the selected global cartesean axes, so that all nodal co-ordinates are positive. Refer to Section 3.2.1 for proper selection of axes.

Exterior boundary surface elements:

Lowest element number 1

Highest element number 4

Interior boundary surface elements:

Lowest element number 5

Highest element number 8

Ballast boundary surface elements:

Lowest element number 9

Highest element number 12

Total number of surface nodes in the cross-section .. 10

INPUT DATA FORM 2 - BUOYANCY

Surface elements nodes and global co-ordinates

Surface element number	Node number	Global nodal co-ordinates m Abscissa	Ordinate
1	1	0	0
	2	0	8
2	2	0	8
	3	12	8
3	3	12	8
	4	12	0
4	4	12	0
	1	0	0
5	8	11	1
	5	1	1
6	5	1	1
	6	1	7
7	6	1	7
	7	11	7
8	7	11	7
	8	11	1
9	9	1	2
	10	11	2
10	10	11	2
	8	11	1
11	8	11	1
	5	1	1
12	5	1	1
	9	1	2

INPUT DATA FORM 3 - BUOYANCY

Average steel plate thicknesses:

Interior m 0.012

Exterior m 0.012

Unit weights of:

Water kN/m^3 10

Concrete kN/m^3 24

Ballast kN/m^3 22

Composite Section
Buoyancy computer output

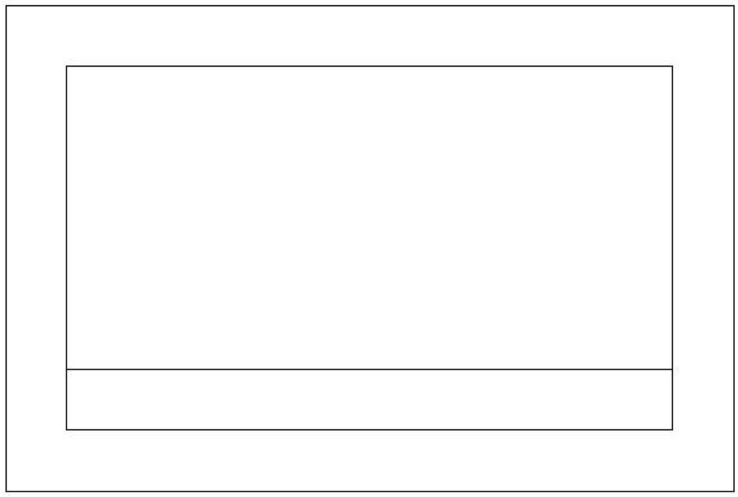


Fig 1 Immersed cross-section

```
Buoyancy data and results per 1m strip
----------------------------------------
Unit weight of water                                 =10kN/m^3
Unit weight of steel                                 =76kN/m^3
Unit weight of concrete                              =24kN/m^3
Unit weight of ballast                               =22kN/m^3
Exterior steel plate thickness                       =.012m
Interior steel plate thickness                       =.012m
Total length of exterior boundary elements           =40m
Total length of interior boundary elements           =32m
Area inscribed within the exterior boundaries        =96m^2
Area inscribed within the interior boundaries        =60m^2
Cross-sectional area of ballast                      =10m^2
Weight of steel plates                               =65.664kN
Weight of structural concrete                        =843.264kN
Weight of ballast                                    =220kN
Weight of cross-section without ballast              =908.928kN
Weight of cross-section with ballast                 =1128.928kN
Water upthrust                                       =960kN
Factor of safety against floatation without ballast=.9468
Factor of safety against floatation with ballast   =1.176
```

Composite Section
Finite element analysis data input

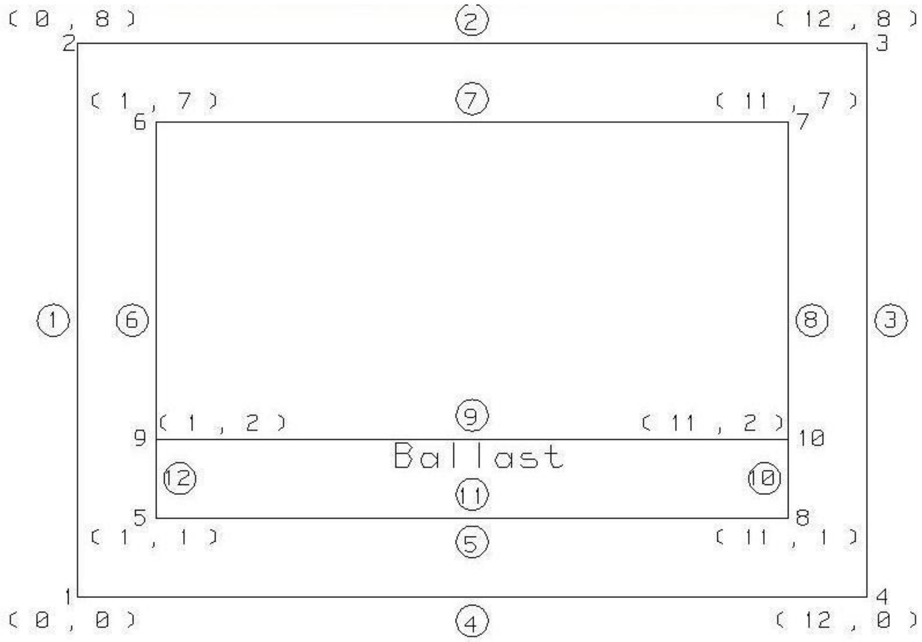


Fig 4.1 Global co-ordinates of tunnel cross-section

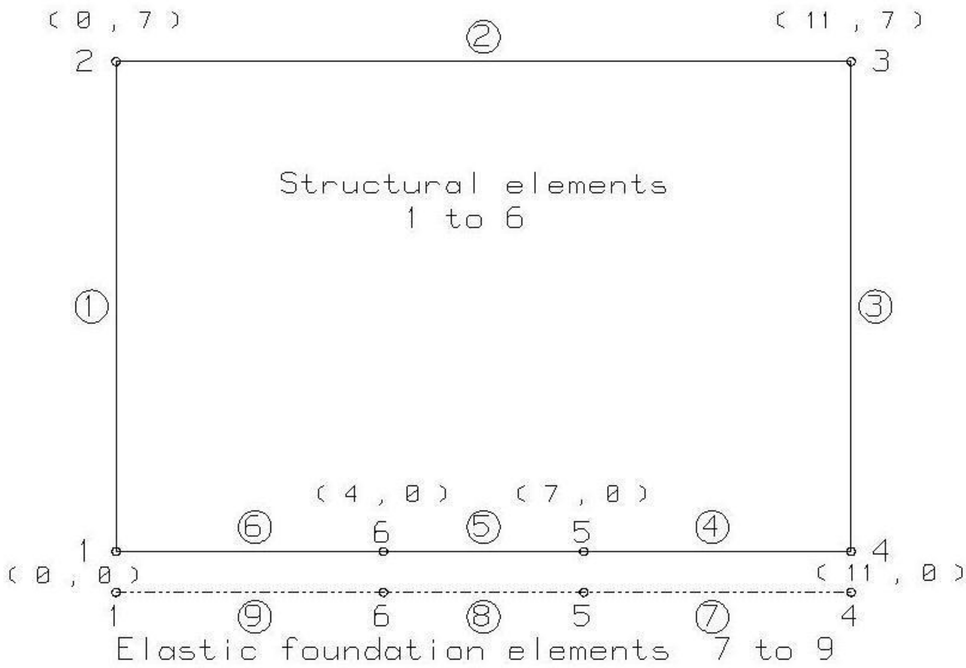


Fig 4.2 Finite elements representation

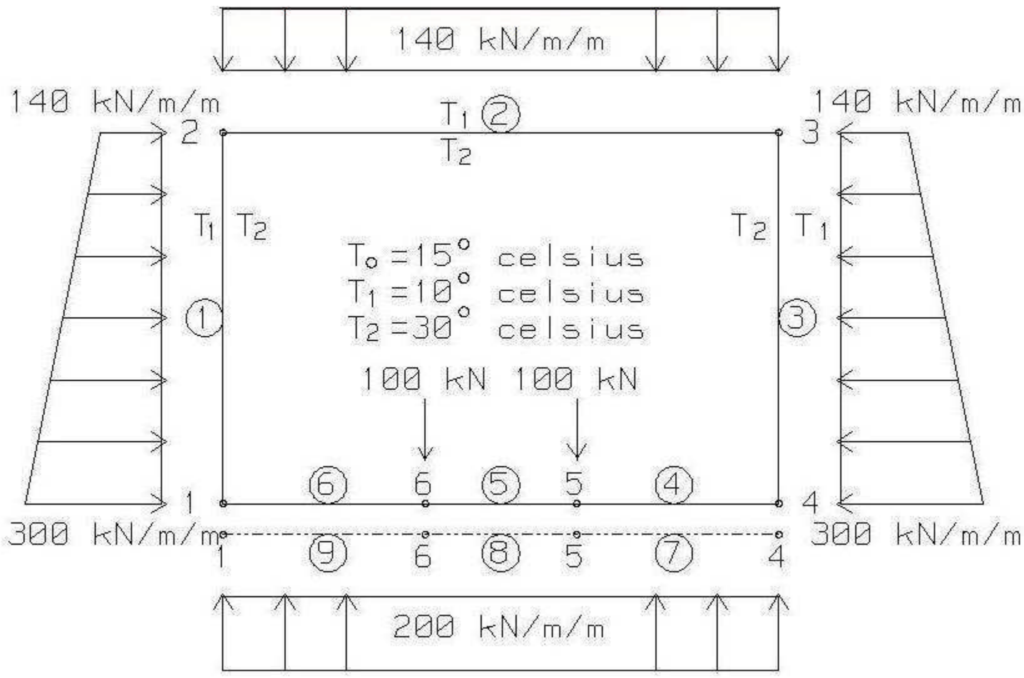


Fig 4.4 Loading diagram

INPUT DATA FORM 4 - FINITE ELEMENT ANALYSIS

Elements nodes and global co-ordinates

Refer to Section 3.2.1 for proper selection of axes

Total number of elements in the cross-section 9

Total number of nodes in the cross-section 6

Element number	Node number	Global nodal co-ordinates m	
		Abscissa	Ordinate
1	1	0	0
	2	0	7
2	2	0	7
	3	11	7
3	3	11	7
	4	11	0
4	4	11	0
	5	7	0
5	5	7	0
	6	4	0
6	6	4	0
	1	0	0
7	4	11	0
	5	7	0
8	5	7	0
	6	4	0
9	6	4	0
	1	0	0

INPUT DATA FORM 5 - FINITE ELEMENT ANALYSIS

Elastic foundation elements

Elastic foundation elements must be consecutively numbered (see Section 3.3.2)

Lowest elastic foundation element number 7

Highest elastic foundation element number 9

Subgrade foundation modulus kN/m^2/m 40,000

INPUT DATA FORM 6 - FINITE ELEMENT ANALYSIS

Structural elements material properties

Element number	Modulus of elasticity kN/m^2	Poisson's ratio	Second moment of area m^4	Cross-sectional area m^2	Unit weight kN/m
1	2.E+7	.2	.08333	1	27
2	1.E+7	.2	.08333	1	27
3	2.E+7	.2	.08333	1	27
4	2.E+7	.2	.08333	1	45
5	2.E+7	.2	.08333	1	45
6	2.E+7	.2	.08333	1	45

Angle between global X'-axis and direction of gravity in ø 90

INPUT DATA FORM 7 - FINITE ELEMENT ANALYSIS

Thermal loading

Refer to Figure 6.1 for the definition of T1 and T2

Element number	Construction temperature T0 øC	Design temperature T2 øC	Design temperature T1 øC	Coefficient of thermal expansion /øC	Depth of section m
1	15	30	10	1.E-5	1
2	15	30	10	1.E-5	1
3	15	30	10	1.E-5	1

INPUT DATA FORM 8 - FINITE ELEMENT ANALYSIS

Trapezoidal/uniformly distributed loading

Element number	Node number	Unit transverse load kN/m
1	1 2	290 140
2	2 3	140 140
3	3 4	140 290
4	4 5	290 290
5	5 6	290 290
6	6 1	290 290

INPUT DATA FORM 9 - FINITE ELEMENT ANALYSIS

Nodal loading

Total number of the loaded nodes 2

Node number	Force in X' direction kN	Force in Y' direction kN	Bending moment kN-m
5	0	100	0
6	0	100	0

INPUT DATA FORM 10 - FINITE ELEMENT ANALYSIS

Boundary conditions (0=fixed 1=free)

Node number	Global nodal displacements		Rotation
	in X' direction	in Y' direction	

INPUT DATA FORM 11 - DESIGN FOR SHEAR CONNECTION

Total number of composite elements 6

Concrete cylinder characteristic strength kN/mm^2... 30

Concrete modulus of elasticity kN/mm^2.......... 20,000

Concrete secant modulus of elasticity kN/mm^2... 32,000

Steel plate yield strength kN/mm^2................ 275

Steel plate modulus of elasticity kN/mm^2.......210,000

Diameter of stud connectors mm..................... 12

Stud ultimate tensile strength kN/mm^2............. 400

INPUT DATA FORM 12 - DESIGN OF SHEAR CONNECTION

Section properties of the composite elements

Element number	Concrete depth mm	Steel plate thicknesses mm	
		Tensile	Compressive
1	1000	12	12
2	1000	12	12
3	1000	12	12
4	1000	12	12
5	1000	12	12
6	1000	12	12

Composite Section
Finite element analysis
Computer output

Table 4 Numbering of elements and nodes

Element number	Node number	
	First node (i)	Second node (j)
1	1	2
2	2	3
3	3	4
4	4	5
5	5	6
6	6	1
7	4	5
8	5	6
9	6	1

Table 5 Finite element nodal global co-ordinates

Element number	Node number	Global co-ordinates		Global element angle in degrees	Element length m
		Abscissa m	Ordinate m		
1	1 2	0 0	0 7	90	7
2	2 3	0 11	7 7	0	11
3	3 4	11 11	7 0	-90	7
4	4 5	11 7	0 0	0	4
5	5 6	7 4	0 0	0	3
6	6 1	4 0	0 0	0	4
7	4 5	11 7	0 0	0	4
8	5 6	7 4	0 0	0	3
9	6 1	4 0	0 0	0	4

From information in Tables 4 and 5 the program plots the geometry of the tunnel section to scale in Fig 1. This plotting is essential because it allows the user to detect any input mistake easily and quickly.

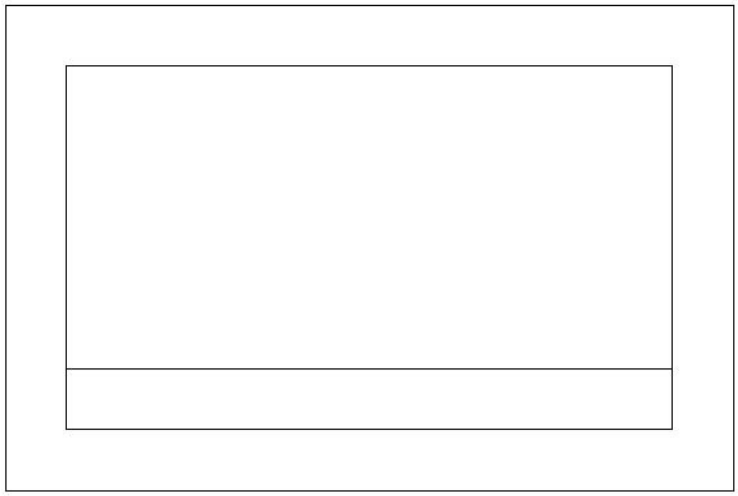


Fig 1 Immersed cross-section

From information obtained from Figures 5.1, 5.2, and 5.3 the program displays Tables 4 and 5, as shown here below

Table 4 Numbering of elements and nodes

Element number	Node number	
	First node (i)	Second node (j)
1	1	2
2	2	3
3	3	4
4	4	5
5	5	6
6	6	1
7	4	5
8	5	6
9	6	1

Table 5 Finite element nodal global co-ordinates

Element number	Node number	Global co-ordinates		Global element angle in degrees	Element length m
		Abscissa m	Ordinate m		
1	1 2	0 0	0 7	90	7
2	2 3	0 11	7 7	0	11
3	3 4	11 11	7 0	-90	7
4	4 5	11 7	0 0	0	4
5	5 6	7 4	0 0	0	3
6	6 1	4 0	0 0	0	4
7	4 5	11 7	0 0	0	4
8	5 6	7 4	0 0	0	3
9	6 1	4 0	0 0	0	4

Table 6 Material properties per 1m strip

Element number	Element second moment of area m^4	Element modulus of elasticity kN/m^2	Element cross-sectional area m^2	Poisson's ratio
1	.08333	2.E+7	1	.2
2	.08333	2.E+7	1	.2
3	.08333	2.E+7	1	.2
4	.08333	2.E+7	1	.2
5	.08333	2.E+7	1	.2
6	.08333	2.E+7	1	.2
7	Elastic foundation:foundation modulus 40000 kN/m^2/m			
8	Elastic foundation:foundation modulus 40000 kN/m^2/m			
9	Elastic foundation:foundation modulus 40000 kN/m^2/m			

Table 7 Equivalent local nodal thermal loading per 1m strip

Element number	Node number	Element depth	Coeff. of thermal expansion	Temperatures			Axial force	Bending moment
				T0	T2	T1		
		m	/C	C	C	C	kN	kN-m
1	1	1	1.E-5	15	30	10	-1000	333.3
	2	1	1.E-5	15	30	10	1000	-333.3
2	2	1	1.E-5	15	30	10	-1000	333.3
	3	1	1.E-5	15	30	10	1000	-333.3
3	3	1	1.E-5	15	30	10	-1000	333.3
	4	1	1.E-5	15	30	10	1000	-333.3

T0 element design construction temperature.
T2 design temperature of element surface in positive quadrant.
T1 design temperature of opposite surface.

Table 8 Equivalent local nodal forces per 1m strip

Element number	Node number	Transverse distributed trapezoidal + dead weight loading ! kN/m	Axial forces of thermal + dead weight loading # kN	Bending moments of trapezoidal + dead+thermal loading kN-m	Transverse forces of trapezoidal + dead weight loading ! kN
1	1	300	-1095	1297	882
	2	140	905.5	-1166	658
2	2	167	-1000	2017	918.5
	3	167	1000	-2017	918.5
3	3	140	-905.5	1166	658
	4	300	1095	-1297	882
4	4	155	0	206.7	310
	5	155	0	-206.7	310
5	5	155	0	116.3	232.5
	6	155	0	-116.3	232.5
6	6	155	0	206.7	310
	1	155	0	-206.7	310

Trapezoidal loading does not produce axial forces.
! Thermal loading does not produce transverse forces.

Table 9 Equivalent nodal global external forces per 1m strip

Node number	Global components of forces		External moment
	in X'direction kN	in Y'direction kN	kN-m
1	882	784.5	1090.32
2	-342	13	850.917
3	342	13	-850.917
4	-882	784.5	-1090.32
5	0	-442.5	-90.4167
6	0	-442.5	90.4167

Table 11 Global nodal forces and displacements per 1m strip

Node number	Global forces			Global displacements		
	X'-Component t' kN	Y'-Component f' kN	Bending moment m' kN-m	X'-Component u' m	Y'-Component v' m	Rotation angle Theta in Radians
1	882	784.5	1090	.0002252	.004707	-.0006446
2	-342	13	850.9	-7.674E-5	.004711	.0008852
3	342	13	-850.9	7.674E-5	.004711	-.0008852
4	-882	784.5	-1090	-.0002252	.004707	.0006446
5	0	-442.5	-90.42	-6.141E-5	-2.979E-5	.0007293
6	0	-442.5	90.42	6.141E-5	-2.979E-5	-.0007293
SUM !	0	710				

! Balanced by elastic foundation element if sum is not zero.

Table 12 Local nodal internal forces and displacements per 1m strip

Number of		Local forces			Local displacements		
Elem.	Node	Axial force t kN	Transverse force f kN	Bending moment m kN-m	Axial displace-ment u m	Transverse displace-ment v m	Rotation angle Theta in Radians
1	1	1108	-819.1	-1440	-.004707	.0002252	-.0006446
	2	-918.5	-720.9	1750	-.004711	-7.674E-5	.0008852
FOR ELEMENT	No. 1 THE SUM OF MOMENTS=-.0425623851888						
2	2	720.9	-918.5	-1750	-7.674E-5	.004711	.0008852
	3	-720.9	-918.5	1750	7.674E-5	.004711	-.0008852
FOR ELEMENT	No. 2 THE SUM OF MOMENTS= 1.81898940355E-12						
3	3	918.5	-720.9	-1750	.004711	-7.674E-5	-.0008852
	4	-1107	-819.1	1440	.004707	.0002252	.0006446
FOR ELEMENT	No. 3 THE SUM OF MOMENTS=-.0145041527732						
4	4	818.9	-835.6	-1295	.0002252	-.004707	.0006446
	5	-818.9	215.6	-811.1	6.141E-5	2.979E-5	.0007293
FOR ELEMENT	No. 4 THE SUM OF MOMENTS=-9.97424365323E-13						
5	5	818.8	-232.5	693.8	6.141E-5	2.979E-5	.0007293
	6	-818.8	-232.5	-693.8	-6.141E-5	2.979E-5	-.0007293
FOR ELEMENT	No. 5 THE SUM OF MOMENTS= 5.41233724505E-16						
6	6	818.9	215.6	811.1	-6.141E-5	2.979E-5	-.0007293
	1	-818.9	-835.6	1295	-.0002252	-.004707	-.0006446
FOR ELEMENT	No. 6 THE SUM OF MOMENTS= 4.17887946469E-13						

From information in Table 12, the program plots the deflected shape of the tunnel finite elements in Fig 3. We should note that in the method of finite element analysis only nodal displacements are determined. If the user wishes to determine displacements elsewhere on the element, nodes should be created at the desired location.

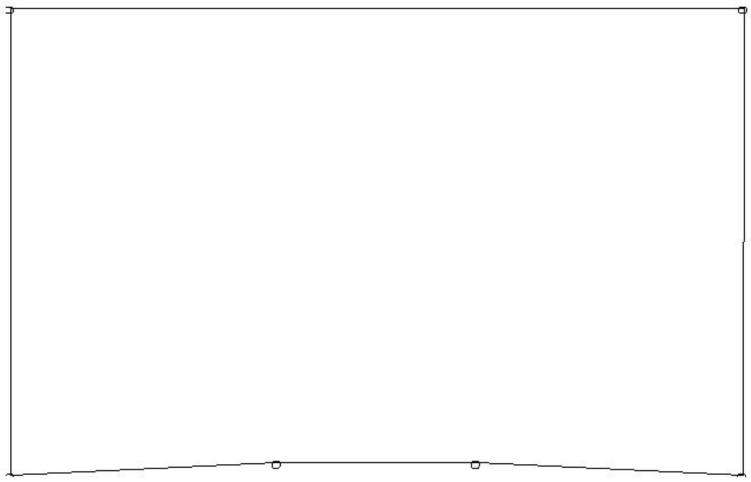
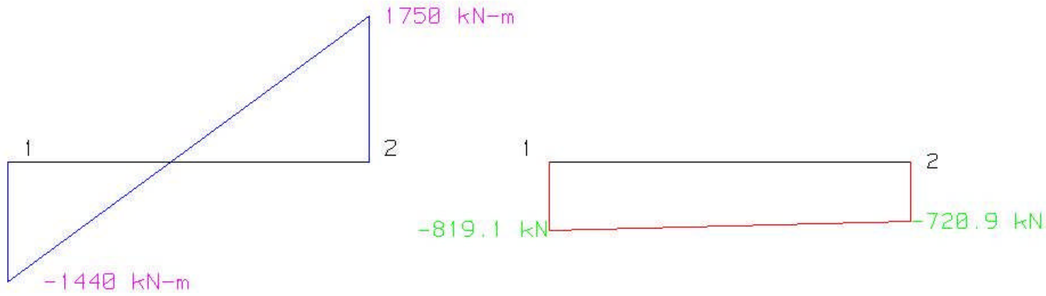


Fig 3 Nodal global displacements magnified 40 times

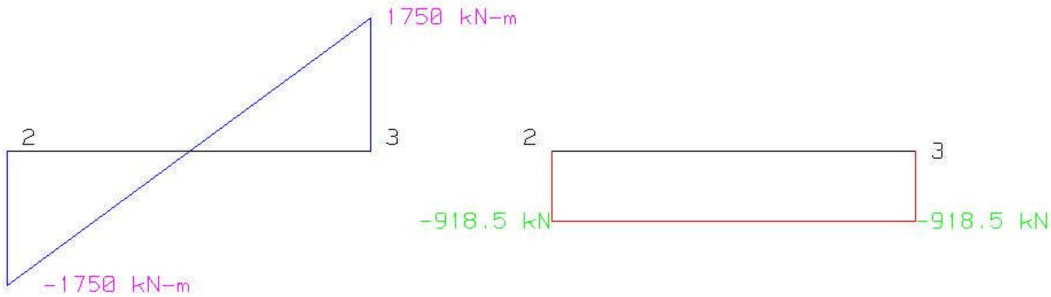
The shear and moment diagrams dor selected nodes are plotted by the program here below. We should note that in the method of finite element analysis only nodal displacements are determined. If the user wishes to determine displacements elsewhere on the element, nodes should be created at the desired location..



Element length= 7 m

Moment diagram Shear diagram

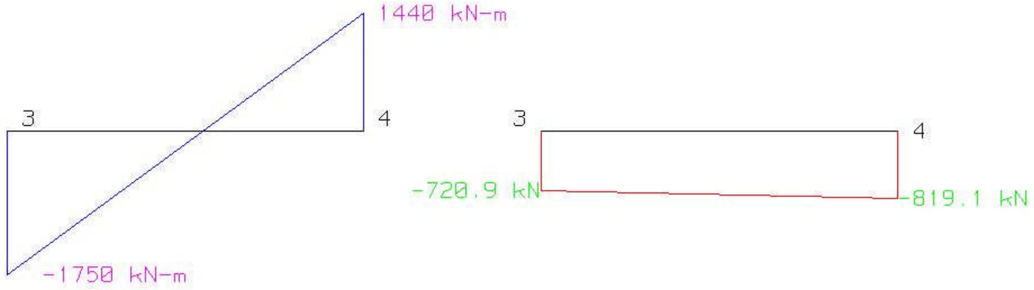
Internal nodal forces diagrams of element No. 1



Element length= 11 m

Moment diagram Shear diagram

Internal nodal forces diagrams of element No. 2



Element length= 7 m

Moment diagram Shear diagram

Internal nodal forces diagrams of element No. 3

Design of composite elements

Table 13 gives the section properties. Tables 14 and 15 give the design of studs

Table 13 Section properties.

Element No.	Concrete depth mm	Steel plate thicknesses: Compression mm	Steel plate thicknesses: Tension mm	Diameter of shear studs mm
1	1000	12	12	12
2	1000	12	12	12
3	1000	12	12	12
4	1000	12	12	12
5	1000	12	12	12
6	1000	12	12	12

Steel plate modulus of elasticity = 210000 N/mm^2
Concrete characteristic compressive strength = 30 N/mm^2
Concrete modulus of elasticity = 20000 N/mm^2
Concrete secant modulus of elasticity = 32000 N/mm^2
Steel plate yield strength = 275 N/mm^2
Steel plate/concrete modular ratio = 10.5
Studs ultimate tensile strength = 400 N/mm^2

Table 14 Design of stud shear connectors

Element number	Node number	Depth of centroid surfaces ! m	Second moment of area of the DSC section ! m^4	Studs to resist buckling of plate in comp Spacing m c/c	Studs to provide steel plate shear connection: comp Spacing m c/c	Studs to provide steel plate shear connection: tens Spacing m c/c	Studs to act as transverse shear reinforcement Spacing m c/c
1	1	.3097	.0836	.48	.1965	.1146	.1212
	2	.3097	.0836	.48	.2094	.1221	.1243
2	2	.3097	.0836	.48	.1856	.1082	.1101
	3	.3097	.0836	.48	.1856	.1082	.1101
3	3	.3097	.0836	.48	.2094	.1221	.1243
	4	.3097	.0836	.48	.1965	.1146	.1212
4	4	.3097	.0836	.48	.1945	.1134	.1217
	5	.3097	.0836	.48	.383	.2233	.2478
5	5	.3097	.0836	.48	.3688	.2151	.2398
	6	.3097	.0836	.48	.3688	.2151	.2398
6	6	.3097	.0836	.48	.383	.2233	.2478
	1	.3097	.0836	.48	.1945	.1134	.1217

! Based conservatively on a fully cracked section neglecting axial forces
Spacings of studs in the transverse and longitudinal directions are assumed to be equal. Maximum stud spacing is limited to 1/2 of the concrete depth

Table 15 Design of stud shear connectors (based on ACI-318 Section 1700)

Element number	Node number	Depth of centroid surfaces !	Second moment of area of the DSC section !	Studs to resist buckling of plate in comp	Studs to provide steel plate shear connection		Studs to act as transverse shear reinforcement
					comp	tens	
				Spacing	Spacing	Spacing	Spacing
		m	m^4	m c/c	m c/c	m c/c	m c/c
1	1	.3097	.0836	.48	.1965	.1146	.2734
	2	.3097	.0836	.48	.2094	.1221	.3206
2	2	.3097	.0836	.48	.1856	.1082	.2223
	3	.3097	.0836	.48	.1856	.1082	.2223
3	3	.3097	.0836	.48	.2094	.1221	.3206
	4	.3097	.0836	.48	.1965	.1146	.2734
4	4	.3097	.0836	.48	.1945	.1134	.267
	5	.3097	.0836	.48	.383	.2233	.5
5	5	.3097	.0836	.48	.3688	.2151	.5
	6	.3097	.0836	.48	.3688	.2151	.5
6	6	.3097	.0836	.48	.383	.2233	.5
	1	.3097	.0836	.48	.1945	.1134	.267

! Based conservatively on a fully cracked section neglecting axial forces
Spacings of studs in the transverse and longitudinal directions are assumed to be equal. Maximum stud spacing is limited to 1/2 of the concrete depth

Fig 5 check the section resistance to bending moments at selected nodes

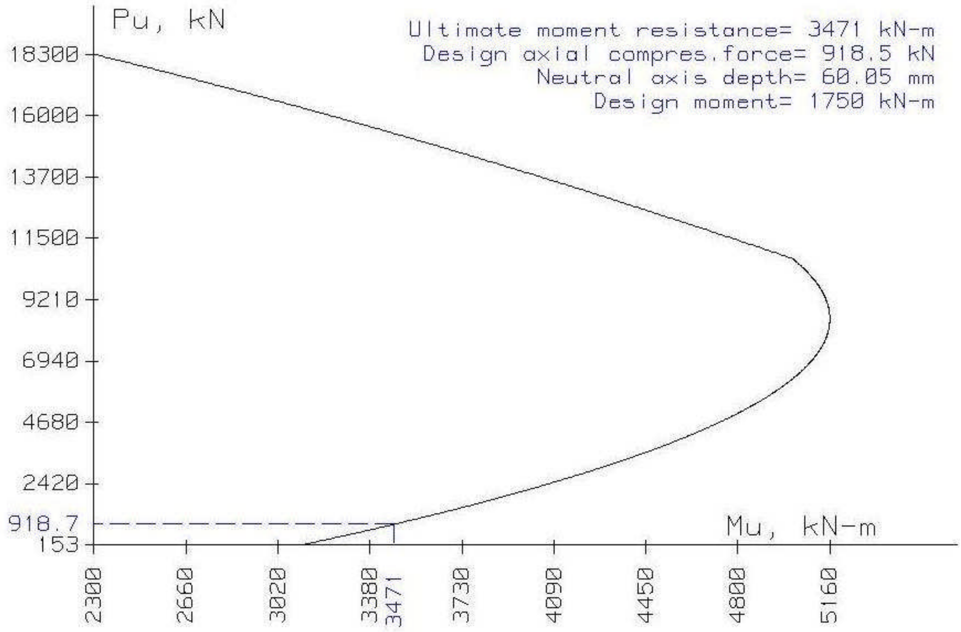


Fig 5 El.1 Node 2 axial compression and bending moment interaction diagram/1 m length

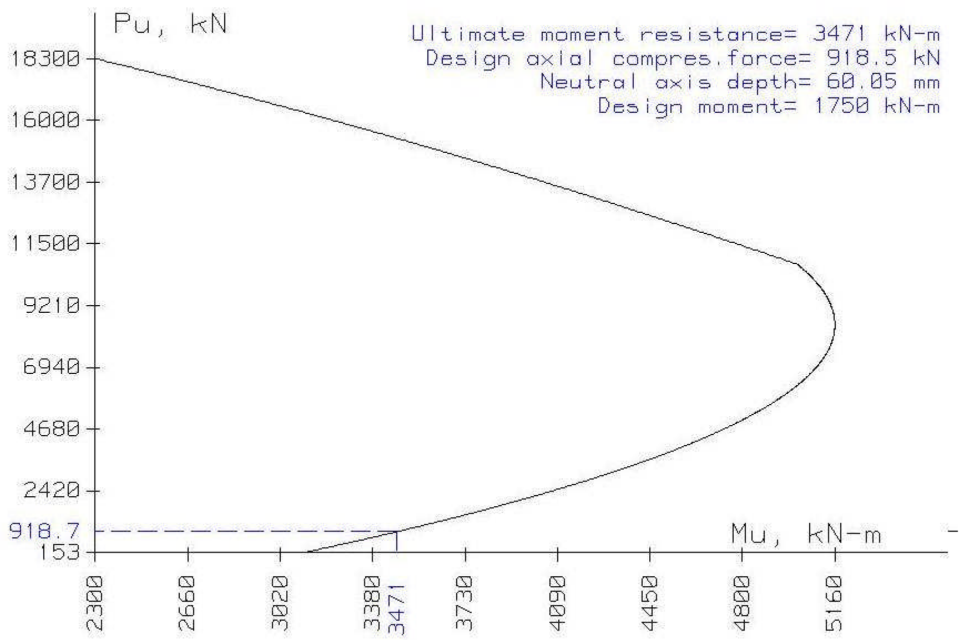


Fig 5 El.3 Node 3 axial compression and bending moment interaction diagram/1 m length

Fig 1 sections (a) and (b) gives details of the shear connectors. Sections (c) and (d) gives suggested corner details of the composite tunnel section.

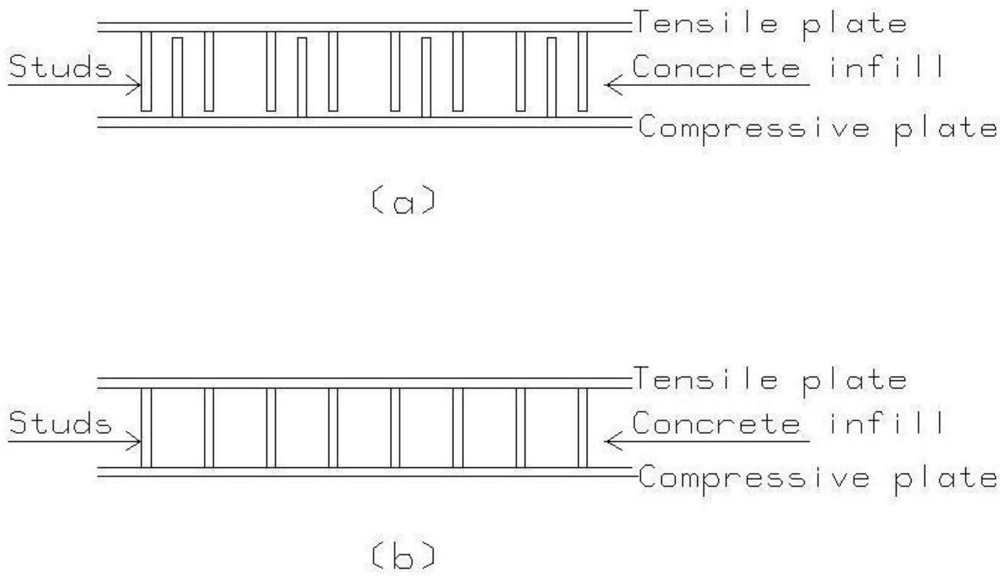
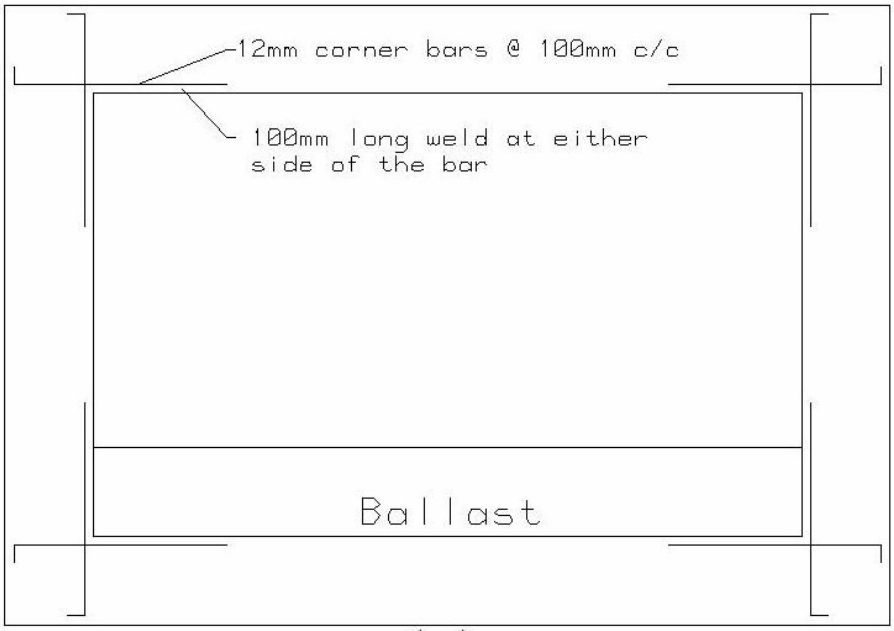
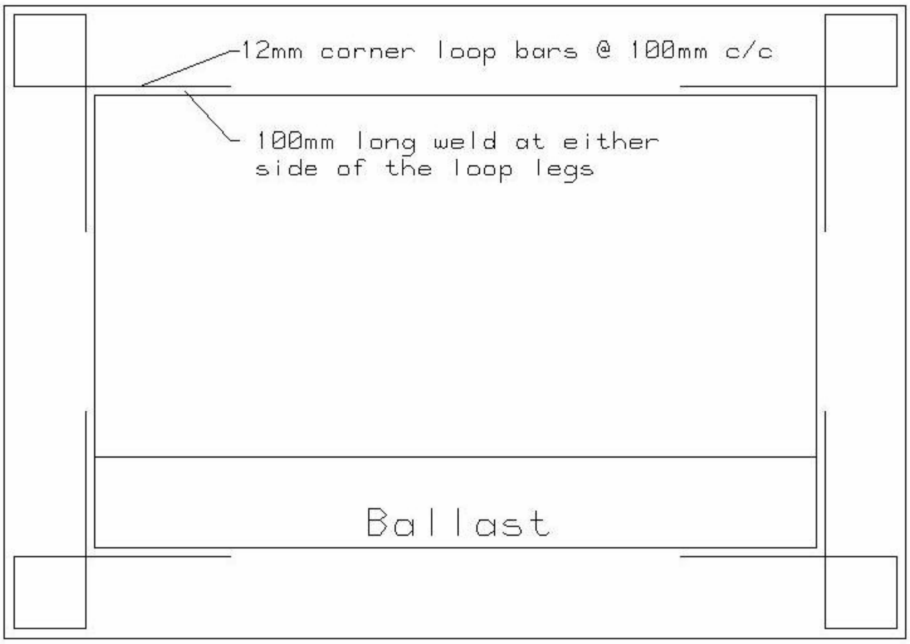


Fig 1 Stud distribution. a) electrically welded studs at one end b) friction welded studs at both ends



(c)

Fig 1 Corner details. a) corner loops b) tongue and groove construction c) corner bars



(a)

Design of continuous reinforced concrete frame

4.3 REINFORCED CONCRETE CONTINUOUS FRAME

The same procedure explained in section 4.2 was followed in the design of the continuous reinforced concrete frame shown in Fig 1_B. The frame geometry, loading, local and global axes are given in Fig 1_B. This structure is idealized by 31 elements and 20 nodes and is subject to its self weight, concentrated forces and bending moments at some nodes, and triangular, trapezoidal, uniformly distributed and thermal loads on some elements. The frame has 4 boundary nodes: 1, 12, 13 and 14 and 3 foundation elements 14, 21 and 20 resisted by elastic foundation elements 29, 30 and 31. Note that the elastic foundation elements share their nodes with the foundation elements 20, 21 and 14. Since this frame has 4 boundary nodes, Table 10 was included in the program output. Fig 1_B details the loads acting on this frame as follows:

Node 3 is acted upon by a concentrated horizontal force of:	+ 50 kN
Node 8 is acted upon by a concentrated vertical force of:	+ 100 kN
Node 10 is acted upon by a concentrated horizontal force of:	– 50 kN
Node 16 is acted upon by a bending moment of:	– 50 kN-m
Node 19 is acted upon by a bending moment of:	+ 50 kN-m
Element 4 is subject to horizontal uniformly distributed load of:	+ 40 kN/m
Element 15 is subject to vertical triangular load that varies from:	0 to 80 kN/m
Element 6 is subject to vertical trapezoidal load that varies from:	60 kN/m to 80 kN/m
Element 8 is subject to thermal gradient that varies from:	10^{o} C to 100^{o} C
Element 10 is subject to thermal gradient that varies from:	15^{o} C to 200^{o} C

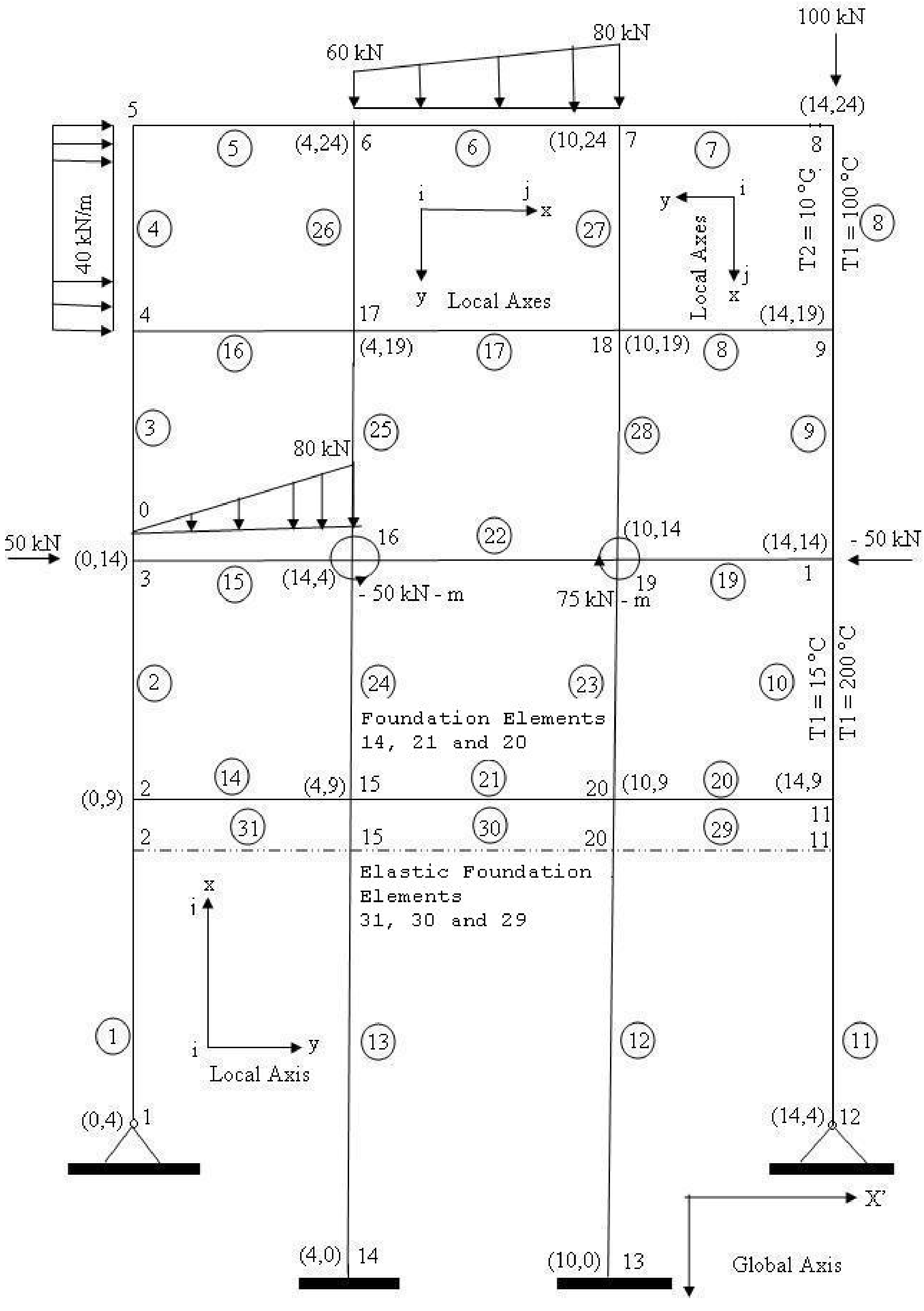


Fig 4_B Finite element representation of a continuous re-inforced concrete frame

Table 4 Numbering of elements and nodes

Element number	Node number	
	First node (i)	Second node (j)
1	1	2
2	2	3
3	3	4
4	4	5
5	5	6
6	6	7
7	7	8
8	8	9
9	9	10
10	10	11
11	11	12
12	20	13
13	15	14
14	2	15
15	3	16
16	4	17
17	17	18
18	18	9
19	19	10
20	20	11
21	15	20
22	16	19
23	20	19
24	15	16
25	16	17
26	17	6
27	18	7
28	19	18
29	20	11
30	15	20
31	2	15

Table 5 Finite element nodal global co-ordinates

Element number	Node number	Global co-ordinates		Global element angle in degrees	Element length
		Abscissa m	Ordinate m		m
1	1 2	0 0	4 9	90	5
2	2 3	0 0	9 14	90	5
3	3 4	0 0	14 19	90	5
4	4 5	0 0	19 24	90	5
5	5 6	0 4	24 24	0	4
6	6 7	4 10	24 24	0	6
7	7 8	10 14	24 24	0	4
8	8 9	14 14	24 19	-90	5
9	9 10	14 14	19 14	-90	5
10	10 11	14 14	14 9	-90	5
11	11 12	14 14	9 4	-90	5
12	20 13	10 10	9 0	-90	9
13	15 14	4 4	9 0	-90	9
14	2 15	0 4	9 9	0	4
15	3 16	0 4	14 14	0	4

Table 5 Finite element nodal global co-ordinates (cont'd)

Element number	Node number	Global co-ordinates		Global element angle in degrees	Element length
		Abscissa m	Ordinate m		m
16	4 17	0 4	19 19	0	4
17	17 18	4 10	19 19	0	6
18	18 9	10 14	19 19	0	4
19	19 10	10 14	14 14	0	4
20	20 11	10 14	9 9	0	4
21	15 20	4 10	9 9	0	6
22	16 19	4 10	14 14	0	6
23	20 19	10 10	9 14	90	5
24	15 16	4 4	9 14	90	5
25	16 17	4 4	14 19	90	5
26	17 6	4 4	19 24	90	5
27	18 7	10 10	19 24	90	5
28	19 18	10 10	14 19	90	5
29	20 11	10 14	9 9	0	4
30	15 20	4 10	9 9	0	6
31	2 15	0 4	9 9	0	4

From information in Tables 4 and 5 the program plots the geometry of the tunnel section to scale in Fig 2. This plotting is essential because it allows the user to detect any input mistake easily and quickly.

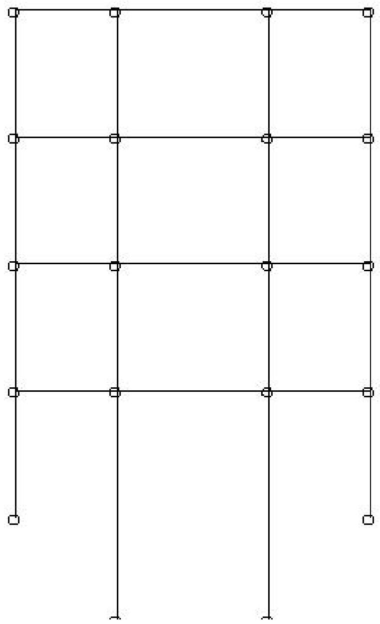


Fig 2 Finite element representation

Table 6 Material properties per 1m strip

Element number	Element second moment of area m^4	Element modulus of elasticity kN/m^2	Element cross-sectional area m^2	Poisson's ratio
1	.08333	2.E+7	1	.2
2	.08333	2.E+7	1	.2
3	.08333	2.E+7	1	.2
4	.08333	2.E+7	1	.2
5	.08333	2.E+7	1	.2
6	.08333	2.E+7	1	.2
7	.08333	2.E+7	1	.2
8	.08333	2.E+7	1	.2
9	.08333	2.E+7	1	.2
10	.08333	2.E+7	1	.2
11	.08333	2.E+7	1	.2
12	.08333	2.E+7	1	.2
13	.08333	2.E+7	1	.2
14	.08333	2.E+7	1	.2
15	.08333	2.E+7	1	.2
16	.08333	2.E+7	1	.2
17	.08333	2.E+7	1	.2
18	.08333	2.E+7	1	.2
19	.08333	2.E+7	1	.2
20	.08333	2.E+7	1	.2
21	.08333	2.E+7	1	.2
22	.08333	2.E+7	1	.2
23	.08333	2.E+7	1	.2
24	.08333	2.E+7	1	.2
25	.08333	2.E+7	1	.2
26	.08333	2.E+7	1	.2
27	.08333	2.E+7	1	.2
28	.08333	2.E+7	1	.2
29	Elastic foundation:foundation modulus 175000 kN/m^2/m			
30	Elastic foundation:foundation modulus 175000 kN/m^2/m			
31	Elastic foundation:foundation modulus 175000 kN/m^2/m			

Table 7 Equivalent local nodal thermal loading per 1m strip

Element number	Node number	Element depth m	Coeff. of thermal expansion /°C	Temperatures T0 °C	T2 °C	T1 °C	Axial force kN	Bending moment kN-m
8	8	1	1.E-5	15	10	100	-8000	-1500
	9	1	1.E-5	15	10	100	8000	1500
10	10	1	1.E-5	15	15	200	-18500	-3083
	11	1	1.E-5	15	15	200	18500	3083

T0 element design construction temperature.
T2 design temperature of element surface in positive quadrant.
T1 design temperature of opposite surface.

Table 8 Equivalent local nodal forces per 1m strip

Element number	Node number	Transverse distributed trapezoidal + dead weight loading ! kN/m	Axial forces of thermal + dead weight loading # kN	Bending moments of trapezoidal + dead+thermal loading kN-m	Transverse forces of trapezoidal + dead weight loading ! kN
1	1	0	-67.5	0	0
	2	0	-67.5	0	0
2	2	0	-67.5	0	0
	3	0	-67.5	0	0
3	3	0	-67.5	0	0
	4	0	-67.5	0	0
4	4	40	-67.5	83.33	100
	5	40	-67.5	-83.33	100
5	5	27	0	36	54
	6	27	0	-36	54
6	6	87	0	285	279
	7	107	0	-297	303
7	7	27	0	36	54
	8	27	0	-36	54
8	8	0	-7933	-1500	0
	9	0	8068	1500	0
9	9	0	67.5	0	0
	10	0	67.5	0	0
10	10	0	-18430	-3083	0
	11	0	18570	3083	0
11	11	0	67.5	0	0
	12	0	67.5	0	0
12	20	0	121.5	0	0
	13	0	121.5	0	0
13	15	0	121.5	0	0
	14	0	121.5	0	0
14	2	27	0	36	54
	15	27	0	-36	54
15	3	27	0	78.67	102
	16	107	0	-100	166

Table 8 Equivalent local nodal forces per 1m strip (cont'd)

Element number	Node number	Transverse distributed trapezoidal + dead weight loading ! kN/m	Axial forces of thermal + dead weight loading # kN	Bending moments of trapezoidal + dead+thermal loading kN-m	Transverse forces of trapezoidal + dead weight loading ! kN
16	4 17	27 27	0 0	36 -36	54 54
17	17 18	27 27	0 0	81 -81	81 81
18	18 9	27 27	0 0	36 -36	54 54
19	19 10	27 27	0 0	36 -36	54 54
20	20 11	27 27	0 0	36 -36	54 54
21	15 20	27 27	0 0	81 -81	81 81
22	16 19	27 27	0 0	81 -81	81 81
23	20 19	0 0	-67.5 -67.5	0 0	0 0
24	15 16	0 0	-67.5 -67.5	0 0	0 0
25	16 17	0 0	-67.5 -67.5	0 0	0 0
26	17 6	0 0	-67.5 -67.5	0 0	0 0
27	18 7	0 0	-67.5 -67.5	0 0	0 0
28	19 18	0 0	-67.5 -67.5	0 0	0 0

Trapezoidal loading does not produce axial forces.
! Thermal loading does not produce transverse forces.

Table 9 Equivalent nodal global external forces per 1m strip

Node number	Global components of forces in X'direction kN	Global components of forces in Y'direction kN	External moment kN-m
1	0	67.5	0
2	0	189	36
3	50	237	78.6667
4	100	189	119.333
5	100	121.5	-47.3333
6	0	400.5	249
7	0	424.5	-261
8	0	-7778.5	-1535.94
9	0	8189	1463.94
10	-50	-18311	-3119.21
11	0	18689	3047.21
12	0	67.5	0
13	0	121.5	0
14	0	121.5	0
15	0	324	45
16	0	382	-69
17	0	270	45
18	0	270	-45
19	0	270	30
20	0	324	-45

Table 10 Boundary conditions.

Node number	Global nodal displacements in X' direction	Global nodal displacements in Y' direction	Rotation
1	Fixed	Fixed	Free
12	Fixed	Fixed	Free
13	Fixed	Fixed	Fixed
14	Fixed	Fixed	Fixed

Table 11 Global nodal forces and displacements per 1m strip

Node number	Global forces			Global displacements		
	X'-Component t' kN	Y'-Component f' kN	Bending moment m' kN-m	X'-Component u' m	Y'-Component v' m	Rotation angle Theta in Radians
1	-101.4	-942.5	0	0	0	.0009874
2	0	189	36	.003732	.0002356	.0002203
3	50	237	78.67	.003937	.0004834	-5.256E-5
4	100	189	119.3	.002688	.0006465	-.0001715
5	100	121.5	-47.33	.0008986	.0007115	-.0001935
6	0	400.5	249	.0008534	.0008326	-7.562E-6
7	0	424.5	-261	.0007259	-.0001062	-.00068
8	0	-7778	-1536	.0006724	-.005346	-.001737
9	0	8189	1464	.002675	-.003428	.0001912
10	-50	-18310	-3119	.004013	-.003727	-.001577
11	0	18690	3047	.003863	.0005494	.001362
12	116.1	-2198	0	0	0	.000502
13	-102.8	169.6	-460.1	0	0	0
14	-89.51	-897.5	-419.5	0	0	0
15	0	324	45	.003759	.0004039	8.017E-5
16	0	382	-69	.00394	.0006106	-7.592E-5
17	0	270	45	.002674	.000743	-.0001641
18	0	270	-45	.002683	-.0001615	-.0005431
19	0	270	30	.003982	-8.85E-5	-.0002249
20	0	324	-45	.003821	-7.632E-5	-1.301E-5
SUM !	22.44	322				

! Balanced by elastic foundation element if sum is not zero.

Table 12 Local nodal internal forces and displacements per 1m strip

Number of		Local forces			Local displacements		
Elem.	Node	Axial force t kN	Transverse force f kN	Bending moment m kN-m	Axial displace-ment u m	Transverse displace-ment v m	Rotation angle Theta in Radians
1	1	1010	-101.5	.0338	0	0	.0009874
	2	-875	101.5	-510.8	-.0002356	.003732	.0002203
FOR ELEMENT	No. 1 THE SUM OF MOMENTS= 2.31814567542E-13						
2	2	1059	30.77	167.7	-.0002356	.003732	.0002203
	3	-923.6	-30.77	-14.03	-.0004834	.003937	-5.256E-5
FOR ELEMENT	No. 2 THE SUM OF MOMENTS=-.50375951935						
3	3	719.9	98.59	286.5	-.0004834	.003937	-5.256E-5
	4	-584.9	-98.59	207.2	-.0006465	.002688	-.0001715
FOR ELEMENT	No. 3 THE SUM OF MOMENTS=-.531457819689						
4	4	327.5	25.75	238.5	-.0006465	.002688	-.0001715
	5	-192.5	-225.7	390.6	-.0007115	.0008986	-.0001935
FOR ELEMENT	No. 4 THE SUM OF MOMENTS=-.362903679551						
5	5	225.7	-192.5	-390.6	.0008986	.0007115	-.0001935
	6	-225.7	84.54	-163.6	.0008534	.0008326	-7.562E-6
FOR ELEMENT	No. 5 THE SUM OF MOMENTS=-1.03805852802E-14						
6	6	425.2	-375.4	-387.4	.0008534	.0008326	-7.562E-6
	7	-425.2	-206.6	-178.7	.0007259	-.0001062	-.00068
FOR ELEMENT	No. 6 THE SUM OF MOMENTS= 3.38062910998E-14						
7	7	267.2	53	619.1	.0007259	-.0001062	-.00068
	8	-267.2	-161	-189.6	.0006724	-.005346	-.001737
FOR ELEMENT	No. 7 THE SUM OF MOMENTS=-5.21804821574E-13						
8	8	261	-267.3	189.8	-.005346	-.0006724	-.001737
	9	-396	267.3	-1525	-.003428	-.002675	.0001912
FOR ELEMENT	No. 8 THE SUM OF MOMENTS=-.0907784604722						
9	9	1129	-305.3	-174	-.003428	-.002675	.0001912
	10	-1264	305.3	-1351	-.003727	-.004013	-.001577
FOR ELEMENT	No. 9 THE SUM OF MOMENTS=-.361164379633						

Table 12 Local nodal internal forces and displacements per 1m strip (cont'd 1)

Number of		Local forces			Local displacements		
Elem.	Node	Axial force t kN	Transverse force f kN	Bending moment m kN-m	Axial displace- ment u m	Transverse displace- ment v m	Rotation angle Theta in Radians
10	10	1327	-98.24	1860	-.003727	-.004013	-.001577
	11	-1462	98.24	-2351	.0005494	-.003863	.001362
FOR ELEMENT	No. 10 THE SUM OF MOMENTS=-.541756641171						
11	11	2130	116.1	572	.0005494	-.003863	.001362
	12	-2265	-116.1	.0003297	0	0	.000502
FOR ELEMENT	No. 11 THE SUM OF MOMENTS=-.521556556845						
12	20	-291.1	-102.8	-464.9	-7.632E-5	-.003821	-1.301E-5
	13	48.09	102.8	-460.1	0	0	0
FOR ELEMENT	No. 12 THE SUM OF MOMENTS=-.928544682554						
13	15	776	-89.51	-389.9	.0004039	-.003759	8.017E-5
	14	-1019	89.51	-419.5	0	0	0
FOR ELEMENT	No. 13 THE SUM OF MOMENTS=-.913348072467						
14	2	-135.4	60.61	251.6	.003732	.0002356	.0002203
	15	135.4	-168.6	206.8	.003759	.0004039	8.017E-5
FOR ELEMENT	No. 14 THE SUM OF MOMENTS= 9.44383460322E-15						
15	3	-17.78	-203.7	-272.4	.003937	.0004834	-5.256E-5
	16	17.78	-64.26	-113.2	.00394	.0006106	-7.592E-5
FOR ELEMENT	No. 15 THE SUM OF MOMENTS=-4.04242611607E-14						
16	4	72.89	-257.3	-445.7	.002688	.0006465	-.0001715
	17	-72.89	149.3	-367.6	.002674	.000743	-.0001641
FOR ELEMENT	No. 16 THE SUM OF MOMENTS= 1.09690034833E-13						
17	17	-30.98	-185.3	-288.8	.002674	.000743	-.0001641
	18	30.98	23.34	-337.3	.002683	-.0001615	-.0005431
FOR ELEMENT	No. 17 THE SUM OF MOMENTS=-7.28375693093E-14						
18	18	37.99	624.6	1015	.002683	-.0001615	-.0005431
	9	-37.99	-732.6	1699	.002675	-.003428	.0001912
FOR ELEMENT	No. 18 THE SUM OF MOMENTS=-1.69031455499E-13						
19	19	-157	-44.55	545.9	.003982	-8.85E-5	-.0002249
	10	157	-63.45	-508.7	.004013	-.003727	-.001577
FOR ELEMENT	No. 19 THE SUM OF MOMENTS= 1.09801057135E-13						

Table 12 Local nodal internal forces and displacements per 1m strip (cont'd 2)

Number of		Local forces			Local displacements		
Elem.	Node	Axial force t kN	Transverse force f kN	Bending moment m kN-m	Axial displace-ment u m	Transverse displace-ment v m	Rotation angle Theta in Radians
20	20	-211.1	495	488.9	.003821	-7.632E-5	-1.301E-5
	11	211.1	-603	1707	.003863	.0005494	.001362
FOR ELEMENT	No. 20	THE SUM OF MOMENTS= 2.76112466224E-13					
21	15	-208.5	-22.54	120.2	.003759	.0004039	8.017E-5
	20	208.5	-139.5	230.4	.003821	-7.632E-5	-1.301E-5
FOR ELEMENT	No. 21	THE SUM OF MOMENTS=-9.57289802983E-14					
22	16	-137.7	-98.42	-91.9	.00394	.0006106	-7.592E-5
	19	137.7	-63.58	-12.69	.003982	-8.85E-5	-.0002249
FOR ELEMENT	No. 22	THE SUM OF MOMENTS= 4.64767113684E-14					
23	20	18.77	-108.4	-200.2	7.632E-5	.003821	-1.301E-5
	19	116.2	108.4	-341.5	8.85E-5	.003982	-.0002249
FOR ELEMENT	No. 23	THE SUM OF MOMENTS=-.515858156974					
24	15	894.6	-24.5	-9.35	-.0004039	.003759	8.017E-5
	16	-759.6	24.5	-113.3	-.0006106	.00394	-7.592E-5
FOR ELEMENT	No. 24	THE SUM OF MOMENTS=-.507415595815					
25	16	596.9	95.5	268.4	-.0006106	.00394	-7.592E-5
	17	-461.9	-95.5	209.7	-.000743	.002674	-.0001641
FOR ELEMENT	No. 25	THE SUM OF MOMENTS=-.531937907383					
26	17	425.9	199.4	446.7	-.000743	.002674	-.0001641
	6	-290.9	-199.4	551	-.0008326	.0008534	-7.562E-6
FOR ELEMENT	No. 26	THE SUM OF MOMENTS=-.360935523257					
27	18	288.6	-158	-349.1	.0001615	.002683	-.0005431
	7	-153.6	158	-440.4	.0001062	.0007259	-.00068
FOR ELEMENT	No. 27	THE SUM OF MOMENTS=-.362190185855					
28	19	-224.4	-89.04	-116.7	8.85E-5	.003982	-.0002249
	18	359.4	89.04	-328.9	.0001615	.002683	-.0005431
FOR ELEMENT	No. 28	THE SUM OF MOMENTS=-.537516762702					

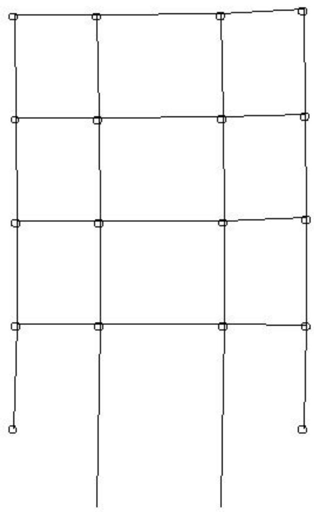


Fig 3 Nodal global displacements magnified 40 times

Table 13 Section properties. Design of stirrups come next

Element No.	Effective concrete depth (mm)	Steel reinforcement areas: Compression (mm^2/mm)	Steel reinforcement areas: Tension (mm^2/mm)	Diameter of stirrups (mm)
1	1000	12	12	12
2	1000	12	12	12
3	1000	12	12	12
4	1000	12	12	12
5	1000	12	12	12
6	1000	12	12	12
7	1000	12	12	12
8	1000	12	12	12
9	1000	12	12	12
10	1000	12	12	12
11	1000	12	12	12
12	1000	12	12	12
13	1000	12	12	12
14	1000	12	12	12
15	1000	12	12	12
16	1000	12	12	12
17	1000	12	12	12
18	1000	12	12	12
19	1000	12	12	12
20	1000	12	12	12
21	1000	12	12	12
22	1000	12	12	12
23	1000	12	12	12
24	1000	12	12	12
25	1000	12	12	12
26	1000	12	12	12
27	1000	12	12	12
28	1000	12	12	12

Steel reinforcement modulus of elasticity = 210000 N/mm^2
Concrete characteristic compressive strength = 30 N/mm^2
Concrete modulus of elasticity = 20000 N/mm^2
Concrete secant modulus of elasticity = 32000 N/mm^2
Steel reinforcement yield strength = 275 N/mm^2
Steel reinforcement/concrete modular ratio = 10.5
Stirrups yield strength = 200 N/mm^2

Table 14 Design of stirrups for RC elements

Element number	Node number	Stirrups are designed to act as transverse shear reinforcement, Spacing m c/c
1	1	.5
	2	.5
2	2	.5
	3	.5
3	3	.5
	4	.5
4	4	.5
	5	.5
5	5	.5
	6	.5
6	6	.5
	7	.5
7	7	.5
	8	.5
8	8	.5
	9	.5
9	9	.5
	10	.5
10	10	.5
	11	.5
11	11	.5
	12	.5
12	20	.5
	13	.5
13	15	.5
	14	.5
14	2	.5
	15	.5
15	3	.5
	16	.5
16	4	.5
	17	.5
17	17	.5
	18	.5
18	18	.4519
	9	.258
19	19	.5
	10	.5
20	20	.5
	11	.4268
21	15	.5
	20	.5
22	16	.5
	19	.5

Table 14 Design of stirrups for RC elements (cont'd)

Element number	Node number	Stirrups are designed to act as transverse shear reinforcement, Spacing m c/c
23	20	.5
	19	.5
24	15	.5
	16	.5
25	16	.5
	17	.5
26	17	.5
	6	.5
27	18	.5
	7	.5
28	19	.5
	18	.5

This design is based on ACI-318 Section 1700
Maximum spacing is limited to 1/2 of the concrete depth

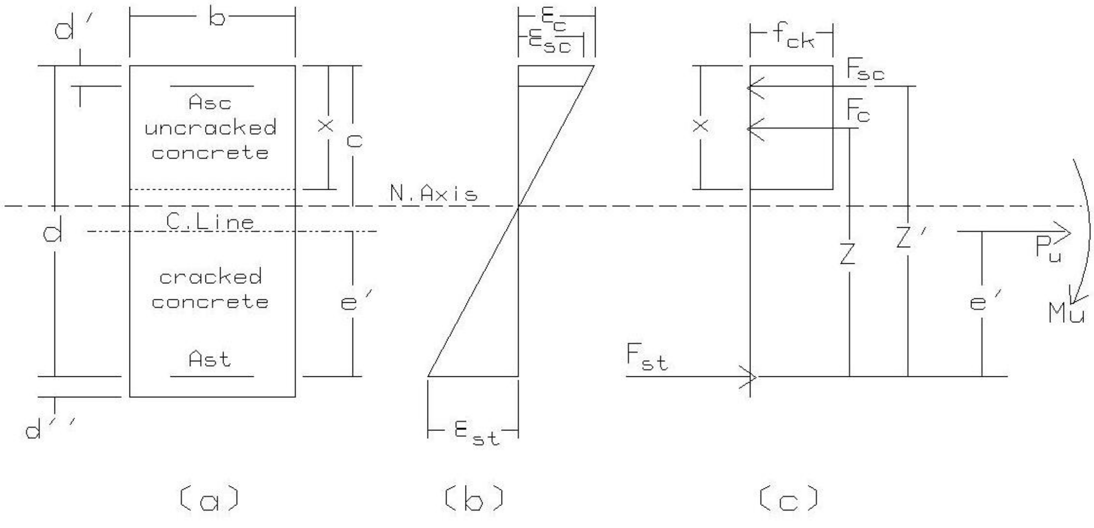


Fig 4 Re-inforced concrete element subjected to axial force and bending a) cross-section b) strain diagram c) stress block diagram

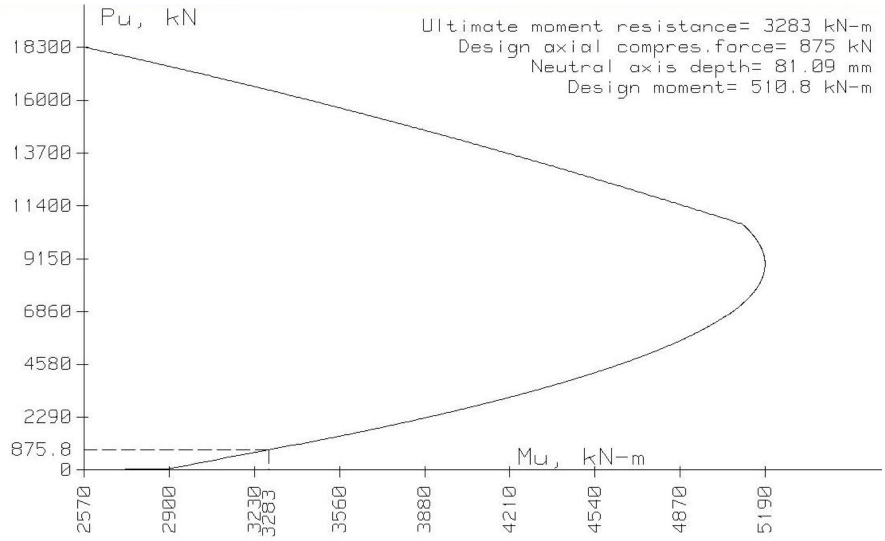


Fig 5 El.1 Node 2 axial compression and bending moment interaction diagram/1 m length

REFERENCES

1. Richards, T. H., Energy Methods in Stress Analysis, Ellis Horwood Ltd., New York, USA, 1922
2. Roark, Raymond J. 'Roark's Formulas for Stress and Strain'. McGraw-Hill Book Co. New York, USA, 1989
3. Chages, A., Principles of Structural Stability Theory, Prentice Hall, New Jersey, USA, 1974
4. Robert, T.M., Static and fatigue resistant design of welded stud connectors in double skin composite construction – draft report. School of Engineering, University of Wales College of Cardiff, 1994.
5. American Concrete Institute, Recommended Practice for Design of Concrete Pavements, (ACI 325 – 58)
6. Helou, Anis J, Ph.D. Thesis, School of Engineering, University of Wales, College of Cardiff, 1993
7. ACI – 318 – 64 : Part IV-B. "Structural analysis and proportioning of members – Ultimate strength design". American Concrete Institute, Michigan 48219, USA, 1965
8. Eurocode No. 4: Design of composite steel and concrete structures: Part 1.1 : General rules and rules for buildings, 1992
9. Reynold, Charles E. and Steedman, James C., "Reinforced concrete design handbook", Cement and Concrete Association, Wexham Springs, UK, 1981
10. BS8110 : Structural use of concrete : Part 1. Code of practice for design and construction, 1985
11. BS5400 : Steel concrete and composite bridges : Part 10 : Code of practice for fatigue: 1980.