Use of Composite Materials for High-Rise Buildings

**Abstract**

Theory of non-homogeneous anisotropic materials is formulated by means of asymptotic integration method. As an application a column of laminated materials is considered. Great structural advantages are obtained. Due to the anisotropic nature of composite materials, six different stresses and six different strains must be examined from a three-dimensional element of the material, thus we are not allowed to ignore any of 36 elastic constants without reasonable elimination method. The solution simplifies all natural characteristics of the material originally considered, agrees reasonably with that of conventional characteristics of conventional material. Using composite materials in high-rise building construction will result in great advantages.

Keywords: Asymptotic Integration Method; Composite materials; Concrete Core wrapped with Laminated Composites; Cylindrical Shell Theory; High Strength Columns for High Rise

**Introduction**

Composite materials are being widely used in aerospace and automobile industries today but not are not so common for building structural applications. This is due to the fact that the economy of the materials is not yet feasible for the building projects when compared to conventional materials. Also, the mechanics of the materials have not been extensively analyzed for high strength/density and modulus/density ratios. Composite materials are generally composed of filaments and matrix material. The filaments are embedded in the matrix materials to give additional stiffness and thus they are often called reinforcing fibers. They can be arranged arbitrarily so as to make a structure that is more load-resistant. As the mechanical properties of composite materials vary depending on the direction of the fiber arrangement, it is necessary to analyze them by use of an anisotropic theory. Composite materials are also, in general, constructed of thin layers that may have different thicknesses and different angle of fibers called ply angles. The cross-ply angle is the angle between major elastic axis of the material and reference axis (see Figure 2). The variation in properties in the direction of the thickness implies non-homogeneity of the material and composite structures must thus be analyzed according to theories that allow for non-homogeneous anisotropic material behavior.

For a high-rise building, a circular shape will have apparent advantages for wind and seismic loadings, which will be free from torsional motion. Wind loads in particular will increase exponentially as the height of building increases, as follows:

\[
\left( \frac{V}{V_0} \right) = \left( \frac{H}{H_0} \right)^{3\alpha} \tag{1.1}
\]

Where \( H \) is elevation of the building, \( V \) is the wind velocity of a point of concern and \( V_0 \) and \( H_0 \) are those of ground elevation, \( \alpha \) is a factor to be determined by the condition of the wind and terrain. Once we obtained the wind velocity, we will be able to obtain the pressure due to the wind as follows:

\[
\left( \frac{P}{P_0} \right) = \left( \frac{V}{V_0} \right)^3 \tag{1.2}
\]

The authors recommend a circular or close to circular shape for high-rise buildings, as it will have definite structural advantages. Composite materials are a mixture of fibers that are placed into an embedded matrix, as shown in the figures. B

Structures of composite materials are normally fabricated in the form of a laminate. We will start with a development of a cylindrical shell theory, which are simple to compare with other structural forms and can be applied to most relevant members.
The theory of shells is a part of the theory of elasticity; it is concerned with the study of deformations of thin elastic bodies under the influence of loadings. According to the exact three-dimensional theory of elasticity, a shell element is considered as a volume element. All possible stresses and strains are assumed to exist and no simplifying assumptions are allowed in the formulation of the theory. We therefore allow for six stress components, six strain components, and three displacements. There are then a total of 21 to solve for in a general three-dimensional elasticity problem. On the other hand, three equilibrium equations and six strain displacement equations can be obtained for a volume element, and six generalized Hook’s law equations can be used. A total of 15 equations can thus be formulated so it is possible to arrive at a solution for a three-dimensional elasticity problem. It is however very difficult to reach a unique solution which satisfies both the above 15 equations as well as the associated boundary conditions. This led to the development of various technical solutions for the structures.

One way to step back from the classical assumptions is to apply the asymptotic method to the three-dimensional elasticity equations, and thus obtain "rational two-dimensional shell theories." The purpose of asymptotic methods is, at their foundation, a desire to obtain a solution that is approximately valid when a physical parameter (or a variable) of the problem is very small (or very large).

Formulation of Shell Theory

Consider a non-homogeneous, anisotropic volume element of a cylindrical body with longitudinal, circumferential, angular, and radial coordinates being noted as \( r, \theta, z \) respectively, and subjected to all possible stresses and strains (see Figure 1). The cylinder occupies the space between \( a \leq r \leq a+h \) and the edges are located at \( z=0 \) and \( z=L \). Here, \( a \) is the inner radius, \( h \) is the thickness, and \( L \) is the length.

Assuming that the deformations are sufficiently small so that linear elasticity theory is valid, the following equations govern the problem:

\[
\begin{align*}
\sigma_{rr} + \sigma_{\theta\theta} + \sigma_{zz} + \tau_{r\theta} + \tau_{r\phi} + \tau_{\phi\phi} &= 0 \\
\tau_{r\theta} + \tau_{\theta\phi} + \tau_{\phi\phi} + \tau_{\phi\phi} &= 0 \\
\tau_{r\phi} + \tau_{\phi\phi} &= 0
\end{align*}
\]

\[ (1.2) \]

Equilibrium Equations

\[
\begin{align*}
(r \tau_{r,z})_r + \tau_{r,\theta} + (r \sigma_{r,z})_r &= 0 \\
(r \tau_{r,\theta})_r + \sigma_{\theta,\theta} + (r \tau_{\phi,\phi})_r + \tau_{r,\phi} &= 0 \\
(r \tau_{r,\phi})_r + \tau_{\phi,\phi} + (r \tau_{r,\phi})_r - \sigma_{\phi} &= 0
\end{align*}
\]

\[ (2.1) \]

Stress-Displacement Equations

\[
\begin{align*}
u_{rr} &= S_{11} \sigma_r + S_{12} \sigma_\theta + S_{13} \sigma_z \\
&+ S_{14} \tau_{r\theta} + S_{15} \tau_{r\phi} + S_{16} \tau_{\phi\phi} \\
\frac{1}{r}(u_{r,\theta} + u_{\phi,\phi}) &= S_{12} \sigma_r + S_{22} \sigma_\theta + \ldots \\
&+ S_{26} \tau_{\phi\phi}
\end{align*}
\]

\[
\begin{align*}
u_{r,\theta} &= S_{13} \sigma_r + \ldots + S_{36} \tau_{\phi\phi} \\
\frac{1}{r}(u_{r,\theta} + u_{\phi,\phi}) &= S_{13} \sigma_r + \ldots + S_{36} \tau_{\phi\phi}
\end{align*}
\]

\[ (2.2) \]

Each layer is of anisotropic material of different cross-ply, this non-homogeneity is now restricted such that it only occurs in the radial direction.

\[
S_{ij} = S_{ij}(r)
\]

\[ (2.3) \]

The principal material axes \( (r', \theta', z') \) generally do not coincide with the body axes of the cylinder \( (r, \theta, z) \) if the material properties \( S_{ij} \) with respect to material axes specified, then the properties with respect to the body axes are given by the following transformation equations:

\[
\begin{align*}
S_{11} &= S'_{11} \cos^2 \gamma + (2S'_{12} + S'_{66}) \sin^2 \gamma \cos^2 \gamma + S'_{22} \sin^2 \gamma \\
&+ (S'_{16} \cos^2 \gamma + S'_{26} \sin^2 \gamma) \sin^2 \gamma, \\
S_{22} &= S'_{11} \sin^2 \gamma + (2S'_{12} + S'_{66}) \sin^2 \gamma \cos^2 \gamma + S'_{22} \cos^2 \gamma - (S'_{16} \sin^2 \gamma + S'_{26} \cos^2 \gamma) \sin^2 \gamma,
\end{align*}
\]

\[
\begin{align*}
S_{12} &= S'_{12} \cos \gamma \sin \gamma + S'_{16} \sin \gamma, \\
S_{21} &= S'_{12} \cos \gamma \sin \gamma + S'_{26} \sin \gamma, \\
S_{16} &= S'_{16} \cos \gamma - S'_{26} \sin \gamma, \\
S_{26} &= S'_{16} \cos \gamma - S'_{26} \sin \gamma,
\end{align*}
\]
\[ S'_{16} = S'_{22} + (S'_{11} + S'_{22} - 2S'_{16}) \sin^2 \gamma \cos^2 \gamma + 12(S'_{26} - S'_{16}) \sin \gamma \cos \gamma \]

\[ S_{66} = S_{66} + 4(S'_{11} + S'_{22} - 2S'_{16}) \sin^2 \gamma \cos^2 \gamma + 12(S'_{26} - S'_{16}) \sin \gamma \cos \gamma \]

The maximum pressure the concrete core can take is, according to American Concrete Institute specification, needs further experimental verification.

**Formulation of the Equations as a Boundary Layer Problem**

A theory of cylindrical shells is distinguished from the exact three-dimensional formulation by the fact that one of the coordinates – the \( z \), longitudinal – is suppressed in the mathematical description. It will simplify the procedure used here for obtaining two-dimensional thin shell equations is that obtained through the asymptotic integration of the equations (2.1) and (2.2).

As a first step towards integrating the above two equations, we must non-dimensionalize the coordinates as follows:

\[
X = (z/L), \quad Y = [(r-a)/h], \quad \Theta = (\theta/\beta) = (\theta a/l)
\]

where \( L \) and \( l \) \((=b a)\) are quantities which are to be determined later.

Next, the compliance matrix, the stresses, and the deformations are non-dimensionalized through the use of a representative stress level \( \sigma \) and representative material property \( S \), and the cylindrical shell radius \( a \) as follows:

\[
S'_{ij} = S S_{ij}
\]

Also, where \( L \) is the length of the cylinder and \( p \) is lateral pressure on the cylinder wall due resulting from the wet to wet state of concrete or the pressure after the concrete is cured and maximum loading capacity of the structure. \( q \) is the uniformly distributed pressure on the concrete core and composite materials cylinder.

The maximum pressure the concrete core can take is, according to American Concrete Institute specification, needs further experimental verification.

**Stress-Displacement Relations**

\[
\sigma_x = \sigma_{r\theta}, \sigma_\theta = \sigma_{r\theta}, \sigma_r = \sigma_{r\theta}
\]

\[
\tau_{r\theta} = \sigma_{r\theta}, \tau_{rz} = \sigma_{r\theta}, \tau_{r\theta} = \sigma_{r\theta}
\]

\[
u_x = \sigma_{r\theta}, \nu_\theta = \sigma_{r\theta}, \nu_r = \sigma_{r\theta}
\]

\[
u_x = (l/a)\left[S_{11} t + S_{12} t + S_{13} t + S_{14} t + S_{15} t + S_{16} t\right]
\]

\[
u_{y} = \lambda v_{y} + (l/a)(1+\lambda y)v_{y} = \lambda (l/a)(1+\lambda y)\left[S_{41} t + S_{42} t + S_{43} t + S_{44} t + S_{45} t + S_{46} t\right]
\]

\[
u_{z} = (l/a)\left[S_{11} t + S_{12} t + S_{13} t + S_{14} t + S_{15} t + S_{16} t\right]
\]
(a/L)v_{\theta,\theta} + v_z = 
(l + \lambda y)[S_{21} t_z + S_{22} t_{\theta,\theta} + S_{23} t_{\theta} + S_{24} t_{r\theta} + S_{25} t_{rz} + S_{26} t_{r\theta}]

(a/L)(1 + \lambda y)v_{\theta,\theta} + (a/L)v_{z,\theta} = 
(1 + \lambda y)[S_{61} t_z + S_{62} t_{\theta,\theta} + S_{63} t_{\theta} + S_{64} t_{r\theta} + S_{65} t_{rz} + S_{66} t_{r\theta}]

(3.5)

Equilibrium Equations

\[
\left[ t_{rx} (1 + \lambda y) \right]_{y} + (\lambda a/l) t_{\theta,\theta} = 0
\]

\[
\left[ t_{ry} (1 + \lambda y) \right]_{y} + (\lambda a/l) t_{\theta,\theta} = 0
\]

\[
\left[ t_{r} (1 + \lambda y) \right]_{y} + (\lambda a/l) t_{r \theta,\theta} = 0
\]

(3.6)

In the above, \( \lambda \) is a small parameter defined as follows:

\[
\lambda = h/a
\]

(3.7)

The compliance matrix \( S_{ij} \) are assumed to be expanded in terms of a finite sum as follows:

\[
S_{ij}(y;\lambda) = \sum_{n=0}^{N} S_{ij}^{(n)}(y) \lambda^{n/2}
\]

(3.9)

We will then assume the components displacement and stress can be expanded in terms of power series in \( \lambda^{1/2} \) as follows:

\[
v(y, x, \phi; \lambda) = \sum_{m=0}^{M} \phi^{(m)}(y, x, \phi) \lambda^{m/2}
\]

\[t(y, x, \phi; \lambda) = \sum_{m=0}^{M} t^{(m)}(y, x, \phi) \lambda^{m/2}\]

(3.10)

We will now apply the characteristic length scales as follows in longitudinal and circumferential directions. It is assumed to be realistic approach for the loading and boundary conditions. The cylindrical shell will deform axi-symmetric circumferentially and the governing deformation is in the longitudinal direction. The geometric boundary and loading conditions are as we defined in the equation (2.5), the shell is under the internal pressure \( p \) due to the concrete core wrapped by shell of non-homogeneous anisotropic materials.

\[L = [(ah)1/2l] = a\]

(5.1)

Substituting the above length scales into general equilibrium and stress displacement relations described by equations (3.3) and (3.4) we obtain:

\[v_{\theta,\theta} = \lambda1/2 \left[ S_{11} t_z + S_{12} t_{\theta,\theta} + S_{13} t_{\theta} + S_{14} t_{r\theta} + S_{15} t_{rz} + S_{16} t_{r\theta} \right]
\]

\[v_{\theta,\theta} = \lambda1/2 \left[ S_{21} t_z + S_{22} t_{\theta,\theta} + S_{23} t_{\theta} + S_{24} t_{r\theta} + S_{25} t_{rz} + S_{26} t_{r\theta} \right]
\]

(5.2)

Equilibrium Equations

\[
\left[ t_{rx} (1 + \lambda y) \right]_{y} + \lambda t_{\theta,\theta} = 0
\]

\[
\left[ t_{ry} (1 + \lambda y) \right]_{y} + \lambda t_{r \theta,\theta} = 0
\]

\[
\left[ t_{r} (1 + \lambda y) \right]_{y} + \lambda t_{r \theta,\theta} = 0
\]

(5.3)

From the examining of the above equations (5.4) we will find the dominant stresses are in-plane with normal stress. The radial, longitudinal, and circumferential displacements are of order zero, one, and two, respectively in \( \lambda^{1/2} \) while all other in-plane components of the compliance matrix are of zero order zero. Integration of the first three equations of equation (5.4) with respect to the thickness of coordinate \( y \), we will obtain:

\[v_{r}^{(0)} = v_{r}^{(1)}(x, \theta) - v_{r}^{(0)}(x, 0)
\]

\[v_{z}^{(1)} = v_{z}^{(1)}(x, \theta) - v_{r}^{(0)}(x, 0)
\]

(5.4)

The quantities of \( V_r, V_z, V_{\theta} \) and \( V_{\theta,\theta} \) are integration constants which correspond to the displacement as prescribed in the boundary conditions defined by the equation (2.5).

The mid-surface equations of (5.4) can now be solved for the in-plane stresses as shown below:

\[v_{r}^{(0)} = 0
\]

\[v_{z}^{(1)} + v_{r}^{(0)} = 0
\]

\[v_{r}^{(1)} = v_{r}^{(0)}(x, \theta) - v_{r}^{(1)}(x, \theta)
\]

(5.5)
\[
\begin{bmatrix}
t_z^{(0)} \\
t_\theta^{(0)} \\
t_z^{(1)} \\
t_\theta^{(1)}
\end{bmatrix} = [C] \begin{bmatrix}
\varepsilon_1 \\
\varepsilon_2 \\
\varepsilon_{12}
\end{bmatrix} + [C] \begin{bmatrix}
k_1 \\
k_2 \\
k_{12}
\end{bmatrix} \gamma
\]

(5.6)

Where \( C_{ij} \) (\( i,j=1,2,3 \)) are the components of a symmetric matrix given by:

\[
[C] = \begin{bmatrix}
S_{11}^{(0)} & S_{12}^{(0)} & 0 \\
S_{21}^{(0)} & S_{22}^{(0)} & 0 \\
0 & 0 & S_{66}^{(0)}
\end{bmatrix}^{-1}
\]

(5.7)

\( \varepsilon_1, \varepsilon_2, \varepsilon_{12} \) are the in-plane strain components of the \( y=0 \) surface.

\[
\varepsilon_1 = V_{r,x}^{(1)} \\
\varepsilon_2 = V_r^{(0)} \\
\varepsilon_{12} = V_{r,\theta}^{(1)} + V_{\theta,x}^{(2)}
\]

(5.8)

We will bring the changes of curvature as follows:

\[
K_1 = -V_{r,xx}^{(0)} \\
K_2 = 0 \\
K_{12} = -2V_{r,\theta}^{(0)}
\]

(5.9)

Strain components at the surface \( y = \) constant are given by:

\[
\varepsilon_{1y} = \varepsilon_1 + K_1 y \\
\varepsilon_{2y} = \varepsilon_2 \\
\varepsilon_{12y} = \varepsilon_{12} + K_{12} y
\]

(5.10)

Substituting the first approximation in-plane stress-strain relations of (5.6) into the equation (5.4) and integrating with respect to \( y \), we can obtain the following solution for transverse stresses:

(See Equation 5.11 below)

Application

For the purpose of demonstrating the applicability of the previously derived theories, the problem of a laminated circular cylindrical shell under internal pressure and edge loadings will next be examined. The shell is assumed to build with boron/epoxy composite layers. Each layer is taken of a laminated circular cylindrical shell under internal pressure and edge loadings will next be characterized. It will also predict the stresses of columns made of composite materials cored by reinforced concrete; the differential equations can be solved with applying proper boundary conditions, and consequently we can predict maximum allowable stress levels consequently.

Although as mentioned above, the theory developed can consider random layering, numerical results are to be carried out for a four-layer symmetric angle ply configuration. For this configuration the angle of elastic axes \( Y \) is oriented at \( +Y, -Y, -Y, +Y \) with the shell axis and the layers are of equal thickness.

Use of laminated composite materials for high-rise buildings are itemized as follows:

- Columns
- Beams and girders
- Slab
- Wall panel

We will first apply the developed shell theory to the column, where outer shell is laminated circular cylindrical shell and inside will be filled with high strength concrete material.

Let the cylinder be subjected to an internal pressure \( p \), an axial force per unit circumferential length \( N \) and a torque \( T \). The axial force is taken to be applied at \( r = a + h \) such that a moment \( N(h-d) \) is produced about the reference surface \( r = a + h \). We introduce dimensionless external force and moments as follows:

\[
\begin{align*}
N &= N/(\sigma \lambda a) \\
M &= \left[N(H-d)\right]/(\sigma \lambda^2 a) \\
T &= T/[2\pi \sigma \lambda^3 a(1+d/a)]
\end{align*}
\]

(9.1)

The cylinder is taken to be hinged at both ends but free to rotate and extend axially at one end. The edge conditions can thus be written as:

\[
\begin{align*}
V_i &= V_{r,xx} = V_z = V_{\theta} = 0, \\
&= 0, y = d/h \\
V_{r,i} &= 0, N_z = N, M_z = M, \\
&= L, y = d/h \\
(1+d/a) N_{z\theta} + \lambda M_{z\theta} &= T
\end{align*}
\]

(9.2)

Equation 5.11
Here, $L$ is the dimensionless length of the cylinder.

In the theories developed in the previous chapters, the distance $d$ at which the stress resultants were defined was left arbitrary. We now choose it to be such that there exists no coupling between $N_z$ and $K_1$ and $M_z$ and $\varepsilon_{id}$.

As the loading applied at the both ends of the shell, as column load and also the lateral pressure load due to the pressurized core material taken as, $p$, are all axi-symmetric, the stresses and strains are also taken to be axi-symmetric. We thus can set all the derivatives in the expressions for the stresses and strains and in the equations for the displacements equal to zero.

Numerical calculations are now carried out for a shell of various dimensions:

We used $\lambda = 0.025(0.1/0.4)$. Each of the layers is taken to be 0.025 inches thick and thus the dimensionless distances from the bottom of the first layer are given by

$S_1 = 0, S_2 = 0.25, S_3 = 0.5, S_4 = 0.75, S_5 = 1.0$

Each layer of the symmetric angle ply configuration elastic symmetry axes $\gamma$ are oriented at ($+\gamma, -\gamma, -\gamma, +\gamma$) is taken to be orthotropic with engineering elastic coefficients representing those for a boron/epoxy material system,

$E_1 = 35 \times 10^3 \text{ ksi}$

$G_{12} = 0.75 \times 10^3 \text{ ksi}$

Here direction 1 signifies the direction parallel to the fibers while 2 is the transverse direction. Angles chosen were $\gamma = 0, 15, 30, 45, 60$. Use of the transformation equations (2.6) then yields the mechanical properties for the different symmetric angle ply configurations.

We next apply the following edge loads:

$N = p$ and take $\sigma = p/\lambda$.

$H = (3/4)h$ and the reference surface we take $(d/h) = (1/2)$.

Shown in figures 3 to figure 6 is the variation of the dimensionless radial displacement with the actual distance along the axis for the different theories. The reference surface for the chosen configuration is given by $(d/h) = (1/2)$. The integration constants determined from the edge conditions. The radial deformations of the length scales $(ah)1/2$ is shown in figure 3. One will notice the radial deformation is rapidly increases along the length scale.
In each case, the displacements increase with large cross-ply angles and thereafter decrease. For weak and at take place with change in the cross-ply in the magnitude of radial displacement. We also observed that wide variations in the radial pressure will produce lateral deformation, as well as lateral pressure to be applied to the wall of the cylindrical shell.

We also observed that wide variations in the magnitude of radial displacement take place with change in the cross-ply angle. The maximum displacement occurs at $\gamma = 30$ degree while the minimum displacement is at $\gamma = 60$ degree.

In each case, the displacements increase with increase in $\gamma$ up to $\gamma = 30$ degree and thereafter decrease. For weak and smooth edge effects are normal the case for with large cross-ply angles $\gamma$. near the edge, while further inside deformations are not much of change. This is so-called "edge effect zone" or "boundary layer." The American Concrete Institute presented high-strength concrete core material under the direct pressure load will produce lateral deformation, as well as lateral pressure to be applied to the wall of the cylindrical shell.

Through the As a result of the application of this method, one can obtain approximations of shell approximate theory of various orders in a systematic manner. The first approximation theories derived in this thesis represent the simplest possible shell theories for the corresponding length scales considered. Although twenty one elastic coefficients are present in the original formulation of the problem, only six are appear in the first approximation theories. The shell theories thus assumed the existence of a plane of elastic symmetry. It was seen that use of the asymptotic method employed in the thesis also yields expressions for all stress components, including the transverse ones. The fact that these expressions can be determined is extremely useful when discussing the possible failure of composite shells. It was seen that various shell theories are obtained by using different combinations of the length scales introduced in the non-dimensionalization of the coordinates and that each theory possess unique properties such as the orders of magnitudes of the stress and displacement components and edge effect penetration.

To illustrate the use of these theories, the application to layered shells was shown. The particular problem considered consisted of a symmetric angle-ply configuration under load and edge conditions used in the laboratory to determine the mechanical properties of composites. The results of the analysis showed the radial displacement first increases with increase of the angle between the axis of elastic symmetry and longitudinal shell axis, being largest at 30 degree. It was then decreases with further increase in angle. The theory of axial and circumferential length scale of $(ah)^{1/2}$ show a significant edge effect exists and that the penetration of the edge effect

Conclusion

We have applied asymptotic integration method to solve for the problem of stresses and deformations of a cylindrical shell filled with high strength concrete core material, all subject to the vertical column loads as well as lateral pressure due to the deformed core material. The first approximation shell theories are derived by use of the method of asymptotic integration of the exact three-dimensional elasticity equations for a non-homogeneous anisotropic circular cylindrical shell.

The analysis is valid for materials which are non-homogeneous to the extent that their properties are allowed to vary with the radial (thickness) coordinate.

The American Concrete Institute is so-called "edge effect zone" or "boundary near the edge, while further inside deformations are not much of change. This is so-called "edge effect zone" or "boundary layer." The American Concrete Institute presented high-strength concrete core material under the direct pressure load will produce lateral deformation, as well as lateral pressure to be applied to the wall of the cylindrical shell.

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The above is more significant for high-rise buildings (Source: University of Utah)
changes with the angle in similar fashion as for the radial displacement, being deepest at 30 degree.

In this thesis, the different theories were applied separately to the solution of a layered shell problem. The solution of a general non-homogeneous anisotropic shell problem can be obtained by a the theories derived here but the theory is limited to only for the case of longitudinal and circumferential characteristic length scales of \((ah)^{1/2}\). It would will be necessary to investigate the case of different shell theories with length scales for different loadings and different materials. The solutions of the theories presented here are expected to approximate the three-dimensional solution accurately outside the very narrow boundary layer of length scale h. Also the effect of the stresses and deformations acted by the core materials is important and further studies are demanded.

For fabrication and erection we need to evaluate and located exact neutral axes and work points for each member and joints. There can be considerable secondary bending moments caused by the eccentricity produced by poor location of work points at each joints as follows:

\[ M = \sum (p_i e_i) = 1 k_i \]

Where \(p_i\) is force acting on the member and \(e_i\) is eccentricity on each member and \(k_i\) is distribution carry over factor.

The above is more significant for high-rise buildings.

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