CLT Diaphragms Properties

Date: July 7, 2015

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CLT Diaphragms Properties

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1. INTRODUCTION

A testing program related to the evaluation of the mechanical properties of CLT diaphragms used in construction was carried out by the Advanced Building Systems (ABS) Department of FPInnovations in response to a request made by the Client, Nordic Engineered Wood Products. The main objective of this study was to determine the in-plane stiffness and potentially strength properties of CLT panels used in diaphragm applications. The test matrix consisted of three (3) series of two (2) specimens each. The CLT specimens were tested under third-point loading during the program. All specimens were manufactured by Nordic Engineered Wood Products and delivered to FPInnovations' testing facilities in Québec City. The CLT panels were made of nominal 2x4 Black Spruce lumber (CLT Grade E1 – ANSI PRG 320).

2. TECHNICAL TEAM

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3. DATE OF RECEPTION OF SAMPLES

The specimens were received on June 5, 2015 at FPInnovations' laboratory in Québec City.

4. DATES OF TESTING

Testing commenced on June 10, 2015 and concluded on June 16, 2015.

5. METHOD IDENTIFICATION

The testing procedure for the determination of the apparent modulus of elasticity (E_{app}) and bending stiffness (K) was performed according to the ASTM D198-14 Standard Test Methods for Static Tests of Lumber in Structural Sizes, sections 4 through 12. For composite elements such as CLT, this procedure gives a measure of the effective in-plane modulus of elasticity. Load-deflection curves were obtained by testing a simply supported CLT deep beam under third-point loading.

6. DESCRIPTION OF SAMPLES AND SAMPLING METHOD

6.1 Apparent Modulus of Elasticity (E_{app}) and Bending Stiffness (K)

6.1.1 Test Setup and Parameters

This test procedure covers the determination of the apparent modulus of elasticity (E_{app}) and bending stiffness (K) of cross-laminated timber (CLT) beams/diaphragms.

Three (3) different series of two (2) specimens were tested resulting in a total of six (6) specimens. The description of the series is provided in Table 1 and a sketch of the cross sectional area is presented in Figure 1. Each specimen was tested using third-point loading. CLT specimens with three (3) different spans (L), measured from the center of one reaction support to the other, as shown in the schematic on Figure 2, have been tested. Different diaphragm lengths have been tested to investigate the effect of the aspect ratio on the stiffness of the diaphragm:

Series A: 2 diaphragm specimens 1.22 m x 3.66 m (4' x 12')

Series B: 2 diaphragm specimens 1.22 m x 6.10 m (4' x 20')

Series C: 2 diaphragm specimens 1.22 m x 8.54 m (4' x 28')

The length of the two reaction support plates was 152 mm (6 in.), while it was 300 mm (12 in.) for the load-transfer blocks. Plates were of sufficient thickness and were extending entirely across the CLT beam width to eliminate high-stress concentration and crushing. Pin and roller support reactions were considered in order to prevent translation while ensuring that no restraints were present for the longitudinal deformation and end rotations of the specimens. Figures 3 and 4 present specimens from Series A and C respectively ready for testing.

The load application system had a maximum loading capacity of 500 kN. CLT panels were instrumented with LVDTs and lasers along the length of the diaphragms (in the middle and at the third points).

Two (2) lasers (LZ) were placed to measure deflections at the midspan. Since different spans were used for the same cross-section of a 5-ply CLT panel, the measuring limit for the mid-span deflection was the same for series A and B (max of 50 mm) but was different for series C (max of 120 mm). Furthermore, the loading rate was selected to get a maximum number of readings until the maximum load was reached. A load speed of 1.0 mm per minute was used for all specimens.

To get additional deformation data, two (2) linear differential variable transformers (LVDT) and two (2) lasers were placed to measure deflections at the third points. Figure 5 to 7 present schematics of the test specimens with the position of the lasers and LVDTs.

Table 1 - Test matrix (175-5s CLT)

Series	# of Specimens	Span, L (mm)	Width, b (mm)	Depth, h (mm)	Outer Layer Orientation
A 4 ft x 12 ft	2	3505	175	1220	H
B 4 ft x 20 ft	2	5944	175	1220	H
C 4 ft x 28 ft	2	8382	175	1220	H

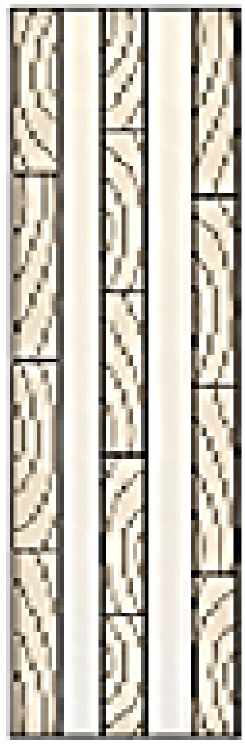

Figure 1. Cross section sketch of the CLT specimen tested (175-5s)

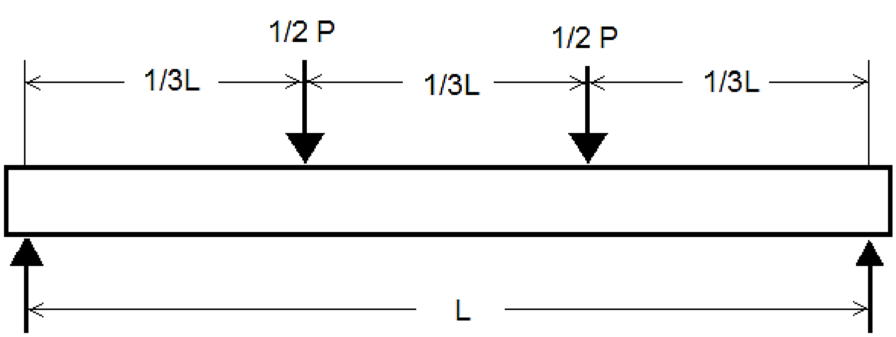

Figure 2. Schematic of the third-point loading setup

Figure 3. Photo of a specimen from Series A (4 feet x 12 feet) ready for testing

Figure 4. Photo of a specimen from Series C (4 feet x 28 feet) ready for testing

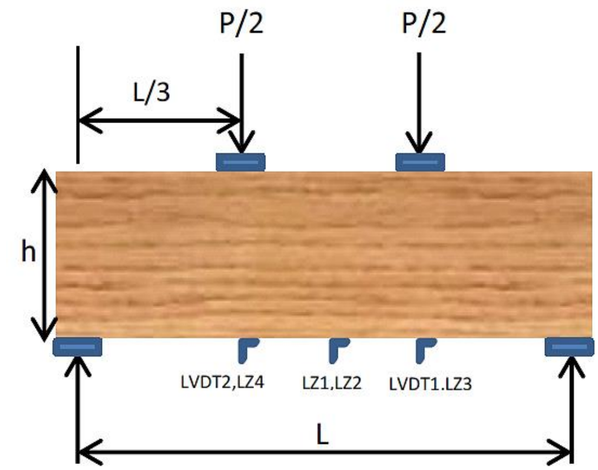

Figure 5. Loading patern and instrumentation for the 4 feet x 12 feet specimens (Series A)

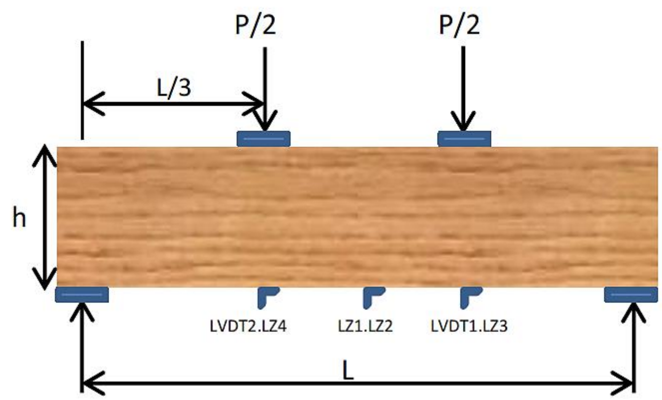

Figure 6. Loading patern and instrumentation for the 4 feet x 20 feet specimens (Series B)

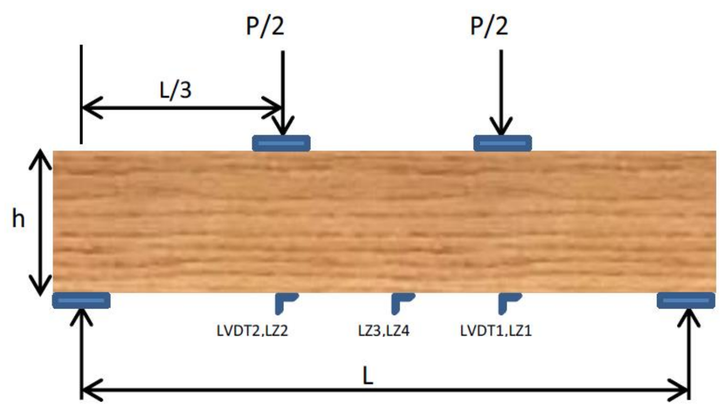

Figure 7. Loading patern and instrumentation for the 4 feet x 28 feet specimens (Series C)

6.1.2 Computations for Determination of Modulus of Elasticity

The modulus of elasticity, **E**, as referred to in this study, can be more precisely termed the apparent modulus of elasticity (**E_{app}**) since no corrections for shear deformations were considered. It was obtained from the load deformation data (P/Δ) during the initial loading phase of each test and the equation [1] for third-point loading. The apparent Modulus of Elasticity (**E_{app}**) was determined for each specimen as:

$$E, app = \frac{23PL^3}{108\, bh^3\Delta} \qquad \textbf{[1]}$$

where:

L = span from center to center of reactions,
b = specimen width and,
h = specimen depth.

Testing and data acquisition were controlled through MTS Systems Corporation's TestWorks™ program. The system allows for selection of the units (SI or Imperial) so no units are attributed to the different variables as shown above. The apparent Modulus of Elasticity (**E_{app}**) was determined using the slope of the load-deflection curve. The linear segment was defined between two markers (markers B and M) as shown in Figure 8. These markers could be moved on the data set to determine the best fitted line for measuring the slope of the linear segment of the load-deflection curve. The engineer's judgment was used to evaluate the best linear fit over the data set.

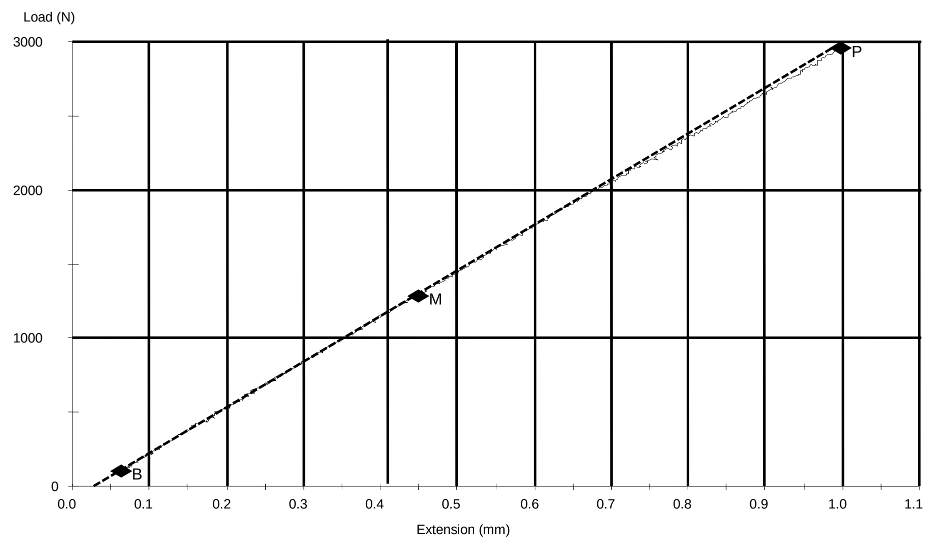

Figure 8. Typical load-deflection curve and determination of the slope

7. RESULTS OF APPARENT MODULUS OF ELASTICITY AND BENDING STIFFNESS (K)

The apparent modulus of elasticity (E_{app}) and bending stiffness (K) obtained for each series are presented in Table 2. The loads (kN) and deformation levels (mm) from which the stiffness was determined for each specimen are given in Table 3. Specimens of Series A (4 ft x12 ft) and B (4 ft x 20 ft) did not reach failure at the maximum load of approximately 500 kN. Specimens of Series C (4 ft x 28 ft) experienced an initial bending/shear failure at around 450 kN but still continued to carry load until the maximum capacity of the actuator (i.e. around 500 kN). The load-displacement curves for each specimen are provided in the Appendix. Figure 9 illustrates the linear relationship between the apparent Modulus of Elasticity (E_{app}) and the span to depth ratio (L/H).

Table 2 - Results for Apparent Modulus of elasticity and Bending Stiffness for all series (175-5s)

Series	Specimen #	Width,b (mm)	Depth, h (mm)	Span L (mm)	L/h	E_{app} (MPa)	Stiffness K (N/mm)
A	1	175	1220	3505	2.875	1014	35139
4 ft x 12 ft	2	175	1220	3505	2.875	1012	35077
					Average	**1013**	**35108**
B	1	175	1220	5944	4.875	3122	22190
4 ft x 20 ft	2	175	1220	5944	4.875	3400	24165
					Average	**3261**	**23178**
C	1	175	1220	8382	6.875	4762	12065
4 ft x 28 ft	2	175	1220	8382	6.875	5075	12861
					Average	**4919**	**12463**

Table 3 - Loads and deformation levels selected for the computation of the stiffness K

Specimen	Selected Points	Load (KN)	Displacement (mm)
4 x 12-1	B	110.1	4.1
	M	250.0	8.2
4 x 12-2	B	129.4	4.9
	M	299.1	9.8
4 x 20-1	B	120.3	6.2
	M	289.1	13.8
4 x 20-2	B	130.9	6.0
	M	280.3	12.1
4 x 28-1	B	113.0	9.8
	M	208.3	18.6
4 x 28-2	B	117.6	9.9
	M	287.3	24.4

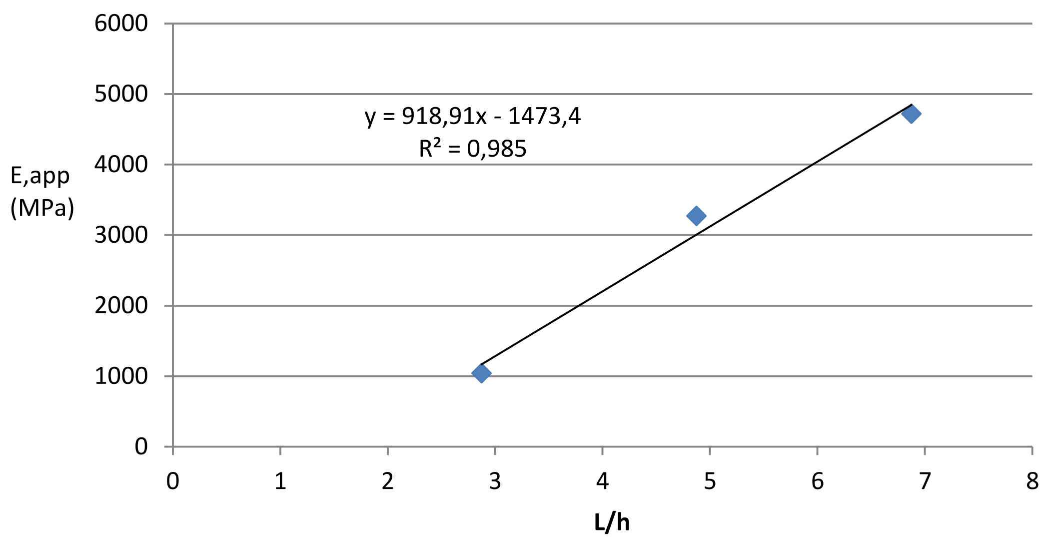

Figure 9. The relationship between the apparent Modulus of Elasticity (E,app) and the span to depth ratio (L/h) for all specimens tetsed

8. CONCLUSIONS AND OBSERVATIONS

A testing program was performed at FPInnovations' testing facilities in Québec City for Nordic Engineered Wood with the objective of evaluating the mechanical properties of CLT diaphragms used in construction. The main objective of this study was to determine the in-plane stiffness and potentially strength of CLT panels used as diaphragms.

Based on the analysis and observations made during the course of this study, the following conclusions and observations can be made:

- No evidence of bending/shear failure was observed for specimens of Series A and B at the maximum load of around 500 kN;
- Specimens of Series C (4 ft x 28 ft) experienced an initial bending/shear failure at approximately 450 kN, but still continued to carry load until the maximum capacity of the actuator (approximately 500 kN);
- The linear relationship between the apparent Modulus of Elasticity (E_{app}) and the span to depth ratio (L/h) was evident with a coefficient of determination (R^2) of 0.985.

It should be noted that all results and discussion presented in this report refer exclusively to the specimens tested.

9. REFERENCE

ASTM 2014. Annual Book of ASTM Standards, Volume 04.10 Wood. ASTM, Philadelphia, Pa.

APPENDIX

Load-displacement Curves

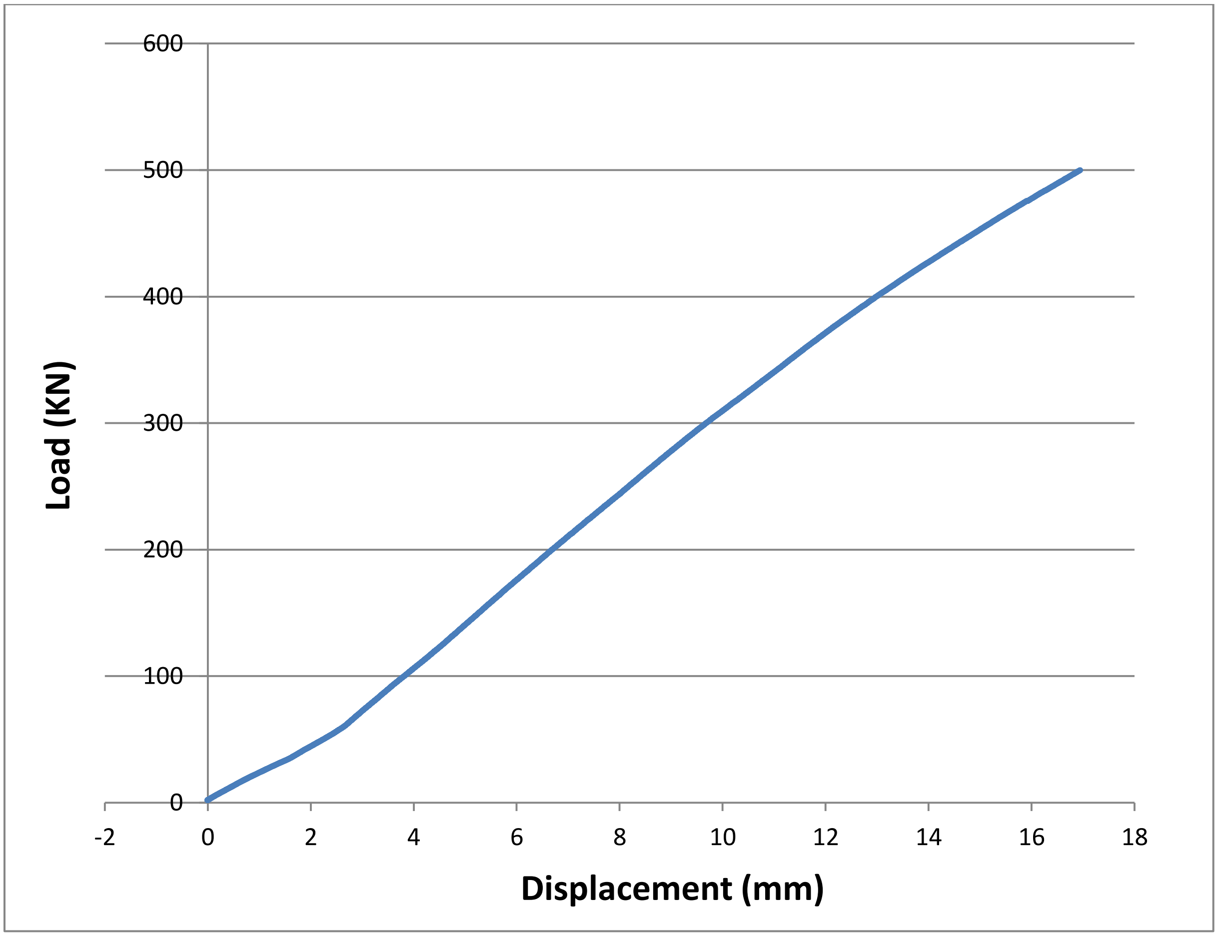

Figure A1. Load-Displacement curve for the CLT specimen 4x12-1

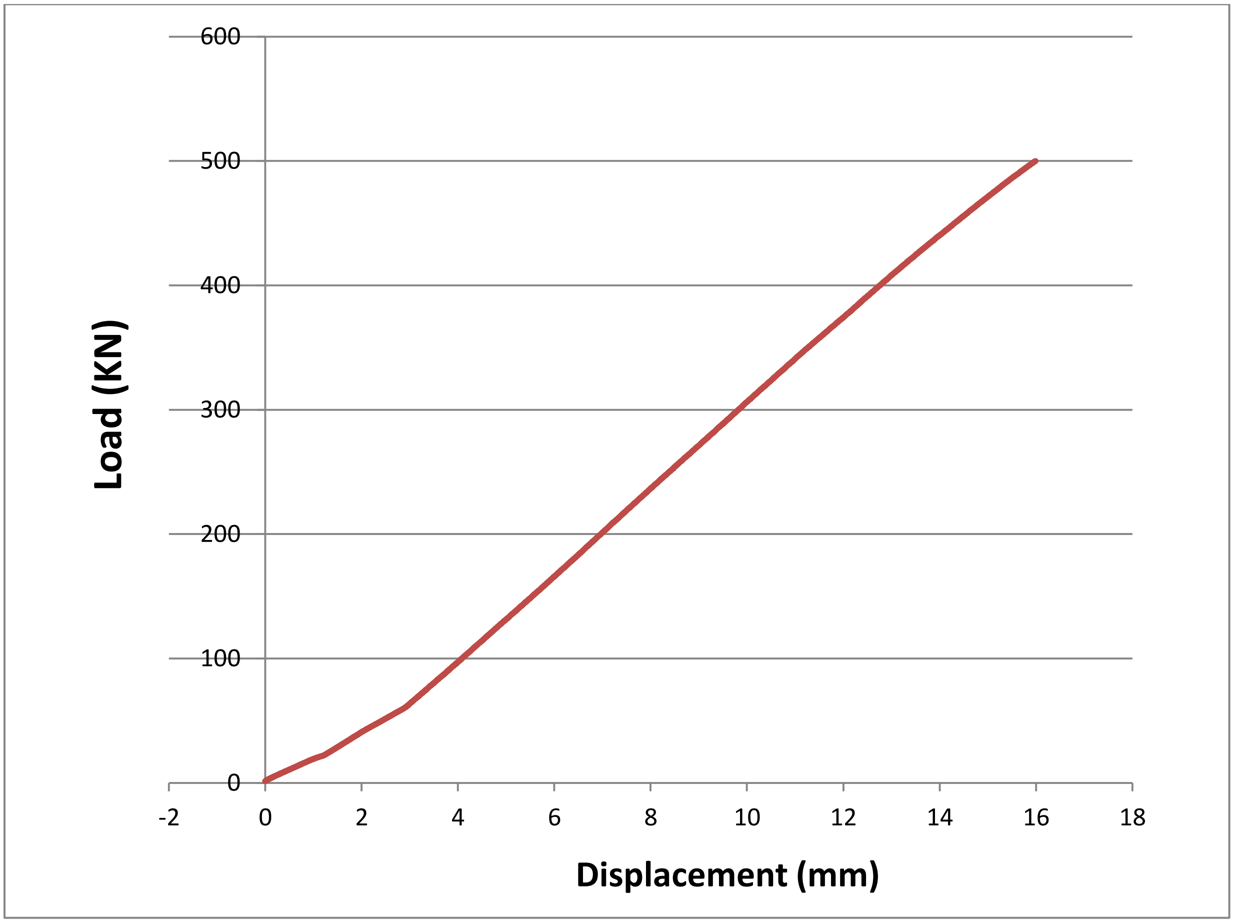

Figure A2. Load-Displacement curve for the CLT specimen 4x12-2

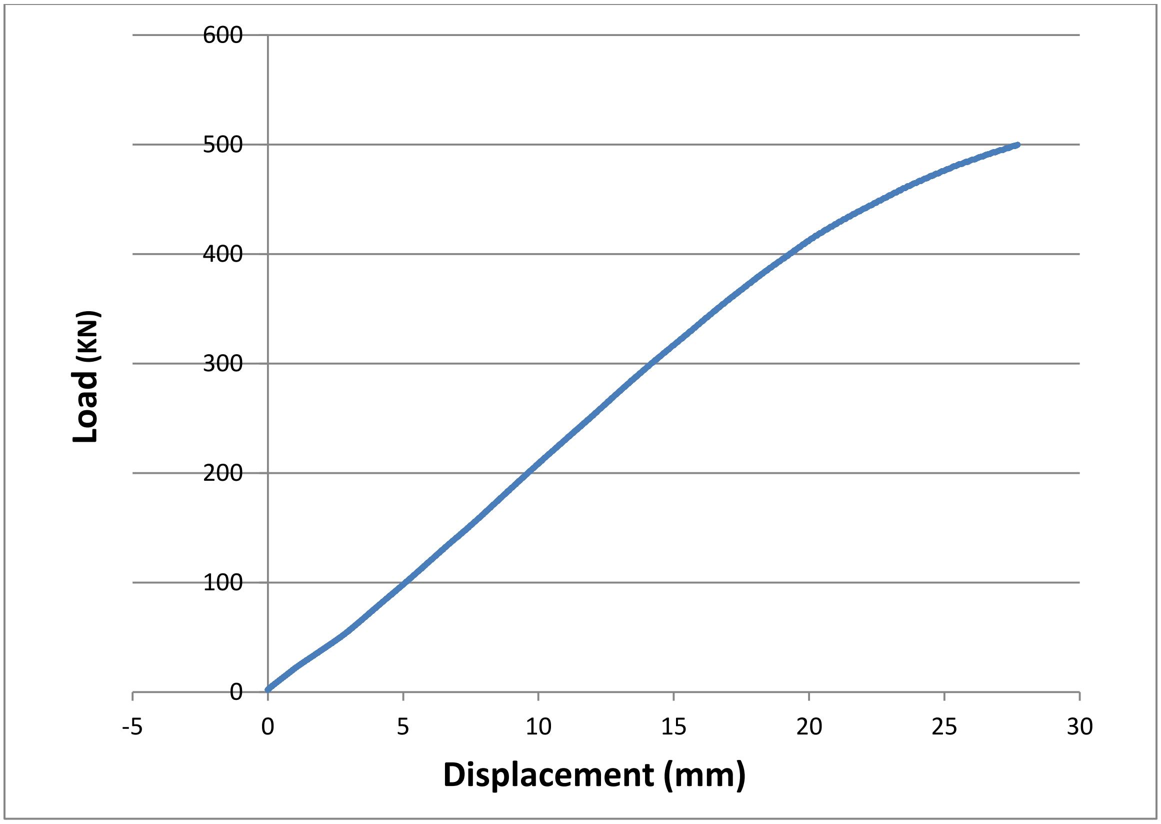

Figure A3. Load-Displacement curve for the specimen 4x20-1

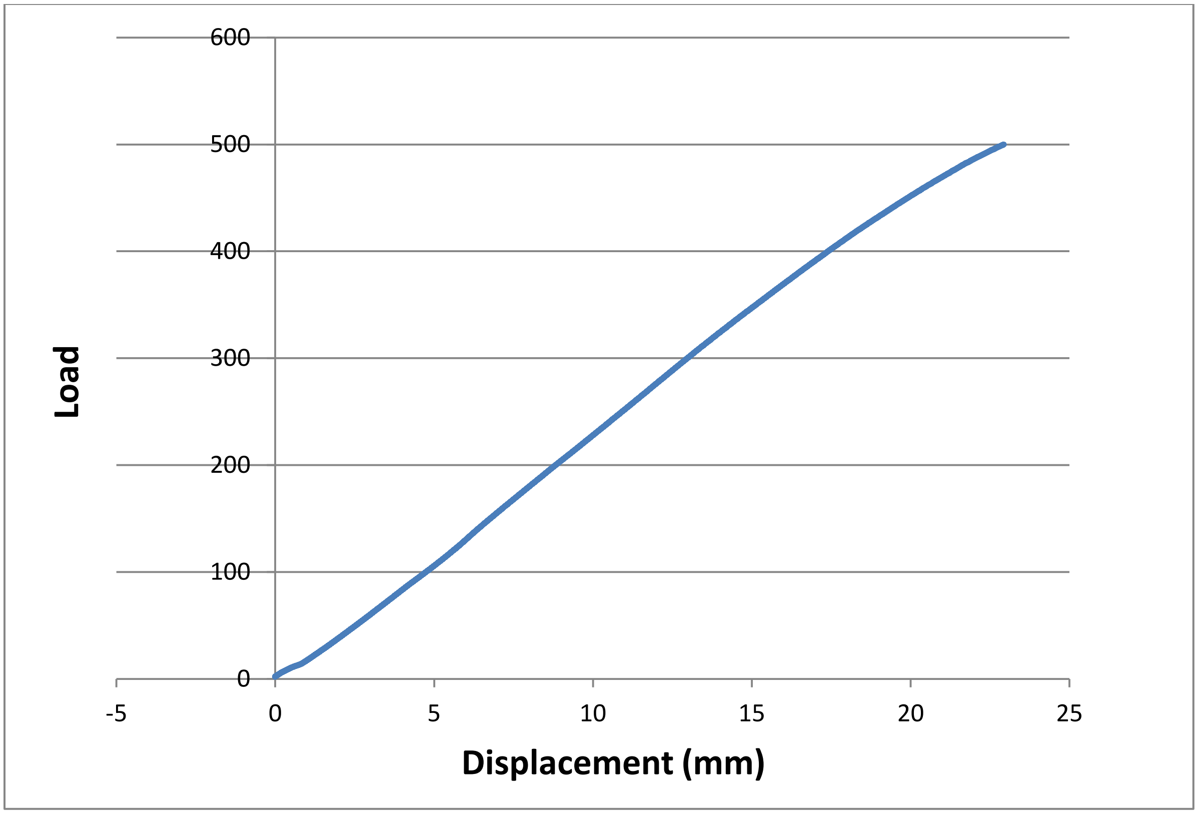

Figure A4. Load-Displacement curve for the specimen 4x20-2

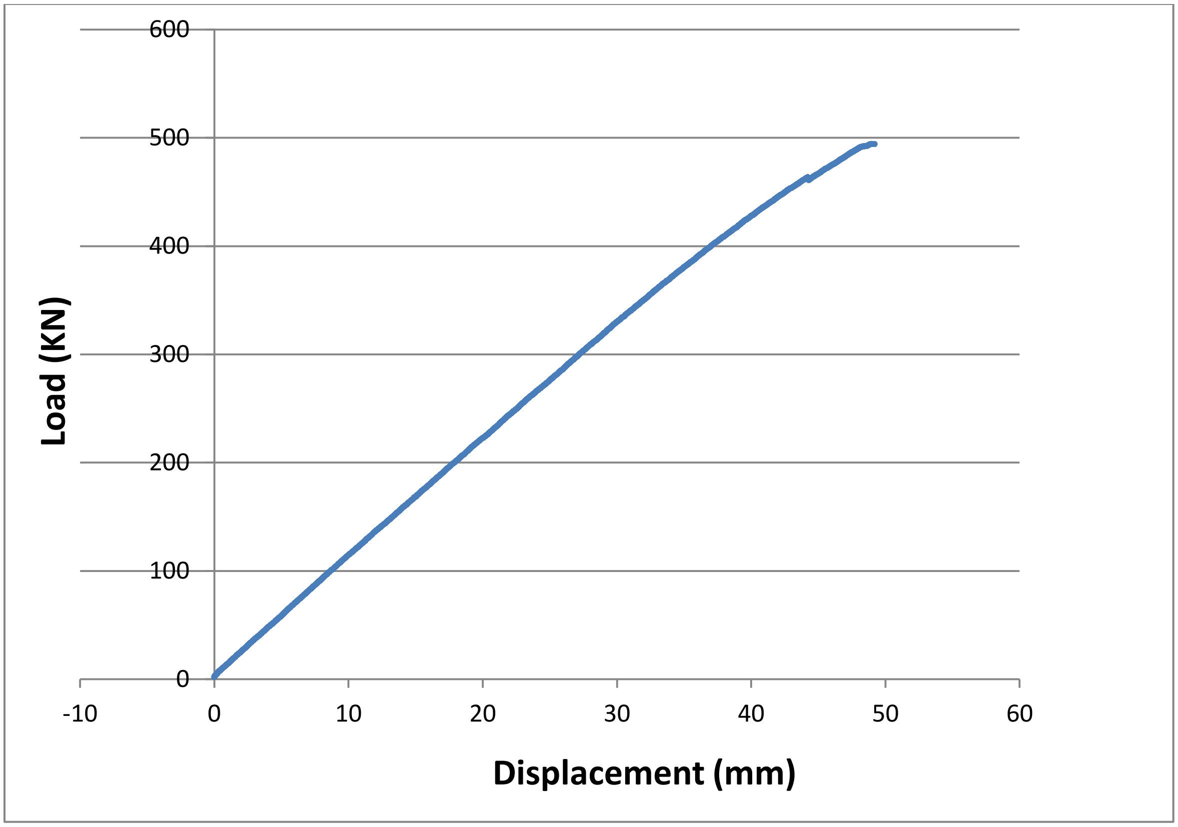

Figure A5. Load-Displacement curve for the specimen 4x28-1

Figure A6. Load-Displacement curve for the specimen 4x28-2

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