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TNO report

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Experimental research into the tensile strength of the crop wire connection with GRIPPLE GP90

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Contents

1 Introduction

Van Rooij & Co Draadproducten BV in Rotterdam, supplier of crop wire products for commercial greenhouses, has asked TNO in Delft to assess the bearing capacity of a type of connection for crop wires. The connection is performed with a Gripple GP90. The aim of the research is to determine the design value for the tensile strength of the crop wire, including its connection with a Gripple GP90 to the crop wire arch. The results of the experimental research will be applied in the CASTA program for the structural design of commercial greenhouses.

The assessment of the bearing capacity was carried out on the basis of experimental research, consisting of the following parts:

- Static load test to determine the design value for the tensile strength of the crop wire, including its connection with Gripple GP90. The static load tests were carried out for 3 types of crop wire, namely " galvanized 3.4 mm", "galvanized 3.8 mm" and "Crapal 3.15 mm".
- Test with alternating load, to assess the durability of the connection during the design service life (strength, slip of the wire).

The experimental research was carried out in two phases. In the first phase the resistance to alternating load has been tested. The test results demonstrated, that resistance against alternating load is more than sufficient. The degree of slip of the wire in the connection with the Gripple, which may occur during the design service life, is hardly greater than the slip which occurs during a static load test with the same maximum load level. These tests were performed with Gripple GP90 in combination with crop wire type Crapal 3.15 mm.

The good resistance to alternating load of the connection of crop wires with a Gripple was previously determined for the crop wire connection with “Gripple Large” and with “Gripple Jumbo”, see TNO report 2007-D-R09030.

In the second phase, experimental research was carried out into static strength of the crop wire connection. This was done with a modified model of the Gripple GP90. In order to determine whether this modification affects the resistance to alternating load, an additional test with alternating load was carried out for the connection of the new Gripple GP90. For each of the three types of crop wire, a test with a limited number of load cycles was performed. Here, the upper limit of the tensile force in the tests was taken equal to the design value for the tensile strength, that was assessed by the static loading tests.

2 Description of the crop wire system

Gripple 90GP is used for the connection of crop wires to a crop wire arch, consisting of a steel rod, 12 mm or 14 mm in diameter. The Gripple is an aluminium casting element containing a clamping mechanism. The clamping mechanism introduces a permanent deformation (ridges) on one side of the crop wire as soon as a tensile force is introduced in the crop wire. This deformation prevents the crop wire from sliding along the clamping mechanism.

The Gripple 90GP is equipped with a hook, in which the crop wire arch fits. The hook can rotate around the crop wire arch and thus follow the direction of the crop wire. With a stainless steel screw M6 + locknut the position of the Gripple 90GP on the crop wire arch can be fixed.

Photo 1: connection of crop wires to steel rod 14 mm with Gripple 90GP in the test setup.

During the experimental tests 3 types of crop wire were applied, with the following characteristics, regarding the design value for the tensile strength:

- Galvanized 3.40 mm: Fg;d;t1 = $\frac{1}{4} * \pi * 3.4^2 * 305.6 = 2774$ N
- Crapal 3.15 mm: Fg;d;t2 = $\frac{1}{4} * \pi * 3.15^2 * 356.0 = 2774$ N
- Galvanized 3.80 mm: Fg;d;t3 = $\frac{1}{4} * \pi * 3.8^2 * 305.6 = 3466$ N

Here $\sigma = 305.6$ N/mm^2 is the yield strength for the type galvanized crop wires and $\sigma = 356.0$ N/mm^2 is the yield strength for Crapal crop wires. In the CASTA program, these design values are taken representative for the tensile strength of the crop wire, including its connection to the crop wire arch.

3 Loads on the crop wire

The tensile load in the crop wire is determined by the type of use. The most important parameters for calculating the tensile load are the crop load per running meter of crop wire, the span of the crop wire and the sag of the crop wire. The crop load per running meter is calculated as the product of the crop load per square meter and the distance between the crop wires. The maximum crop load generally occurs with a return period of 1 year.

3.1 Calculation of the static tensile force in the crop wire

An example calculation is given below, with which the tensile force in the crop wire is determined. Starting points for this calculation are:

- Section length: 5.0 meter
- Nominal sag of the crop wire: 200 mm
- Distance between the crop wires: 0.80 meter
- Crop load: 200 N/m^2
- Load factor according to EN13031-1:2019: $\gamma = 1.275$
- The sag of the crop wire has been corrected from 200 mm to 191 mm

In the calculation model the influence of temperature changes is taken into account by a reduction of the sag of the crop wire. This effect is relevant when aluminium gutters are used in combination with steel crop wires. The effect of temperature changes on the tensile force in the crop wire is relatively large with a relatively small sag of the crop wire.

```
Tensile force in the crop wire:
                                hohgdo²          4 * fdT'
        Tgd' = qcrop * hohgd * -------- * [1 +(---------)²]1/2
                                8 * fdT'           hohgdo

        with: fdT' = f' * ( 1 - 3/8 * alfa * dT * hohgdo²/f'²)1/2

Tgd'   = Tensile force in the crop wire in SLS [N].
qcrop = crop load belonging tot the load combination
         to be verified.
hohgd  = heart to heart distance between crop wires[m].
hohgdo = heart to heart distance support crop wires[m].
f'     = minimal dip of crop wires in load situation [m].
fdT'   = adjusted dip of the crop wires with a reduction-
         factor resulting from expansion of the gutters [m].
         For gutters, according to NEN3859: alfa * dT = 48*10e-5.

Entry of the known data results in:

   fdT' = 0.200 * ( 1 - 3/8 * 48*10e-5 * 4.50 ²/0.200²)1/2 = 0.191  m

                          4.50²          4 * 0.191
   Tgd' =  200 * 0.8 * --------- * [1 +( --------- )²]1/2 = 2154   N
                       8 * 0.191            4.50
Analogue, ULS conditions: Tgd = 2747 N
```

3.2 Alternating load on the crop wire

The greenhouse gutter will expand and shrink due to temperature changes (e.g. day/night). In order to investigate the resistance of the crop wire connection to this and other types of alternating load, an estimate was made of the relevant load actions.
The effect of the temperature differences on the tensile force in the crop wires:

- Temperature changes: $\Delta T = 10\ ^0C$, 100x per year (approx. 3 months per year, 1x per day). As a result of this the tensile force in the crop wire will vary between 2616 N and 2718 N.

In consultation with DLV Plant the frequency of types of work in tomato cultivation has been determined. The effects of these types of work on the tensile force in the crop wire has been assumed as a load cycle with respect to a maximum crop load of 150 N/m^2. The representative tensile forces, taken into account in the test with alternating load, are given in Table 1.

Table 1: Tensile forces in the crop wire for the test with alternating load

Type of load	Frequency (per year)	Load	Tensile force
Characteristic crop load	1	150 N/m^2	+2774 N *)
Plant maintenance	2x15x21=630	20 N	+77 N
Harvesting	26	15 N/m^2	-231 N
Repositioning plants	15x25=375	40 N	-154 N
Person leaning on the wire	25	80 N	+370 N
Temperature changes	100		2616 N to 2718 N
*) the selected design value for the tensile force in the crop wire is equal to the design value for the tensile strength of crop wire Crapal 3.15 mm, including its connection to the crop wire arch.			

The design service life according to NEN-EN1990 for horticultural greenhouses is 15 years. The load spectrum for the test with alternating load is safely attuned to the alternating load that occurs during twice the design service life.

During the test, the alternating load that corresponds to 1 year design service life (see table 1) was repeated 30 times. Table 2 shows the load intervals, the number of load cycles and the frequency of the load spectrum during the tests.

Table 2: load spectrum “1 year” for he tests with alternating load

Frequency [Hz]	Count	Shape (cycles)	Level1 [N] (+ = tensile force)	Level2 [N] (+ = tensile force)
0,1	1	½ Sine	100	2774
1	100	Sine	2616	2718
2	630	Sine	2774	2851
0,5	26	Sine	2543	2774
0,5	25	Sine	2774	3144
1	375	Sine	2620	2774
0,1	1	½ Sine	2774	100

The number of load cycles in one year is 1157. The intended number of load cycles for a complete test is 2 x 15 x 1157 = 34710.

4 Test setup and assessment of the test results

In order to assess the bearing capacity of the crop wires connection with Gripple GP90, static load tests and tests with alternating load are carried out. The results of these tests will be applied in the CASTA program for the design calculation of the greenhouse structure, based on the European greenhouse standard EN13031-1:2019. The design value for tensile strength given in chapter 2 will be used as the upper limit.

The static load tests were performed by attaching both ends of the crop wire with a Gripple GP90. In this way 2 connections are tested at the same time. The following static load tests have been performed, in which the load is increased until the moment of failure:

- Static load test in tenfold on the connection between Gripple GP90 and crop wire "galvanized 3.4 mm"
- Static load test in tenfold on the connection between Gripple GP90 and crop wire "galvanized 3.8 mm"
- Static load test in tenfold on the connection between Gripple GP90 and crop wire “Crapal 3.15 mm”

These static load tests are performed with a right angled connection of the Gripple GP90 to the crop wire arch (diameter 14 mm). In practice, the crop wire can be connected at an angle of up to about 20 degrees to the direction of the crop wire arch. Therefore, some additional tests have been carried out to determine whether the angled connection affects the design value for tensile strength.

Photo 2 and 3: Crop wire connection with Gripple GP90 in the test setup for static load testing. On the left the right angled connection of the crop wire, on the right the connection of the crop wire at an angle of 20 degrees.

From the test results, the characteristic value for the tensile strength is determined on the basis of par. D7.2(3) of NEN-EN1990. The design value for the tensile strength R_d is determined with the following formula:

$$R_d := \min\left[\frac{\eta_d}{\gamma_m} \cdot m_X \cdot \left(1 - k_{2 \cdot n} \cdot V_x\right), \frac{\eta_d}{\gamma_m} \cdot 0.9 \cdot \mathrm{mean}(Pu)\right]$$

where:

- η.d = 1 factor for representativeness of the test results
- γ.m = 1.25 safety factor, compared to the characteristic value of the tensile strength (used for the design value of joints, see EN1999-1-1)
- k.2n statistical factor, based on 2 test pieces in 1 test
- m.x average value of the failure load
- V.x coefficient of variation
- P.u characteristic value for the tensile strength

The tests with alternating load on the crop wire connection with Gripple GP90 have been carried out to assess the durability of the connection during the design service life (strength, slip of the wire). The alternating load test provides insight into the behaviour of the connection during the design service life. The connection will be judged as “satisfied” when no breakage of the wire occurs and when the wire doesn’t slip too much in the connection with Gripple GP90.

In one test series with alternating load, four wire-Gripple connections were tested at the same time. Two test series were carried out, both with a right angled connection of crop wire type Crapal 3.15 mm to the crop wire arch.

Photo 4: Crop wire connection with Gripple GP90 in the test setup for testing the resistance to alternating load.

5 Test results

Based on the static load tests, the following design values for the tensile strength have been determined for the crop wire connection with Gripple GP90 to the crop wire arch:

- Crop wire galvanized 3.40 mm: R_d = 2883 N
- Crop wire Crapal 3.15 mm: R_d = 3404 N
- Crop wire galvanized 3.80 mm: R_d = 3658 N

The test results are based on test with a right angled connection of the crop wire to the crop wire arch. Additional tests with an angled connection (20 degrees) of the crop wire to the crop wire arch show, that an angled connection does not adversely affect the tensile strength. This test also shows, that the bolt for mounting the Gripple not necessarily needs to be tightened firmly, to prevent the Gripple from shifting.

During the static load tests, "slip" of the crop wire in the Gripple GP90 occurs. This deformation, which amounts to a maximum of 1.5 cm, is common for the wire to properly connect to the clamping mechanism in the Gripple GP90. As an example, the chart of a test with Gripple GP90 and crop wire 3.80 mm is given below. This shows that most of the deformation takes place until a tensile force of approximately 1000 N is reached.

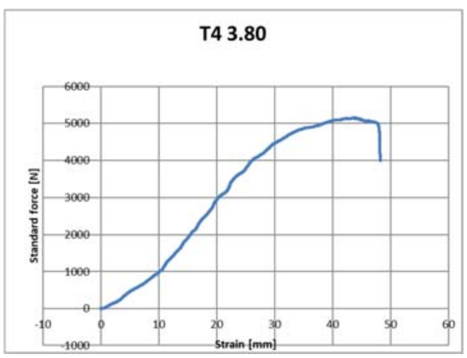

Figure 1: chart of a static load test on the connection between Gripple GP90 and crop wire galvanized 3.80 mm.

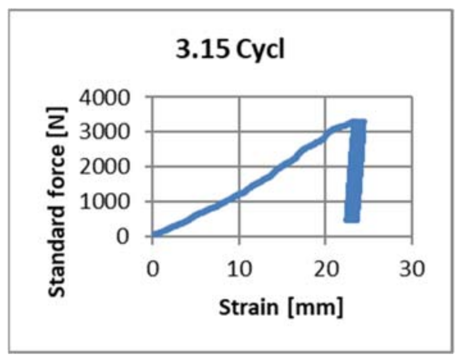

Figure 2: chart of a test with alternating load on the connection between Gripple GP90 and crop wire Crapal 3.15 mm.

The tests with alternating load show, that the size of the slip of the crop wire in the Gripple GP90 is limited to about 1 cm, as a result of the load cycles during the design service life. This test result has been assessed as more than sufficient.

Check of the design value for the tensile strength of the connection of crop wires with Gripple GP90, for application in the CASTA program, for the design calculation of greenhouse structures based on the European greenhouse standard EN13031-1:2019:

- crop wire galvanized 3.40 mm: R_d = 2883 N > 2774 N → Satisfied
- crop wire Crapal 3.15 mm: R_d = 3404 N > 2774 N → Satisfied
- crop wire galvanized 3.80 mm: R_d = 3658 N > 3466 N → Satisfied

The clamping mechanism in the Gripple GP90 creates a deformation in one side of the crop wire. This deformation results in a reduction of the effective cross section of the crop wire. This is also the reason why during the static load tests the wire fails in the clamping mechanism of the Gripple GP90. On the pictures below (shot with a microscope), both of a broken wire and of a not-broken wire Crapal 3.15 mm, the shape of the deformation is easily recognizable.

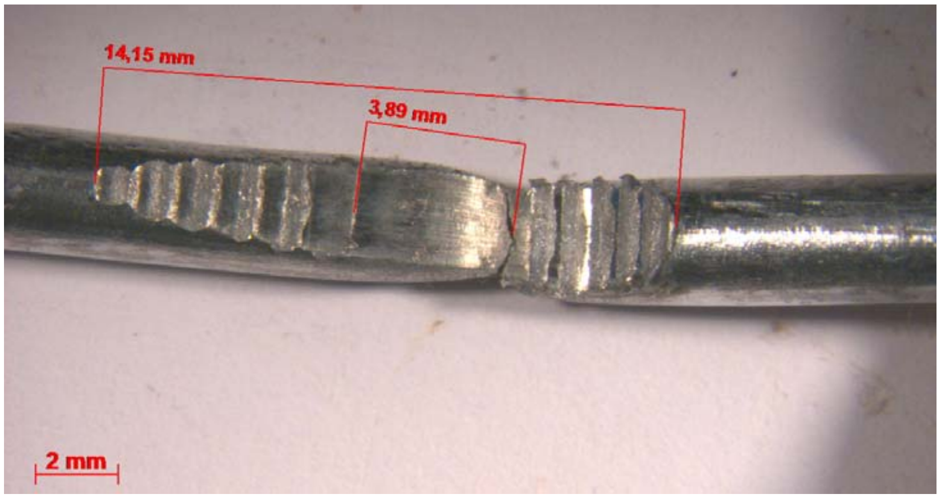

Photo 5: Deformation of crop wire Crapal 3.15 mm in the connection with Gripple GP90, after breakage of the wire.

Photo 6: Deformation of crop wire Crapal 3.15 mm in the clamping mechanism of Gripple GP90, after performing a static load test.

6 Conditions

The dimensions and material properties, mentioned in this report, are based on data provided by and under his responsibility of Van Rooij & Co Draadproducten BV. The test results are valid for the situations that these dimensions and material properties are also met in practice.

It should be avoided that too much pre-tensioning is applied to the bolt for mounting the Gripple GP90 on the crop wire arch. This can lead to breakage of the bolt holder in the aluminium casting element of the Gripple, as a result of which the Gripple can possibly shift in the longitudinal direction of the crop wire arch.

7 Conclusions and recommendations

Commissioned by Van Rooij & Co Draadproducten BV in Rotterdam, supplier of crop wire products for commercial greenhouses, TNO in Delft has carried out research into the tensile strength of a type of connection for crop wires. The crop wire connection with Gripple GP90 to a crop wire arch has been tested with three types of crop wire:

- connection of crop wire galvanized 3,4 mm with Gripple GP90
- connection of crop wire Crapal 3,15 mm with Gripple GP90
- connection of crop wire galvanized 3,8 mm with Gripple GP90

The test results show that the design value for the tensile strength of the crop wire connection with Gripple GP90 meets the requirements of the European greenhouse standard EN13031-1:2019. The test results will be applied in the CASTA program for the design calculation of greenhouses structures, based on EN13031-1:2019.

During the tests no unacceptable deformations occurred in the connection of the crop wires with Gripple GP90 to the crop wire arch. This applies both to the static load tests and to the tests with alternating load.

It is recommended to include the maximum value for preload in the bolt, for mounting the Gripple GP90 to the crop wire arch, in the crop wire assembly manual.

8 Signature

Delft, 6 October 2020

TNO

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A Results of the static loading tests

Determination of the design value for the tensile strength of the crop wire connection with Gripple GP90.

Customer: Van Rooij & Co Draadproducten B.V.

Results of the static loading test with Gripple GP90 and crop wire gavanized 3,4 mm:

Test nr. 1: $Pu_0 := 4670 \cdot N$

Test nr. 2: $Pu_1 := 4830 \cdot N$

Test nr. 3: $Pu_2 := 4740 \cdot N$

Test nr. 4: $Pu_4 := 4730 \cdot N$

Test nr. 5: $Pu_3 := 4670 \cdot N$ $n := rows(Pu)$ $n = 5$

Type fo failure:
Breakage of the crop wire in the clamping mechanism of the Gripple GP90.

The 5% statistical value $k_{n,}$ to determine the factor Vx "not known", is based on the Bayesian probability theory as given in D7.2(3) of NEN-EN 1990. This factor depends on the number of tests. Per static loading test two test pieces have been tested. This has been taken into account when assuming the 5% statistical value k_n.

$k_3 := 3.37$ $k_5 := 2.33$ $k_7 := 2.09$ $k_9 := 1.96$

$k_4 := 2.63$ $k_6 := 2.18$ $k_8 := 2.00$ $k_{10} := 1.92$ result: $k_{2n} = 1.92$

On the basis of the Normal distribution:

$m_X := mean(Pu)$ $m_X = 4728 \cdot N$

$$s_x := \sqrt{\frac{1}{n-1} \cdot \sum_{i=0}^{n-1} \left(Pu_i - m_X\right)^2}$$ $s_x = 65.72671 \cdot N$

$$V_x := \frac{s_x}{m_X}$$ $V_x = 0.0139$

Determination of the design value R_d for the tensile strength of the connection:

$\gamma_m := 1.25$ γ.m = γ.M2 according to table 8.1 of NEN-EN 1999-1-1

$\eta_d := 1$

Design value: $$R_{d.op} := \min\left[\frac{\eta_d}{\gamma_m} \cdot m_X \cdot \left(1 - k_{2 \cdot n} \cdot V_x\right), \frac{\eta_d}{\gamma_m} \cdot 0.9 \cdot mean(Pu)\right]$$ result: $R_{d.op} = 3404 \cdot N$

Determination of the design value for the tensile strength of the crop wire connection with Gripple GP90.

Customer: Van Rooij & Co Draadproducten B.V.

Results of the static loading test with Gripple GP90 and crop wire Crapal 3,15 mm:

Test nr. 1: $Pu_0 := 4080 \cdot N$

Test nr. 2: $Pu_1 := 4060 \cdot N$

Test nr. 3: $Pu_2 := 4000 \cdot N$

Test nr. 4: $Pu_4 := 3950 \cdot N$

Test nr. 5: $Pu_3 := 3930 \cdot N$ $n := rows(Pu)$ $n = 5$

Type fo failure:
Breakage of the crop wire in the clamping mechanism of the Gripple GP90.

The 5% statistical value k_n, to determine the factor Vx "not known", is based on the Bayesian probability theory as given in D7.2(3) of NEN-EN 1990. This factor depends on the number of tests. Per static loading test two test pieces have been tested. This has been taken into account when assuming the 5% statistical value k_n.

$k_3 := 3.37$ $k_5 := 2.33$ $k_7 := 2.09$ $k_9 := 1.96$

$k_4 := 2.63$ $k_6 := 2.18$ $k_8 := 2.00$ $k_{10} := 1.92$ $k_{2n} = 1.92$

On the basis of the Normal distribution:

$m_X := mean(Pu)$ $m_X = 4004 \cdot N$

$$s_x := \sqrt{\frac{1}{n-1} \cdot \sum_{i=0}^{n-1} \left(Pu_i - m_X\right)^2} \qquad s_x = 65.80274 \cdot N$$

$$V_x := \frac{s_x}{m_X} \qquad V_x = 0.01643$$

Determination of the design value R_d for the tensile strength of the connection:

$\gamma_m := 1.25$ γ.m = γ.M2 according to table 8.1 of NEN-EN 1999-1-1

$\eta_d := 1$

Design value: $$R_d := min\left[\frac{\eta_d}{\gamma_m} \cdot m_X \cdot \left(1 - k_{2 \cdot n} \cdot V_x\right), \frac{\eta_d}{\gamma_m} \cdot 0.9 \cdot mean(Pu)\right]$$ result: $R_d = 2883 \cdot N$

Determination of the design value for the tensile strength of the crop wire connection with Gripple GP90.

Customer: Van Rooij & Co Draadproducten B.V.

Results of the static loading test with Gripple GP90 and crop wire gavanized 3,8 mm:

Test nr. 1: $Pu_0 := 5000 \cdot N$

Test nr. 2: $Pu_1 := 5210 \cdot N$

Test nr. 3: $Pu_2 := 5120 \cdot N$

Test nr. 4: $Pu_4 := 5150 \cdot N$

Test nr. 5: $Pu_3 := 4920 \cdot N$

$n := rows(Pu)$ $n = 5$

Type fo failure:
Breakage of the crop wire in the clamping mechanism of the Gripple GP90.

The 5% statistical value $k_{n,}$ to determine the factor Vx "not known", is based on the Bayesian probability theory as given in D7.2(3) of NEN-EN 1990. This factor depends on the number of tests. Per static loading test two test pieces have been tested. This has been taken into account when assuming the 5% statistical value k_n.

$k_3 := 3.37$ $k_5 := 2.33$ $k_7 := 2.09$ $k_9 := 1.96$

$k_4 := 2.63$ $k_6 := 2.18$ $k_8 := 2.00$ $k_{10} := 1.92$ result: $k_{2n} = 1.92$

On the basis of the Normal distribution:

$m_X := mean(Pu)$ $m_X = 5080 \cdot N$

$$s_x := \sqrt{\frac{1}{n-1} \cdot \sum_{i=0}^{n-1} \left(Pu_i - m_X\right)^2} \qquad s_x = 117.68602 \cdot N$$

$$V_x := \frac{s_x}{m_X} \qquad V_x = 0.02317$$

Determination of the design value R_d for the tensile strength of the connection:

$\gamma_m := 1.25$ γ.m = γ.M2 according to table 8.1 of NEN-EN 1999-1-1

$\eta_d := 1$

Design value: $$R_d := \min\left[\frac{\eta_d}{\gamma_m} \cdot m_X \cdot \left(1 - k_{2 \cdot n} \cdot V_x\right), \frac{\eta_d}{\gamma_m} \cdot 0.9 \cdot mean(Pu)\right]$$ result: $R_d = 3658 \cdot N$