

Chapter 3 – Structural Design

3.0 General

3.0.1 Design Overview

Greenhouse buildings are a complete structure including the structural support and enclosure elements.

The primary structural system includes:

- The Primary Roof system - This is typically a truss, rigid frame, arch or similar system
- Secondary Structural System - This includes bracing elements and enclosure support components such as purlins, glazing bars, ridge beam and gutters as well as girts. End wall framing may be a primary or secondary structural system. Many of these secondary components have several roles, supporting the glazing, dead and live load, as well as bracing a structure, and axial load.
- Columns - Columns, end walls, enclosing walls or other elements
- Foundations - The foundation may be spread footings, continuous concrete footings or flagpole type foundations placed directly in the earth. Sometimes the flagpole type footings may be backfilled with concrete or other fill. In greenhouse design, flagpole type footings are usually designed as unrestrained foundations. Where there is a slab on grade present, a restrained pole footing may be used. Such a footing requires a positive “hoop” tie that extends into the slab and around the pole, and the pole footing cannot be isolated by an expansion joint.
- Cladding - Cladding may be of many materials including glass, polycarbonates, fiberglass or polyethylene. Cladding support and fastening systems vary by material. Cladding is not part of the structural system and is not covered in this structural design manual. Cladding, and its design criteria, is discussed at length in a separate document.

3.0.2 Structural Design

The IBC requires all buildings to have a rational analysis. Rational engineering analysis is a computational analysis, either by hand or computer, that uses accepted load distribution and determination methods. Such analysis shall follow acceptable engineering practices. Where the code is non-specific in the method of analysis, as with trusses vs. arches, the engineer shall analyze the system using a method acceptable to the approving authority. Thus, each engineer will analyze the system using an accepted method. However, the detailed design must accommodate all the forces and moments on the individual members as discussed above.

Manual or graphical solutions are permissible if such analysis can account for the various unbalanced load or other special design requirements. For most structures a computer modeling type analysis will be necessary. Based on the typical greenhouse design, the sections herein

specify acceptable types of design methods.

Allowable stresses for various materials will be obtained from ASTM Standards and industry sources, such as AISC, AISI or AA, as applicable.

Steel design criteria is established by the American Institute of Steel Construction (AISC) for hot-rolled structural members, and the American Iron and Steel Institute (AISI) for cold-formed light gauge steel design. Cold-formed steel is usually less than 3/16" thick and is made from a variety of steel types. These are generally high strength materials when compared to conventional, small shapes in structural steel. Cold-formed materials may be formed to any shape but are typically the shape of a channel, square or round tube. Structural steel has 3/16" or greater thickness and is available in a range of shapes including I-shape, channel, angle, flat bar, pipes, and tubing. The AISC standards are in their handbook, which includes a commentary. The AISI provisions are in other handbooks. These books provide both the design formulas and the allowable stresses.

There are two design approaches for steel today. Allowable stress design (ASD) is the traditional methodology used by engineers. Load and resistance factor design (LRFD) is a newer, strength design approach. Its usefulness to small structures such as short trusses will need to be determined by the individual design. The design approach used will determine whether ASD or LRFD load combinations are used.

Many manufacturers use aluminum components as part of the truss system. Aluminum design shall be in accordance with the Aluminum Handbook published by the Aluminum Association.

This manual includes a general discussion of typical greenhouse roof structural systems. It also includes specific design issues related to individual roof systems and elements.

Because some issues cross all different structural systems and components, a general discussion of issues related to bracing and connections is included in this section.

3.0.3 Bracing

Steel and other structures include secondary bracing members incorporated into the system of main members. These bracing elements include the following:

Slender compression members: trusses, beams, etc. are laterally supported or braced so as to resist the tendency to buckle in a direction normal to the stress path.

Needed structural rigidity is provided by the secondary bracing members or by rigid joints between members. (Trusses, being rigid, do not require additional rigidity in the plane of the truss.)

Bracing may be needed during erection. Good design integrates this bracing as part of the total structure.

There are no fixed rules or specifications for lateral bracing of beams. Tests and studies indicate that it takes a rather small force to balance the lateral thrusts of initial buckling. Most engineers use the rule of thumb of 2% of the axial load of columns or 2% of the total compressive stress in beam flanges. (Studies indicate that these values are conservative.) NGMA designs shall be laterally braced for a minimum of 2% of the axial load.

3.0.4 Connection Materials

Regardless of the specific roof framing system and materials, the components must be fastened together. The individual sections of this manual describe specific connection considerations. This section describes some of the considerations for fasteners and fastening methods. Examples of approvals and manufacturer's information are provided at the end of this manual.

Connections may be made with:

- Structural Steel Bolts - When structural steel shapes of A-36 are used. Such bolts are usually 5/8 inch diameter or larger. The allowable loads are published in the AISC Handbook.
- Bolts - Bolts are usually steel of 1/2 inch diameter or less. These are used for light gauge steel members. Values for bolts shall be obtained from AISI publications.
- Screws - Screws may be placed in drilled holes or be self-tapping. Values for screws are usually obtained from manufacturer's literature. Manufacturers' literature may recommend design values or may report test results. Some will report an average ultimate, others the low ultimate or range of test results. Screws having Building Code Evaluation Reports are recommended. Screws not having Building Code Evaluation Reports are subject to the Building Official's approval. *Usually these screws have a Factor of safety of 3.5 for the average ultimate test value or 2.5 from the lowest ultimate test value.*
- Welding - Published values for weld metal and strengths shall be obtained from AWS, AISC books or Aluminum Association literature.

3.0.5 Technical Definitions and Explanations

In the course of the following chapter the terms listed below are used frequently.

- CONSENSUS STANDARD – a consensus standard is developed by an organization that is accredited by ANSI. These are voluntary consensus standard for products and processes and require that there be a balanced committee consisting of producers, consumers, and general interest persons. Within the consensus standard process there is openness and due process. Building codes adopt consensus standards by reference. But it takes a building code to implement to provide an enforcement context to them.
- RATIONAL ENGINEERING ANALYSIS – a computational analysis, either by hand or computer, that uses accepted load distribution and determination methods. *As late as the 1997 UBC, 'rationality' was included in the code (Section 1605.2) with the statement "Any system or method of construction to be used shall be based on a rational analysis in accordance with well-established principles of mechanics. Such analysis shall result in a system which provides a complete load path capable of transferring all loads and forces from their point of origin to the load-resisting elements."*
- TRUSS ANALYSIS – a hand or computer analysis of a truss system that follows the principles of statics and mechanics.

3.1 Roof Support Systems

3.1.1 Primary Systems

The primary roof supporting structure shall be designed, along with secondary components and bracing, to take vertical loads as well as lateral wind and seismic loads.

Vertical loads consist of dead load, live load, collateral loads, plant loads, snow load, wind load, and rain load. The loads are transferred through the roof systems to vertical supports, such as columns or end walls, and are then distributed through the foundations into the soil. Lateral loads consist of wind and seismic loads that are transferred through a continuous load path from the roof to the foundation.

Section 1604.4 of the IBC requires all structures to be designed. The code states “Load effects on structural members and their connections shall be determined by methods of structural analysis that take into account equilibrium, general stability, geometric compatibility, and both short- and long-term material properties.”

The IBC goes on to state “Any system or method of construction to be used shall be based on a rational analysis in accordance with well-established principles of mechanics. Such analysis shall result in a system that provides a complete load path capable of transferring loads from their point of origin to the load-resisting system.”

This section is comprised of a discussion of primary roof systems. These roof systems include the following:

- Trusses
- Parallel Chord Trusses
- Arches
- Rigid Frames

Individual elements, such as connections and bracing, are described for each system. The discussion is further organized into a series of divisions, as follows.

- Criteria
- Commentary
- Design Approach and Assumptions
- Building Code and Referenced Consensus Standards (typically adopted by reference) – a consensus standard is a standard that has been developed using an American National Standards Institute (ANSI) approved consensus process.
- Industry Standards – have not been developed by an ANSI approved consensus process.
- Manufacturers’ Literature – the engineer must verify the manufacturers’ literature and critically review the supplied information for code compliance.

- Engineering Judgement and Technical Literature – the basis for the evaluation and design process that utilizes published engineering journals as a design resource.

3.1.1.1 Trusses

General Requirements

Trusses shall be analyzed by a rational procedure as required by the building code and discussed in earlier sections. Where trusses do not meet all the assumptions listed, or are of unusual shape or configuration, the truss and its individual members shall be designed using a rational analysis method that considers the specific configuration conditions.

Several shapes can be considered for truss designs. Typically a peaked or curved top chord is seen. Some shapes will require a more rigorous analysis.

Each member must be designed for the actual load acting on it including both vertical and lateral loads. The member shall be sized for the combined load.

The appropriate load combinations and allowable stress increases shall be considered in determining the member sizing.

The building code requires a rational analysis. Since there is a well established body of knowledge of statics for truss analysis, as long as the basic assumptions are followed the design should be acceptable. However, the detailed design must accommodate all the forces and moments on the individual members as discussed above.

Steel design criteria is established by the American Institute of Steel Construction (AISC) for hot-rolled structural members, and the American Iron and Steel Institute (AISI) for cold-formed light gauge steel design. The AISC standards are in their handbook, which includes a commentary. The AISI provisions are in their handbook. These books give both the design formulas and the allowable stresses.

Many manufacturers use aluminum components as part of the truss system. Aluminum design shall be in accordance with the Aluminum Handbook published by the Aluminum Association.

Design of Truss Top Chords

In theoretical analysis, chord elements are assumed straight and pinned at each end. Chord elements that are continuous, curved, arched or of other configurations not in compliance with the assumptions described above shall be analyzed using rigorous methods.

All top chords shall be designed for the vertical loads specified in the loads chapter of this manual or the building code. Where the cladding supports, purlins and other members are applied to a top chord at other than the panel point, the effect of such loads as a bending moment shall be accounted for in the truss and member design. Such loads are in addition to the axial (and bending) determined by the analysis.

Collateral loads applied on the top chord shall be considered for their imposed load and the effects on the truss.

Design of Bottom Chords

Truss analysis develops loads, which are axial, in the bottom chord. Bottom chords shall be designed for the specific applied loads in addition to the computed axial loads. Collateral and plant loads shall be applied linearly along the bottom chord to account for irrigation equipment, hanging baskets, etc. The moments created by collateral loads shall be considered in the design of the bottom chord.

Design of Truss Diagonals

Diagonal and vertical truss elements typically carry only axial loads. Diagonal members shall be designed for the axial load determined in the truss analysis. Where loads other than axial loads occur due to the truss joint conditions, or for other element or load conditions, the members shall be designed for the specific loads.

Where elements are “non-prismatic” at any point in their length, the effect of the change of section shall be considered in determining the load carrying capacity. *See commentary for additional remarks regarding non-prismatic elements.*

Design of Connections

All connections of elements are assumed to have their centroids coincide at a point. Where members entering the joint are not concentric the effect on the members, connector plates and fasteners shall be analyzed. All stresses induced in the truss members shall be considered.

Design of Lateral Bracing

Lateral support shall be provided for top and bottom chord members to resist loads due to compressive forces. The reduced stress based on the l/r ratio of the section with bracing shall be considered and a reduced allowable stress used. Purlins, ridges and other elements serving as lateral bracing shall be designed for the bracing load.

Bracing shall be designed for a minimum of 2% of the axial load of columns or 2% of the compressive stress in the member.

Where cable type bracing is proposed, the design and detailing shall provide a method of applying and adjusting tension to the cables.

Commentary - Trusses

a. Design Approach and Assumptions

General

Component Description – *A truss is any framework of “bars” placed together to form triangles. (“Bars” is the original steel term for selected elements.) Typically trusses of this type are statically determinate internally because all of the stresses in the elements can be computed by use of the equations of statics. Whenever a truss member forms the sides of more than two triangles it is statically indeterminate. (The equations of statics cannot be used to calculate the*

loads in the members.)

There are fundamental assumptions made in truss design. These are:

- The center of gravity lines of all bars meeting at a joint intersect at a point
- All joints are pinned with a frictionless pin
- There is no bending in the members. (For the truss analysis)
- The bars are any structural element, such as an angle, I-shape, tube or flat bar.
- All members are straight.

In the initial analysis, the truss is assumed to be composed of axially loaded members. When the detailed design of the truss and sizing of members is conducted, the design is more complex. The initial design determines the axial load in each member. The detailed design requires each member to be analyzed for the specific loads imposed on the member.

For example a top chord, which in preliminary design had only axial loads from roof loads, which are applied at the panel points, may actually have loads at several points. This includes loads applied by purlins, collateral loads, or by equipment not at the panel point. Further, in some designs, the top chord may not be straight, therefore the member needs to be designed for the axial load, the moments created by the applied loads and the moment caused by the curved top chord.

Top Chord

Technical Issues – The top chord is loaded by the dead load and the live load and snow load or the lateral load. A unique issue in greenhouse design is the lateral bracing of the top and bottom chords. A compression member may buckle under compression. Top chord lateral stability must be considered. The allowable stresses are determined and considered for the actual unbraced length. Typically roof purlins provide bracing. See the discussion on bracing for recommended criteria.

One design approach is to extend the top chord beyond the connection with the bottom chord to connect with the column. The cantilevered top chord design must consider the moments and shear loads resulting from the cantilever. Since this is a continuous member, the stresses in the top chord in the truss itself (beyond the bottom chord joint) must also be considered. If this is accomplished by a sleeve over part of the top chord, to provide additional section, the sleeve, its length and the imposed stress on the truss must be considered.

Curved top chords will have a moment created by the eccentricity of the chord to the theoretical straight chord. This additional moment must be considered in the design of the member.

Bottom Chord

Technical Issues- The bottom chord is a tension member under live and dead load. It may be a compression member under wind loads. The bottom chord becomes a compression member due to the uplift caused by wind. The bottom chord must be checked for stability under various load combinations. The criteria for tension members are not as restrictive as for compression members. Under wind uplift conditions the bottom chord could be a compression member

requiring special evaluation and bracing. The stability of the bottom chord under lateral load shall be demonstrated and bracing provided if required by the analysis. Design load on the bracing would be 2% of the compression load in the bottom chord.

Truss Diagonals

Technical Issues- Diagonal members usually are simple axially loaded members. Their design is much more straightforward. An exception would be the loading of the diagonal with other loads such as sprinklers or equipment. In such cases the diagonal would have to be designed for these additional loads. (An issue to be considered, is owner installed equipment occurring after construction is completed. This should be considered in the collateral load determination)

Industry Practice

Where elements have a shape change, typically at the ends of members, for fabrication and are “non-prismatic” at any point in their length, the effect of the change of section shall be considered in determining the load carrying capacity. (Such conditions occur when a shape is bent or flattened.) The practice of a number of engineers notes that when the change in shape occurs within 2 times the least dimension of the element from the end of the element, the effects of shape change may be ignored. If this practice is used, computations justifying this should be on file.

Connections

Technical Issues- Connections in trusses are assumed to have the resultant (center of gravity) of each member joining at a common point. This is easy to accomplish with two members. With three members entering a joint it becomes a challenge. The eccentric joint creates a moment in the members that must be considered in design.

Out-of-Plane Bracing

Technical Issues- Bracing between the trusses is required to stabilize the buckling potential of the top chord, the bottom chord, and other long compression elements such as struts. The bracing can be spaced to meet the client needs. But increased bracing spacing means that the truss members will be larger to limit the potential for buckling. Each engineer and manufacturer will select their desired and economical top and bottom chord bracing spacing. The bracing should be designed for the 2% of the axial load criteria noted above. The size of the bracing will depend on the unbraced length of the span between trusses and whether it is straight or diagonal.

b. Building Codes and Consensus Standards

c. Industry Standards

d. Manufacturers’ Literature

Manufacturers’ literature will provide the specific structural properties of the structural sections used. Manufacturer’s literature needs to be reviewed by the designer to verify that values provided in the literature are the same as assumed in the design.

Manufacturers’ literature may be a valuable resource for certain types of connection methods.

e. Engineering Judgement and Technical Literature

Connections

The effect of an eccentric connection may be ignored where it does not exceed the depth of member. The reason for this is that the stiffness of the member will distribute the load and it will not effect the chord or diagonal. Where such assumptions are used, an analysis of a typical condition should be made to verify this.

Values for screws may be reported based on test values, such as an average of X tests or as a range of values. The engineer must determine the factor of safety to use under these conditions. A minimum factor of safety of 3.5 against the average ultimate bolt value is suggested. (AISI)

Books on structural analysis and design cover the subject of truss analysis and design. Books such as the Structural Engineers Handbook, AISC Manual of Steel Construction and the Building Code provide criteria for the design of the individual truss members and connections.

Any design that does not meet all the conditions noted above, such as curved top chord, continuous members and eccentric connections, will require additional analysis. This may be by computer analysis with a truss or finite element analysis, or by other numerical analysis methods with engineering judgement. The engineer must carefully consider the effects of the non-standard truss condition. Further, the connection conditions and assumptions must be considered.

ASTM standards provide yield and ultimate strengths for various steel grades. Care must be taken in selecting materials.

The Aluminum Handbook will provide the criteria for aluminum.

3.1.1.2 Parallel Chord Trusses

General Requirements

A parallel chord truss is a truss in which the top and bottom chords are parallel. Parallel chord trusses shall be designed using all of the principles discussed under truss design.

This type of truss, because they frequently have rigid connections, will require analysis by rigorous methods or by physical testing by an independent approved lab. All imposed loads, including point loads, shall be considered.

Where additional structure is added above the parallel chord truss, the system shall be designed to support the superimposed loads.

Commentary - Parallel Chord Trusses

Design Approach and Assumptions

Component Description - Parallel chord trusses are used to span in the transverse direction of a structure, or they may be spaced more closely and span in the longitudinal direction of the

building. The beams are supported on columns or on beams that convey the load to columns. The purlins are solid or may be open web metal joists.

Sections

Literature from product manufacturers may be relevant for some systems.

Connections

Connections are required from the parallel chord truss to the support members. This is usually a pinned connection with no lateral or moment type loads.

Connection design shall consider any eccentricity in the connection and on the beam.

Bracing

Bracing shall be provided between parallel chord trusses when the span to depth ratio exceeds 10. Regardless, evaluation of the potential of load-induced rotation must be considered by the engineer.

Engineering Judgement

In some cases, when the bar joist extends over a column creating a cantilever, a stiffener may be required to prevent local buckling. Analysis of the reaction and local buckling is especially warranted in these cases, and may require stiffeners.

3.1.1.3 Arches

General Requirements

Arch type roof structures shall be analyzed and designed using rational methods as required by the building code and discussed in earlier sections. All imposed loads including point loads shall be considered. Unbalanced loads shall be considered for all elements of the arch.

Each arch, and the individual members shall be designed for the actual load acting on it including both vertical and lateral loads. The member shall be sized for the combined load

Collateral and plant loads, based on the projected area, shall be applied at the arch quarter points.

Design of Tension Ties

The tension tie shall be designed for the loads resulting from the horizontal force of the arch analysis. The tension tie shall be designed considering any superimposed vertical loads. Alternate methods to resist the tension force may be used. Industry practice examples include columns, gutters and other elements.

Design of Connections

Connections shall consider the effects of the tension and other loads on the arch.

Design of Bracing

Arch bracing shall be provided. Such bracing shall be designed for a minimum of 2% of the axial load in the arch.

Commentary - Arches

Design Approach and Assumptions

Component Description - An arch is a curved beam acting in compression. It has a very large radius of curvature relative to its section depth. The vertical loads induce both bending and direct compressive stress in an arch. Further there may be horizontal deflection in addition to vertical deflection.

Stability of an arch is similar to that of the truss. The arch is loaded by the dead load and the live load or the lateral load. A unique issue in greenhouse design is the lateral bracing of the arch. A compression member tries to buckle under compression. Arch lateral stability must be considered. The allowable stresses are determined and considered for the actual unbraced length. Typically roof purlins provide bracing. See the truss discussion on bracing for recommended criteria.

Reactions from an arch have horizontal components even though the loads are vertical. The horizontal reaction in an arch is significantly different than in a truss design. There are no horizontal components at the truss supports. It may be resisted by a tension tie between the supports or by the columns or beams (gutters) acting as buttresses. The specific slope of the arch will determine the type of stresses that must be designed for.

An arch may be shaped several ways depending on the material and spans. The typical arch is a radial arch or bow, but it can be a gothic shape or even an "A" frame. A common arch shape seen in greenhouses is that of the Quonset hut.

The arch may span between columns, beams, gutters or may spring from a foundation near grade.

Gutters that are located on the exterior wall may have an unbalanced load conditions that must be considered. Gutters connecting these arches also produce valley loading that must be considered in the gutter design.

Technical Issues-

Reactions

The reaction at each end of an arch will include a horizontal force outward. This must be resisted by either a tension tie or a beam or gutter or support that can resist this outward load.

Consideration of buckling and shear to the beam, gutter or support is required in a complete design. Anchorage of the roof arch at the top of a cantilevered column must consider these forces. The vertical component of the arch reaction is similar to truss reactions and can be treated in the same manner.

Connections

Connections are required from the arch to the support members. The supporting members require consideration for the horizontal components, as well as the vertical components, of the arch reaction. A connection to the tension tie, if applicable, is also required. Special care is warranted when designing this critical connection.

Bracing

Bracing out of plane is necessary to prevent the arch from lateral buckling.

3.1.1.4 Rigid Frame

General requirements

Rigid frames shall be designed considering all loads on the system. Consideration shall be made for the moment connections and the required details. All superimposed loads described in the general section or in the truss sections shall be considered in the design.

Component design, bracing and connections shall be designed as described in this handbook.

Appropriate unbalanced and collateral loads shall be applied as required.

Rigid frames will have both horizontal and vertical reactions at the column bases. Structural elements to be supported by foundations, building walls and other means that are to be designed or evaluated by others, shall have the design reactions noted on the plans.

Commentary - Rigid Frame

Design Approach and Assumptions

Component Description - A system of beams and columns in which the connections between the members are designed to transfer moment. The connection is designed to allow translation and rotation of all the members without allowing rotation between the members. The angle between the members remains constant. Frames are designed to resist vertical and horizontal loads. Rigid frames are similar to an arch in concept when one considers the connections as a continuation of the structure.

A "Gothic" type roof structure can be designed as a rigid frame, provided the same moment-resisting connections that one would find in a rigid frame are used. However, not all connections in a Gothic roof structure will necessarily be moment resisting.

The critical design feature of a rigid frame is the beam to column connection. This connection must carry the moments as well as the other loads. The vertical and horizontal loads should be adequately transferred to the foundation. The members are designed for bending, shear, and axial stresses. Rigid frames have a horizontal component to their reaction at the column base.

Sections

Section properties of various elements may be obtained from manufacturer's literature.

Connections

Connections must be adequately designed to allow the frame joints to take moments and act as one unit. As stated above, the connection allows the members to have translation and rotation as a unit without allowing rotation between the individual members. The detailing of the rigid connection requires close attention.

Bracing

Bracing shall be provided based on the AISC provisions.

3.1.2 Secondary Systems

Secondary systems, including gutters, ridges, purlins and glazing bars, shall be designed for all loads, including dead and live loads, lateral and applicable collateral loads. Load combinations as required by the building code shall be considered. Designs shall use the analysis methods described earlier in this chapter.

Material properties and strengths shall be as permitted by applicable codes and industry standards.

3.1.2.1 Gutters / Primary and Secondary (Eave Members)

General Requirements

Gutters shall be designed for the loads described in the paragraph 3.1.2 above. Gutters may act as the edge purlin (and carry vertical loads), or may support glazing bars. These gutters may also support arch ends and carry horizontal reaction loads and bending moments along their weak axis. In addition, gutters shall be designed for any lateral loads when used as a collector for lateral forces.

For polyethylene enclosed structures, the gutters shall be assumed to carry the entire upward wind load of the polyethylene when it is attached to the gutter.

Sections

Gutter sections properties shall be noted in the calculations. The details of the gutter section shall be shown on the plans. In some cases the sections properties of the gutter section may be obtained from the metal fabricator.

Connections

Gutter connections to support elements shall be detailed on the plans.

Design Approach and Assumptions

Component Description - The role of the gutters in the structure include the following.

- Bracing element - the gutter acts as a horizontal bracing element between the framing members.
- Distribution member - The gutter may act to distribute the wind loads as part of the bracing system.
- Purlin - the gutter acts as a purlin and carries vertical loads from the enclosure material.
- Beam - the gutter transfers both vertical and horizontal loads.
- Convey water - the gutter conveys water and provides proper drainage for the roof.

3.1.2.2 Ridge

General Requirements

Ridge shall be designed for the loads described in paragraph 3.1.2 in this section. In addition, ridge members shall be designed for any lateral loads that may be imposed when acting as a brace for the end walls or when used as a collector for lateral forces. Ridges used to convey lateral loads shall be designed for the compressive forces in addition to the vertical loads using the load combinations specified in this handbook.

Sections

Structural section properties for ridge members shall be noted in the calculations. The details of the ridge section shall be shown on the plans. Section properties of various elements may be obtained from manufacturer's literature or computed based on the section.

Connections

Ridge member connections to support elements shall be detailed on the plans.

Design Approach and Assumptions

Component Description - The roles of the ridge in the structure are the following.

- Bracing element - the ridge acts as a horizontal bracing element between the framing members.
- Purlin - the ridge acts as a purlin and carries vertical loads.
- Beam – carries glazing bar reactions

3.1.2.3 Purlins

General Requirements

Purlins support the cladding and glazing bars. Purlins shall be designed for roof dead load and other loads such as snow and wind as determined by building code requirements. Purlin design shall consider the actual field installation conditions such as simple or continuous members and the point loads of glazing bars. Purlins shall be designed for the loads described in paragraph 3.1.2 in this section

Sections

Purlin section details and properties shall be shown in the calculations and on the plans. Manufactures literature may provide the design information for structural purlin sections.

Connections

Purlin connections to support elements shall be detailed on the plans.

Design Approach and Assumptions

Component Description - The purlins support vertical loads of the enclosure material and also act as bracing elements between the framing members.

Based on the roof slope, the load direction on the purlin may not be normal to the main axis of the member. When this occurs, the design shall address the horizontal component of the roof load acting on the weak direction of the purlin.

Building Codes and Consensus Standards

Purlins supporting glazing may require special consideration.

Engineering Judgement and Technical Literature

The decision of whether the glazing bars impose a point load or are to be considered a continuous load is usually a matter of engineering judgement. Where relative stiffness can be analyzed and the load distribution determined, an analysis is preferred.

3.1.2.4 Roof Glazing Bars

General Requirements

Roof glazing bars shall be designed for tributary dead, live, wind and snow loads and load combinations as described in paragraph 3.1.2. (Glazing bars shall be designed to support appropriate loads regardless of the cladding type.)

Sections

Glazing bar section details and properties shall be shown in the calculations and on the plans.

Section properties of various elements may be obtained from manufacturer's literature.

Connections

Glazing bar connections to support elements shall be detailed on the plans.

Design Approach and Assumptions

Component Description - Glazing bars shall be designed as a beam element. Glazing bars may be simple or continuous members, span between purlins and support vertical loads of the enclosure element. When designed for the loads, they can also act as bracing elements between the purlins. *Typically, purlins are designed so bracing is not required. In such a case, the glazing bar may have no axial load.*

3.2 Wall Elements and Columns

3.2.1 General

Wall elements consist of side and end walls and their components. Walls may be constructed with horizontal girts connecting to columns. End walls may consist of similar elements.

Walls must be designed for the wind loads on a building. Each element and its connection must be analyzed for adequacy.

All wall loads must be resisted by a system that conveys the loads in a continuous path. For side walls, this is often a braced system using the column or truss. In some cases it is a rigid frame. End walls take the wind load through columns to the roof bracing systems. Then the load path consists of diagonal braces in the plane of the roof, or in the plane of the bottom chord of the truss. The load then is conveyed through diagonal braces along the side walls to the foundation or through the gutter to columns with moment resisting bases.

All wall elements and columns shall be designed for all loads, including dead and live loads, cladding, lateral and applicable collateral loads. Designs shall use the analysis methods described earlier in this chapter. Live load reductions based on tributary areas are permitted for columns and some roof members.

Adjacent structures

Part of the greenhouse can be supported by the wall or other element of an adjacent building. This is often a "commercial or institutional" greenhouse.

The building code requires that the load imposed on existing structural elements by a new structure, such as a greenhouse addition, not create an unsafe condition by overloading existing structural elements and foundations. *Codes for existing building, now under development, specify that an overstress of less than 5 percent is acceptable. Where an overstress of 5 percent or greater occurs, a new element and/or new foundation would be required.*

3.2.2 Columns

General Requirements

Columns support the roof system. They also act as part of the lateral force bracing system. In many structures there is a knee brace or “kicker” from the truss to the column. In other cases, diagonal x-bracing may be used from truss to truss. Both types of lateral bracing systems may be used in a structure.

Sections

Columns shall support all imposed vertical and lateral loads

Section properties of various elements may be obtained from manufacturer’s literature.

Connections

All elements shall be connected to columns to convey the design loads.

Design Approach and Assumptions

Columns carry vertical loads to the foundation.

End wall columns take wind loads but may not carry any vertical load.

The column section must be designed for bending, shear, and axial stresses depending on the type of primary support structure (truss vs. rigid frame) and applied forces as well as the type of secondary lateral bracing system (knee braces and diagonal bracing).

The connection at the top and bottom of the column must be adequately designed to transfer loads through the column and into the foundation, including uplift. Pinned connections shall be adequately detailed to assure adequacy of the connection as well as providing for others designing the foundations. Base plates for columns shall be designed in accordance with the building code and shall be shown on the contract drawings.

A column that attaches to a footing must have adequate anchor bolt embedment to transfer all design loads, including uplift, to the foundation. Anchor bolt embedment length is an important element in the design of a greenhouse.

Anchor bolts, even if installed by others, shall be shown on the contract drawings.

Where sleeved connections are used, the lap length shall be verified as well as the adequacy of the elements and connections. Adequate protection against movement at both ends of the sleeve shall be provided.

Consideration shall be given to local column buckling and the need for stiffeners at connections, especially due to lateral loads.

Some designers use “flagpole” type footings for columns to act as bracing elements by transferring moment to the ground.

The connection from the column to the footing shall be capable of developing the moment at the

base of the column. This may be accomplished by embedment of the column a sufficient length, or by anchor bolts extending into the foundation the length required by the concrete design standards.

3.2.3 End walls

End Walls

The end walls of a greenhouse structure shall be designed to resist the loads specified in this manual. The reactions of such loads and the end wall members shall be resisted by a calculated system that provides a continuous load path from the wall through the structure to the ground. The construction drawings should contain sufficient details to show the load path. This continuous load path will include horizontal and/or vertical wall elements such as columns and braces.

Bracing

End walls elements shall be braced as required for member stability. Bracing shall be designed for loads as specified for truss bracing.

Sections

End wall sections may be of any type. Section properties of various elements may be obtained from manufacturer's literature.

Connections

End wall members shall be capable of conveying all required vertical and lateral loads.

Design Approach and Assumptions

End walls may carry vertical loads from the roof system to the foundation. They can also be designed for applicable lateral loads. In this case they distribute the lateral load, namely wind or earthquake load, to the foundation.

Engineering Judgement

The engineering approach to the design of end walls and the conveying of the lateral loads through a continuous stress path will vary by individual practice, but shall be analyzed and shall comply with all building code requirements.

3.2.4 Girts

General Requirements

Girts shall be designed for the tributary lateral load. Girts shall be considered as simple or multiple span elements and connected to each column.

Sections

Girt sections may be any formed section, often C, Z, rectangular or other shape. They must be capable of supporting the lateral loads. Girts shall be supported as required to keep from sagging. Section properties of various elements may be obtained from manufacturer's literature.

Connections

Girts shall be connected to columns to transfer the lateral (wind) or other loads.

Design Approach and Assumptions

Girts are usually horizontal members spanning between vertical members such as columns that frame the walls. It is also possible to design a girt to span vertically. Whether horizontal or vertical, girts. They are designed for lateral loads, typically wind, that are applied perpendicular to the exterior walls. Girts transfer these loads to columns, which then transfer the loads to the foundation.

Girts acts as beams and are typically designed for bending stresses but may carry axial loads too. Girts braced by typical greenhouse enclosure materials need to have their unbraced length considered in their design.

3.3 Lateral Load Resisting System

General Requirements

Frames or shear resisting elements shall be calculated for the loads, and load combinations specified in the International Building Code.

All buildings require a system to resist lateral loads such as wind and earthquakes. Wind is usually the governing load in greenhouse design except for a few structures in the highest seismic zones. The effective seismic weight, W , of a structure shall include 20% of the flat roof snow load, p_f , where the flat roof snow load exceeds 30 psf.

The lateral force resisting system may consist of bracing or moment resisting systems. The most important factor in lateral load design is to provide a continuous stress path for the loads. The design engineer should take into consideration the various code requirements for load combinations when considering lateral loads.

Even when wind is the governing load, lateral force-resisting systems are required to meet the seismic detailing requirements and limitations prescribed in the code.

3.3.1 Knee Braces

General Requirements

Knee braces and their connections shall be sized for the design loads based on the design code.

Sections

Any section type is permitted. Section properties of various elements may be obtained from manufacturer's literature.

Connections

Knee braces shall be connected to convey all loads.

Design Approach and Assumptions

Knee braces are diagonal braces connecting two members. The members act together as a braced frame and are able to carry horizontal loads to the foundation. The columns must be designed for the loads imposed by the knee brace.

3.3.2 Diagonal Bracing

General Requirements

Diagonal bracing that acts as a part of the lateral load resisting system shall be designed for all required loads. Bracing used for temporary support during erection of a structure shall comply with all applicable construction safety requirements.

Diagonal bracing may be in the plane of a sloped roof, or parallel the floor at the bottom chord, to act as a horizontal truss to brace the building for lateral loads. Such bracing shall be designed for the applied loads.

Diagonal bracing in the plane of the wall shall convey the lateral forces from the roof system to the foundations.

Sections

Bracing may be of any section including, but not limited to, rods, steel cable, or structural sections.

Connections

Connections for all bracing elements shall be adequate to convey the required loads. The design shall permit adjusting the bracing to assure the required tension in rod or cable bracing systems. [IBC Section 2211.7.5]

Design Approach and Assumptions

Diagonal bracing runs from joint to joint, creating a triangle with the framing members. The addition of diagonal bracing results in a unit that can be designed like a truss. The bracing members are designed for axial stresses.

The unbraced length of compression members shall be checked for l/r due to lateral loads.

Engineering Judgement

Engineering judgement is often used to define the lateral force bracing system. The designed system shall be fully analyzed and calculated, with design assumptions noted.

3.4 Foundations

General Requirements

Foundations may be designed by the engineer responsible for the greenhouse structure or by other engineers. If the design by others is to be used, the building's base reactions at columns and wall loads shall be shown on the construction drawings. In addition the contract drawings should show the anchor bolts and base plate layout.

Foundations may be several forms. Each foundation style follows standard design practice.

3.4.1 Flagpole Footings (Designs Employing Lateral Bearing)

General Requirements

Flagpole footing shall be designed for the vertical and lateral loads. Flagpole footing shall be designed per IBC Section 1805.7. Unless otherwise noted, all flagpole type footings shall be designed as non-constrained. Exception: Buildings with slabs on grade may be designed as a constrained footing when adequate anchorage is provided when the floor slab is properly designed to provide restraint.

Understanding the soil at the site is critical in providing an adequate design.

The design criteria, including lateral soil bearing pressures, shall be noted on the drawings.

Design Approach and Assumptions

Flagpole footings are designed for vertical and horizontal loads. The footing must be adequate for the vertical loads. It must also be able to distribute the lateral bearing to the soil produced by a lateral load applied to the column. Greenhouse footings will typically be the non -constrained type.

A constrained flagpole footing design can be used when there is a slab on grade surrounding the flagpole footing. There shall be adequate positive load transfer to any constraining elements. See earlier discussions regarding hoop ties and column anchorage.

Engineering Judgement

Assumptions, options and other design issues should be noted on the plans. Where assumptions such as lateral bearing and allowable stress increases permitted by the code in soil shall be noted on the plans.

3.4.2 Spread Footings

General Requirements

Spread footing shall be designed to support all vertical and lateral loads on the supporting soil.

Where the design of the foundation system is by others, the reactions and other design information for the foundations shall be provided on the greenhouse drawings.

Design Approach and Assumptions

Spread footings are designed to distribute vertical and horizontal loads to the soil. The size of the footing is determined by the vertical load acting on the footing and the bearing pressure of the soil. Care should be taken to align the load to act at the center of the footing, otherwise moments must be taken into account. Horizontal load is resolved by lateral bearing on the soil.

Engineering Judgement

Settlement, soil pressure and other factors will have to be considered depending on the use of the building.

3.4.3 Continuous Footings

General Requirements

Continuous footings are frequently used for greenhouses. They will often be constructed with a curb to act as a base for the glazing. Where the curb is more than a foot in height and supports the columns in bearing or as a flagpole, the reactions at the column base should be noted on the design drawings for use by others.

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