TU Date first recieved 21 April, 2005; Date accepted for publication 20 May, 2005



# Strength and Physical Properties of Zambian Grown Eucalyptus Poles

E. Lusambo* and M. N. Mulenga**

*Department of Agricultural Engineering, University of Zambia, PO Box 32379, Lusaka, Zambia

**Department of Civil and Environmental Engineering, University of Zambia, P O Box 32379, Lusaka, Zambia

**Abstract**

*Poles used for overhead power and telecommunication lines and buildings are specified by species, physical properties such as moisture content, and dimensions as well as strength properties such as ultimate load. These properties vary from species to species. Design stresses may be determined using testing methods specified in various codes to arrive at grade stresses. For example, in Australia and New Zealand, the poles are assigned one stress grade higher than the highest grade of the same sawn timber. Design stresses for American preservative-treated round poles were established following tests specified by ASTM Standards D3200. In the United Kingdom, BS 1990 Parts 1 and 2 give specifications for wood poles for overhead power and telecommunication lines. In Zambia, there is no standard that deals specifically with overhead power and telecommunication lines. However, it is necessary to test Zambian plantation-grown poles and establish basic physical and structural properties. This paper aims to present a method that can be used for for establishing a Zambian standard for poles.*

*Eucalyptus poles are used in fencing, overhead power and telecommunication lines, mine props, support structures, building structures and in the production of sawn timber. In all these uses, the physical and strength properties of the poles are of great importance. This paper presents test results on Eucalyptus grandis and Eucalyptus cloesiana poles which were tested following guidelines for testing poles used for overhead power and telecommunication lines are contained in BS 1990 Part 1.*

***Keywords:*** *Poles; Eucalyptus; Structural properties; Testing*

## Introduction

In Zambia the two main plantation grown species of poles generally sold on the market include *E. grandis* (also called blue gum) and *E. cloesiana* which are both hardwoods with straight grain. They are both only moderately susceptible to insect and fungal attack. Eucalyptus poles are used in fencing, overhead power and telecommunication lines, mine props, support structures, building structures and for sawing. In all these uses, the physical and strength properties of the poles are of great importance. For example, poles used for overhead power lines have to have a certain minimum load capacity for them to meet the service conditions.

Poles used for transmission lines and buildings are specified by species, moisture content, grade and dimensions, and their properties vary from species to species. Design stresses in wood poles for transmission are derived from static bending tests of poles using methods that apply maximum stress at the ground line (Parker, 1986). In countries such as Australia and New Zealand, poles are assigned one stress grade higher than the highest grade of the same species of sawn timber, because the occurrence of natural defects is compensated for by the inherent strength of round poles (Jayanetti, 1990). Design stresses for selected American preservative-treated round poles are presented in ASAE Standards EP388.2 (ASAE Standards, 1992). These stresses were established following tests as carried out to ASTM Standards D3200. In the United Kingdom BS 1990: Part 1 (1984) for softwood poles and BS 1990: Part 2 for hardwood poles provide specifications for testing wood poles for overhead power and telecommunication lines. In Zambia, no such standard exists. However, it is necessary to test poles and establish basic physical and structural properties, such as:

(i) density;
(ii) ultimate bending strength; and
(iii) modulus of elasticity.

This paper presents test results on *E. grandis* and *E. cloesiana* poles which were performed following BS 1990 Part 1. The standard outlines the method of preparing the poles, the test set-up and the method of applying the load. The standard also provides formulae for computing the maximum stresses, modulus of elasticity and other parameters.

A test rig normally used for testing beams was used in this study. The loading arrangement was, however, adapted to suit the requirements for testing poles of up to 12m. The adaptation involved the construction of a loading frame on which a hydraulic jack was mounted. Two other frames were fabricated for supporting the poles in either cantilever or simply supported configurations.

## Methods for Testing Poles

The testing rig consisted of steel frames mounted on a structural concrete floor. The load was applied using a hydraulic ram mounted on a separate steel frame.

The instrumentation included a Linear Variable Differential Transducer (LVDT) and a strain gauge-based load cell connected to a datalogger. The load-deflection data collected by the datalogger was monitored and stored directly on a computer.

The test arrangement was consistent with the provisions of BS 1990 Part 1. Figures 1 and 2 show the arrangement for testing simply supported and cantilever poles respectively. Figures 3 to 6 show simply supported poles and cantilever poles being tested.

Four lengths of poles were tested, i.e. 12m, 10m, 9m and 8m. For each length, four *E. grandis* and four *E. cloesiana* poles (i.e. eight poles of each length) were tested. The tests were then arranged such that from each length, four poles (two from each species) were tested as cantilevers and the other four as simply supported beams. The density of the poles was measured as per BS 1990: Part 1 (1984) for both species. Ten specimens were tested in each case and the mean values are reported here.

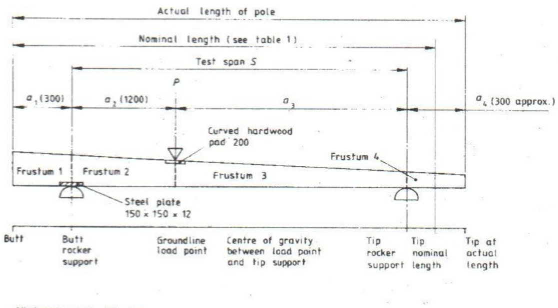


Figure 1: Testing arrangement for a simply supported pole (From BS 1990: Part)

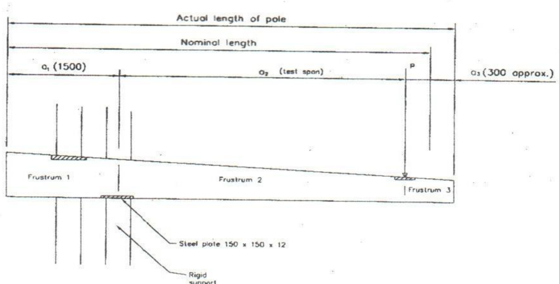


Figure 2: Testing arrangement for a cantilever pole

Figure 3: Testing a simply supported 12m pole

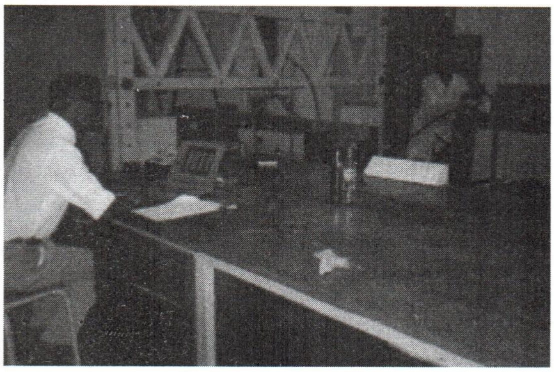

Figure 4: Testing a simply supported 4.5m cross arm

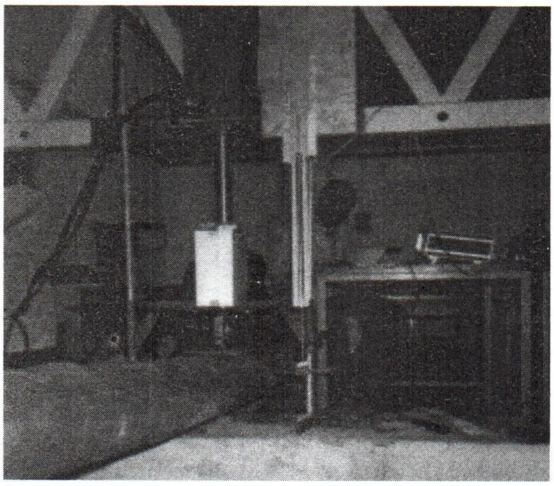

Figure 5: Testing a cantilever pole (load end)

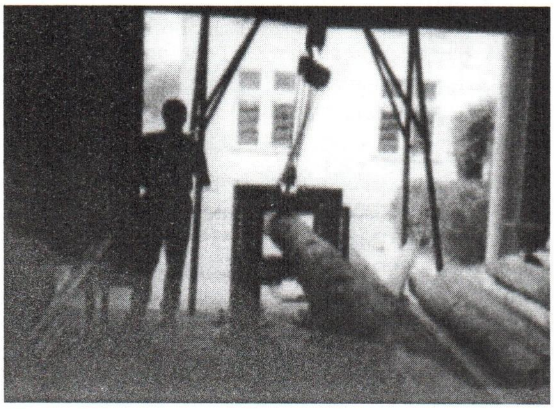

Figure 6: Testing a cantilever pole (support end)

**Results**

The results of the tests on poles are given in Appendix 1. Due to limitations in the testing equipment (i.e. the rig and instrumentation), the poles were not tested to failure. Large loads and deflections are required to reach failure. However, for the purpose of this study, testing to failure was not a requirement, as the aim was to obtain the modulus of elasticity, from the load-deflection curves.

Appendix 1 shows the average modulus of elasticity for the poles of the two species of timber.

The results of the analysis for forces required to cause specified stresses (i.e. 55Mpa and 75Mpa) are shown in Appendices 2 and 3, for simply supported and cantilever configurations, respectively.

**Discussion**

***Moisture content at time of testing***

The moisture content was measured using the oven dry method. The average moisture content for each species was found to be equal to the following values on a dry basis:

(a) Eucalyptus grandis: 16.8%;
(b) Eucalyptus cloesiana: 18.7%.

***Density of the poles and cross arms***

The poles were found to have mean densities as follows:

(a) Eucalyptus grandis: 600kg/m³ (at 16.8% moisture content);
(b) Eucalyptus cloesiana: 650kg/m³ (at 18.7% moisture content).

***Loading on poles***

The loads presented in Appendices 2 and 3 are for loading configurations shown in Figures 1 and 2. In both cases, the groundline is located at 1.5m from the butt for poles. For simply supported loading, the load is applied at the groundline itself, while for cantilever loading, the support is at the groundline and the load is applied at a point near the tip.

## Modulus of elasticity

The modulus of elasticity is the ratio of the stress to strain. It can also be evaluated from test results using standard equations relating load (P) to deflection ($\delta$). The load-deflection curves were plotted for all specimens and the slope of the curve i.e. $\Delta P/\Delta\delta$ evaluated. Figures 7 and 8 show the load-deflection curves for 10m poles under simply supported loading and cantilever loading, respectively. The values of ΔP/Δä were used in evaluating the modulus of elasticity according to the deflection formulae.

The self-weight of the poles was not taken into account in plotting the load deflection curves. This procedure is valid as the modulus of elasticity is a ratio of change in load over change in deflection.

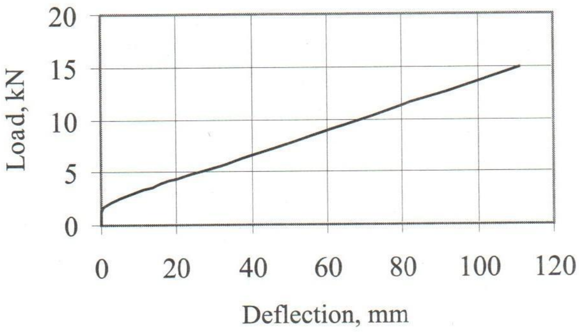


Figure 7: Typical load-deflection curve for 10m simply supported loaded pole

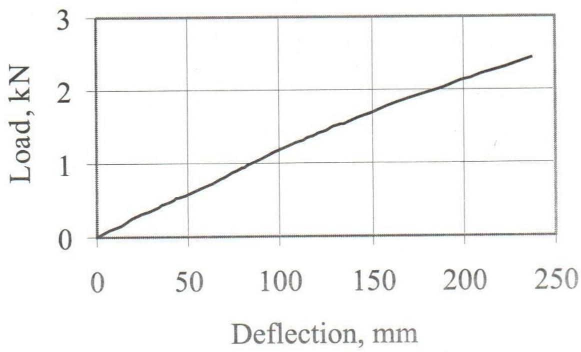


Figure 8: Typical load-deflection curve for 10m cantilever loaded pole

It may be noted that the average modulus of elasticity values are higher for simply supported poles compared to those for cantilever-loaded poles. This difference was attributed to errors within the testing methods. Overall, when many samples are tested, the normal distribution of values may be expected.

The values are, however, within the range expected for sawn timber from species as contained in ZS 032 (1986). In nearly all cases, *E. cloesiana* gave higher values of modulus of elasticity.

**Loads required to cause a given stress**

The mean ultimate strengths of poles were chosen to be equal to 55N/mm² (lower limit) and 75N/mm² (upper limit). These values were consistent with the requirements of one of the major users of poles in Zambia, i.e. the Zambia Electricity Supply Corporation (ZESCO, 2001). The loads required to cause the above mentioned stresses (either 55N/mm² or 75N/mm²) at the groundline are evaluated on the basis of the mean material properties for each size of pole and for each species of timber. The groundline is considered to be the critical section and corresponds to the assumed planting depth of power transmission and telegraph poles.

For simply supported loading (see Figure 1), the load is evaluated from equation 1:

$$F=\frac{fZS}{A_2a_3}$$

Where:

$f$ is the required stress in N/mm²;
$Z$ is the section modulus at the critical section (i.e. Groundline);
$a_2$ is the distance from the butt support to the application of the load in mm;
$a_3$ is the distance from the point of application of the load to the tip support in mm.

For cantilever loading (see Figure 2), the load is evaluated from Equation 2:

$$F=\frac{fZ}{a_2}$$

Where:

$f$ is the required stress in N/mm²;
$Z$ is the section modulus at the critical section (i.e. Groundline);
$a_2$ is the distance from the support to the point of application of the load in mm.

The results of these calculations are given in Appendices 2 and 3.

***Load per millimetre of deflection at the tip of the simply supported poles***

Poles are generally used as cantilevers in practice. Even when poles are tested as simply supported beams, the deflection at the tip of the poles may be of significance. For simply supported poles, the loading point may also occur at the tip support. In this case, the pole behaves as if it is loaded like a cantilever. With this consideration, BS 1990: Part 1 recommends the use of the following formula to evaluate load per millimetre of deflection at the tip of the poles:

$$F=\frac{3E\pi d_1^3 d_2}{64h^3}$$

Where:

$E$ is the modulus of elasticity in N/mm²;
$d_1$ is the diameter at the groundline in mm;
$d_2$ is the distance from the support to the point of application of the load in mm;
$h$ is the distance from the groundline to the point of application of the load in mm.

Forces computed based on these equations are presented in Appendices 2 and 3.

**Conclusions**

1. Zambian grown wood poles were tested in accordance with BS 1990: Part 1 (1984). The testing procedure was found to be suitable for testing under Zambian condition.
2. The average moisture contents were found to be 16.8 and 18.7% for *E. grandis* and *E. cloesiana*, respectively.
3. The moduli of elasticity for *E. grandis* and *E. cloesiana* determined from the load-deflection tests given in Table 1(a) and 1(b) conform to ZS 032 (1986).
4. Forces required to cause stresses of 55N/mm² (55MPa) and 75N/mm² (75MPa) were evaluated as recommended by BS 1990: Part 1 (1984) and are shown in Tables 2(a), 2(b), 3(a) and 3(b) for simply supported loading and cantilever loading.
5. The forces required to cause 1mm deflection were evaluated as recommended by BS 1990: Part 1 (1984) and are shown in Tables 2(a), 2(b), 3(a) and 3(b) for simply supported loading and cantilever loading.

**References**

ASAE Standards, (1992), EP388.2 Design Properties of Round, Sawn and Laminated Preservative-Treated Construction Poles and Posts, American Society of Agricultural Engineers, St. Joseph, USA.

BS 1990: Part 1 (1984), Wood poles for overhead power and telecommunications lines, British Standards Institution, Milton Keynes, UK.

Jayanetti L. (1990), Timber Pole Construction, Intermediate Technology Publications, London, UK.

ZS 032 (1986) : Zambian Standard Code of Practice for Structural Use of Locally Grown Timber, Zambia Bureau of Standards, Lusaka, Zambia.

ZESCO (2001), Private Letter.

## Appendix 1: Results of Load Tests on Poles

*Table 1(a) Results of Simply Supported (three-point loading) Tests on Poles*

| Pole | Length | Species | Butt dia. | Dia. 1.5m from butt | Tip dia. | Max. Applied load | Deflection at max. load | Max. Groundline stress due to applied load | Modulus of Elasticity | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | GR* | CL** |
| | m | | mm | mm | mm | kN | mm | N/mm² | N/mm² | N/mm² |
| Ss1201 | 12 | CL | 270.6 | 238.7 | 175.1 | 18.6 | 204.8 | 15.0 | | 20385.8 |
| SS1202 | 12 | GR | 288.1 | 261.0 | 211.7 | 24.9 | 216.8 | 15.3 | 16359.4 | |
| SS1203 | 12 | GR | 275.0 | 235.6 | 191.0 | 17.7 | 195.1 | 14.8 | 13976.4 | |
| SS1204 | 12 | CL | 264.2 | 227.6 | 191.0 | 20.1 | 186.3 | 18.6 | | 19266.1 |
| SS1001 | 10 | GR | 246.7 | 227.6 | 203.7 | 12.6 | 88.8 | 11.4 | 12723.2 | |
| SS1002 | 10 | CL | 222.8 | 208.5 | 175.1 | 15.8 | 101.5 | 18.5 | | 17147.1 |
| SS1003 | 10 | CL | 248.3 | 234.0 | 181.4 | 12.5 | 21.9 | 10.4 | | 18732.7 |
| SS1004 | 10 | GR | 248.3 | 241.9 | 191.0 | 14.7 | 16.5 | 11.0 | 17666.3 | |
| SS901 | 9 | GR | 232.4 | 227.6 | 192.6 | 16.8 | 21.4 | 14.9 | | |
| SS902 | 9 | GR | 237.1 | 226.0 | 168.7 | 15.1 | 27.2 | 13.7 | 19154.9 | |
| SS903 | 9 | CL | 214.9 | 210.1 | 170.3 | 15.7 | 29.2 | 17.7 | | 23279.8 |
| SS904 | 9 | CL | 232.4 | 227.6 | 192.6 | 16.8 | 21.4 | 14.9 | | 23624.9 |
| SS802 | 8 | GR | 168.7 | 163.9 | 120.1 | 15.6 | 85.1 | 36.2 | 16461.0 | |
| SS803 | 8 | GR | 165.5 | 162.3 | 119.4 | 19.5 | 133.4 | 46.7 | 16215.7 | |
| Ss804 | 8 | CL | 168.7 | 163.9 | 119.8 | 16.4 | 145.2 | 38.1 | | 15911.6 |
| Ave. | | | | | | | | | **16079.6** | **19764.0** |

*Table 1(c)* *Results of Cantilever Tests on Poles*

| Pole | Length | Species | Butt dia. | Dia. 1.5m from butt | Tip dia. | Max. Applied load | Deflection at max. load | Max. Groundline stress due to applied load | Modulus of Elasticity GR* | CL** |
|---|---|---|---|---|---|---|---|---|---|---|
| | m | | mm | mm | mm | kN | mm | N/mm² | N/mm² | N/mm² |
| Can1201 | 12 | GR | 282.1 | 270.0 | 185.0 | 0.81 | 191.3 | 4.40 | 11503.4 | |
| Can1202 | 12 | GR | 304.4 | 290.1 | 190.2 | 1.14 | 170.8 | 4.99 | 10960 | |
| Can1203 | 12 | CL | 275.9 | 265.2 | 190.1 | 0.67 | 61.1 | 3.84 | | 18969 |
| Can1204 | 12 | CL | 255.8 | 245.1 | 170.0 | 1.11 | 233.9 | 8.06 | | 16109.9 |
| Can1001 | 10 | CL | 235.0 | 226 | 175.1 | 1.6 | 209.2 | 12.00 | | 13511.7 |
| Can1002 | 10 | CL | 254.1 | 245.1 | 194.2 | 2.44 | 237.5 | 14.35 | | 15215.1 |
| Can1003 | 10 | GR | 260.1 | 248.3 | 181.4 | 0.9 | 158.2 | 5.09 | 10126.6 | |
| Can1004 | 10 | GR | 250.9 | 241.9 | 191.0 | 0.98 | 128.4 | 5.99 | 12633.85 | |
| Can901 | 9 | GR | 222.3 | 213.4 | 168.7 | 1.69 | 217.5 | 13.29 | | 18154.1 |
| Can902 | 9 | GR | 227.9 | 219.6 | 178.2 | 1.63 | 144.6 | 11.76 | 13607.6 | |
| Can903 | 9 | GR | 233.0 | 222.8 | 171.9 | 1.99 | 220.4 | 13.75 | 14778.3 | |
| Can904 | 9 | CL | 288.7 | 267.4 | 160.8 | 2.0 | 232.6 | 7.99 | | 9370.5 |
| Can801 | 8 | GR | 181.5 | 170.0 | 120.0 | 0.4 | 239.7 | 5.39 | 10324.0 | |
| Can802 | 8 | GR | 175.4 | 165.0 | 120.0 | 0.5 | 213.3 | 7.66 | 11888.1 | |
| Can803 | 8 | CL | 193.1 | 185.0 | 150.0 | 1.2 | 233.9 | 12.86 | | 17464.7 |
| Can804 | 8 | CL | 189.2 | 180.0 | 140.0 | 1.1 | 172.2 | 12.03 | | 15828.2 |
| Ave. | | | | | | | | | **11977.7** | **15577.9** |

*GR: E. grandis; **CL: E.cloesiana

## Appendix 2: Forces in Poles – Simply Supported Three-Point Loading

*Table 2(a) Forces required to cause stresses of 55N/mm² and 75N/mm² in Eucalyptus grandis poles*

| S/N | Pole Length | Assumed depth of Planting | Position of tip support From tip | Min. Tip Dia. | Min. Dia. 1.5m from Butt end | Force required to cause stress of 55N/mm² | Force required to cause stress of 75N/mm² | Force per millimeter of deflection at tip end |
|---|---|---|---|---|---|---|---|---|
| | M | m | m | mm | mm | kN | kN | N/mm |
| 1 | 8 | 1.5 | 0.3 | 120 | 170 | 26.39 | 35.98 | 5.9 |
| 2 | 9 | 1.5 | 0.3 | 160 | 220 | 55.90 | 76.22 | 10.8 |
| 3 | 10 | 1.5 | 0.3 | 170 | 240 | 71.31 | 97.24 | 10.1 |
| 4 | 12 | 1.5 | 0.3 | 180 | 260 | 88.39 | 120.53 | 7.1 |

*Table 2(b) Forces required to cause stresses of 55N/mm² and 75N/mm² in Eucalyptus cloesiana poles*

| S/N | Pole Length | Assumed depth of Planting | Position of tip support From tip | Min. Tip Dia. | Min. Dia. 1.5m from Butt end | Force required to cause stress of 55N/mm² | Force required to cause stress of 75N/mm² | Force per millimeter of deflection at tip end |
|---|---|---|---|---|---|---|---|---|
| | M | m | m | mm | mm | kN | kN | N/mm |
| 1 | 8 | 1.5 | 0.3 | 120 | 170 | 26.39 | 35.98 | 7.2 |
| 2 | 9 | 1.5 | 0.3 | 160 | 220 | 55.90 | 76.22 | 13.3 |
| 3 | 10 | 1.5 | 0.3 | 170 | 240 | 71.31 | 97.24 | 12.4 |
| 4 | 12 | 1.5 | 0.3 | 180 | 260 | 88.39 | 120.53 | 8.7 |

**Appendix 3: Forces in Poles – Cantilever Loading**

*Table 3(a) Forces required to cause stresses of 55N/mm² and 75N/mm² in Eucalyptus grandis poles*

| S/N | Pole Length | Assumed depth of Planting | Position of tip support From tip | Min. Tip Dia. | Min. Dia. 1.5m from Butt end | Force required to cause stress of 55N/mm² | Force required to cause stress of 75N/mm² | Force per millimeter of deflection at tip end |
|---|---|---|---|---|---|---|---|---|
| | M | m | m | mm | mm | kN | kN | N/mm |
| 1 | 8 | 1.5 | 0.3 | 120 | 170 | 4.28 | 5.83 | 4.4 |
| 2 | 9 | 1.5 | 0.6 | 160 | 220 | 8.33 | 11.36 | 12.6 |
| 3 | 10 | 1.5 | 0.6 | 170 | 240 | 9.45 | 12.88 | 17.4 |
| 4 | 12 | 1.5 | 0.6 | 180 | 260 | 9.59 | 13.07 | 23.4 |

*Table 3(b) Forces required to cause stresses of 55N/mm² and 75N/mm² in Eucalyptus cloesiana poles*

| S/N | Pole Length | Assumed depth of Planting | Position of tip support From tip | Min. Tip Dia. | Min. Dia. 1.5m from Butt end | Force required to cause stress of 55N/mm² | Force required to cause stress of 75N/mm² | Force per millimeter of deflection at tip end |
|---|---|---|---|---|---|---|---|---|
| | M | m | m | mm | mm | kN | kN | N/mm |
| 1 | 8 | 1.5 | 0.3 | 120 | 170 | 4.28 | 5.83 | 5.7 |
| 2 | 9 | 1.5 | 0.6 | 160 | 220 | 8.33 | 11.36 | 16.4 |
| 3 | 10 | 1.5 | 0.6 | 170 | 240 | 9.45 | 12.88 | 22.6 |
| 4 | 12 | 1.5 | 0.6 | 180 | 260 | 9.59 | 13.07 | 30.5 |