Structural Analysis of a RC Shear Wall by Use of a Truss Model

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Abstract

Purpose of present work is to develop a reliable and simple method for structural analysis of RC Shear Walls. The shear wall is simulated by a truss model as the bar of a truss is the simplest finite element. An iterative method is used. Initially, there are only concrete bars. Repeated structural analyses are performed. After each structural analysis, every concrete bar exceeding tensile strength is replaced by a steel bar. For every concrete bar exceeding compressive strength, first its section area is increased. If this is not enough, a steel bar is placed at the side of it. For every steel bar exceeding tensile or compressive strength, its section area is increased. After the end of every structural analysis, if all concrete and steel bars fall within tensile and compressive strengths, the output data are written and the analysis is terminated. Otherwise, the structural analysis is repeated. As all the necessary conditions (static, elastic, linearized geometric) are satisfied and the stresses of ALL concrete and steel bars fall within the tensile and compressive strengths, the results are acceptable. Usually, the proposed method exhibits a fast convergence in 4 - 5 repeats of structural analysis of the RC Shear Wall.

Keywords

Reinforced Concrete Shear Wall, Structural Analysis, Truss Model, Iterative Method, Computer Program, Boundary Columns and Beam, Grid of Horizontal and Diagonal Reinforcing Steel Bars

1. Introduction

The study of behavior of structural shear walls is recently of great interest for Civil Engineers [1] [2]. The structural analysis of a RC shear wall can be performed by the FEM (Finite Element Method).

The FEM, appeared in about 1965 [3] [4] [5], was a revolution in structural...
analysis, because it allowed the analysis of structures of any shape, any support conditions and any loading. However, in the case of nonlinear structural analysis, physical (of stress-strain law) or geometrical one, the FEM exhibits some problems [6] [7]. Even in the linear case, the local stiffness matrices of FEM are complicated.

The bar of a truss is the simplest possible finite element [8]. Its local stiffness matrix reduces to its axial stiffness \( k = \frac{EA}{l_0} \), where \( E \) Young (Elasticity) modulus, \( A \) section area and \( l_0 \) initial undeformed length of the bar. And any nonlinear stress-strain law can be easily described by its uniaxial \( \sigma - \varepsilon \) law [9].

Even geometric nonlinearity can be easily taken into account by a truss model, by simply considering the equilibrium conditions with respect to the deformed truss [10], within an incremental loading procedure.

Here, a computer program, developed for the 2D structural analysis of overdetermined trusses, will be applied to the truss model of a typical RC (reinforced concrete) shear wall. And the computer program will be documented, step-by-step, by applying it to this specific example.

Initially, it will be assumed that the shear wall consists only of concrete, obeying a linear elastic stress-strain law. After every structural analysis, four steps are performed, for strengthening of the shear wall:

1) Every concrete bar exceeding tensile strength is replaced by a steel bar. 2) For every concrete bar exceeding compressive strength, its section area is increased by local increase of width of shear wall. 3) If this is not enough, the compressed concrete bar remains by receiving a part of the compressive axial force and a steel bar is added, to the side of it, by receiving the excess of compressive force. 4) For every steel bar exceeding tensile or compressive strength, its section area is increased.

At the compressed side of shear wall, due to overturning moments from horizontal seismic loading, the concrete section is enlarged near the base, in order to avoid stress concentrations.

Usually, in about 4 - 5 runs of the computer program, the stresses, of ALL concrete and steel bars, fall within the permissible limits of corresponding tensile and compressive strengths. So, the proposed method exhibits a rapid convergence. And, as all the necessary conditions (static, elastic, linearized geometric) are satisfied, as will be shown in the following, the results of the proposed iterative method are acceptable.

2. Application

2.1. Input Data

A typical ground floor shear wall of a building is considered, as shown in Figure 1, fixed at the base, with length \( l = 3.0 \) m, height \( h = 4.0 \) m, width \( w = 30 \) cm, subjected to vertical loading, from weights of storeys above it, with resultant \( R = 12,000 \) kN, thus loading intensity \( q = 12,000 \) kN/(300 cm \( \times \) 30 cm) = 1.333 kN/cm\(^2\), by assuming uniform distribution of loading. And a horizontal seismic
load $H = 6000 \text{kN}$ is considered, at the top left corner of shear wall, directed to right.

It is assumed that the shear wall initially consists only of concrete obeying the stress-strain $\sigma$-$\varepsilon$ law of Figure 2.

### 2.2. Discretization

The shear wall is discretized to a grid of $8 \times 6 = 48$ equal square elements with dimensions $50 \text{ cm} \times 50 \text{ cm} \times 30 \text{ cm}$, as shown in Figure 3(a). One of these square elements is shown enlarged in Figure 3(b).

### 2.3. Truss Model

Every continuum square element is simulated by an elementary square plane truss, as shown in Figure 4.

By combining the stress-strain equations of the continuum square element of Figure 4(a), with the force-displacement equations of the elementary square plane truss model of Figure 4(b), by taking into account the relations between

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**Figure 1.** The typical shear wall under consideration.

**Figure 2.** Concrete stress-strain $\sigma$-$\varepsilon$ law of present application. Initial Young (Elasticity) modulus $E_y = \sigma_y / \varepsilon_y = 3.0 \text{kN/cm}^2 / 0.002 = 1500 \text{kN/cm}^2$.
Figure 3. (a) Discretization of the shear wall. (b) One of the square elements enlarged.

Figure 4. (a) Stress-Strain relations of the continuum square element. (b) Force-deformation relations of the elementary square truss model.

strains and displacements $\{\epsilon_x, \epsilon_z\} = \frac{2}{a} \{u_x, u_z\}$, the relations between stresses and forces $\{\sigma_x, \sigma_z\} = \frac{2}{aw} \{F_x, F_z\}$ and by assuming a Poisson ratio $\nu = 1/3$, the bars section areas of the elementary square truss model are obtained with respect to the dimensions of the continuum square element: $A_1 = \frac{3}{8} aw$, $A_2 = \sqrt{2} A_1 = \frac{3\sqrt{2}}{8} aw$. 
2.4. Numbering of Nodes and Bars

For the structural analysis of the truss model of the shear wall, the $9 \times 7 = 63$ nodes and $8 \ (7 + 6 + 2 \times 6) = 200$ bars, of the whole truss model of the shear wall, are systematically numbered, as shown in Appendix A. In the same figure, are also shown the external loads $P_x, P_z$ at the top nodes of the wall, as well as the reference axes system Oxz.

2.5. Computer Program

The computer program, developed here for the 2D structural analysis of the truss model of a RC (reinforced concrete) shear wall, will be documented, in the following, step-by-step, by applying it on the specific example under consideration.

First, the main program MAIN reads the input data, as shown in the flow-chart of Figure 5.

The numbers of nodes $n = 63$ and bars $b = 200$ are read. For every node are read: its support codes $K_x, K_z$, which have the value 0 if the corresponding displacement $u_x$ or $u_z$ is free or 1 if it is restricted. So, $K_x, K_z$ are equal to 1 only for the support nodes 1 up to 7. Then, the initial co-ordinates $x, z$ in m of the node, with respect to global reference axes system Oxz, are read, and the external loads $P_x, P_z$ in kN, acting on the node, which are here nonzero only for top nodes 57 up to 63.

For every bar, the numbers $l_r$ of nodes it connects, left and right, are read, its section area $A$ in cm$^2$ and its initial undeformed length $l_0$ in m, which is 0.5 m for all vertical and horizontal bars and $l_0 = \sqrt{2} \times 0.5 \ m = 0.7071 \ m$ for all diagonal bars.

Then, subroutine STIF is called to form the global stiffness matrix $K$ (126 $\times$126) of the truss model. To the diagonal elements $(2k − 1) (2k − 1)$ and $(2k) (2k)$ of matrix $K$ corresponding to restricted displacements $u_x, u_z$ of a support node $k$,
very large values 10^{13} \text{kN/m} (practically infinite) are given, in order, for the corresponding support displacements \( u_x, u_z \) to tend to zero, \( u_x \rightarrow \emptyset, u_z \rightarrow \emptyset \), as shown in Figure 6.

Within subroutine STIF, for every concrete bar, its axial elastic stiffness is determined \( k = E_0 A / l_0 \), where \( E_0 = 1500 \text{kN/cm}^2 \) initial Young (Elasticity) modulus of concrete (later, when steel bars will be considered, \( E_0 = 7000 \text{kN/cm}^2 \) will be used, too, as initial Young (Elasticity) modulus of steel). \( A \) is section area in cm\(^2\) of the bar and \( l_0 \) initial undeformed length in m of the bar. The initial projections \( l_x = x_x - x_l, l_z = z_z - z_l \) of bar axis are found and its initial direction cosines \( c_x = l_x / l_0, c_z = l_z / l_0 \). The quantities \( K_x = kc_x^2, K_z = kc_z^2, K_{xz} = kc_x c_z \) are determined and the \( 2 \times 2 \) stiffness matrix of the bar is formed \( K = \begin{pmatrix} K_x & K_{xz} \\ K_{xz} & K_z \end{pmatrix} \), which, with positive or negative sign, is summed to appropriate submatrices \( 2 \times 2 \) of the global stiffness matrix \( K \), as shown in Figure 7, where \( l, r \) numbers of nodes that the bar connects, left and right. When this procedure is completed for

\[ K = \begin{bmatrix} 2k-1 & 2k \\ 2k-1 & 2k \end{bmatrix} \begin{bmatrix} 10^{13} \text{kN/m} & 0 \\ 0 & 10^{13} \text{kN/m} \end{bmatrix} \Rightarrow u_x \rightarrow 0, u_z \rightarrow 0 \]

Figure 6. Giving very large (practically infinite) values \( 10^{13} \text{kN/m} \) to the diagonal elements \((2k-1)(2k-1)\) and \((2k)(2k)\) of global stiffness matrix \( K \), corresponding to restricted displacements \( u_x, u_z \) of a support node \( k \), so that to obtain, for these displacements, values tending to zero, \( u_x \rightarrow 0, u_z \rightarrow 0 \).

\[ K = \begin{bmatrix} 2r-1 & 2r \\ 2r-1 & 2r \end{bmatrix} \begin{bmatrix} K_x & K_{xz} \\ K_{xz} & K_z \end{bmatrix} \begin{bmatrix} -K_x & -K_{xz} \\ -K_{xz} & -K_z \end{bmatrix} \]

Figure 7. Summing of the \( 2 \times 2 \) stiffness matrix \( \pm k = \pm \begin{pmatrix} K_x & K_{xz} \\ K_{xz} & K_z \end{pmatrix} \) of every bar to appropriate positions of the global stiffness matrix \( K \), so that to form \( K \), where \( l, r \) numbers of nodes that the bar connects, left and right.
all the bars, the global stiffness matrix $\mathbf{K}$ of the structure is formed. This formulation is based on the consideration of the linearized equations expressing the nodal forces $F_x, F_z$ with respect to the nodal displacements $u_x, u_z$.

The global load vector $\mathbf{p}$ (126) is formed, containing the external loads $P_x, P_z$ in kN of all nodes, which, in present application, are zero in all nodes, except of the seven top nodes (57 up to 63), where the external loads are applied.

Now, we have to solve the linear algebraic system, $\mathbf{Ku} = \mathbf{p}$, which will give, as result, the global vector $\mathbf{u}$ (126) of nodal displacements $u_x, u_z$.

Subroutine GAUS is called to solve the linear algebraic system, $\mathbf{Ku} = \mathbf{p}$. By successive eliminations, this algebraic system is triangularized, so that we can easily solve it by beginning from bottom equation, with only one unknown, and proceeding upwards, one by one equation, by substituting the already known nodal displacements, so by solving, each time, only one equation, with only one unknown nodal displacement $u_x$ or $u_z$.

So, all the nodal displacements $u_x, u_z$ are, successively, easily determined.

For every node, its displacements $u_x, u_z$ in mm and its new co-ordinates $x + u_x, z + u_z$ in m, are written as output in Appendix B.

Then, the main program MAIN calls subroutine NONL, which applies the geometrically nonlinear equations of the problem.

For every bar, first the present projections of its axis $l_x = x_r - x_l, l_z = z_r - z_l$ are determined, where $l_r$ the numbers of nodes that the bar connects, left and right, then its present length $l = (l_x^2 + l_z^2)^{1/2}$, and its direction cosines $c_x = l_x/l$, $c_z = l_z/l$, its elongation $\Delta l = l - l_0$, its dimensionless elongation $\epsilon = \Delta l/l_0$, its stress $\sigma = E_0 \epsilon$, where $E_0 = 1500$ kN/cm$^2$ initial Young (Elasticity) modulus of concrete (or $E_0 = 7000$ kN/cm$^2$, for steel bars later) and $N = \sigma A$ axial force of the bar, where $A$ its section area.

All the above data, $\Delta l, \epsilon, E_0, \sigma, A, N$, for every bar, are written as output, for first run of computer program, in Appendix C.

Then, the quantities $\pm Nc_x, \pm Nc_z$ are formed for every bar, which are summed to the nodal forces $F_{lx}, F_{lz}$ and $F_{rx}, F_{rz}$ of the nodes $l, r$, that the bar connects, left and right, as shown in Figure 8:

For left node: $F_{lx} \leftarrow F_{lx} + Nc_x, F_{lz} \leftarrow F_{lz} + Nc_z$

For right node: $F_{rx} \leftarrow F_{rx} - Nc_x, F_{rz} \leftarrow F_{rz} - Nc_z$

Figure 8. Summation of the quantities $\pm Nc_x, \pm Nc_z$ of a bar to the forces $F_x, F_z$ of the nodes $l, r$, that the bar connects, left and right.
Initially, the nodal forces are equal to the external loads $P_x, P_z$. After completion of above procedure for all the bars, the nodal forces $F_x, F_z$ obtain their total values, which are included in the previously mentioned Appendix B of nodal results, for first run of program.

The total nodal forces $F_x, F_z$ have small values in all the nodes, except of the support nodes, 1 up to 7, where they are opposite to the external reactions $R_x, R_z$. In all the other nodes their small nonzero values are due to ignoring of geometric nonlinearity. Only at the nodes 50, 51, 57, 58, at top left corner of shear wall, where larger deformations occur, the geometric nonlinearity error is somewhat larger, but it does not significantly affects the global equilibrium equations, as will be shown below.

From the nodal displacements $u_x, u_z$ of first run of Appendix B, the deformed configuration of the structure has been drawn in Figure 9, by using a

**Figure 9.** First run. Deformed configuration and equilibrium equations $\sum F_x = 0$, $\sum F_y = 0$, $\sum M_z = 0$ of the shear wall.
displacements scale (1:1) 25 times larger than lengths scale (1:25). The largest displacement $u_x = 21.41$ mm is observed at the top left corner of the wall.

In the same figure, the external reactions $R_x, R_y$ of support nodes, 1 up to 7, are noted, as opposite of corresponding nodal forces $F_x, F_y$, as well as the external loads $P_x, P_y$ at the top nodes 57 up to 63. By use of external loads $P_x, P_y$ and external reactions $R_x, R_y$, the global equilibrium equations $\sum F_i = 0, \sum F_j = 0, \sum M_0 = 0$ are written with respect to global reference axes $Oxz$. And, it is observed that they are verified with high accuracy, with errors only 0.542‰ up to 2.667‰ (per thousand), as demonstrated in Figure 9.

From the bars results of subroutine NONL, for first run, in Appendix C, is obtained, in the summarizing Table 1, that, in the first run, 66 concrete bars exceed tensile strength, $\sigma > +0.3$ kN/cm$^2$ (12 vertical + 25 horizontal + 27 ascending diagonals + 2 descending diagonals), 13 concrete bars exceed compressive strength, $\sigma < -3.0$ kN/cm$^2$ (9 vertical + 2 horizontal + 2 descending diagonals). So, remain 121 concrete bars with stresses within tensile and compressive strengths, $-3.0$ kN/cm$^2 < \sigma < +0.3$ kN/cm$^2$ (35 vertical + 21 horizontal + 21 ascending diagonals + 44 descending diagonals).

Based also on Appendix C, Figure 10 shows, for the first run, the stresses in kN/cm$^2$ of the 66 concrete bars exceeding tensile strength, $\sigma > +0.3$ kN/cm$^2$, as well as the stresses in kN/cm$^2$ of the 13 concrete bars exceeding compressive strength, $\sigma < -3.0$ kN/cm$^2$.

3. Four Steps for the Strengthening of the Shear Wall

After every run of the program, the following four steps are performed, for the strengthening of the shear wall, as described by the flow-chart of Figure 11.

Step 1
Every concrete bar exceeding tensile strength, $\sigma > +0.3$ kN/cm$^2$, is replaced by a steel reinforcing bar with section area $A_s = A_i E_i / E_s$, where $E_i = 1500$ kN/cm$^2$ and $E_s = 7000$ kN/cm$^2$. Young moduli of concrete and steel, respectively, according to stress-strain $\sigma$-$\varepsilon$ laws of concrete and steel of Figure 12 and $A_i, A_s$ section areas of concrete and steel bar, respectively. So, $A_s$ results $E_i / E_s = 1500 / 7000 = 1 / 4.667$ times smaller than $A_i$, and the initial axial stiffnesses of the failed concrete bar and the replacing steel bar result equal

| $\sigma$ | $A_s$ (cm$^2$) | $\varepsilon_s$ |
|----------|----------------|----------------|
| $+0.3$ kN/cm$^2 < \sigma$ | 12 | 25 |
| $\sigma < -3.0$ kN/cm$^2$ | 9 | 2 |
| $-3.0$ kN/cm$^2 < \sigma < +3.0$ kN/cm$^2$ | 35 | 21 |
| Total | 56 | 48 | 48 | 48 | 200 |
Figure 10. First run of computer program. Based on bars results of Appendix C, drawing of diagram of stresses in kN/cm² of the 66 concrete bars exceeding tensile strength, \( \sigma > +0.3 \text{kN/cm}^2 \) as well as stresses in kN/cm² of the 13 concrete bars exceeding compressive strength, \( \sigma < -3.0 \text{kN/cm}^2 \).

Figure 11. Flow-chart of the proposed iterative method for strengthening of the RC Shear Wall.
Figure 12. Concrete bar stress-strain $\sigma$-$\varepsilon$ curve compared with b. Steel bar stress-strain $\sigma$-$\varepsilon$ curve.

\[ K_s = E_sA_s/h_s = E_cA_c/h_c = K_c, \]  
so the structural behavior is not disturbed.

If the replacing steel bar exceeds its tensile strength, $\sigma > +14 \text{kN/cm}^2$, its section area $A_s$ is increased.

**Step 2**
For every concrete bar exceeding compressive strength, $\sigma < -3.0 \text{kN/cm}^2$, first its section area is increased, by increasing the corresponding local width $w$ of the shear wall, so that to achieve, as far as possible, a reduction of compressive stress $\sigma$ of concrete bar.

**Step 3**
If the above step 2 is not enough to allow a sufficient reduction of concrete bar compressive stress, the compressed concrete bar is maintained by receiving a part of the axial compression $N_0 = \sigma_{cc} \times A_c$, where $\sigma_{cc} = 3.0 \text{kN/cm}^2$ compressive strength of concrete and $A_c$ section area of concrete bar. And a steel bar is added, at the side of the compressed concrete bar, in order to receive the excess of the axial compression $\Delta N = N - N_0$, with section area $A_s = \Delta N/\sigma_{sc}$, where $\sigma_{sc} = 14.0 \text{kN/cm}^2$ compressive strength of steel. So, for the limit axial compressive deformation $\varepsilon_{c} = -0.002$, for both compressed bars, the initial concrete bar and the additional steel bar at the side of it, the total axial compressive force of two bars tends to $N_0 + \Delta N = N$, as is required. If any of two bars slightly exceeds the corresponding compressive strength, the steel bar section area is increased.

**Step 4**
For every steel bar exceeding tensile or compressive strength, its section area is increased.

At the right side of the shear wall, compressed due to overturning moments of horizontal seismic loading, it is here advised that the concrete section is increased, near the base, in order to avoid stress concentrations.
Usually, the performing of above four steps takes only 3 - 4 runs of the computer program, after which, ALL stresses $\sigma$, of concrete and steel bars, fall within the permissible limits of corresponding tensile and compressive strengths: $-3.0 \text{kN/cm}^2 < \sigma < +0.3 \text{kN/cm}^2$ for concrete bars and $-14 \text{kN/cm}^2 < \sigma < +14 \text{kN/cm}^2$ for steel bars.

So, the proposed iterative method, for strengthening of a shear wall, exhibits a rapid convergence, in 4 - 5 runs of the computer program.

And, as all the necessary conditions (static, elastic, linearized geometric) are satisfied, according to what mentioned in previous sections, the results of the proposed here iterative method, for the strengthening of a shear wall, are acceptable.

4. Fourth and Final Run of the Computer Program

In the fourth and final run of the computer program, for the present application, the number of nodes is $\nu_n = 66$, that is 63 initial nodes and 3 additional ones, of the truss model for right base enlargement, as shown in Figure 13.

Whereas, the number of bars is $\nu_b = 212$, that is the 200 initial bars, plus 4 new compressed vertical steel bars at the right lower side of the shear wall and 2 new compressed horizontal steel bars at the top left corner of the shear wall, as well as the 6 new bars of the truss model, for right base enlargement, as shown in Figure 13.

The numbering of 3 additional nodes and 12 additional bars, for the fourth and final run of the computer program, is shown in Figure 13.

Figure 13. Fourth and final run of computer program. Numbering of additional 3 nodes and additional 12 bars.
As shown in Appendix E, in the results of bars of fourth and final run of computer program, for present application, ALL stresses $\sigma$ of concrete and steel bars, fall within the permissible limits of corresponding tensile and compressive strengths: $-3.0 \text{kN/cm}^2 < \sigma < +0.3 \text{kN/cm}^2$ for concrete bars and $-14 \text{kN/cm}^2 < \sigma < +14 \text{kN/cm}^2$ for steel bars.

And, as all the necessary conditions (static, elastic, linearized geometric) are satisfied, as mentioned in previous sections, the results of the proposed here iterative method, for strengthening of a shear wall, are acceptable.

By use of nodal displacements $u_x, u_z$, of the fourth and final run of present application, from Appendix D, the final deformed configuration of the RC (reinforced concrete) shear wall has been drawn in Figure 14, with displacements...
scale 1:1, 25 times larger than lengths scale 1:25 and maximum displacement $u_x = 15.66$ mm at the top left corner of the shear wall.

In the same Figure 14, by using, from Appendix D, of nodal results of final run, the opposites of nodal forces $F_x, F_z$ of supports, as external reactions $R_x, R_z$, the three final global equilibrium equations $\sum F_x = 0, \sum F_z = 0, \sum M_0 = 0$ are written, which are verified with further higher accuracy than in the first run, with errors only 0.417‰ up to 1.000‰ (per thousand), as shown in Figure 14.

5. Conclusions

An iterative method is proposed for the nonlinear 2D structural analysis of a truss model of a RC shear wall, which is applied on a typical RC shear wall.

A relevant computer program has been developed, which is documented, step-by-step, by applying it on the specific example under consideration.

Initially, the truss model of the shear wall is assumed consisting only of concrete bars obeying a linear elastic axial $\sigma$-$\varepsilon$ law.

After every structural analysis of truss model, the following four steps are performed:

1) Every concrete bar exceeding tensile strength is replaced by a steel bar.

2) For every concrete bar exceeding compressive strength, its section area is increased.

3) If the above is not enough, the concrete bar is maintained, by receiving part of axial compression and a steel bar is added at the side of it.

4) For every steel bar exceeding tensile or compressive strength, its section area is increased.

At the lower part of side of shear wall, compressed due to overturning moments from horizontal seismic loading, the concrete section is enlarged, in order to avoid stress concentration.

Usually, in 4 - 5 runs of the computer program, ALL stresses of concrete and steel bars fall within tensile and compressive strengths. So, the proposed here iterative method exhibits a rapid convergence.

And, as all necessary conditions (static, elastic, linearized geometric) are satisfied, the results of proposed here iterative method are acceptable.

Because of alternating nature, in direction of the horizontal seismic loading, the results of the application have to be symmetrically extended to both sides of the shear wall.

The results of the application confirm the need for boundary columns, at the two sides of the shear wall, and a boundary horizontal beam at the top, as well as the need for a grid of ascending diagonal and horizontal steel bars, receiving tension and shear, in the main body of the shear wall.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.
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Appendices

Appendix A. Systematic Numbering of the $9 \times 7 = 63$ Nodes and $8 (7 + 6 + 2 \times 6) = 200$ Bars of the Whole Truss Model of the Shear Wall

![Systematic Numbering Diagram]
### Appendix B

**FIRST RUN, RESULTS OF NODES**

| Node number | $U_x$ mm | $U_z$ mm | $X$ m | $Z$ m | $F_x$ kN | $F_z$ kN | layer |
|-------------|----------|----------|-------|-------|----------|----------|-------|
| 1           | 0.0000   | 0.0000   | -1.5000000 | 0.0000000 | 1023.8   | 3133.9   | 0     |
| 2           | 0.0000   | 0.0000   | -1.0000000 | 0.0000000 | 356.8    | 2451.0   |       |
| 3           | 0.0000   | 0.0000   | -0.5000000 | 0.0000000 | 479.5    | 119.7    |       |
| 4           | 0.0000   | 0.0000   | 0.0000000  | 0.0000000 | 593.4    | -1852.8  |       |
| 5           | 0.0000   | 0.0000   | 0.5000000  | 0.0000000 | 741.5    | -3823.7  |       |
| 6           | 0.0000   | 0.0000   | 1.0000000  | 0.0000000 | 824.0    | -6261.9  |       |
| 7           | 0.0000   | 0.0000   | 1.5000000  | 0.0000000 | 1966.0   | -5734.1  |       |
| 8           | 0.9848   | 1.2520   | -1.4990152 | 0.5012520 | 5.5      | -0.1     | 1     |
| 9           | 0.7222   | 0.4859   | -0.9992778 | 0.5004859 | 0.0      | 8.0      |       |
| 10          | 0.6779   | 0.0109   | -0.4993221 | 0.5000109 | -0.4     | 7.1      |       |
| 11          | 0.7245   | -0.3925  | 0.007245    | 0.4996075 | -0.7     | 7.0      |       |
| 12          | 0.8343   | -0.7965  | 0.5008343   | 0.4992035 | -1.3     | 8.5      |       |
| 13          | 1.0540   | -1.2890  | 1.0010540   | 0.4987110 | -0.4     | 10.6     |       |
| 14          | 1.5810   | -2.2290  | 1.5015810   | 0.4977710 | -5.3     | -5.7     |       |
| 15          | 2.2680   | 2.2470   | -1.4977320 | 1.0022470 | 13.5     | 0.1      | 2     |
| 16          | 2.0560   | 0.9639   | -0.9979440 | 1.0009639 | -2.0     | 10.4     |       |
| 17          | 2.0040   | -0.0082  | -0.4979960 | 0.9999918 | -1.1     | 9.7      |       |
| 18          | 2.0890   | -0.8327  | 0.0020890   | 0.9991673 | -0.6     | 9.5      |       |
| 19          | 2.2850   | -1.6530  | 0.5022850   | 0.9983470 | 0.5      | 9.5      |       |
| 20          | 2.6210   | -2.6470  | 1.0026210   | 0.9973530 | 3.7      | 10.1     |       |
| 21          | 3.1070   | -4.0530  | 1.5031070   | 0.9959470 | -16.8    | -6.6     |       |
| 22          | 3.9850   | 3.0340   | -1.4960150 | 1.5030340 | 22.9     | 0.9      | 3     |
| 23          | 3.8270   | 1.3180   | -0.9961730 | 1.5013180 | -3.6     | 12.6     |       |
| 24          | 3.8190   | -0.0897  | -0.4961810 | 1.4999103 | -2.2     | 12.0     |       |
| 25          | 3.9460   | -1.3120  | 0.0039460   | 1.4986880 | -0.5     | 10.6     |       |
| 26          | 4.1850   | -2.5070  | 0.5041850   | 1.4974930 | 0.7      | 9.8      |       |
| 27          | 4.5240   | -3.8710  | 1.0045240   | 1.4961290 | 3.9      | 10.0     |       |
| 28          | 4.9590   | -5.6150  | 1.5049590   | 1.4943850 | -24.0    | -7.6     |       |
| 29          | 6.0760   | 3.6470   | -1.4939240 | 2.0036470 | 33.1     | 1.6      | 4     |
| 30          | 5.9730   | 1.5350   | -0.9940270 | 2.0015350 | -5.1     | 13.0     |       |
| 31          | 6.0200   | -0.2658  | -0.4939800 | 1.9997342 | -3.4     | 11.3     |       |
|    |       |       |         |         |         |       |       |
|----|-------|-------|---------|---------|---------|-------|-------|
| 32 | 6.185 | −1.826 | 0.006185 | 1.998174 | −2.2 | 9.1 |
| 33 | 6.431 | −3.313 | 0.506431 | 1.996687 | 1.1 | 8.7 |
| 34 | 6.741 | −4.941 | 1.006741 | 1.995059 | 4.5 | 8.6 |
| 35 | 7.111 | −6.938 | 1.507111 | 1.993062 | −30.3 | −7.1 |
| 36 | 8.504 | 4.134 | −1.491496 | 2.504134 | 46.1 | 4.9 |
| 37 | 8.451 | −0.556 | −0.491449 | 2.499443 | −8.0 | 11.9 |
| 38 | 8.551 | −4.053 | 0.508941 | 2.495947 | 0.8 | 5.2 |
| 39 | 8.728 | −2.371 | 0.008728 | 2.497629 | −4.2 | 6.8 |
| 40 | 8.941 | −4.053 | 0.508941 | 2.495947 | 0.8 | 5.2 |
| 41 | 9.194 | −5.851 | 1.009194 | 2.494149 | −34.7 | −8.4 |
| 42 | 9.487 | −8.003 | 1.509487 | 2.494149 | −8.0 | 11.9 |
| 43 | 11.330 | 4.582 | −1.488670 | 3.004582 | 68.3 | 13.0 |
| 44 | 11.300 | 1.489 | −0.988700 | 3.001489 | −22.3 | 27.7 |
| 45 | 11.410 | −0.970 | −0.488590 | 2.999030 | −16.3 | 8.6 |
| 46 | 11.490 | −2.917 | 0.011490 | 2.997083 | −7.2 | 2.8 |
| 47 | 11.590 | −4.702 | 0.511590 | 2.995298 | −0.9 | 1.0 |
| 48 | 11.750 | −6.594 | 1.011750 | 2.993406 | 4.5 | −0.2 |
| 49 | 11.960 | −8.800 | 1.511960 | 2.991200 | −35.9 | −7.3 |
| 50 | 14.820 | 5.078 | −1.485180 | 3.505078 | 108.5 | 57.9 |
| 51 | 14.790 | 1.133 | −0.985210 | 3.501133 | −86.6 | 39.8 |
| 52 | 14.540 | −1.408 | −0.485460 | 3.498592 | −29.7 | −3.1 |
| 53 | 14.300 | −3.384 | 0.014300 | 3.496616 | −8.8 | −7.5 |
| 54 | 14.190 | −5.224 | 0.514190 | 3.494776 | −0.2 | −6.8 |
| 55 | 14.230 | −7.175 | 1.014230 | 3.492825 | 3.9 | −4.5 |
| 56 | 14.360 | −9.368 | 1.514360 | 3.490632 | −33.9 | −6.8 |
| 57 | 21.410 | 5.576 | −1.478590 | 4.005576 | 57.0 | 95.0 |
| 58 | 18.940 | 1.018 | −0.981060 | 4.001018 | 58.0 | −18.5 |
| 59 | 17.500 | −1.629 | −0.482500 | 3.998371 | 3.4 | −54.9 |
| 60 | 16.740 | −3.698 | 0.016740 | 3.996302 | 6.3 | −36.0 |
| 61 | 16.460 | −5.625 | 0.516460 | 3.994375 | 7.2 | −31.4 |
| 62 | 16.470 | −7.639 | 1.016470 | 3.992361 | 6.6 | −32.5 |
| 63 | 16.610 | −9.825 | 1.516610 | 3.990175 | −14.2 | −19.7 |
### Appendix C

#### FIRST RUN, RESULTS OF BARS

| Bar number | \( \Delta l = l - \bar{l} \) mm | \( \varepsilon = \Delta l/\bar{l} \) - | \( E \) kN/cm\(^2\) | \( \sigma = \varepsilon E \) kN/cm\(^2\) | \( A \) cm\(^2\) | \( N = \sigma A \) kN | Mater. code | Bars failed |
|------------|-------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|--------------|-------------|
| 1          | 1.2530                        | 0.0025060       | 1500            | 3.7600          | 562.5           | 2115.0          | 1            | +           | 1           |
| 2          | 0.4864                        | 0.0009729       | 1500            | 1.4590          | 1125.0          | 1642.0          | 1            | +           |             |
| 3          | 0.0114                        | 0.0000228       | 1500            | 0.0342          | 1125.0          | 38.4            | 1            |             |             |
| 4          | -0.3920                       | -0.0007839      | 1500            | -1.1760         | 1125.0          | -1323.0         | 1            |             |             |
| 5          | -0.7958                       | -0.0015920      | 1500            | -2.3870         | 1125.0          | -2686.0         | 1            |             |             |
| 6          | -1.2880                       | -0.0025760      | 1500            | -3.8640         | 1125.0          | -4347.0         | 1            | -           |             |
| 7          | -2.2260                       | -0.0044530      | 1500            | -6.6790         | 562.5           | -3757.0         | 1            | -           |             |
| 8          | -0.2620                       | -0.0005239      | 1500            | -0.7859         | 1125.0          | -884.1          | 1            |             |             |
| 9          | -0.0441                       | -0.0000882      | 1500            | -0.1323         | 1125.0          | -148.9          | 1            |             |             |
| 10         | 0.0467                        | 0.0000935       | 1500            | 0.1402          | 1125.0          | 157.7           | 1            |             |             |
| 11         | 0.1100                        | 0.0002201       | 1500            | 0.3301          | 1125.0          | 371.4           | 1            | +           |             |
| 12         | 0.2205                        | 0.0004410       | 1500            | 0.6614          | 1125.0          | 744.1           | 1            | +           |             |
| 13         | 0.5273                        | 0.0010550       | 1500            | 1.5820          | 1125.0          | 1780.0          | 1            | +           |             |
| 14         | 0.8543                        | 0.0012080       | 1500            | 1.8120          | 795.5           | 1442.0          | 1            | +           |             |
| 15         | 0.1909                        | 0.0002700       | 1500            | 0.4050          | 795.5           | 322.2           | 1            | +           |             |
| 16         | 0.4872                        | 0.0006890       | 1500            | 1.0340          | 795.5           | 822.2           | 1            | +           |             |
| 17         | -0.1666                       | -0.0002356      | 1500            | -0.3534         | 795.5           | -281.1          | 1            |             |             |
| 18         | 0.2351                        | 0.0003325       | 1500            | 0.4988          | 795.5           | 396.8           | 1            | +           |             |
| 19         | -0.4715                       | -0.0006668      | 1500            | -1.0000         | 795.5           | -795.6          | 1            |             |             |
| 20         | 0.0277                        | 0.0000392       | 1500            | 0.0588          | 795.5           | 46.8            | 1            |             |             |
| 21         | -0.7898                       | -0.0011170      | 1500            | -1.6750         | 795.5           | -1333.0         | 1            |             |             |
| 22         | -0.1640                       | -0.0002319      | 1500            | -0.3478         | 795.5           | -276.7          | 1            |             |             |
| 23         | -1.1530                       | -0.0016310      | 1500            | -2.4460         | 795.5           | -1946.0         | 1            |             |             |
| 24         | -0.4531                       | -0.0006407      | 1500            | -0.9611         | 795.5           | -764.5          | 1            |             |             |
| 25         | -1.6570                       | -0.0023440      | 1500            | -3.5160         | 795.5           | -2797.0         | 1            | -           |             |
| 26         | 0.9963                        | 0.0019930       | 1500            | 2.9890          | 562.5           | 1681.0          | 1            | +           | 2           |
| 27         | 0.4798                        | 0.0009596       | 1500            | 1.4390          | 1125.0          | 1619.0          | 1            | +           |             |
| 28         | -0.0174                       | -0.0000348      | 1500            | -0.0521         | 1125.0          | -58.6           | 1            |             |             |
| 29         | -0.4383                       | -0.0008767      | 1500            | -1.3150         | 1125.0          | -1479.0         | 1            |             |             |
| 30         | -0.8541                       | -0.0017080      | 1500            | -2.5620         | 1125.0          | -2883.0         | 1            |             |             |
| 31         | -1.3550                       | -0.0027100      | 1500            | -4.0650         | 1125.0          | -4573.0         | 1            | -           |             |
| 32         | -1.8220                       | -0.0036430      | 1500            | -5.4650         | 562.5           | -3074.0         | 1            | -           |             |

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|    |   |    |    |    |    |    |
|----|---|---|---|---|---|---|
| 33 | -0.2101 | -0.0004203 | 1500 | -0.6304 | 1125.0 | -709.2 | 1 |
| 34 | -0.0511 | -0.0001022 | 1500 | -0.1532 | 1125.0 | -172.4 | 1 |
| 35 | 0.0855 | 0.0001709 | 1500 | 0.2564 | 1125.0 | 288.5 | 1 |
| 36 | 0.1975 | 0.0003951 | 1500 | 0.5926 | 1125.0 | 666.7 | 1 + |
| 37 | 0.3367 | 0.0006734 | 1500 | 1.0100 | 1125.0 | 1136.0 | 1 + |
| 38 | 0.4882 | 0.0009764 | 1500 | 1.4650 | 1125.0 | 1648.0 | 1 + |
| 39 | 0.5541 | 0.0007837 | 1500 | 1.1760 | 795.5 | 935.1 | 1 + |
| 40 | 0.1563 | 0.0002211 | 1500 | 0.3317 | 795.5 | 263.8 | 1 + |
| 41 | 0.5579 | 0.0007890 | 1500 | 1.1830 | 795.5 | 941.5 | 1 + |
| 42 | -0.2986 | -0.0004222 | 1500 | -0.6333 | 795.5 | -503.8 | 1 |
| 43 | 0.4028 | 0.0005697 | 1500 | 0.8545 | 795.5 | 679.7 | 1 + |
| 44 | -0.6319 | -0.0008937 | 1500 | -1.3410 | 795.5 | -1066.0 | 1 |
| 45 | 0.2156 | 0.0003049 | 1500 | 0.4573 | 795.5 | 363.8 | 1 + |
| 46 | -0.9120 | -0.0012900 | 1500 | -1.9350 | 795.5 | -1539.0 | 1 |
| 47 | -0.0401 | -0.0000567 | 1500 | -0.0851 | 795.5 | -677.7 | 1 |
| 48 | -1.1270 | -0.0015940 | 1500 | -2.3910 | 795.5 | -1902.0 | 1 |
| 49 | -0.4944 | -0.0006991 | 1500 | -1.0490 | 795.5 | -834.2 | 1 |
| 50 | -1.0310 | -0.0014580 | 1500 | -2.1870 | 795.5 | -1739.0 | 1 |
| 51 | 0.7898 | 0.0015800 | 1500 | 2.3690 | 562.5 | 1333.0 | 1 + 3 |
| 52 | 0.3577 | 0.0007154 | 1500 | 1.0730 | 1126.0 | 1208.0 | 1 + |
| 53 | -0.0782 | -0.0001565 | 1500 | -0.2347 | 1125.0 | -264.0 | 1 |
| 54 | -0.4760 | -0.0009520 | 1500 | -1.4280 | 1125.0 | -1607.0 | 1 |
| 55 | -0.8509 | -0.0017020 | 1500 | -2.5530 | 1125.0 | -2872.0 | 1 |
| 56 | -1.2210 | -0.0024410 | 1500 | -3.6620 | 1125.0 | -4119.0 | 1 |
| 57 | -1.5590 | -0.0031170 | 1500 | -4.6760 | 562.5 | -2630.0 | 1 |
| 58 | -0.1545 | -0.0003091 | 1500 | -0.4636 | 1125.0 | -521.5 | 1 |
| 59 | -0.0059 | -0.0000117 | 1500 | -0.0176 | 1125.0 | -19.8 | 1 |
| 60 | 0.1283 | 0.0002565 | 1500 | 0.3848 | 1125.0 | 432.9 | 1 + |
| 61 | 0.2398 | 0.0004797 | 1500 | 0.7195 | 1125.0 | 809.5 | 1 + |
| 62 | 0.3408 | 0.0006816 | 1500 | 1.0220 | 1125.0 | 1150.0 | 1 + |
| 63 | 0.4380 | 0.0008761 | 1500 | 1.3140 | 1125.0 | 1478.0 | 1 + |
| 64 | 0.4485 | 0.0008343 | 1500 | 0.9515 | 795.5 | 756.9 | 1 + |
| 65 | 0.1053 | 0.0001489 | 1500 | 0.2234 | 795.5 | 177.7 | 1 |
| 66 | 0.5047 | 0.0007138 | 1500 | 1.0710 | 795.5 | 851.7 | 1 + |
| 67 | -0.3477 | -0.0004918 | 1500 | -0.7377 | 795.5 | -586.8 | 1 |
|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 68 | 0.4551 | 0.0006437 | 1500 | 0.9655 | 795.5 | 768.1 | 1 | + |
| 69 | −0.6964 | −0.0009848 | 1500 | −1.4770 | 795.5 | −1175.0 | 1 |
| 70 | 0.3030 | 0.0004285 | 1500 | 0.6428 | 795.5 | 511.4 | 1 | + |
| 71 | −0.9320 | −0.0013180 | 1500 | −1.9770 | 795.5 | −1573.0 | 1 |
| 72 | 0.0210 | 0.0000297 | 1500 | 0.0445 | 795.5 | 35.4 | 1 |
| 73 | −1.0060 | −0.0014220 | 1500 | −2.1340 | 795.5 | −1697.0 | 1 |
| 74 | −0.4361 | −0.0006168 | 1500 | −0.9252 | 795.5 | −736.0 | 1 |
| 75 | −0.8718 | −0.0012330 | 1500 | −1.8490 | 795.5 | −1471.0 | 1 |
| 76 | 0.6172 | 0.0012340 | 1500 | 1.8520 | 562.5 | 1042.0 | 1 | + | 4 |
| 77 | 0.2208 | 0.0004417 | 1500 | 0.6625 | 1125.0 | 745.3 | 1 | + |
| 78 | −0.1711 | −0.0003422 | 1500 | −0.5133 | 1125.0 | −577.4 | 1 |
| 79 | −0.5089 | −0.0010180 | 1500 | −1.5270 | 1125.0 | −1718.0 | 1 |
| 80 | −0.8009 | −0.0016020 | 1500 | −2.4030 | 1125.0 | −2703.0 | 1 |
| 81 | −1.0650 | −0.0021310 | 1500 | −3.1960 | 1125.0 | −3596.0 | 1 | − |
| 82 | −1.3190 | −0.0026370 | 1500 | −3.9560 | 562.5 | −2225.0 | 1 | − |
| 83 | −0.0981 | −0.0001961 | 1500 | −0.2941 | 1125.0 | −330.9 | 1 |
| 84 | 0.0504 | 0.0001009 | 1500 | 0.1513 | 1125.0 | 170.2 | 1 |
| 85 | 0.1675 | 0.0003350 | 1500 | 0.5025 | 1125.0 | 565.3 | 1 | + |
| 86 | 0.2483 | 0.0004965 | 1500 | 0.7448 | 1125.0 | 837.9 | 1 | + |
| 87 | 0.3126 | 0.0006251 | 1500 | 0.9377 | 1125.0 | 1055.0 | 1 | + |
| 88 | 0.3731 | 0.0007461 | 1500 | 1.1190 | 1125.0 | 1259.0 | 1 | + |
| 89 | 0.3504 | 0.0004955 | 1500 | 0.7432 | 795.5 | 591.2 | 1 | + |
| 90 | 0.0638 | 0.0000903 | 1500 | 0.1354 | 795.5 | 107.7 | 1 |
| 91 | 0.4357 | 0.0006161 | 1500 | 0.9242 | 795.5 | 735.2 | 1 | + |
| 92 | −0.3692 | −0.0005221 | 1500 | −0.7832 | 795.5 | −623.0 | 1 |
| 93 | 0.4513 | 0.0006382 | 1500 | 0.9573 | 795.5 | 761.5 | 1 | + |
| 94 | −0.7233 | −0.0010230 | 1500 | −1.5340 | 795.5 | −1221.0 | 1 |
| 95 | 0.3496 | 0.0004944 | 1500 | 0.7416 | 795.5 | 589.9 | 1 | + |
| 96 | −0.9306 | −0.0013160 | 1500 | −1.9740 | 795.5 | −1570.0 | 1 |
| 97 | 0.0957 | 0.0001353 | 1500 | 0.2029 | 795.5 | 161.4 | 1 |
| 98 | −0.9525 | −0.0013470 | 1500 | −2.0210 | 795.5 | −1607.0 | 1 |
| 99 | −0.3283 | −0.0004643 | 1500 | −0.6964 | 795.5 | −554.0 | 1 |
| 100 | −0.7821 | −0.0011060 | 1500 | −1.6590 | 795.5 | −1320.0 | 1 |
| 101 | 0.4932 | 0.0009865 | 1500 | 1.4800 | 562.5 | 832.3 | 1 | + | 5 |
| 102 | 0.0734 | 0.0001467 | 1500 | 0.2201 | 1125.0 | 247.6 | 1 | + |
| 103 | -0.2843 | -0.0005687 | 1500 | -0.8530 | 1125.0 | -959.7 | 1 |
| 104 | -0.5381 | -0.0010760 | 1500 | -1.6140 | 1125.0 | -1816.0 | 1 |
| 105 | -0.7339 | -0.0014680 | 1500 | -2.2020 | 1125.0 | -2477.0 | 1 |
| 106 | -0.9035 | -0.0018070 | 1500 | -2.7110 | 1125.0 | -3049.0 | 1 |
| 107 | -1.0590 | -0.0021190 | 1500 | -3.1780 | 562.5 | -1788.0 | 1 | - |
| 108 | -0.0471 | -0.0000941 | 1500 | -0.1412 | 1125.0 | -158.8 | 1 |
| 109 | 0.1052 | 0.0002104 | 1500 | 0.3156 | 1125.0 | 355.1 | 1 | + |
| 110 | 0.1798 | 0.0003597 | 1500 | 0.5395 | 1125.0 | 606.9 | 1 | + |
| 111 | 0.2160 | 0.0004320 | 1500 | 0.6480 | 1125.0 | 729.0 | 1 | + |
| 112 | 0.2562 | 0.0005125 | 1500 | 0.7687 | 1125.0 | 864.8 | 1 | + |
| 113 | 0.2971 | 0.0005941 | 1500 | 0.8912 | 1125.0 | 1003.0 | 1 | + |
| 114 | 0.2407 | 0.0003404 | 1500 | 0.5106 | 795.5 | 406.2 | 1 | + |
| 115 | 0.0573 | 0.0000811 | 1500 | 0.1216 | 795.5 | 96.8 | 1 |
| 116 | 0.3522 | 0.0004981 | 1500 | 0.7471 | 795.5 | 594.3 | 1 | + |
| 117 | -0.3915 | -0.0005536 | 1500 | -0.8305 | 795.5 | -660.6 | 1 |
| 118 | 0.4345 | 0.0006144 | 1500 | 0.9216 | 795.5 | 733.2 | 1 | + |
| 119 | -0.7707 | -0.0010900 | 1500 | -1.6350 | 795.5 | -1301.0 | 1 |
| 120 | 0.3825 | 0.0005409 | 1500 | 0.8114 | 795.5 | 645.4 | 1 | + |
| 121 | -0.9537 | -0.0013490 | 1500 | -2.0230 | 795.5 | -1609.0 | 1 |
| 122 | 0.1692 | 0.0002392 | 1500 | 0.3588 | 795.5 | 285.5 | 1 | + |
| 123 | -0.9243 | -0.0013070 | 1500 | -1.9610 | 795.5 | -1560.0 | 1 |
| 124 | -0.2120 | -0.0002998 | 1500 | -0.4497 | 795.5 | -357.8 | 1 |
| 125 | -0.7010 | -0.0009913 | 1500 | -1.4870 | 795.5 | -1183.0 | 1 |
| 126 | 0.4564 | 0.0009128 | 1500 | 1.3690 | 562.5 | 770.2 | 1 | + | 6 |
| 127 | -0.1051 | -0.0002103 | 1500 | -0.3154 | 1125.0 | -354.9 | 1 |
| 128 | -0.4053 | -0.0008105 | 1500 | -1.2160 | 1125.0 | -1368.0 | 1 |
| 129 | -0.5386 | -0.0010770 | 1500 | -1.6160 | 1125.0 | -1818.0 | 1 |
| 130 | -0.6422 | -0.0012840 | 1500 | -1.9270 | 1125.0 | -2167.0 | 1 |
| 131 | -0.7366 | -0.0014730 | 1500 | -2.2100 | 1125.0 | -2486.0 | 1 |
| 132 | -0.7912 | -0.0015820 | 1500 | -2.3730 | 562.5 | -1335.0 | 1 |
| 133 | -0.0198 | -0.0000396 | 1500 | -0.0595 | 1125.0 | -66.9 | 1 |
| 134 | 0.1166 | 0.0002333 | 1500 | 0.3499 | 1125.0 | 393.7 | 1 | + |
| 135 | 0.0897 | 0.0001793 | 1500 | 0.2689 | 1125.0 | 302.6 | 1 |
| 136 | 0.1034 | 0.0002068 | 1500 | 0.3102 | 1125.0 | 349.0 | 1 | + |
| 137 | 0.1603 | 0.0003206 | 1500 | 0.4808 | 1125.0 | 540.9 | 1 | + |
|    |        |          |      |      |      |      |  |  |
|----|--------|----------|------|------|------|------|---|---|
| 138| 0.2130 | 0.0004261| 1500 | 0.6391| 1125.0| 719.0| 1 | +|
| 139| 0.1138 | 0.0001609| 1500 | 0.2414| 795.5 | 192.0| 1 | |
| 140| 0.0873 | 0.0001234| 1500 | 0.1851| 795.5 | 147.3| 1 | |
| 141| 0.2820 | 0.0003989| 1500 | 0.5983| 795.5 | 476.0| 1 | +|
| 142| -0.4862| -0.0006876| 1500 | -1.0310| 795.5 | -820.5| 1 | |
| 143| 0.4203 | 0.0005944| 1500 | 0.8917| 795.5 | 709.3| 1 | +|
| 144| -0.8975| -0.0012690| 1500 | -1.9040| 795.5 | -1515.0| 1 | |
| 145| 0.3861 | 0.0005460| 1500 | 0.8190| 795.5 | 651.5| 1 | +|
| 146| -0.9953| -0.0014080| 1500 | -2.1110| 795.5 | -1680.0| 1 | |
| 147| 0.1991 | 0.0002816| 1500 | 0.4224| 795.5 | 336.0| 1 | |
| 148| -0.8794| -0.0012440| 1500 | -1.8660| 795.5 | -1484.0| 1 | |
| 149| -0.1205| -0.0001704| 1500 | -0.2555| 795.5 | -203.3| 1 | |
| 150| -0.5985| -0.0008464| 1500 | -1.2700| 795.5 | -1010.0| 1 | |
| 151| 0.5084 | 0.0010170| 1500 | 1.5250| 562.5 | 857.9| 1 | + | 7 |
| 152| -0.3440| -0.0006880| 1500 | -1.0320| 1125.0| -1161.0| 1 | |
| 153| -0.4286| -0.0008572| 1500 | -1.2860| 1125.0| -1446.0| 1 | |
| 154| -0.4594| -0.0009188| 1500 | -1.3780| 1125.0| -1550.0| 1 | |
| 155| -0.5144| -0.0010290| 1500 | -1.5430| 1125.0| -1736.0| 1 | |
| 156| -0.5749| -0.0011500| 1500 | -1.7250| 1125.0| -1940.0| 1 | |
| 157| -0.5617| -0.0011230| 1500 | -1.6850| 562.5 | -947.8| 1 | |
| 158| -0.0170| -0.0000339| 1500 | -0.0509| 1125.0| -57.2| 1 | |
| 159| -0.2362| -0.0004724| 1500 | -0.7086| 1125.0| -797.2| 1 | |
| 160| -0.2365| -0.0004729| 1500 | -0.7094| 1125.0| -798.0| 1 | |
| 161| -0.1064| -0.0002128| 1500 | -0.3192| 1125.0| -359.1| 1 | |
| 162| 0.0389 | 0.0000777| 1500 | 0.1166| 1125.0| 131.2| 1 | |
| 163| 0.1397 | 0.0002793| 1500 | 0.4190| 1125.0| 471.3| 1 | +|
| 164| 0.0250 | 0.0000353| 1500 | 0.0530| 795.5 | 42.1| 1 | |
| 165| 0.0650 | 0.0000919| 1500 | 0.1378| 795.5 | 109.6| 1 | |
| 166| 0.2616 | 0.0003700| 1500 | 0.5549| 795.5 | 441.5| 1 | +|
| 167| -0.8928| -0.0012630| 1500 | -1.8940| 795.5 | -1507.0| 1 | |
| 168| 0.3514 | 0.0004970| 1500 | 0.7455| 795.5 | 593.0| 1 | +|
| 169| -1.0840| -0.0015330| 1500 | -2.2990| 795.5 | -1829.0| 1 | |
| 170| 0.2878 | 0.0004071| 1500 | 0.6106| 795.5 | 485.7| 1 | +|
| 171| -0.9789| -0.0013840| 1500 | -2.0770| 795.5 | -1652.0| 1 | |
| 172| 0.1251 | 0.0001769| 1500 | 0.2654| 795.5 | 211.1| 1 | |
Continued

| 173 | -0.7545 | -0.0010670 | 1500 | -1.6000 | 795.5 | -1273.0 | 1 |
| 174 | -0.1026 | -0.0001451 | 1500 | -0.2176 | 795.5 | -173.1 | 1 |
| 175 | -0.4513 | -0.0006383 | 1500 | -0.9574 | 795.5 | -761.6 | 1 |
| 176 | 0.5405  | 0.0010810  | 1500 | 1.6210  | 562.5 | 912.1  | 1  + 8 |
| 177 | -0.0976 | -0.0001953 | 1500 | -0.2929 | 1125.0 | -329.5 | 1 |
| 178 | -0.2116 | -0.0004231 | 1500 | -0.6347 | 1125.0 | -714.0 | 1 |
| 179 | -0.3080 | -0.0006161 | 1500 | -0.9241 | 795.5  | -761.6 | 1 |
| 180 | -0.4587 | -0.0009174 | 1500 | -1.3560 | 1125.0 | -1548.0 | 1 |
| 181 | -0.4520 | -0.0009040 | 1500 | -1.3560 | 562.5  | -762.8 | 1 |
| 182 | -2.4450 | -0.0048900 | 1500 | -7.3350 | 562.5  | -4126.0 | 1 |
| 183 | -1.4400 | -0.0028790 | 1500 | -4.3190 | 562.5  | -2429.0 | 1 |
| 184 | -0.7485 | -0.0014970 | 1500 | -2.2450 | 562.5  | -1263.0 | 1 |
| 185 | -0.2812 | -0.0005623 | 1500 | -0.8435 | 562.5  | -474.4 | 1 |
| 186 | 0.0173  | 0.0000347  | 1500 | 0.0520  | 562.5  | 29.3  | 1 |
| 187 | 0.1401  | 0.0002801  | 1500 | 0.4202  | 562.5  | 236.4 | 1  + |
| 188 | 0.0688  | 0.0000973  | 1500 | 0.1459  | 795.5  | 116.1 | 1 |
| 189 | -1.4980 | -0.0021180 | 1500 | -3.1780 | 795.5  | -2528.0 | 1 |
| 190 | -0.0250 | -0.000354  | 1500 | -0.0531 | 795.5  | -42.3 | 1 |
| 191 | -1.3790 | -0.0019510 | 1500 | -2.9260 | 795.5  | -2328.0 | 1 |
| 192 | -0.0559 | -0.0000791 | 1500 | -0.1186 | 795.5  | -94.4 | 1 |
| 193 | -1.0080 | -0.0014260 | 1500 | -2.1390 | 795.5  | -1701.0 | 1 |
| 194 | -0.0531 | -0.0000751 | 1500 | -0.1127 | 795.5  | -89.6 | 1 |
| 195 | -0.7190 | -0.0010170 | 1500 | -1.5250 | 795.5  | -1213.0 | 1 |
| 196 | -0.0882 | -0.0001248 | 1500 | -0.1871 | 795.5  | -148.9 | 1 |
| 197 | -0.4764 | -0.0006737 | 1500 | -1.0110 | 795.5  | -803.9 | 1 |
| 198 | -0.1824 | -0.0002579 | 1500 | -0.3869 | 795.5  | -307.8 | 1 |
| 199 | -0.2635 | -0.0003727 | 1500 | -0.5590 | 795.5  | -444.7 | 1 |
## Appendix D

### FOURTH AND FINAL RUN RESULTS OF NODES

| Node numb. | $U_x$ mm | $U_z$ mm | $X$ m | $Z$ m | $F_x$ kN | $F_z$ kN | layer |
|------------|----------|----------|-------|-------|---------|---------|-------|
| 1          | 0.0000   | 0.0000   | $-1.5000000$ | 0.0000000 | 302.8   | 1562.9  | 0     |
| 2          | 0.0000   | 0.0000   | $-1.0000000$ | 0.0000000 | 78.6    | 628.3   |       |
| 3          | 0.0000   | 0.0000   | $-0.5000000$ | 0.0000000 | 7.7     | 78.9    |       |
| 4          | 0.0000   | 0.0000   | 0.0000000   | 0.0000000 | 134.5   | $-539.8$ |       |
| 5          | 0.0000   | 0.0000   | 0.5000000   | 0.0000000 | 303.6   | $-1298.7$ |       |
| 6          | 0.0000   | 0.0000   | 1.0000000   | 0.0000000 | 249.3   | $-2963.2$ |       |
| 7          | 0.0000   | 0.0000   | 1.5000000   | 0.0000000 | 1266.6  | $-5034.1$ |       |
| 8          | 0.3606   | 0.5960   | $-1.4996394$ | 0.5005960 | 0.9     | 0.5     | 1     |
| 9          | 0.2897   | 0.3024   | $-0.9997103$ | 0.5003024 | 0.5     | 0.3     |       |
| 10         | 0.2565   | 0.1028   | $-0.4997435$ | 0.5001028 | $-0.2$  | 0.7     |       |
| 11         | 0.2553   | $-0.1231$ | 0.0002553   | 0.4998769 | $-1.2$  | 1.6     |       |
| 12         | 0.3149   | $-0.2858$ | 0.5003149   | 0.4997142 | $-1.2$  | 1.6     |       |
| 13         | 0.2281   | $-0.3952$ | 1.0002281   | 0.4996048 | $-0.6$  | 6.3     |       |
| 14         | 0.4366   | $-0.5891$ | 1.5004366   | 0.4994109 | $-5.0$  | $-0.3$  |       |
| 15         | 0.9935   | 1.2350   | $-1.4990065$ | 1.0012350 | 2.2     | 0.7     | 2     |
| 16         | 0.9249   | 0.6745   | $-0.9990751$ | 1.0006745 | $-1.4$  | 2.5     |       |
| 17         | 0.9192   | 0.2297   | $-0.4990808$ | 1.0002297 | $-0.4$  | 4.3     |       |
| 18         | 0.9513   | $-0.2722$ | 0.0009513   | 0.9997278 | $-2.1$  | 4.4     |       |
| 19         | 1.1020   | $-0.5864$ | 0.5011020   | 0.9994136 | $-1.7$  | 5.4     |       |
| 20         | 1.0990   | $-0.8180$ | 1.0010990   | 0.9991820 | $-3.0$  | 10.1    |       |
| 21         | 1.1330   | $-1.4770$ | 1.5011330   | 0.9985230 | $-31.7$ | 21.8    |       |
| 22         | 2.0400   | 1.9000   | $-1.4979600$ | 1.5019000 | 5.9     | $-1.2$  | 3     |
| 23         | 1.9540   | 1.0600   | $-0.9980460$ | 1.5010600 | $-1.9$  | 3.7     |       |
| 24         | 1.9470   | 0.2321   | $-0.4980530$ | 1.5002321 | $-3.5$  | 7.4     |       |
| 25         | 2.1840   | $-0.4892$ | 0.0021840   | 1.4995108 | $-2.2$  | 6.1     |       |
| 26         | 2.5410   | $-0.9587$ | 0.5025410   | 1.4990413 | $-0.6$  | 5.4     |       |
| 27         | 2.8470   | $-1.3540$ | 1.0028470   | 1.4986460 | 2.6     | 4.1     |       |
| 28         | 3.6620   | $-2.4710$ | 1.5036620   | 1.4975290 | 1.8     | $-13.5$ |       |
| 29         | 3.4900   | 2.6490   | $-1.4965100$ | 2.0026490 | 10.3    | $-3.1$  | 4     |
| 30         | 3.4350   | 1.4620   | $-0.9965650$ | 2.0014620 | $-1.2$  | 4.4     |       |
| 31         | 3.4680   | 0.1558   | $-0.4965320$ | 2.0001558 | $-8.4$  | 10.8    |       |
Continued

|   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|
| 32 | 3.9090 | −0.8231 | 0.0039090 | 1.9991769 | −3.4 | 6.2 |
| 33 | 4.3880 | −1.4880 | 0.5043880 | 1.9985120 | −3.3 | 6.0 |
| 34 | 4.9910 | −2.1300 | 1.0049910 | 1.9978700 | 0.3 | 3.6 |
| 35 | 5.8100 | −3.3850 | 1.5058100 | 1.9966150 | −5.0 | −5.4 |
| 36 | 5.4150 | 3.4690 | −1.4945850 | 2.5034690 | 18.9 | −3.8 |
| 37 | 5.3750 | 1.7470 | −0.9946250 | 2.5017470 | −11.8 | 27.8 |
| 38 | 5.6090 | −0.0430 | −0.4943910 | 2.4999570 | −5.4 | 11.2 |
| 39 | 6.0410 | −1.2670 | 0.0060410 | 2.4987330 | −6.5 | 7.3 |
| 40 | 6.6910 | −2.0530 | 0.5066910 | 2.4979470 | −1.0 | 1.5 |
| 41 | 7.3560 | −2.8050 | 1.0073560 | 2.4971950 | 14.3 | −3.2 |
| 42 | 7.9660 | −4.2680 | 1.5079660 | 2.4957320 | −3.0 | −4.9 |
| 43 | 7.8790 | 4.2400 | −1.4921210 | 3.0042400 | 18.9 | −3.6 |
| 44 | 7.8610 | 1.6960 | −0.9921390 | 3.0016960 | −31.4 | 9.6 |
| 45 | 8.2200 | −0.3921 | −0.4917800 | 2.9996079 | −11.2 | 12.2 |
| 46 | 8.6020 | −1.7130 | 0.0086020 | 2.9982870 | −6.3 | −0.6 |
| 47 | 9.0250 | −2.6130 | 0.5090250 | 2.9973870 | −1.8 | −3.1 |
| 48 | 9.4280 | −3.6250 | 1.0094280 | 2.9963750 | 7.7 | 1.3 |
| 49 | 9.8170 | −5.1370 | 1.5098170 | 2.9948630 | −12.6 | −8.0 |
| 50 | 11.2400 | 4.8340 | −1.4887600 | 3.5048340 | 130.2 | 32.4 |
| 51 | 11.2700 | 1.4410 | −0.9887300 | 3.5014410 | −85.9 | 122.4 |
| 52 | 11.2300 | −0.7857 | −0.4887700 | 3.4992143 | −32.1 | 16.0 |
| 53 | 11.1200 | −2.0920 | 0.0111200 | 3.4979080 | −4.1 | −6.3 |
| 54 | 11.0900 | −3.1040 | 0.5110900 | 3.4968960 | 4.8 | −3.3 |
| 55 | 11.1500 | −4.2630 | 1.0111500 | 3.4957370 | 3.5 | 3.9 |
| 56 | 11.4600 | −5.7110 | 1.5114600 | 3.4942890 | −9.9 | −5.5 |
| 57 | 15.6600 | 5.1340 | −1.4843400 | 4.0051340 | 135.6 | −33.3 |
| 58 | 14.6900 | 1.4040 | −0.9853100 | 4.0014040 | −60.8 | −156.3 |
| 59 | 13.7700 | −0.9570 | −0.4862300 | 3.9990430 | −16.6 | −58.7 |
| 60 | 12.8900 | −2.4150 | 0.0128900 | 3.9975850 | 2.8 | −19.3 |
| 61 | 12.5700 | −3.5290 | 0.5125700 | 3.9964710 | 3.7 | −12.8 |
| 62 | 12.6100 | −4.6960 | 1.0126100 | 3.9953040 | 1.8 | −15.3 |
| 63 | 13.0200 | −6.2450 | 1.5130200 | 3.9937550 | −3.6 | −10.4 |
| 64 | 0.0000 | 0.0000 | 2.0000000 | 0.0000000 | 1729.7 | −2501.9 |
| 65 | 0.0000 | 0.0000 | 2.5000000 | 0.0000000 | 1920.4 | −1923.6 |
| 66 | 0.9861 | −0.1533 | 2.0009861 | 0.4998467 | 5.2 | −0.3 |

Right base enlargement
### Appendix E

#### FOURTH AND FINAL RUN. RESULTS OF BARS. ALL BARS WITHIN STRENGTHS LIMITS

| Bar num | \( \Delta L = L_h \) mm | \( \varepsilon = \Delta L_h \) - | \( E \) kN/cm² | \( \sigma = E \varepsilon \) kN/cm² | \( A \) cm² | \( N = \sigma A \) kN | Mater. code | Bars failed | layer |
|---------|-----------------|-----------------|-------|-----------------|-------|-----------------|-------------|-------------|------|
| 1       | 0.5961          | 0.0011920       | 7000  | 8.3450          | 151.1 | 1261.0          | 2           | NONE        | 1    |
| 2       | 0.3025          | 0.0006050       | 7000  | 4.2350          | 117.2 | 496.3           | 2           | NONE        | 1    |
| 3       | 0.1029          | 0.0002058       | 7000  | 1.4400          | 34.3 | 49.4            | 2           | NONE        | 1    |
| 4       | −0.1231         | −0.0002461      | 1500  | −0.3692         | 1125.0| −415.3          | 1           | NONE        | 1    |
| 5       | −0.2857         | −0.0005715      | 1500  | −0.8572         | 1125.0| −964.4          | 1           | NONE        | 1    |
| 6       | −0.3951         | −0.0007903      | 1500  | −1.1850         | 1856.0| −2200.0         | 1           | NONE        | 1    |
| 7       | −0.5889         | −0.0011780      | 1500  | −1.7670         | 1350.0| −2385.0         | 1           | NONE        | 1    |
| 8       | −0.5889         | −0.0011780      | 1500  | −8.2450         | 220.2 | −1816.0         | 2           | NONE        | 2    |
| 9       | −0.0708         | −0.0001417      | 1500  | −0.2125         | 1125.0| −239.1          | 1           | NONE        | 1    |
| 10      | −0.0332         | −0.0000664      | 1500  | −0.0996         | 1125.0| −112.0          | 1           | NONE        | 1    |
| 11      | −0.0011         | −0.0000021      | 1500  | −0.0032         | 1125.0| −3.6            | 1           | NONE        | 1    |
| 12      | 0.0597          | 0.0001193       | 7000  | 0.8353          | 26.5 | 22.1            | 2           | NONE        | 1    |
| 13      | −0.0869         | −0.0001738      | 7000  | −1.2170         | 53.1 | −64.6           | 2           | NONE        | 2    |
| 14      | 0.2087          | 0.0004174       | 7000  | 2.9210          | 127.1 | 371.3           | 2           | NONE        | 1    |
| 15      | 0.4187          | 0.0005922       | 7000  | 4.1450          | 103.0 | 426.9           | 2           | NONE        | 2    |
| 16      | 0.1668          | 0.0002359       | 7000  | 1.6510          | 23.0 | 38.0            | 2           | NONE        | 2    |
| 17      | 0.2540          | 0.0003593       | 7000  | 2.5150          | 59.1 | 148.6           | 2           | NONE        | 2    |
| 18      | 0.0092          | 0.0000130       | 1500  | 0.0195          | 795.5 | 15.5            | 1           | NONE        | 1    |
| 19      | 0.0935          | 0.0001323       | 7000  | 0.9258          | 28.4 | 26.3            | 2           | NONE        | 2    |
| 20      | −0.1086         | −0.0001536      | 1500  | −0.2304         | 795.5 | −183.3          | 1           | NONE        | 1    |
| 21      | 0.0207          | 0.0000293       | 7000  | 0.2053          | 35.4 | 7.3             | 2           | NONE        | 2    |
| 22      | −0.2676         | −0.0003784      | 1500  | −0.5676         | 795.5 | −451.5          | 1           | NONE        | 1    |
| 23      | −0.1181         | −0.0001670      | 7000  | −1.1690         | 18.2 | −21.3           | 2           | NONE        | 2    |
| 24      | −0.4248         | −0.0006008      | 1500  | −0.9011         | 795.5 | −716.9          | 1           | NONE        | 1    |
| 25      | −0.1074         | −0.0001519      | 1500  | −0.2278         | 1591.0| −362.5          | 1           | NONE        | 1    |
| 26      | −0.4407         | −0.0006232      | 1500  | −0.9348         | 1591.0| −1487.0         | 1           | NONE        | 1    |
| 27      | 0.6398          | 0.0012800       | 7000  | 8.9570          | 120.1 | 1076.0          | 2           | NONE        | 2    |
| 28      | 0.3725          | 0.0007449       | 7000  | 5.2150          | 115.6 | 602.8           | 2           | NONE        | 1    |
| 29      | 0.1273          | 0.0002546       | 7000  | 1.7820          | 34.6 | 61.7            | 2           | NONE        | 1    |
| 30      | −0.1486         | −0.0002972      | 1500  | −0.4459         | 1125.0| −501.6          | 1           | NONE        | 1    |
| 31      | −0.3000         | −0.0006000      | 1500  | −0.9000         | 1125.0| −1012.0         | 1           | NONE        | 1    |
| 32      | −0.4221         | −0.0008441      | 1500  | −1.2660         | 1632.0| −2066.0         | 1           | NONE        | 1    |
Continued

|   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|
| 33 | -0.8871 | -0.0017740 | 1500 | -2.6610 | 1013.0 | -2696.0 | 1 |
| 34 | -0.8871 | -0.0017740 | 7000 | -12.4200 | 160.0 | -1987.0 | 2 |
| 35 | -0.0683 | -0.0001366 | 1500 | -0.2048 | 1125.0 | -230.4 | 1 |
| 36 | -0.0055 | -0.0000109 | 1500 | -0.0164 | 1125.0 | -18.4 | 1 |
| 37 | 0.0323 | 0.0000645 | 1500 | 0.0967 | 1125.0 | 108.8 | 1 |
| 38 | 0.1513 | 0.0003027 | 7000 | 2.1190 | 47.7 | 101.1 | 2 |
| 39 | -0.0030 | -0.000061 | 7000 | -0.0426 | 81.2 | -3.5 | 2 |
| 40 | 0.0339 | 0.0000678 | 7000 | 0.4748 | 117.7 | 55.9 | 2 |
| 41 | 0.4546 | 0.0006429 | 7000 | 4.5000 | 160.0 | 300.6 | 2 |
| 42 | 0.1630 | 0.0002305 | 7000 | 1.6130 | 18.9 | 30.5 | 2 |
| 43 | 0.3939 | 0.0005571 | 7000 | 3.9000 | 67.2 | 262.1 | 2 |
| 44 | -0.0679 | -0.0000960 | 1500 | -0.1440 | 795.5 | -114.6 | 1 |
| 45 | 0.2266 | 0.0003204 | 7000 | 2.2430 | 28.4 | 63.7 | 2 |
| 46 | -0.2196 | -0.0003105 | 1500 | -0.4658 | 795.5 | -370.5 | 1 |
| 47 | 0.2720 | 0.0003847 | 7000 | 2.6930 | 26.0 | 70.0 | 2 |
| 48 | -0.4402 | -0.0006225 | 1500 | -0.9338 | 795.5 | -742.8 | 1 |
| 49 | 0.1790 | 0.0002531 | 7000 | 1.7720 | 58.7 | 104.0 | 2 |
| 50 | -0.7533 | -0.0010650 | 1500 | -1.5980 | 795.5 | -1271.0 | 1 |
| 51 | -0.1236 | -0.0001747 | 1500 | -0.2621 | 1591.0 | -417.0 | 1 |
| 52 | -0.6304 | -0.0008915 | 1500 | -1.3370 | 1591.0 | -2128.0 | 1 |
| 53 | 0.6660 | 0.0013320 | 7000 | 9.3240 | 95.2 | 887.7 | 2 |
| 54 | 0.3866 | 0.0007732 | 7000 | 5.4120 | 86.2 | 466.5 | 2 |
| 55 | 0.0035 | 0.0000069 | 1500 | 0.0104 | 1125.0 | 11.7 | 1 |
| 56 | -0.2155 | -0.0004310 | 1500 | -0.6465 | 1125.0 | -727.3 | 1 |
| 57 | -0.3701 | -0.0007403 | 1500 | -1.1100 | 1125.0 | -1249.0 | 1 |
| 58 | -0.5324 | -0.0010650 | 1500 | -1.5970 | 1463.0 | -2337.0 | 1 |
| 59 | -0.9879 | -0.0019760 | 1500 | -2.9640 | 938.0 | -2780.0 | 1 |
| 60 | -0.9879 | -0.0019760 | 7000 | -13.8300 | 174.5 | -2413.0 | 2 |
| 61 | -0.0860 | -0.0001719 | 1500 | -0.2578 | 1125.0 | -290.1 | 1 |
| 62 | -0.0065 | -0.0001294 | 1500 | -0.0194 | 1125.0 | -21.8 | 1 |
| 63 | 0.2378 | 0.0004755 | 7000 | 3.3290 | 30.9 | 102.9 | 2 |
| 64 | 0.3577 | 0.0007154 | 7000 | 5.0080 | 57.9 | 289.9 | 2 |
| 65 | 0.3060 | 0.0006120 | 7000 | 4.2840 | 82.1 | 351.7 | 2 |
| 66 | 0.8164 | 0.0016330 | 7000 | 11.4300 | 105.6 | 1207.0 | 2 |
| 67 | 0.5555 | 0.0007855 | 7000 | 5.4990 | 54.1 | 297.5 | 2 |
|   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|
| 68 | 0.0800 | 0.0001131 | 1500 | 0.1697 | 795.5 | 135.0 | 1 |
| 69 | 0.4104 | 0.0005804 | 7000 | 4.0630 | 60.9 | 247.4 | 2 |
| 70 | -0.1432 | -0.0002025 | 1500 | -0.3037 | 795.5 | -241.6 | 1 |
| 71 | 0.3872 | 0.0005476 | 7000 | 3.8330 | 54.9 | 210.4 | 2 |
| 72 | -0.3464 | -0.0004898 | 1500 | -0.7347 | 795.5 | -584.5 | 1 |
| 73 | 0.6407 | 0.0009062 | 7000 | 6.3430 | 36.5 | 231.5 | 2 |
| 74 | -0.6954 | -0.0009835 | 1500 | -1.4750 | 795.5 | -1174.0 | 1 |
| 75 | 0.6935 | 0.0009808 | 7000 | 6.8650 | 46.0 | 315.8 | 2 |
| 76 | -1.1180 | -0.0015820 | 1500 | -2.3730 | 795.5 | -1887.0 | 1 |
| 77 | 0.6497 | 0.0009188 | 7000 | 6.4320 | 40.9 | 263.1 | 2 |
| 78 | -1.1240 | -0.0015890 | 1500 | -2.3840 | 1326.0 | -3161.0 | 1 |
| 79 | 0.7508 | 0.0015020 | 7000 | 10.5100 | 74.4 | 782.1 | 2 |
| 80 | 0.4039 | 0.0008079 | 7000 | 5.6550 | 53.3 | 301.4 | 2 |
| 81 | -0.0739 | -0.0001477 | 1500 | -0.2216 | 1125.0 | -249.2 | 1 |
| 82 | -0.3308 | -0.0006616 | 1500 | -0.9924 | 1125.0 | -1116.0 | 1 |
| 83 | -0.5259 | -0.0010520 | 1500 | -1.5780 | 1125.0 | -1775.0 | 1 |
| 84 | -0.7721 | -0.0015440 | 1500 | -2.3160 | 1350.0 | -3127.0 | 1 |
| 85 | -0.9090 | -0.0018180 | 1500 | -2.7270 | 938.0 | -2558.0 | 1 |
| 86 | -0.9090 | -0.0018180 | 7000 | -12.7300 | 84.6 | -1077.0 | 2 |
| 87 | -0.0536 | -0.0001072 | 1500 | -0.1608 | 1125.0 | -180.9 | 1 |
| 88 | 0.0356 | 0.0000712 | 1500 | 0.1068 | 1125.0 | 120.1 | 1 |
| 89 | 0.4412 | 0.0008824 | 7000 | 6.1770 | 40.4 | 249.5 | 2 |
| 90 | 0.4799 | 0.0009599 | 7000 | 6.7190 | 59.9 | 402.5 | 2 |
| 91 | 0.6030 | 0.0012060 | 7000 | 8.4420 | 82.1 | 693.1 | 2 |
| 92 | 0.8204 | 0.0016410 | 7000 | 11.4900 | 89.9 | 1033.0 | 2 |
| 93 | 0.6769 | 0.0009573 | 7000 | 6.7010 | 42.2 | 282.8 | 2 |
| 94 | 0.0411 | 0.0000581 | 1500 | 0.0871 | 795.5 | 69.3 | 1 |
| 95 | 0.4339 | 0.0006136 | 7000 | 4.2950 | 52.5 | 225.5 | 2 |
| 96 | -0.1801 | -0.0002547 | 1500 | -0.3820 | 795.5 | -303.9 | 1 |
| 97 | 0.6446 | 0.0009116 | 7000 | 6.3810 | 54.4 | 347.1 | 2 |
| 98 | -0.4508 | -0.0006376 | 1500 | -0.9564 | 795.5 | -760.8 | 1 |
| 99 | 0.8562 | 0.0012110 | 7000 | 8.4760 | 42.2 | 357.7 | 2 |
| 100 | -0.8702 | -0.0012310 | 1500 | -1.8460 | 795.5 | -1468.0 | 1 |
| 101 | 0.9084 | 0.0012850 | 7000 | 8.9920 | 62.8 | 564.7 | 2 |
| 102 | -1.1840 | -0.0016750 | 1500 | -2.5120 | 795.5 | -1998.0 | 1 |
|   |   |   |   |   |   |
|---|---|---|---|---|---|
| 103 | 0.6675 | 0.0009440 | 7000 | 6.6080 | 41.9 |
| 104 | −0.6974 | −0.0009863 | 1500 | −1.4790 | 1326.0 |
| 105 | 0.8241 | 0.0016480 | 7000 | 11.5400 | 59.5 |
| 106 | 0.2891 | 0.0005783 | 7000 | 4.0480 | 29.5 |
| 107 | −0.1943 | −0.0003885 | 1500 | −0.5828 | 1125.0 |
| 108 | −0.4399 | −0.0008797 | 1500 | −1.3200 | 1125.0 |
| 109 | −0.5597 | −0.0011190 | 1500 | −1.6790 | 1125.0 |
| 110 | −0.6692 | −0.0013380 | 1500 | −2.0080 | 1406.0 |
| 111 | −0.8785 | −0.0017570 | 1500 | −2.6350 | 844.0 |
| 112 | −0.0374 | −0.0000747 | 1500 | −0.1121 | 1125.0 |
| 113 | 0.2373 | 0.0004747 | 7000 | 3.3230 | 25.4 |
| 114 | 0.4335 | 0.0008670 | 7000 | 6.0690 | 43.4 |
| 115 | 0.6507 | 0.0013010 | 7000 | 9.1100 | 52.1 |
| 116 | 0.6661 | 0.0013320 | 7000 | 9.3250 | 61.8 |
| 117 | 0.6121 | 0.0012240 | 7000 | 8.5700 | 71.6 |
| 118 | 0.6979 | 0.0009870 | 7000 | 6.9090 | 29.0 |
| 119 | 0.0250 | 0.0000353 | 1500 | 0.0530 | 795.5 |
| 120 | 0.4782 | 0.0006763 | 7000 | 4.7340 | 42.4 |
| 121 | −0.2184 | −0.0003089 | 1500 | −0.4633 | 795.5 |
| 122 | 0.8181 | 0.0011570 | 7000 | 8.0990 | 52.4 |
| 123 | −0.6483 | −0.0009169 | 1500 | −1.3750 | 795.5 |
| 124 | 1.1030 | 0.0015600 | 7000 | 10.9200 | 46.1 |
| 125 | −1.0110 | −0.0014300 | 1500 | −2.1450 | 795.5 |
| 126 | 1.1740 | 0.0016600 | 7000 | 11.6200 | 20.4 |
| 127 | −1.1460 | −0.0016210 | 1500 | −2.4320 | 795.5 |
| 128 | 0.6018 | 0.0008511 | 7000 | 5.9580 | 19.1 |
| 129 | −0.6822 | −0.0009648 | 1500 | −1.4470 | 1193.0 |
| 130 | 0.7766 | 0.0015530 | 7000 | 10.8700 | 55.0 |
| 131 | −0.0451 | −0.0000902 | 1500 | −0.1353 | 1125.0 |
| 132 | −0.3425 | −0.0006849 | 1500 | −1.0270 | 1125.0 |
| 133 | −0.4393 | −0.0008786 | 1500 | −1.3180 | 1125.0 |
| 134 | −0.5551 | −0.0011100 | 1500 | −1.6650 | 1125.0 |
| 135 | −0.8156 | −0.0016310 | 1500 | −2.4470 | 1125.0 |
| 136 | −0.8656 | −0.0017310 | 1500 | −2.5970 | 562.5 |
| 137 | −0.0123 | −0.0000245 | 1500 | −0.0368 | 1125.0 |
Continued

| p | 0.3635 | 0.0007271 | 7000 | 5.0890 | 28.1 | 143.0 | 2 |
| n | 0.3840 | 0.0007681 | 7000 | 5.3760 | 26.5 | 142.5 | 2 |
| e | 0.4235 | 0.0008470 | 7000 | 5.9290 | 24.9 | 147.6 | 2 |
| m | 0.4039 | 0.0008078 | 7000 | 5.6540 | 38.7 | 218.8 | 2 |
| l | 0.3920 | 0.0007839 | 7000 | 5.4870 | 51.3 | 281.5 | 2 |
| a | 0.4815 | 0.0006810 | 7000 | 4.7670 | 34.0 | 162.1 | 2 |
| n | 0.0005 | 0.0000007 | 1500 | 0.0010 | 795.5 | 0.8 | 1 |
| p | 0.5080 | 0.0007184 | 7000 | 5.0280 | 50.7 | 254.9 | 2 |
| e | −0.3572 | −0.0005052 | 1500 | −0.7578 | 795.5 | −602.8 | 1 |
| m | 0.9432 | 0.0013340 | 7000 | 9.3380 | 46.5 | 434.2 | 2 |
| l | −0.9186 | −0.0012990 | 1500 | −1.9490 | 795.5 | −1550.0 | 1 |
| a | 1.1650 | 0.0016470 | 7000 | 11.5300 | 24.0 | 276.8 | 2 |
| n | −1.1090 | −0.0015690 | 1500 | −2.3540 | 795.5 | −1872.0 | 1 |
| e | 0.8303 | 0.0011740 | 7000 | 8.2190 | 51.3 | 421.7 | 2 |
| m | −0.1040 | −0.0014750 | 1500 | −2.2130 | 795.5 | −1760.0 | 1 |
| l | 0.0995 | 0.0001407 | 1500 | 0.2110 | 795.5 | 167.9 | 1 |
| a | −0.5772 | −0.0008163 | 1500 | −1.2240 | 795.5 | −974.1 | 1 |
| n | 0.6054 | 0.0012110 | 7000 | 8.4760 | 61.3 | 519.6 | 2 |
| p | −0.2430 | −0.0004860 | 1500 | −0.7290 | 562.5 | −410.1 | 1 |
| e | −0.3843 | −0.0007686 | 1500 | −1.1530 | 1125.0 | −1297.0 | 1 |
| m | −0.3727 | −0.0007455 | 1500 | −1.1180 | 1125.0 | −1258.0 | 1 |
| l | −0.4866 | −0.0009732 | 1500 | −1.4600 | 1125.0 | −1642.0 | 1 |
| a | −0.6355 | −0.0012710 | 1500 | −1.9070 | 1125.0 | −2145.0 | 1 |
| n | −0.5712 | −0.0011420 | 1500 | −1.7130 | 562.5 | −963.8 | 1 |
| e | 0.0401 | 0.0000802 | 1500 | 0.1203 | 1969.0 | 237.0 | 1 |
| m | −0.0310 | −0.0000621 | 1500 | −0.0931 | 1406.0 | −130.9 | 1 |
| l | −0.1107 | −0.0002214 | 1500 | −0.3321 | 1125.0 | −373.6 | 1 |
| a | −0.0258 | −0.0000516 | 1500 | −0.0774 | 1125.0 | −87.1 | 1 |
| n | 0.0601 | 0.0001202 | 1500 | 0.1802 | 1125.0 | 202.8 | 1 |
| p | 0.3154 | 0.0006307 | 7000 | 4.4150 | 33.7 | 148.8 | 2 |
| e | 0.4306 | 0.0006090 | 7000 | 4.2630 | 25.1 | 107.0 | 2 |
| m | −0.1550 | −0.0002192 | 1500 | −0.3287 | 795.5 | −261.5 | 1 |
| l | 0.6413 | 0.0009070 | 7000 | 6.3490 | 31.5 | 200.0 | 2 |
| a | −0.8505 | −0.0012030 | 1500 | −1.8040 | 795.5 | −1435.0 | 1 |
| n | 0.8558 | 0.0012100 | 7000 | 8.4720 | 42.4 | 359.2 | 2 |
|   |      |      |      |      |      |      |      |      |      |
|---|------|------|------|------|------|------|------|------|------|
| 173 | -1.1990 | -0.0016960 | 1500 | -2.5440 | 795.5 | -2024.0 | 1   |
| 174 | 0.7828  | 0.0011070 | 7000 | 7.7490  | 34.7  | 268.9   | 2   |
| 175 | -1.1100 | -0.0015700 | 1500 | -2.3550 | 795.5 | -1874.0 | 1   |
| 176 | 0.3422  | 0.0004840 | 7000 | 3.3880  | 17.7  | 60.0    | 2   |
| 177 | -0.8077 | -0.0011420 | 1500 | -1.7130 | 795.5 | -1363.0 | 1   |
| 178 | -0.0283 | -0.0000400 | 1500 | -0.0601 | 795.5 | -47.8   | 1   |
| 179 | -0.3241 | -0.0004584 | 1500 | -0.6876 | 795.5 | -547.0  | 1   |
| 180 | 0.3189  | 0.0006379 | 7000 | 4.4650  | 65.1  | 290.7   | 2   |
| 181 | -0.0257 | -0.0000514 | 1500 | -0.0772 | 2250.0 | -173.6  | 1   |
| 182 | -0.1650 | -0.0003300 | 1500 | -0.4950 | 1688.0 | -835.5  | 1   |
| 183 | -0.3195 | -0.0006389 | 1500 | -0.9584 | 1125.0 | -1078.0 | 1   |
| 184 | -0.4227 | -0.0008454 | 1500 | -1.2680 | 1125.0 | -1427.0 | 1   |
| 185 | -0.4309 | -0.0008617 | 1500 | -1.2930 | 1406.0 | -1817.0 | 1   |
| 186 | -0.5324 | -0.0010650 | 1500 | -1.5970 | 562.5  | -898.4  | 1   |
| 187 | -0.9543 | -0.0019090 | 1500 | -2.8630 | 1219.0 | -3490.0 | 1   |
| 188 | -0.9543 | -0.0019090 | 7000 | -13.3600 | 87.5  | -1169.0 | 2   |
| 189 | -0.9129 | -0.0018260 | 1500 | -2.7390 | 938.0  | -2569.0 | 1   |
| 190 | -0.9129 | -0.0018260 | 7000 | -12.7800 | 25.5  | -325.9  | 2   |
| 191 | -0.8801 | -0.0017600 | 1500 | -2.6400 | 562.5  | -1485.0 | 1   |
| 192 | -0.3149 | -0.0006298 | 1500 | -0.9448 | 562.5  | -531.4  | 1   |
| 193 | 0.0355  | 0.0000709 | 1500 | 0.1064  | 562.5  | 59.9    | 1   |
| 194 | 0.4146  | 0.0008292 | 7000 | 5.8050  | 16.9   | 98.1    | 2   |
| 195 | 0.0299  | 0.0000423 | 1500 | 0.0635  | 1723.0 | 109.4   | 1   |
| 196 | -0.4693 | -0.0006636 | 1500 | -0.9955 | 1723.0 | -1715.0 | 1   |
| 197 | 0.0818  | 0.0001157 | 1500 | 0.1735  | 1325.0 | 229.9   | 1   |
| 198 | -0.8846 | -0.0012510 | 1500 | -1.8770 | 1325.0 | -2486.0 | 1   |
| 199 | 0.0225  | 0.0000318 | 1500 | 0.0477  | 795.5  | 37.9    | 1   |
| 200 | -1.0660 | -0.0015080 | 1500 | -2.2620 | 795.5  | -1799.0 | 1   |
| 201 | 0.0135  | 0.0000191 | 1500 | 0.0287  | 795.5  | 22.8    | 1   |
| 202 | -0.7794 | -0.0011020 | 1500 | -1.6530 | 795.5  | -1315.0 | 1   |
| 203 | -0.0525 | -0.0000743 | 1500 | -0.1114 | 795.5  | -88.6   | 1   |
| 204 | -0.4834 | -0.0006836 | 1500 | -1.0250 | 795.5  | -815.7  | 1   |
| 205 | -0.0765 | -0.0001082 | 1500 | -0.1623 | 795.5  | -129.1  | 1   |
| 206 | -0.0879 | -0.0001242 | 1500 | -0.1864 | 795.5  | -148.3  | 1   |
|   |    |      |    |      |      |  |
|---|----|------|----|------|------|---|
| 207 | −0.1523 | −0.0003046 | 1500 | −0.4569 | 1688.0 | −771.2 | 1 |
| 208 | 0.5496 | 0.0010990 | 7000 | 7.6950 | 44.2 | 340.1 | 2 |
| 209 | 0.5894 | 0.0008335 | 7000 | 5.8340 | 52.9 | 308.6 | 2 |
| 210 | −0.7253 | −0.0010260 | 1500 | −1.5390 | 1591.0 | −2448.0 | 1 |
| 211 | −0.8054 | −0.0011390 | 1500 | −1.7080 | 1591.0 | −2718.0 | 1 |
| 212 | −1.0390 | −0.0014690 | 1500 | −2.2040 | 1591.0 | −3507.0 | 1 |

**right base enlargement**