Using VantagePoint to Analyze d-Rebar Data

YieldPoint Inc

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YieldPoint Sensing the future

1.Stacked gauges

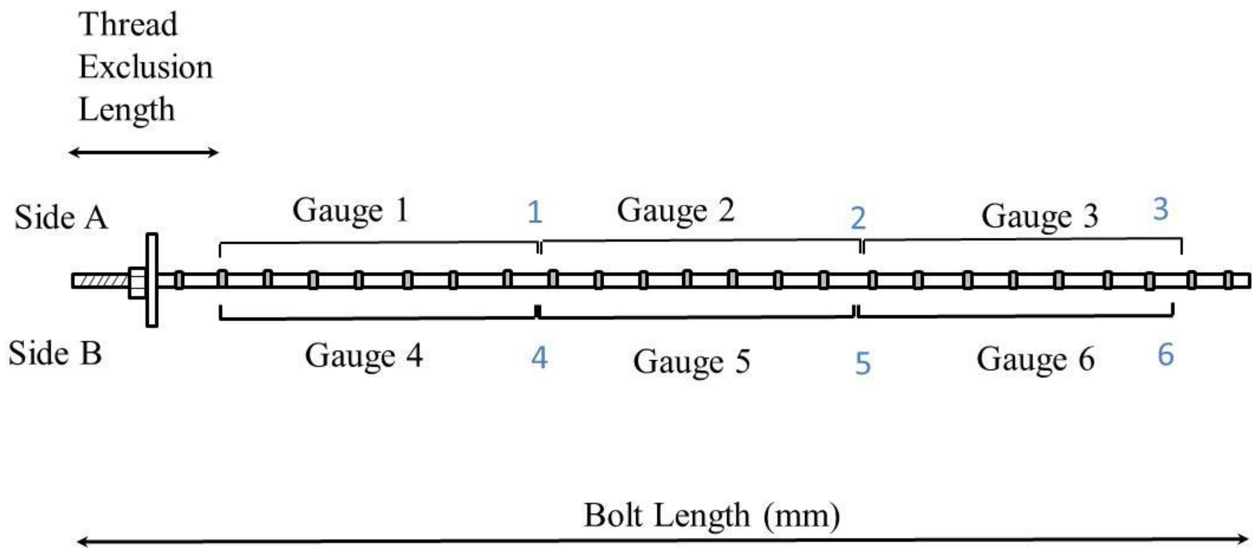


Figure 1 A stacked gauge configuration

The axial strain is calculated from:

$$\varepsilon^{i}_{axial} = (e^{i} + e^{i+3})/2L \qquad i=1,2,3 \qquad (1)$$

where e^i is the stretch (mm), or relative displacement, between the ends of the i^{th} gauge in mm. These results represent the average strain along the length of the gauge and are located at the center of the gauge.

The corresponding bending strain is:

$$\varepsilon^{i}_{bending} = (\varepsilon^{i} - \varepsilon^{i+3})/2. \qquad (3)$$

Since the gauges are arranged end-to-end and monitor the whole length of the bolt the equivalent displacement profile can be written:

$$\Delta u^{i}_{axial} = \sum_{n=3}^{n=i} (\varepsilon^{i}_{axial} \times L) \qquad (4)$$

for i=1,2 and 3.

It should be recognized that a distinction is made between the measured displacement (Δu^i) from each displacement sensor and the calculated axial displacement Δu^{i}_{axial}.which accounts for any bending.

2. Staggered gauges

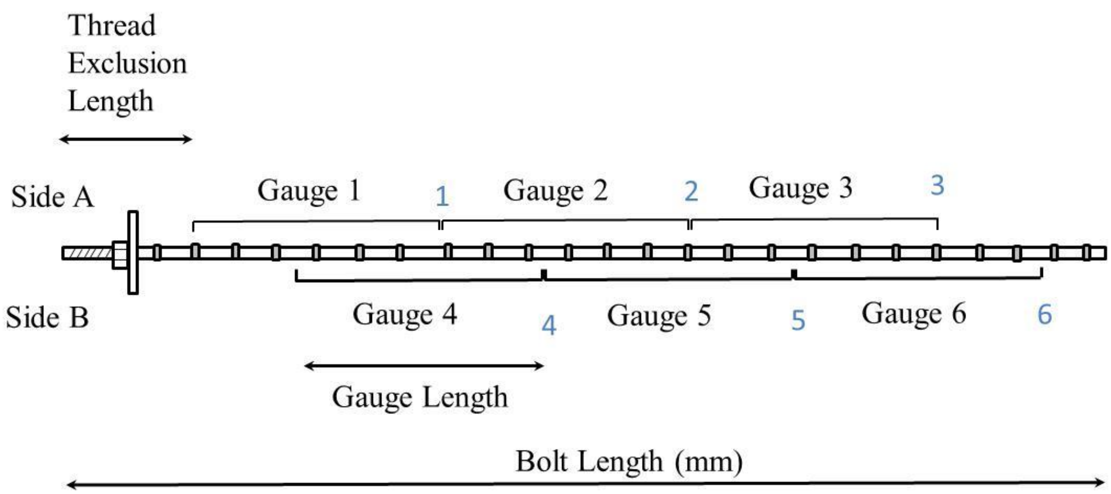


Figure 2 A staggered gauge configuration.

For the staggered configuration, the gauges on Side A of the bolt are offset from those on Side B by one half the base-length of the sensor (L/2). In this case a data reduction scheme is implemented based on the central difference approximation to the second order governing differential equation for displacement variation along a grouted bolt (Farmer[2]). The strains at the i^{th} nodal point can be approximated as:

$$\varepsilon_{axial}^{i} = (3e^{i}+e^{i+3})/4L \qquad i=1 \qquad (5a)$$

$$\varepsilon_{axial}^{i} = (e^{i+2} +2e^{i}+e^{i+3})/4L \qquad i=2,3 \qquad (5b)$$

$$\varepsilon_{axial}^{i} = (e^{i-3} +2e^{i}+e^{i-2})/4L \qquad i=4,5 \qquad (5c)$$

$$\varepsilon_{axial}^{i} = (e^{i-3} +2e^{i})/4L \qquad i=6 \qquad (5d)$$

Where $e^{1} – e^{6}$ are the measured stretch values.

Since the gauges are arranged end-to-end and monitor the whole length of the bolt the corresponding displacement profile at the ith nodal point can be calculated from the summation from toe to head:

$$\Delta u_{axial}^{i} = \sum_{n=6}^{n=i} (e_{axial}^{i} \times \ L/2) \qquad (6)$$

from the toe end of the bolt which is assumed a fixed point ($\Delta u_{axial}^{toe} = 0$).

Force calculation

The force-strain response of a typical rebar is shown above. VantagePoint assumes a tri-linear response (1) elastic, (2) plastic, and (3) hardening.

For the elastic zone (1):

$$F_{axial} = F_e\,(\varepsilon_{axial}\,/\varepsilon_e) \quad .....(7)$$

for zone (2);

$$F_{axial} = (F_p\text{-}F_e).(\varepsilon_{axial}-\varepsilon_{e)}\,/(\varepsilon_p - \varepsilon_e) \qquad (8)$$

and for zone 3;

$$F_{axial}= (F_u\text{-}F_p).(\varepsilon_{axial}-\varepsilon_{p)}\,/(\varepsilon_u - \varepsilon_p). \qquad (9)$$

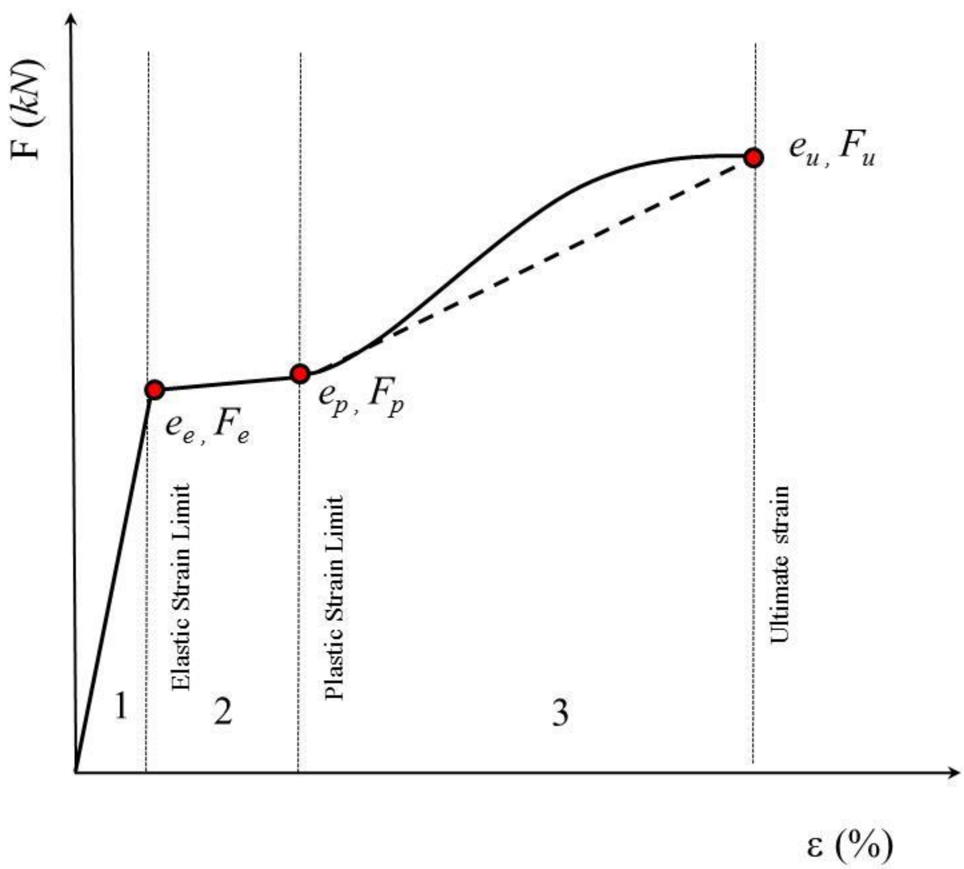
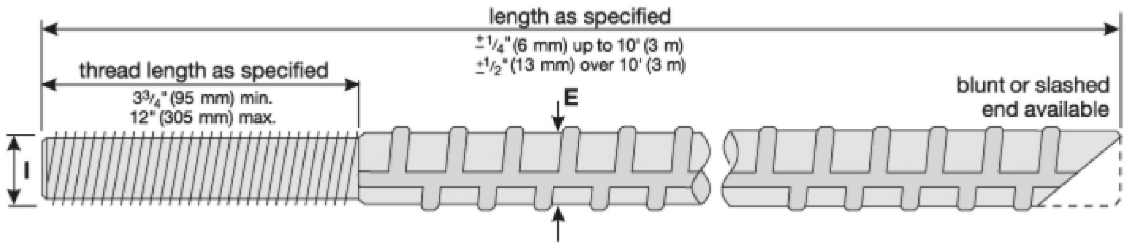


Figure 3: The tri-linear load deformation plot

Threaded Rebar



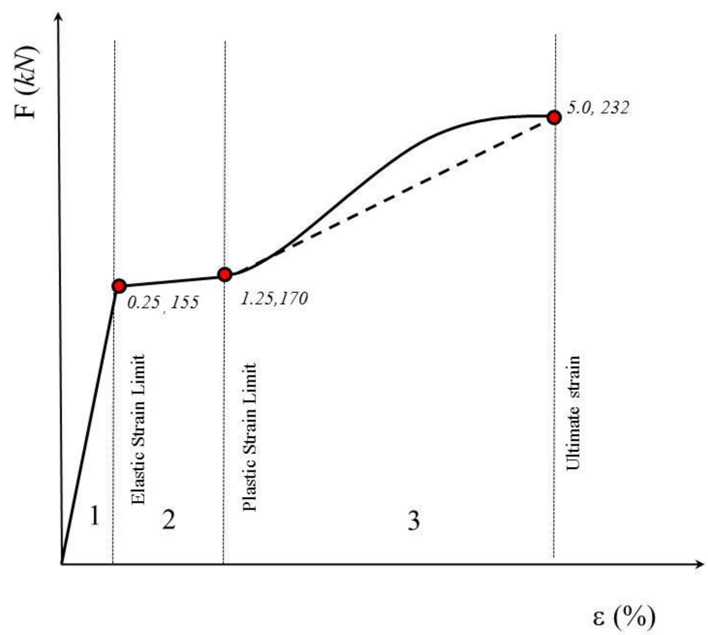
Technical Data - Threaded - grade 60:	5/8" - 11 UNC	3/4" - 10 UNC	7/8" - 9 UNC	1" - 8 UNC
Yield Strength, min.	13,600 lbs (60.5 kN)	20,000 lbs (89 kN)	27,700 lbs (123.2 kN)	36,400 lbs (161.9 kN)
Tensile Strength, min.	20,300 lbs (90.3 kN)	30,100 lbs (133.9 kN)	41,600 lbs (185 kN)	54,500 lbs (242.4 kN)
Elongation in 8" (200mm)	9% minimum	9% minimum	9% minimum	9% minimum

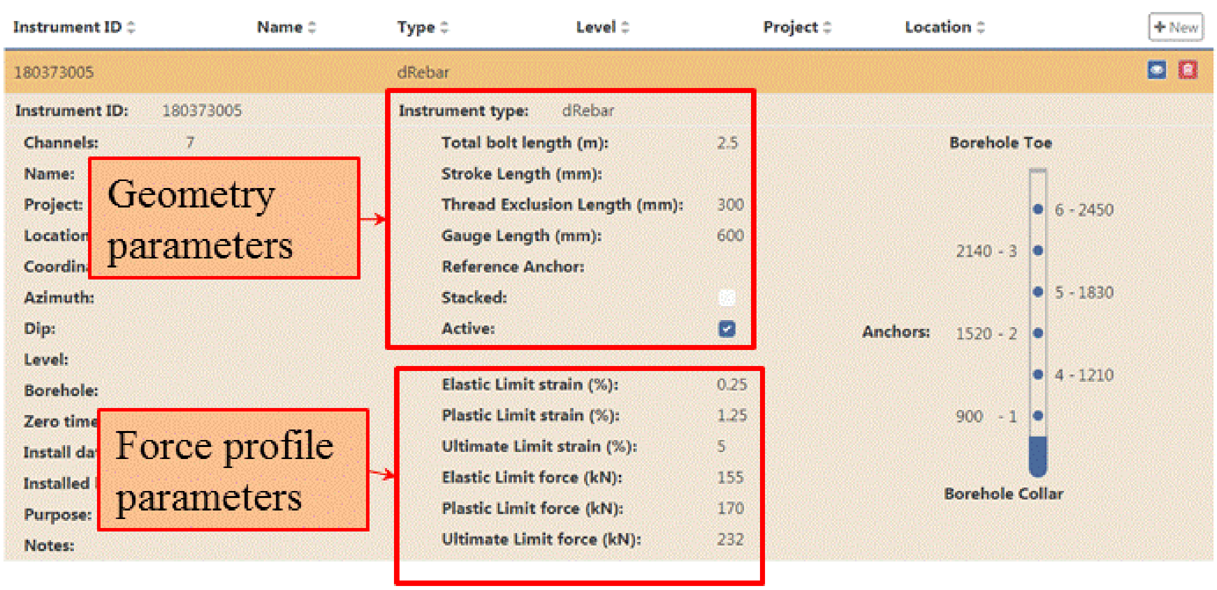
Figure 4: Mechanical properties of some typical rebar (DSI website)

The properties of the rebar depend principally on (i) the cross sectional area and (ii) the grade of steel.

Example 1:

The rebar properties





Instrument ID | Name | Type | Level | Project | Location | + New

180373005 | dRebar

Instrument ID: 180373005

Channels: 7

Name:

Project:

Location

Coordin

Azimuth:

Dip:

Level:

Borehole:

Zero time

Install da

Installed

Purpose:

Notes:

Geometry parameters

Force profile parameters

Instrument type: dRebar

Total bolt length (m):	2.5
Stroke Length (mm):	
Thread Exclusion Length (mm):	300
Gauge Length (mm):	600
Reference Anchor:	
Stacked:	
Active:	☑
Elastic Limit strain (%):	0.25
Plastic Limit strain (%):	1.25
Ultimate Limit strain (%):	5
Elastic Limit force (kN):	155
Plastic Limit force (kN):	170
Ultimate Limit force (kN):	232

Borehole Toe

6 - 2450

2140 - 3

5 - 1830

Anchors: 1520 - 2

4 - 1210

900 - 1

Borehole Collar

Figure 5: The rebar property form.

The load-deformation profile and corresponding force profile values for the rebar are shown in Figure 5. This information will be used to calculate the force in the bolt based on the strain value.

Stretch (e) is the raw data measured from the instrument. Stretch values are plotted at the gauge mid-point. Stretch is the difference in displacement between the two ends of the gauge.

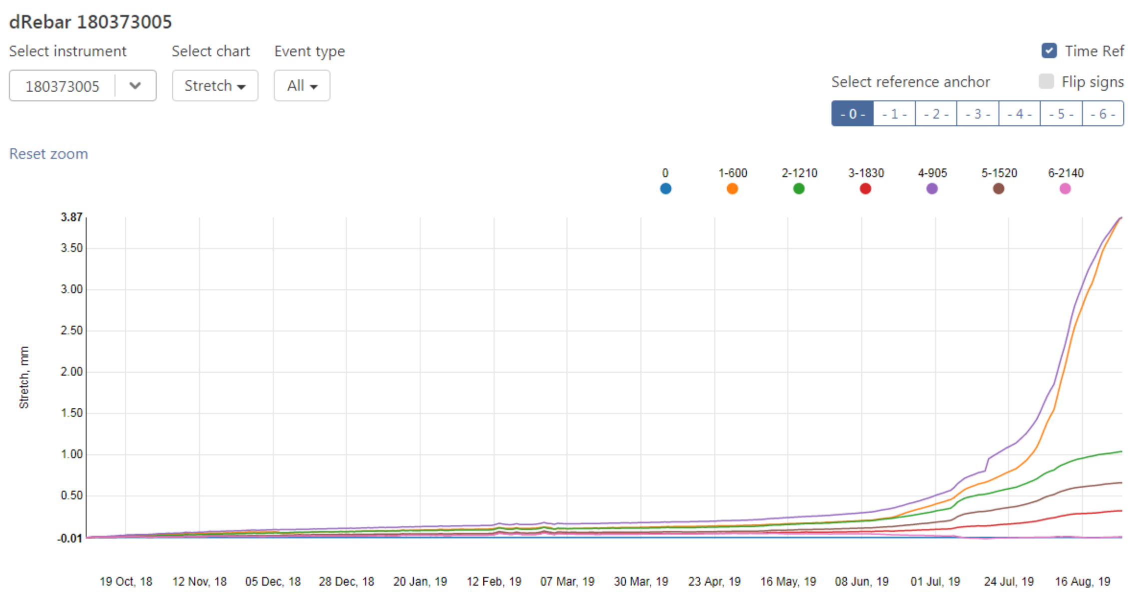


Figure 6: Temporal plot for stretch which is the raw data from the instrument.

The temporal plot for stretch is shown in Figure 6 and the corresponding axial strain (at the center of the re bar) calculated from Equation 5 is shown in Figure 7. The spatial profile for axial strain along the length of the rebar is shown in Figure 7b. In the spatial plot each trace corresponds to a snapshot in time. Hovering over the trace presents the corresponding timestamp.

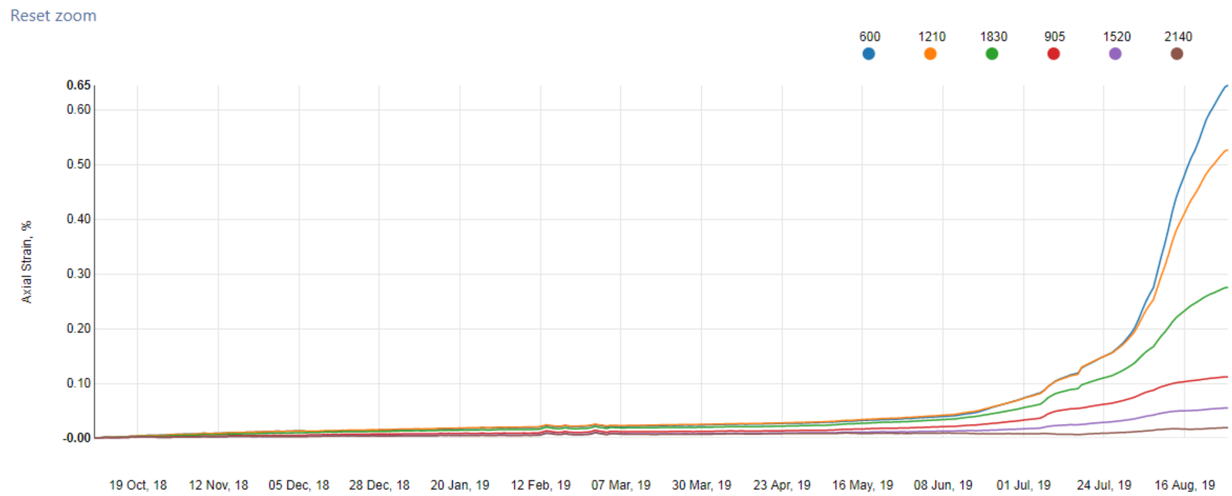


Figure 7a: Temporal plot for axial strain *(ε_{axial})*.

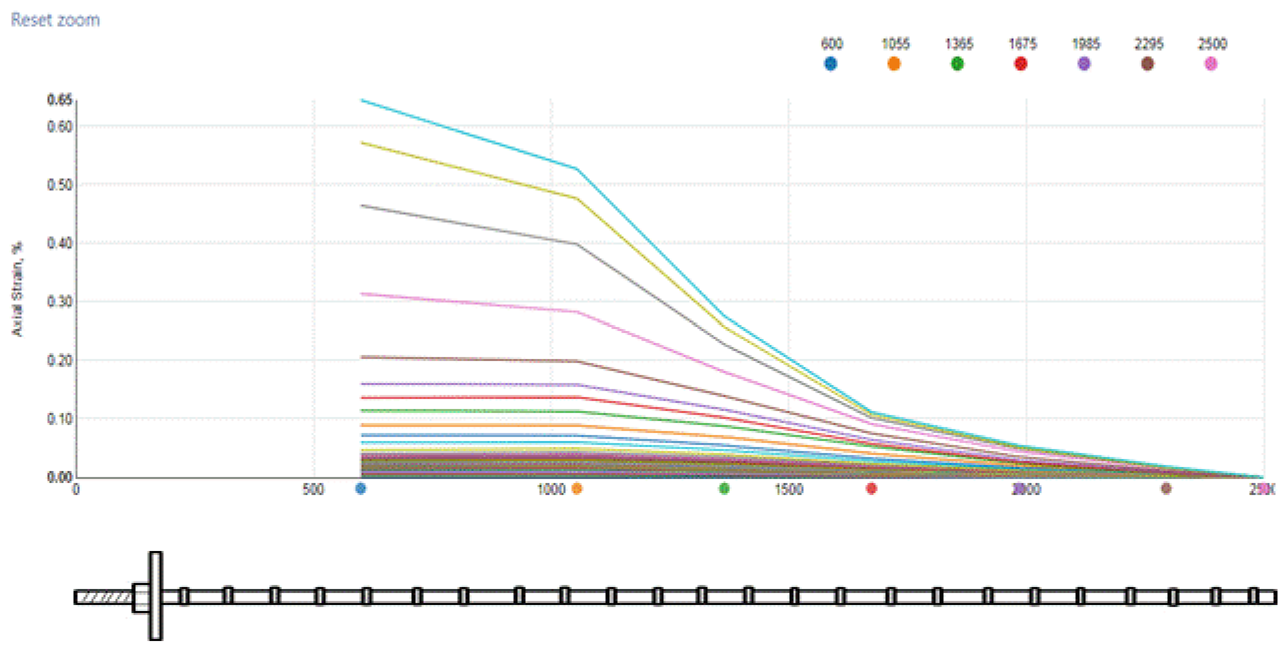


Figure 7b: Spatial plot for axial strain*(ε_{axial})*. The values are plotted at the center of each gauge.

The axial strain represented the strain acting at the center of the rebar in the axial direction.

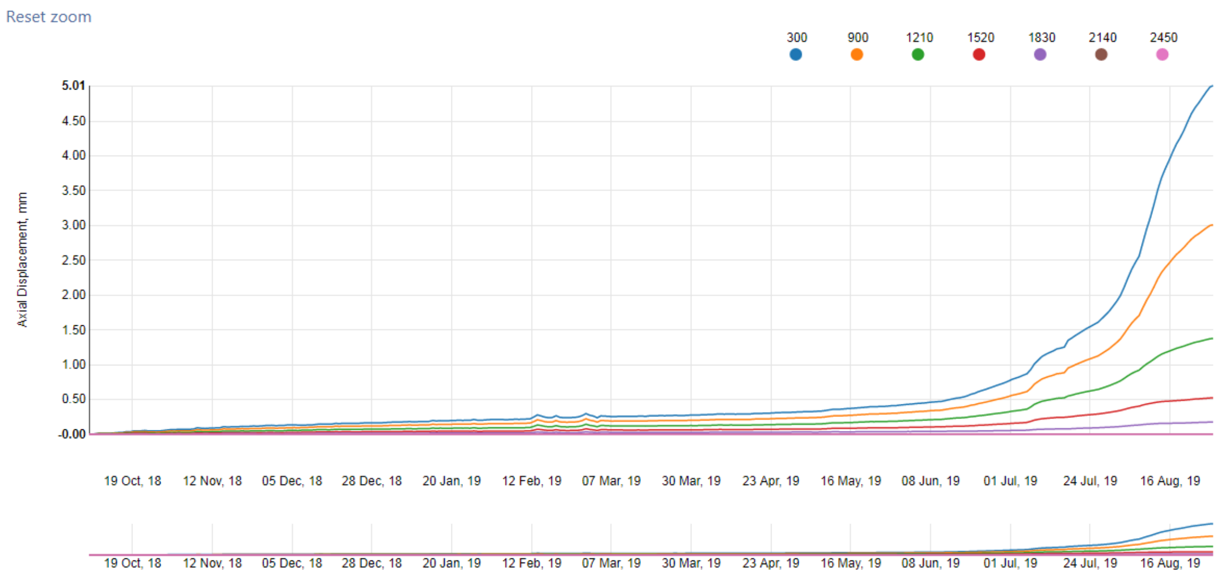


Figure 8a: Temporal plot for axial displacement.

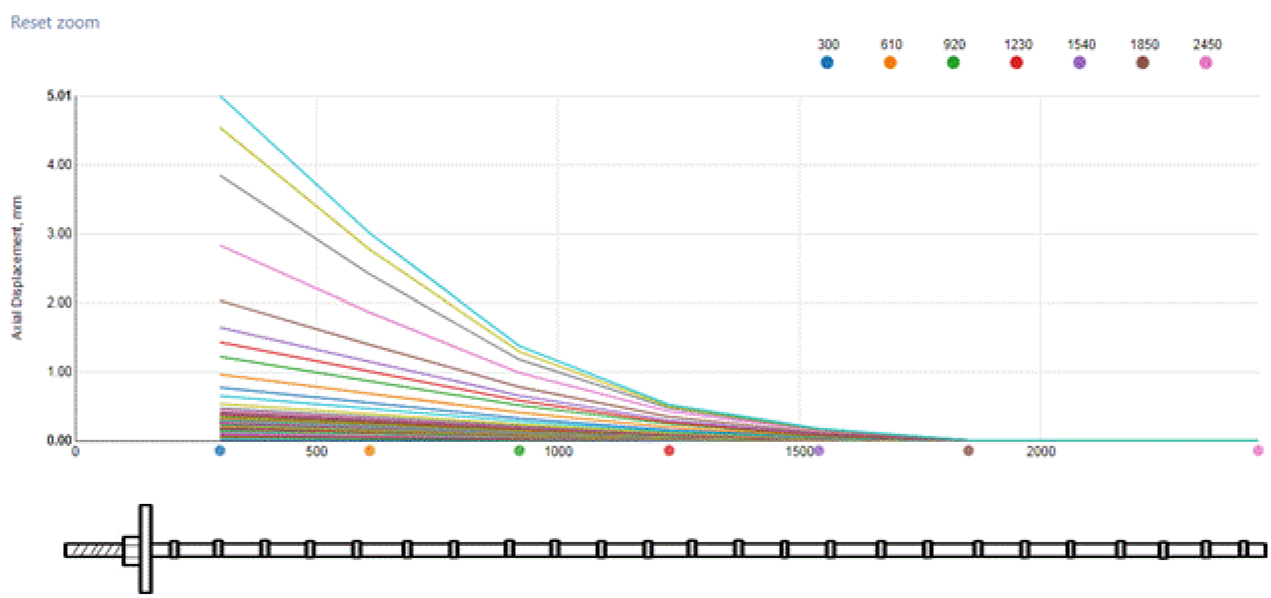


Figure 8b: Spatial plot for axial displacement.

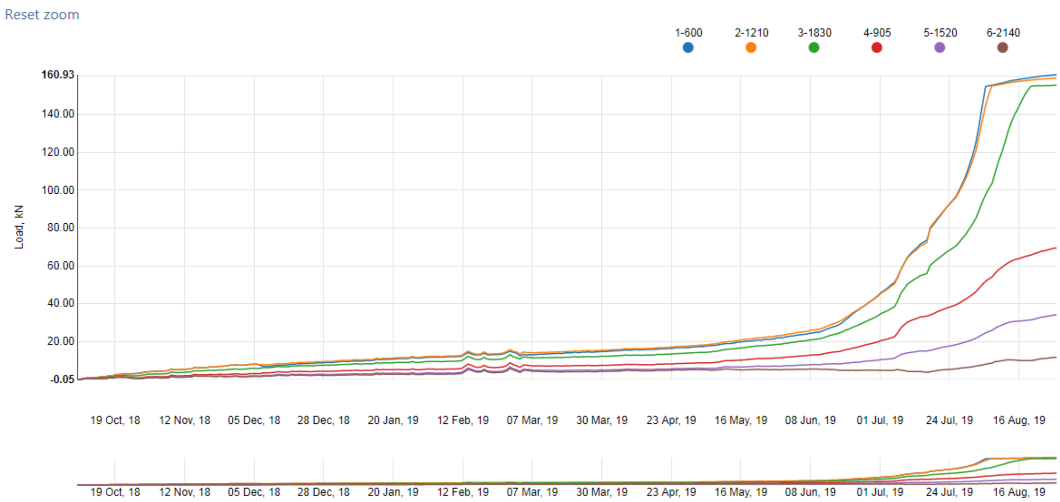


Figure 9a. The temporal plot for axial load. Notice how the load stops rising after the bolt exceeds the elastic limit and enters Zone 2.

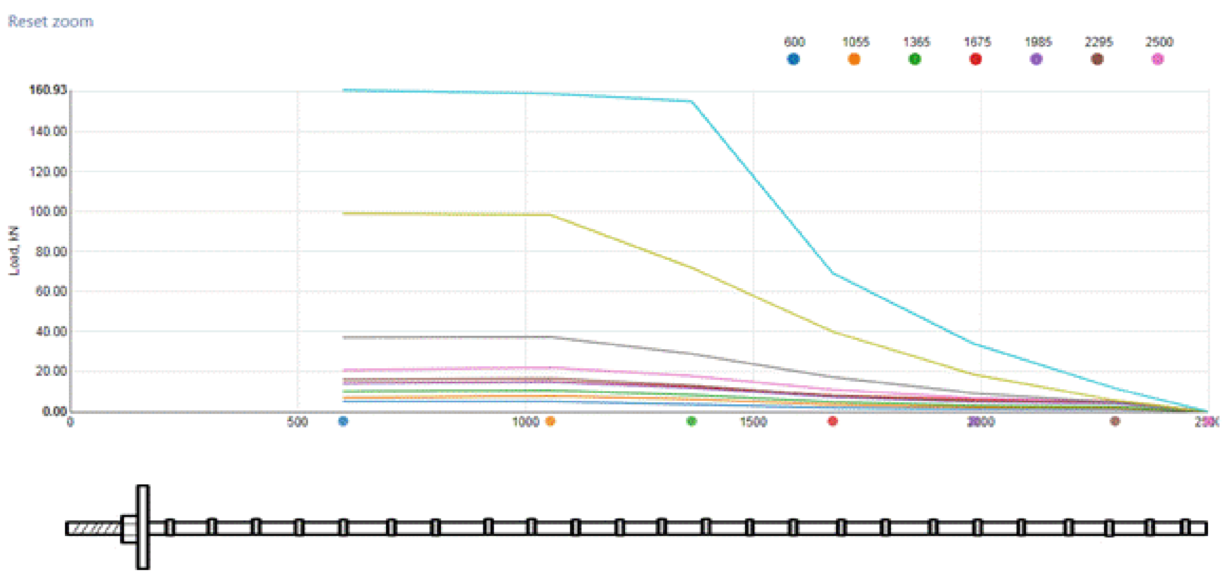


Figure 9b. The corresponding spatial plot for axial load.