STANDARD FOR FILM-COVERED GREENHOUSES

Ing. D. Waaijenberg
Structures Department
Institute of Agricultural Engineering (IMAG)
Wageningen, The Netherlands

Abstract

There is an increase in the construction of film-covered greenhouses in the Netherlands, specially the tunnel-type. At the same time there is an increase in damage (mostly winddamage) with this type of plastic greenhouses. The Dutch Standard for greenhouses NEN 3859 [1] has been developed mostly for glass-covered greenhouses. Therefore there is a need to develop a special Standard for film-covered greenhouses.

One reason for this is the fact that specific structures and details for synthetic film-houses occur such as curved tubes and clamping connections, which are not common in glass-covered greenhouses.

Also the wind and snow loads are different for the tunnel-type of greenhouses compared with greenhouses with saddle-roofs.

The Code of Practice NPR 3860 [2] gave already the first rules according to windloads on tunnels.

The drafting of the Standard aims at reducing the occurrence of damage to greenhouses caused by wind, snow or other loads. Therefore the special Standard gives calculation-rules, among other things for wind- and snowload and describes the requirements for the structure-profiles, the connections, the foundation, the stability-bracings and the fastening of the plastic films.

The IMAG, Wageningen has made a first draft of this specific Standard.

The results of the calculations of the structure of a number of tunnels, according to the proposed Standard will also be presented in this paper as an example.

1. Introduction

The area of film-covered greenhouses in the Netherlands is a little more than 1% of the total greenhouse area. This is only a minor proportion, but demand is growing, and so is, unfortunately, the number of claims for damage to film houses due to heavy weather. Also the export of such greenhouses is important.

Acta Horticulturae 281, 1990
Greenhouse Construction, Design
To improve the quality of film houses the initiative has been taken to draft a special Standard for this category, after Standard NEN 3859 for glasshouses. The Standard shall provide specific requirements as to the loads from wind, snow and other causes on the structures. Further requirements deal with structural elements and connections. The quality of films, its securing and the structural strength of gable ends have to be covered by the new Standard. IMAG in Wageningen have formulated a first draft together with the extension-service CAD-BAT in Wageningen.

2. Structural Parts

Tunnel greenhouses generally consist of bent trusses (hoops) composed of two, three or four sections connected by means of clamps, and of purlin and ridge tubes and stabilizer profiles. The hoops are secured to ground tubes provided with screw anchors or cast in concrete.

2.1. Clamp connections

For the structural connections clamps or bolts through the structural elements have to be used. Hoop sections shall also be connected properly. Consequently, it is not recommended just to slide one tube section into another, without bolts or other fixtures relying on the retaining force exerted by the tensioned skin. The framework has to be able to cope with all loads and has to convey these to the soil.

After erection of the film greenhouse it has to be verified whether the bolts of the clamps are tight.

2.2. Hoops (with and without strengthening bars)

The curvilinear shape of a tunnel greenhouse can be realized by using simple hoops without a horizontal strengthening bar. A horizontal strengthening bar (bar 17 and 18 in figure 1) is often used with a support bar to the ridge (bar 19 in figure 1). This provision is especially found with wide spans and makes quite a difference for the weight of the hoop, even with a span of 6 m.

The moment occurring in a hoop without strengthening bar due to a certain load situation (self-weight and snow load) is more than double that of the moment occurring when the hoop is combined with a strengthening bar. The pressure in the hoop is practically the same in both situations.
Without strengthening bar the moment occurring will be higher in the same load situation for the same span, and therefore this hoop has to be heavier than if no strengthening bar has been provided for.

Additionally it is observed that with a wind load perpendicular to the ridge the strengthening bar together with the hoop creates the effect of a triangle which can better absorb the wind load than without this. As a matter of fact this applies only if the strengthening bar has been designed as a tube of adequate dimensions (e.g. not as a wire) so that the pressure can be absorbed sufficiently. It is not recommended to use these reinforcements as crop support bars (e.g. for hanging pots for strawberry crops) as normally the framework has not been designed for this extra load.

2.3. Hoop buckling

The hoop shape of Figure 1 is subject to a downward pressure load (from both snow and self-weight). Consequently, the hoop is exposed to both bending and buckling forces. To be able to calculate the buckling load, the effective length has to be determined of the hoop sections in the direction in which also bending occurs. Lengthwise, the hoop is supported against buckling by side purlins and ridge tube.

To establish the effective length in the direction of the load a TNO-IBBC report [3] has been published stating the effective length values for four truss shapes and six load cases. By way of example the design value of the effective length has been calculated for a tunnel greenhouse of a span of 8.00 m, as shown in Figure 1. For this e.g. the actual length of the hoop section between the strengthening bar and the ground level (from point 1 to point 4) has to be multiplied by a factor of 2.3 - 2.5 to obtain the effective length value.

2.4. Stabilizers

To prevent longitudinal racking of the greenhouse stabilizers have to be mounted as shown in Figure 2. These should if possible act on the nodes of structural elements, such as the crossings of ridge tube and hoop and of purlin and hoop. To strengthen the gable ends, gable end stabilizers have to be applied.
2.5. Purlins below hoops

The ridge, ground and purlin tubes are often secured to the inside of the hoops. As a result the skin is directly supported by the hoops, not by the longitudinal tubes. This is to be preferred to reduce the wear of the film and to prevent condensate drip zones inside.

3. Loads

The design of film-covered greenhouses shall consider:

a. wind load,

b. snow load,

c. crop support load, if applicable,

d. self-weight.

The following combinations can occur:

- wind load with self-weight,
- snow load with self-weight,
- crop support load, if any, with self-weight.

3.1. Wind load

Greenhouses with an envelope of flexible material tend to have a geometry different from the geometry of saddle roofs to which the coefficients (c) apply as stated in Par. 5.3.4 of Standard NEN 3859 [1]. To establish the coefficients (c) for deviating types, models have been tested in the TNO-IBBC boundary layer wind tunnel. The results are given in TNO-IBBC report [4]. These coefficients (c) are also stated in the Code of Practice NPR 3860 [2].

When designing film houses the thrust pressure values can be taken from Standard NEN 3859, Table 1. This table is based on the expected life of a greenhouse of 15 years. For the structure of film houses the same life has to be adopted. The characteristic wind load is calculated by means of the following equation:

\[ A_z \times C_d \times q = \ldots \text{, or rather } A_z \times C_z \times q = \ldots. \]

Where \( q \) is the thrust pressure value and \( A_d \) and \( A_z \) are the enveloping surfaces to which wind pressure or wind suction, respectively, are applied. Coefficients \( C_d \) and \( C_z \) refer to the figures in the Code of Practice NPR 3860 [2] and the special Standard for filmhouses.
3.1.1. Tunnel greenhouses

Figure 3 shows the coefficients \((c)\) which apply to the single-bay semi-circular shape. The figure shows that with wind load no. 2 on the tunnel both pressure and suction can occur.

In this figure you can see that windload no. 1 causes only wind suction on the external surface.

This is corresponding with the figures given in the Code of Practice NPR 3860 [2]. In the design Standard for filmgreenhouses however and the new draft of NEN 3859 [5] the figure marked with "windload 2" has also to be checked during the design-calculations. As you can see in this figure the forces working on the external surface are a combination of pressure and suction, together with the internal forces.

This load combination is more in accordance with the real occurring windload on semicircular tunnels and is also given for example in the English and French Standards about wind- and snowloads on structures [6]. The not symmetrical windload of figure 3 means a lot for the calculation of the hoops for this tunnels as you can see later on in the calculation-examples of three tunnels.

In addition to these tunnel houses the coefficients \((c)\) have also been established for several straight-sided houses with curvilinear roof types. The values are given in Code of Practice NPR 3860 [2].

3.1.2 Excess pressure and under-pressure

With a view to the potentially greater tightness of greenhouses with double-ply roofs, and when provided with ridge vents, it is recommended to consider an excess pressure of \(p = +0.3q\) or an underpressure of \(p = -0.3q\), in which \(q\) is the thrust pressure as stated in Table 1 of Standard NEN 3859 [1]. This recommendation implies that larger excess and under-pressure shall be taken into account than the values given in Standard NEN 3859, Par. 5.3.6 for glass-covered greenhouses.

For film houses without ridge vents it is recommended to assume an excess pressure of \(p = +0.5q\) or an under-pressure of \(p = -0.3q\). The thrust pressure value \(q\) to be applied for tunnel houses is the value pertaining to the distance from ground level to greenhouse ridge \(H_{eff}\) in Figure 3.
3.2. Snow load on greenhouses

The snow load on which to base designs for single-glazed greenhouses is stated in Standard NEN 3859, Par. 5.2.1, and amounts to 250 N/m² (25 kgf/m²) projected horizontally. This value can also be applied to film houses, however to a width of 1/4 of 1 on either side of the ridge, as indicated in Figure 4.

For multispan houses with gutters between the tunnels, provisions have to be made to compensate for the load of snow collecting in the gutter areas. No provisions have to be made for loads due to snow masses for curved shapes if the clearance at ground level between tunnels is 0.50 m or more.

4. Wind load on films

Claddings of tunnels and greenhouses are constantly exposed to the wind. Therefore, the film shall be able to withstand this exposure. As described before (3.1) the framework has an expected life of fifteen years. In those fifteen years it must resist a storm of a force as occurs once in fifteen years. On the other hand, films have an expected life of some three years, the film must withstand a storm of a force as occurs once in three years. For that reason film life calculations are based on a lower wind pressure value than structural calculations.

The above implies that during the life of a structure it will have to be reclad four times. In those fifteen years the film may be destroyed once or several times because of storms stronger than the film has been designed for [7]. If the same wind load values were to be used for the film as used for the framework, the film should be much thicker and stronger, which would be much less interesting economically.

5. Calculation examples:

To see the effect of the two load combinations the hoops of three different tunnels have been calculated on the basis of the data given in table 1.

The results of the strength calculations of the three different hoops are summarized in table 2 for
- windload 1 with only suction and
- windload 2 with a combination of suction and pressure (see for the windloads figure 3).

In table 2 you can see that in some cases the tubes must become heavier and sometimes the distance between the trusses must change from 2 m to 1.50 m. This is only because of the changed wind pattern. Because the snowload stays the same.
References

[1] Standard NEN 3859. Tuinbouwkassen - Constructieve eisen/ Greenhouses - Structural requirements, 1st edition, June 1978 (also in English)
[2] Code of Practice NPR 3860. Tuinbouwkassen - Aanbevelingen voor en voorbeelden van de constructieve uitvoering gebaseerd op NEN 3859/Greenhouses - Recommendations for and examples of constructional performance based on NEN 3859, 1st edition, December 1985 (also in English)
[4] TNO-IBBC report B-76-273/08.2.467. Bepaling van de vormfactoren van enkele configuraties bedrijfsgebouwen. (Determination of form factors of some commercial building configurations; in Dutch)
[7] TNO-IBBC report B-84-1/63.3.0768. Een ontwerpmethode voor folieomhullingen voor tuinbouwkassen (A design method for film envelopes for greenhouses; in Dutch)

Figure 1: Outline of the steel truss of an 8 m wide tunnel with computer calculation-numbering.
Figure 2: Structure of an 8 m span tunnel.

Figure 3: Coefficients (c) for semi-circular tunnels.
Figure 4: Snow load on a semi-circular tunnel.

Table 1: Starting points strength calculations of tunnel hoops.

<table>
<thead>
<tr>
<th>Span (m)</th>
<th>Ridge Height (m)</th>
<th>Height of Side (m)</th>
<th>Thrust Pressure (N/m²)</th>
<th>Snowload (N/m²)</th>
<th>Load Factor (γ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>3</td>
<td>1</td>
<td>430</td>
<td>250</td>
<td>1.25</td>
</tr>
<tr>
<td>8</td>
<td>3.1</td>
<td>1</td>
<td>433</td>
<td>250</td>
<td>1.25</td>
</tr>
<tr>
<td>9.30</td>
<td>3.1</td>
<td>0</td>
<td>433</td>
<td>250</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Table 2: Tube dimensions and truss distances calculated according NEN 3859 Greenhouses.

<table>
<thead>
<tr>
<th>Wind Load on Tunnel</th>
<th>6 m.</th>
<th>6 m.</th>
<th>9.30 m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only Auction</td>
<td>42.4</td>
<td>48.3</td>
<td>60.3</td>
</tr>
<tr>
<td>Pressure</td>
<td>2.6</td>
<td>2.9</td>
<td>2.9</td>
</tr>
<tr>
<td>Auction</td>
<td>2.00</td>
<td>2.00</td>
<td>1.5</td>
</tr>
<tr>
<td>Pressure</td>
<td>1.60</td>
<td>1.50</td>
<td>2.9</td>
</tr>
</tbody>
</table>

N.B. Dimensions in mm.