Structural Application of ash in concrete
Appendix

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Appendix

A Sewage Sludge Ash

A.1 Chemical composition SSA

Rekvirent :

BIOFOS, Renseanlæg Avedøre
Forbrændingen
Kanalholmen 28
2650 Hvidovre
Att.: Thomas Guildal

Journal nr.: E14-1527

2014.12.23

PRØVNINGSRAPPORT

Undersøgelse af aske

Task nr.	:	114-24465-0005
Rekvisitions nr.	:	139123
Prøve modtaget d.	:	2014.11.25
Prøvningstermin	:	2014.11.25 – 2014.12.22

Resultaterne for prøvningen findes på side: 2 - 4

FORCE Technology

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Rene Hansen
Tekniker

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Side 1 af 4

Rekvirent :

BIOFOS, Renseanlæg Avedøre

Journal nr.: E14-1527

Undersøgelse af slagge/aske fra fast brændsel						
Prøve af	Aske					
Mærket	Askeprøve 25-11-2014					
Prøvens størrelse		1367,5 g	Emballage	Tæt plastspand		
Forbehandling af prøve:				Er foretaget i henhold til DIN 51701		
Bestanddel			Basis:	Vandfri prøve		Indleveret prøve
Vand		ISO 11722		-		0,2 %
Aske		EN 15169 (550°C)		99,8 %		99,6 %
Svovl	(S)	Trykdekomponering/ICP-OES		0,69 %		0,69 %
Chlor	(Cl)	ISO 587		// %		// %
Chlor, vandopløselig	(Cl^-)	FprEN 15105		// %		// %
pH		PVA 551.1, 1% opslemning (L/S=100)				10,2
pH		DS/EN 12457-1, batchudvaskning (L/S = 2)				9,3
Bortglødeligt		Beregnet som 100 – Vand – Aske		0,2 %		0,2 %
Carbon, TC	(C)	EN 13137		// %		// %
Carbonat-carbon, TIC	(C)	EN 13137		// %		// %
TOC (TC – TIC)	(C)	EN 13137		// %		// %
Restenergi		Øvre brændværdi jvf. ISO 1928, uden korr. for S		// MJ/kg		// MJ/kg
Askens smelteforløb		CEN/TS 15370-1	Bestemt i:	Reducerende atm.		Prøveform: Cylinder
		Blødgørings	Temperatur	(DT)		// ° C
		Halvkugle	Temperatur	(HT)		// ° C
		Flyde	Temperatur	(FT)		// ° C
Bemærkninger:						

//: Ikke analyseret parameter.

Rekvirent :

BIOFOS, Renseanlæg Avedøre

Journal nr.: E14-1527

Undersøgelse af slagge/aske

Prøve af	Aske				
Mærket	Askeprøve 25-11-2014				
Prøvens størrelse	1367,5	g	Emballage	Tæt plastspand	

Forbehandling:
Analyserne er foretaget direkte på fremstillet analyseprøve (efter tørring og formaling).
Indhold af aske, tør prøvebasis: 99,8 %
Nedenstående resultater er omregnet til 550 °C aske på tør basis.

Kemisk sammensætning af asken (Askens hovedbestanddele)

Silicium	(1)	15	% Si	~	32	% SiO_2
Aluminium	(1)	5,0	% Al	~	9,4	% Al_2O_3
Jern	(1)	9,6	% Fe	~	14	% Fe_2O_3
Calcium	(1)	12	% Ca	~	16	% CaO
Magnesium	(1)	1,5	% Mg	~	2,6	% MgO
Titan	(1)	0,49	% Ti	~	0,83	% TiO_2
Natrium	(1)	0,62	% Na	~	0,83	% Na_2O
Kalium	(1)	1,3	% K	~	1,6	% K_2O
Phosphor	(1)	8,5	% P	~	20	% P_2O_5

Metoder:

(1) Trykdekomponering i syre/ICP-OES

Bemærkninger:

Rekvirent :

BIOFOS, Renseanlæg Avedøre

Journal nr.: E14-1527

Undersøgelse af slagge/aske fra fast brændsel						
Prøve af	Aske					
Mærket	Askeprøve 25-11-2014					
Prøvens størrelse	1367,5 g		Emballage	Tæt plastspand		
Forbehandling:						
Fremstilling af generel analyseprøve foretaget i henhold til DIN 51701 Teil 2-4.						
Analysen er foretaget direkte på den fremstillede analyseprøve.						
Indhold af sporelementer	**Basis:**		Tør prøve		Indleveret prøve	
Bly	Pb	(1)	180	mg/kg	180	mg/kg
Cadmium	Cd	(1)	3,5	mg/kg	3,5	mg/kg
Chrom	Cr	(1)	47	mg/kg	47	mg/kg
Kobber	Cu	(1)	630	mg/kg	630	mg/kg
Kobolt	Co	(1)	17	mg/kg	17	mg/kg
Mangan	Mn	(1)	760	mg/kg	760	mg/kg
Nikkel	Ni	(1)	53	mg/kg	53	mg/kg
Zink	Zn	(1)	1900	mg/kg	1900	mg/kg
Vanadium	V	(1)	44	mg/kg	44	mg/kg
Sølv	Ag	(2)	11	mg/kg	11	mg/kg
Tin	Sn	(1)	35	mg/kg	35	mg/kg
Thalium	Tl	(1)	0,35	mg/kg	0,35	mg/kg
Kviksølv	Hg	(3)	1,0	mg/kg	1,0	mg/kg
Arsen	As	(1)	17	mg/kg	17	mg/kg
Antimon	Sb	(1)	4,8	mg/kg	4,8	mg/kg
Molybdæn	Mo	(1)	19	mg/kg	19	mg/kg

Metoder:
(1) DS 259/Radial ICP-OES
(2) DS 259/Radial ICP-OES, efter stabilisering med HCl
(3) Thermal Decomposition, AAS

Bemærkninger:

//: Ikke analyseret parameter.

A.2 Chemical composition fly ash

CLASS "F" FLY ASH

MATERIAL SAFETY DATA SHEET
MSDS No. BP - 001

PRODUCT: Class "F" Fly ash, coal fly ash

SECTION I - Manufacturer

Manager, Coal Combustion By-Products
Tennessee Valley Authority
1101 Market Street, LP 5G
Chattanooga, Tennessee 37402-2801
Telephone (423) 751-2422

SECTION II – Product Composition, Constituents, and Ingredients

Constituent	OSHA PEL		ACGIH TLV	
Silica – SiO_2 (40 – 60 %) Crystalline (3-7%) Amorphous (33-57%)	Crystalline:		Crystalline:	
	Quartz (Respirable) CAS 14808-60-7	10 mg/m^3 % SiO_2 + 2	Quartz (Respirable) CAS 14808-60-7	0.05 mg/m^3
	Quartz (Total)	30 mg/m^3 % SiO_2 + 2	Cristobalite (Respirable) CAS 14464-46-1	0.05 mg/m^3
	Amorphous	80 mg/m^3 % SiO_2	Tridymite (Respirable) CAS 15468-32-3	0.05 mg/m^3
			Amorphous:	
			Precipitated silica and silica gel CAS 112926-00-8	10 mg/m^3
Aluminum oxide – Al_2O_3 (18–31%) CAS 1344-28-1	Respirable Total	5 mg/m^3 15 mg/m^3	Total	10 mg/m^3
Iron oxide – Fe_2O_3 (5–25%) CAS 1309-37-1	Total	10 mg/m^3	Total	5 mg/m^3
Calcium oxide – CaO (1–6%) CAS 1305-78-8	Total	5 mg/m^3	Total	2 mg/m^3
Magnesium oxide – MgO (1–2%) CAS 1309-48-4	Total	15 mg/m^3	Total	10 mg/m^3
Titanium oxide – TiO_2 (1-2%) CAS 13463-67-7	Total	15 mg/m^3	Total	10 mg/m^3
Inorganic arsenic (16-210 ppm) CAS 7440-38-4	Total	10 µg/m^3	Total	0.01 mg/m^3

SECTION III – Physical/Chemical Data	SECTION IV – Fire/Explosion Data
Boiling Point: No applicable information (N/A) **Vapor Pressure:** N/A **Vapor Density:** N/A **Water Solubility:** < 0.5% **Melting Point:** >2500ºF **Percent Volatile:** N/A **Evaporation Rate:** N/A **Appearance:** gray-brown or tan to black powdery solid **Odor:** none	**Flash Point:** none **Lower/Upper Flammable Limits**: none/none **Autoignition:** none **Fire/Explosion Hazard**: none/none **Firefighting:** N/A **Extinguishing Data:** N/A

SECTION V – Reactivity/Incompatibility Data

Reactivity: Fly ash is stable under most conditions

Incompatibilities:

Fly ash: N/A

Quartz: Test with small quantities of strong oxidizers before mixing.

Hazardous decomposition: none

Polymerization: none

SECTION VI – Health Hazard Data

Routes of entry: Inhalation? yes Skin? may cause irritation Ingestion? unlikely

Carcinogenicity: NTP? yes IARC? yes OSHA? yes

Inhalation Health Hazards:

Acute: Respiratory tract irritation causing coughing, wheezing, and difficulty breathing

Chronic: The primary routes of exposure are inhalation and contact with eyes and skin. Fly ash is composed of inert dust (possibly irritating to mucous membranes), crystalline silica (a pneumoconiosis producing dust and animal carcinogen),and low concentrations of calcium oxide (possibly irritating to mucous membranes and wet skin). Fly ash contains trace amount of inorganic arsenic (identified as a carcinogen).

Skin and Eye Health Hazards:

Acute: Eye contact can cause severe, mechanical irritation. Skin contact may cause irritation.

Chronic: Skin contact may cause irritation.

SECTION VII – First Aid

Inhalation: Remove person from exposure area to fresh air. Keep person warm and calm. Call for medical help if person has breathing difficulty. Give artificial respiration if person is not breathing.

Eye Contact: Wash-out eyes with warm water for 15 minutes, occasionally lifting eye lids. Send person for medical attention.

Skin Contact: Remove contaminated clothing. Wash with soap and water. Launder clothing before reuse.

SECTION VIII – Exposure Controls and Personal Protective Equipment

General: Do not use compressed air to remove fly ash.

Ventilation: Use local exhaust ventilation to remove airborne fly ash from work areas when feasible.

Eye Protection: Employees should use dust-proof safety goggles in areas of high levels of airborne fly ash. Eye wash facilities should be available in case of eye exposure.

Skin Protection: Employees should wear protective clothing to prevent repeated or prolonged skin contact with fly ash.

Respiratory Protection: Respiratory protection is selected based on a hazard assessment of the work location, including the specific airborne agents, the concentration of the agents, and the permissible exposure levels (PEL). Selection must be done by a knowledgeable person following the requirements in OSHA's Respiratory Protection Standard, 29CFR1910.134(d) in order to obtain adequate protection from the respirators. Employees must be qualified to use a respirator, and all respirators must be certified by NIOSH. The following table gives guidance on selecting an appropriate respirator for inorganic arsenic protection. It also should protect against other airborne particulates associated with fly ash that are not regulated by substance, such as aluminum and iron oxides.

Concentration of Airborne Agent	**Required Respirator**
Not greater than 10X PEL	Half-mask air-purifying respirator equipped with P100 (high efficiency) cartridge(s) or any respirator listed below.
Not greater than 50X PEL	Full facepiece air-purifying respirator equipped with P100 (high efficiency) cartridge(s) or any respirator listed below.
Not greater than 1000X PEL	Powered air-purifying respirator in all inlet face coverings and equipped with P-100 (high efficiency) cartridge(s) or any respirator listed below.
Not greater than 2000X PEL	Supplied air respirator with full facepiece, hood or helmet or suit and operated in positive pressure mode or any respirator listed below.
Greater than 2000X PEL	Self-contained breathing apparatus with full facepiece and operated in positive pressure mode.

SECTION IX – Safe Handling and Use Precautions

Spill Cleanup: Wet material and shovel into container with cover or HEPA vacuum. Avoid generating airborne dust.

Use: Handle material in closed systems if feasible to control dust.

A.3 Risk assessment of SSA (Danish)

Risikovurdering
Slamaske i beton (store mængder)

Slamaske indeholder tungmetaller og er derfor meget farlig i tør tilstand, da de kan optages via luftvejene. Ved langtidsvirkning kan disse kemiske risici resultere i kræft og allergi.

Tungmetallerne er ligeledes skadelige for miljøet, hvilket kræver speciel hensyntagen til opbevaring og afskaffelse.

Foruden ovenstående er asken stærk basisk med en pH på 10 jf. vedlagte prøvningsrapport.

Der skal derfor tages forholdsregler, så man minimerer indånding og hudkontakt med slamaske – både for den person, der aktuelt håndterer slamaske, og for de personer der skal arbejde samme sted kort tid efter blandingen. Dette betyder støv i lokalet skal minimeres.

Følgende anvisning er udarbejdet idét der intet sikkerhedsdatablad forefindes.

Personlige værnemidler:

1. Fuld malerdragt
2. Gummistøvler
3. Nitrilhandsker ved minimal kontakt med beton, men altid med slamaske
4. Gummihandsker ved direkte kontakt med beton og slamaske
5. Tætsluttende beskyttelsesbriller
6. Høreværn benyttes ved blanding og vibrering
7. Hjelm benyttes ved brug af kran

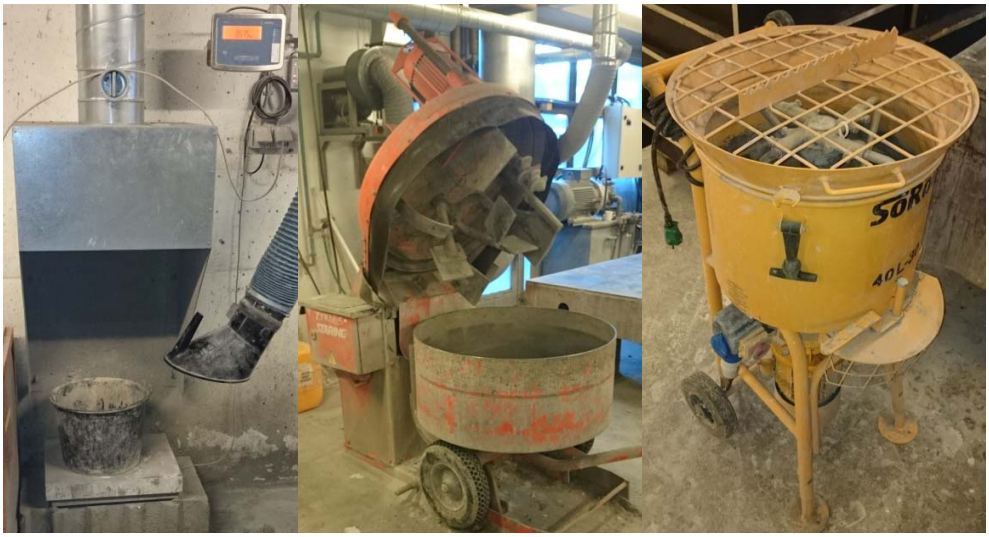
Masker:

8. Ved jævnligt arbejde med afvejning af slamaske skal der bruges helmaske med P3 filter. Masken må højest bruges i 3 timer om dagen, da det kan give væske i lungerne. Filtrene skifte, når det bliver tungt at trække vejret igennem dem.

Støbeprocedure:

Under hele proceduren benyttes støvsuger som backup til punktsug for overskydende støv

1. Tørmaterialer afvejes i spande
   1.1. Tilslag og cement afvejes i murerspande under udsugning. Suget placeres således, at der suges væk fra personen.
   1.2. Slamaske afvejes under kraftig udsugning i spand med tilhørende låg. Spanden forsegles og flyttes dernæst til tvangsblanderen (se Figur 1).
   Skal der benyttes mere end 10kg til samme blanding, afmåles max. 10 kg af gangen.
2. **Slamasken opslæmmes i vand inden videre brug.**
   2.1. Låg med hul og tragt benyttes til at iblandet vandet uden at opstøve asken.
   2.2. For at sikre en homogen blanding vibreres spanden med forseglet låg i 60 sekunder.
3. Alle tørmaterialer hældes i blanderen og blandes 180 sekunder med sug.
4. Opslæmmet slamaske tilsættes blandingen og blandes i 60 sekunder med sug.
5. Resten af vandet tilsættes blandingen og blandes i 300 sekunder med sug.
6. Den færdige blanding hældes i støbeformen.
7. Formene vibreres for at sikre god udstøbning.
   7.1. For bjælker transporteres formene med kran og korrekt sikkerhedsudstyr benyttes.



Figur 1: tv: vægt med punktsug. mf: stor tvangsblander. th: lille tvangsblander

Ved ulykke

Ulykkestilfælde	Handling
Opstøvning af tørmaterialer	Der benyttes vandforstøver til nedslåning af støv
Inhalering af tørmaterialer	Personen fjernes fra lokalet og til frisk luft. Personen holdes Varm og rolig og der tilkaldes hjælp i tilfælde af vejrtrækningsproblemer.
Øjenkontakt	Øjet skylles med øjeskyllevæske eller vand i mindst 15 min. Øjenlåget løftes jævnligt og der opsøges skadestue.
Kontakt med hud	Fjern forurenet tøj og vask hud med vand og sæbe

Rengøring

1. Rester af beton bortskaffes i den brune container til våd beton/mørtel.
2. Blandemaskinen spules ren.
3. Gulves spules rent og vandet skrabes ned i renden.
4. Cylindrene rengøres grundigt med opvaskemiddel og tørres.
5. Formolie smøres på cylindrene.
6. Gummihandskerne og støvler rengøres grundigt med opvaskemiddel og stilles til tørre.

Studerende:	Studienummer:	Navn:
	_____	_____
	_____	_____
	_____	_____
	_____	_____
	_____	_____

Vejleder: _____ Dato: _____ Underskrift: _____

AM-rep: _____ Dato: _____ Underskrift: _____

B Concrete recipe and casting masses

B.1 Concrete recipe

Calculation for recipe

fcm	40	Mpa
K	30	MPa
alpha	0.5	
w/c	0.545	
	per m3 concrete	
Water demand	175	kg water
Cement	321	kg cement
Paste	496	kg
aggregate volume	0.71	m3
sandprocent	0.46	

Pr m3

	density [kg/m3]	mass [kg]	volume [m3]
Cement	3160	321	0.102
Water	1000	175	0.175
0-4	2600	853	0.328
4-8	2600	278	0.107
8-16	2600	723	0.278
air			0.01
total		2351	1.000

				Mass
volume test cylinder		5 stk		[kg]
1.57	liter	7.85 liter	Cement	6.417
		20 liter	Water	3.500
			0-4	17.066
			4-8	5.565
			8-16	14.469

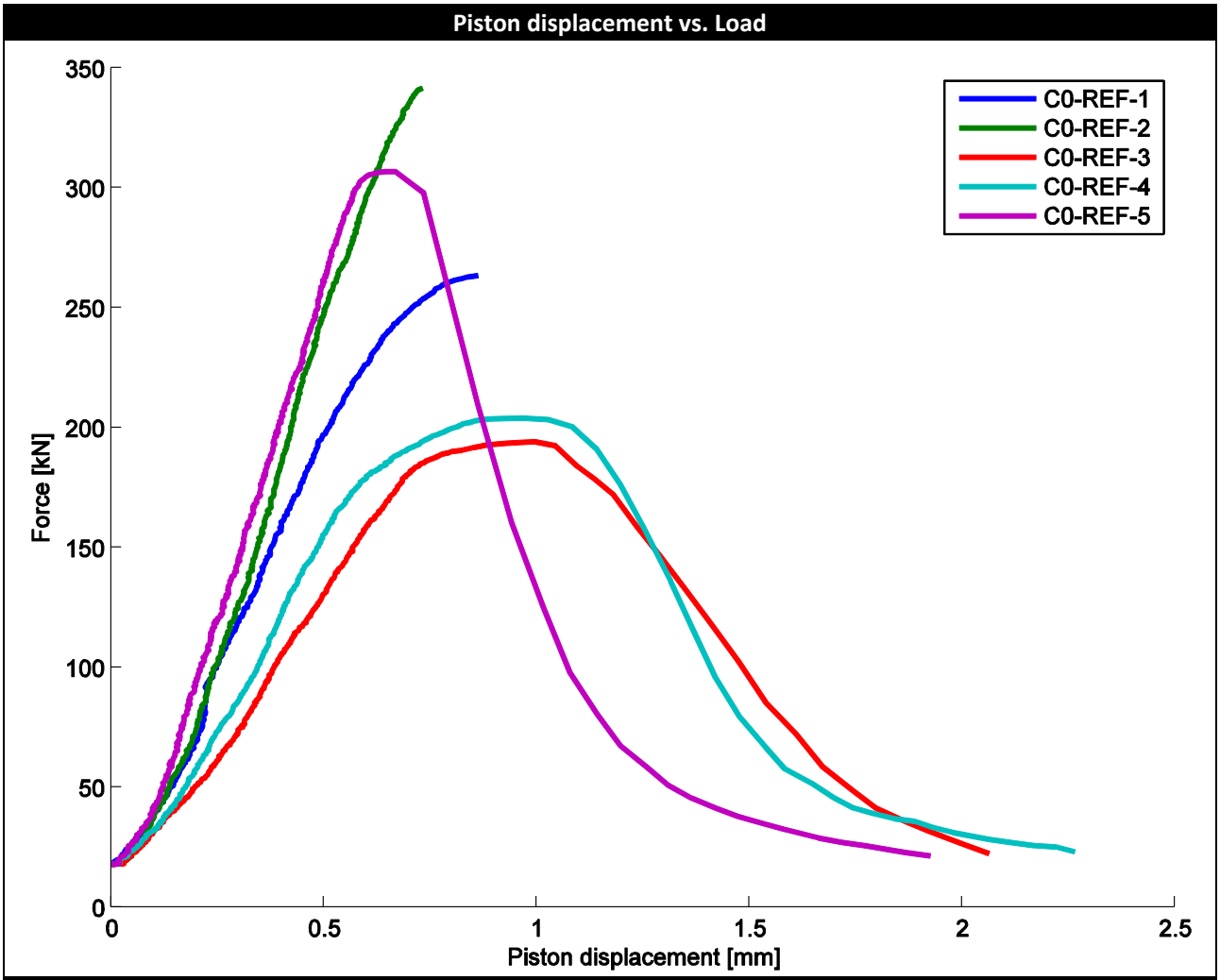
				Mass
volume beams/columns		3 stk		[kg]
66	liter	198 liter	Cement	80.208
		250 liter	Water	43.750
			0-4	213.328
			4-8	69.563
			8-16	180.865
			Total	587.714

B.2 Casting masses

Name		Cement [kg]	SSA [kg]	Water [kg]	Plastifier [kg]	Stone 0-4 [kg]	Stone 4-8 [kg]	Stone 8-16 [kg]
CASTING 0					0.3%			
Only cylinders for testing	C 0 ref	6.417	0.000	3.500	0.019	17.066	5.565	14.469
	C 0 10	5.775	0.642	3.500	0.019	17.066	5.565	14.469
	C 0 20	5.133	1.283	3.500	0.019	17.066	5.565	14.469
	C 0 30	4.492	1.925	3.500	0.019	17.066	5.565	14.469
	C 0 40	3.850	2.567	3.500	0.019	17.066	5.565	14.469
	C 0 50	3.208	3.208	3.500	0.019	17.066	5.565	14.469
	sum	**29**	**10**	**21**	**0.12**	**103**	**34**	**87**
CASTING 1								
Cylinder and beams/co-lumns in same mixture	C/S 1 ref	80.21	0	43.75	0.120	213.33	69.56	180.86
	C/S 1 25	60.16	20.05	43.75	0.401	213.33	69.56	180.86
	C/B 1 50	40.10	40.10	43.75	0.802	213.33	69.56	180.86
	Sum	**181**	**61**	**132**		**640**	**209**	**543**

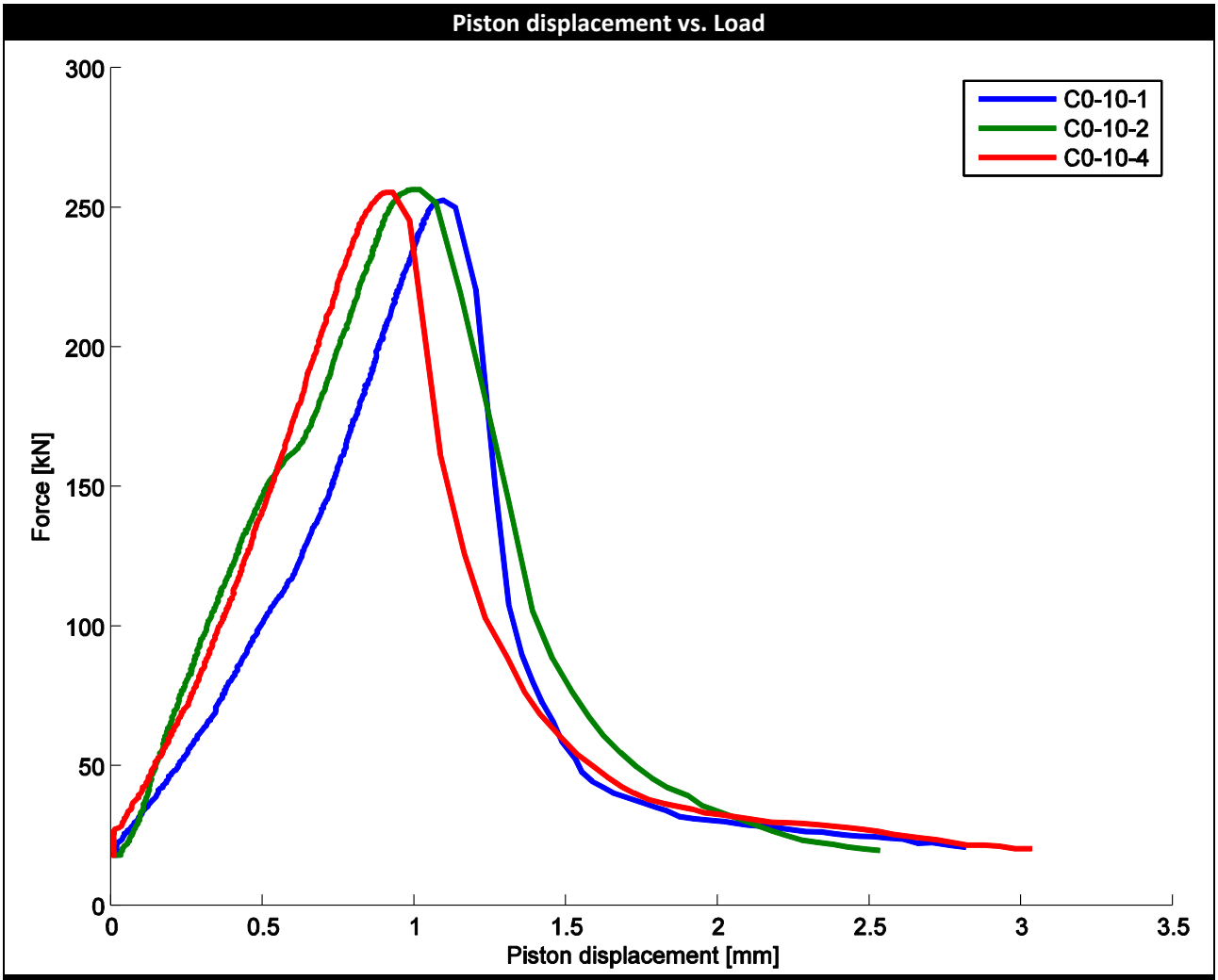
C Concrete strengths

C.1 C0-REF



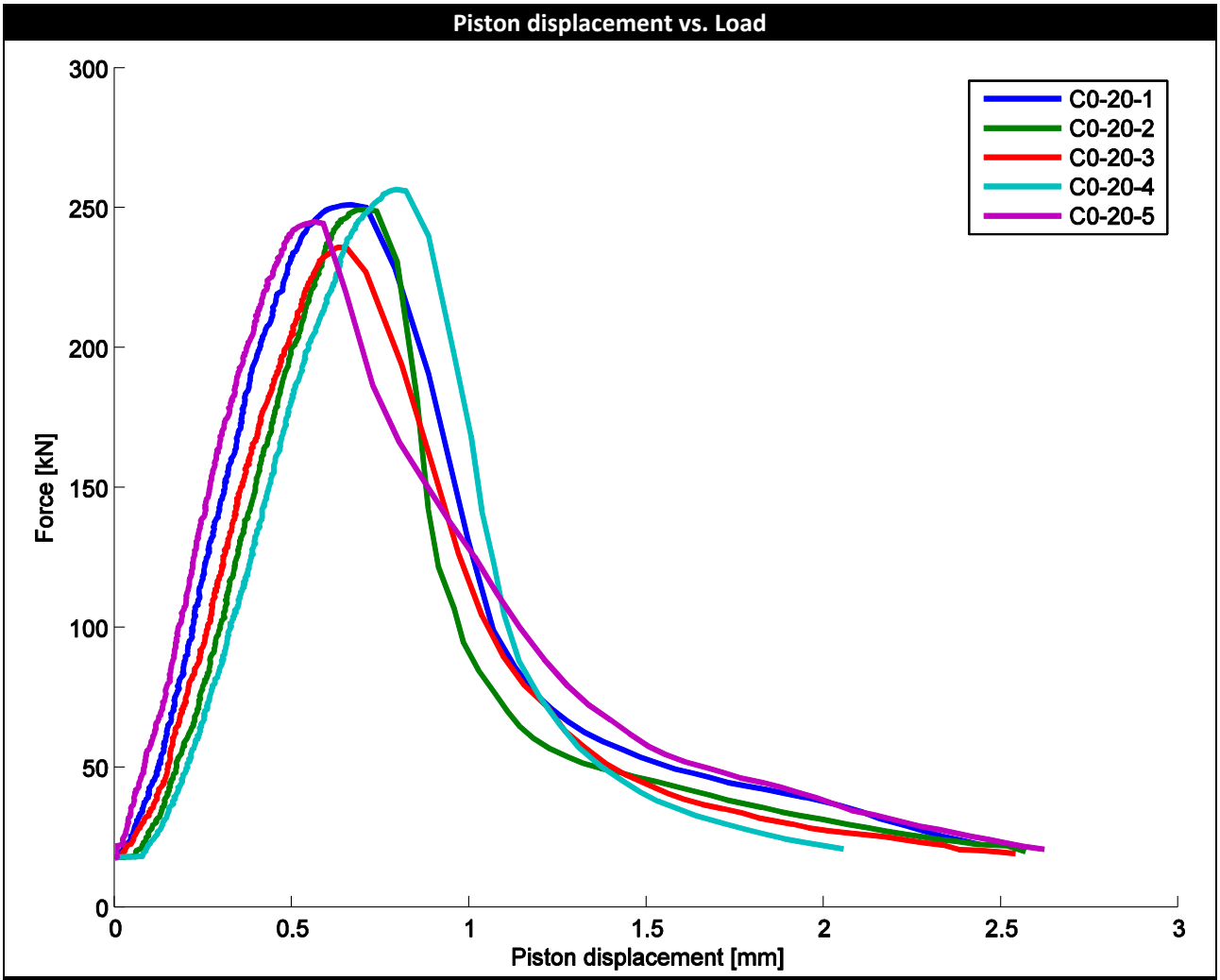
Sample	1	2	3	4	5	Mean	Std. Dev.
$f_c\ [MPa]$	33.83	44.02	24.85	26.21	39.28	33.64	8.25

C.2 C0-10



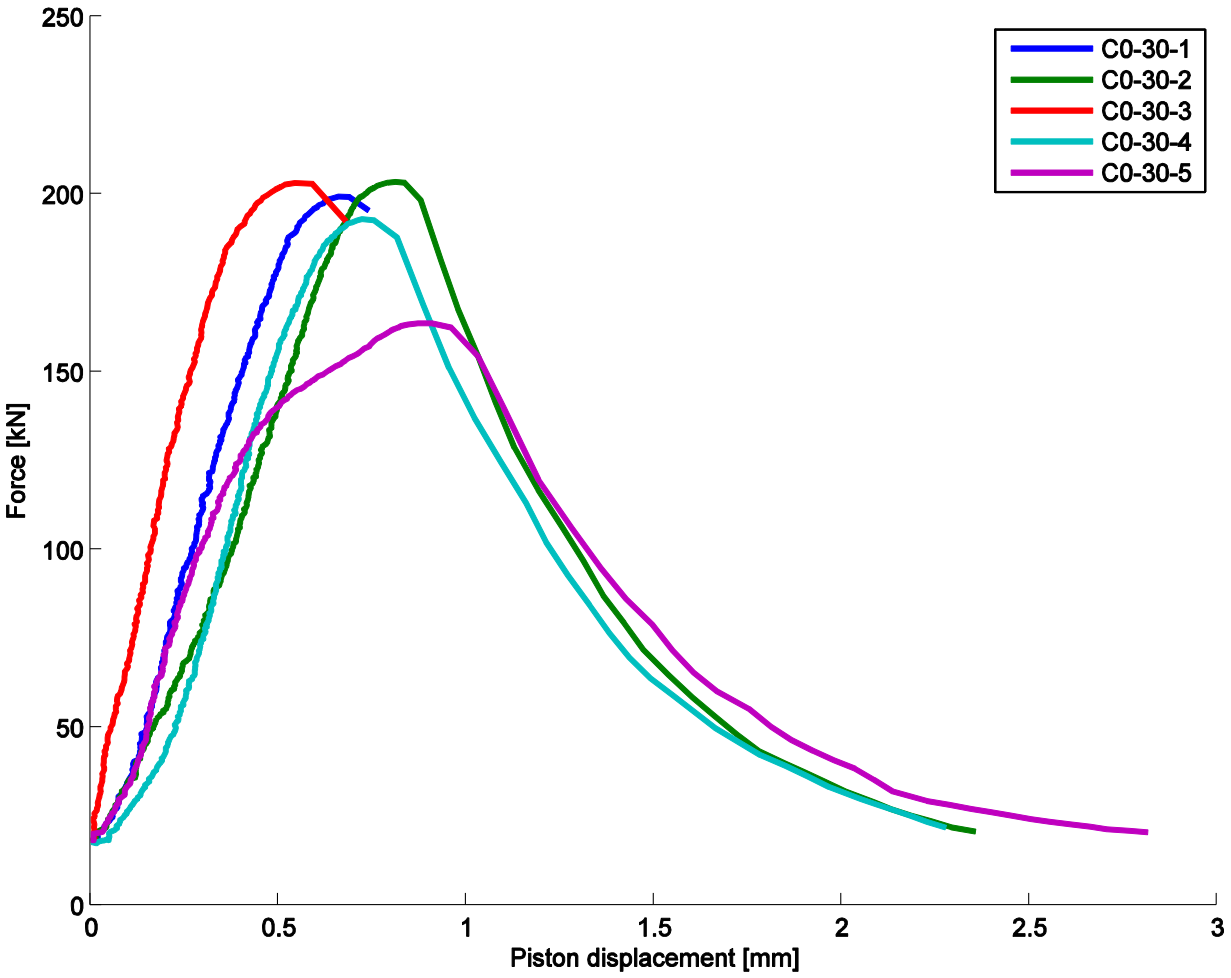
Sample	1	2	3	4	5	Mean	Std. Dev.
f_c $[MPa]$	32.46	33.10		32.73		32.76	0.321

C.3 C0-20



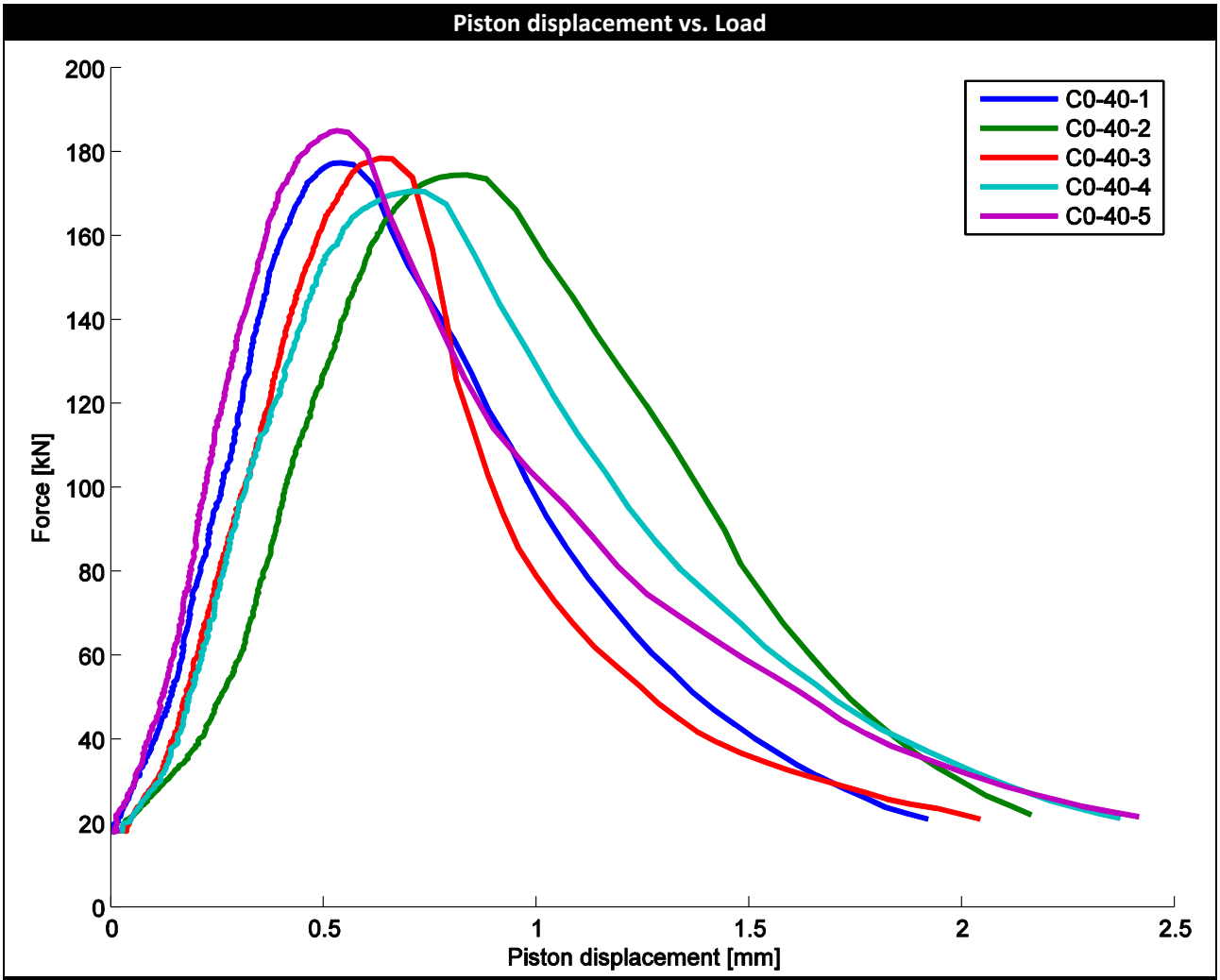
Sample	1	2	3	4	5	Mean	Std. Dev.
f_c $[MPa]$	32.22	32.16	30.34	32.90	31.45	31.81	0.972

C.4 C0-30



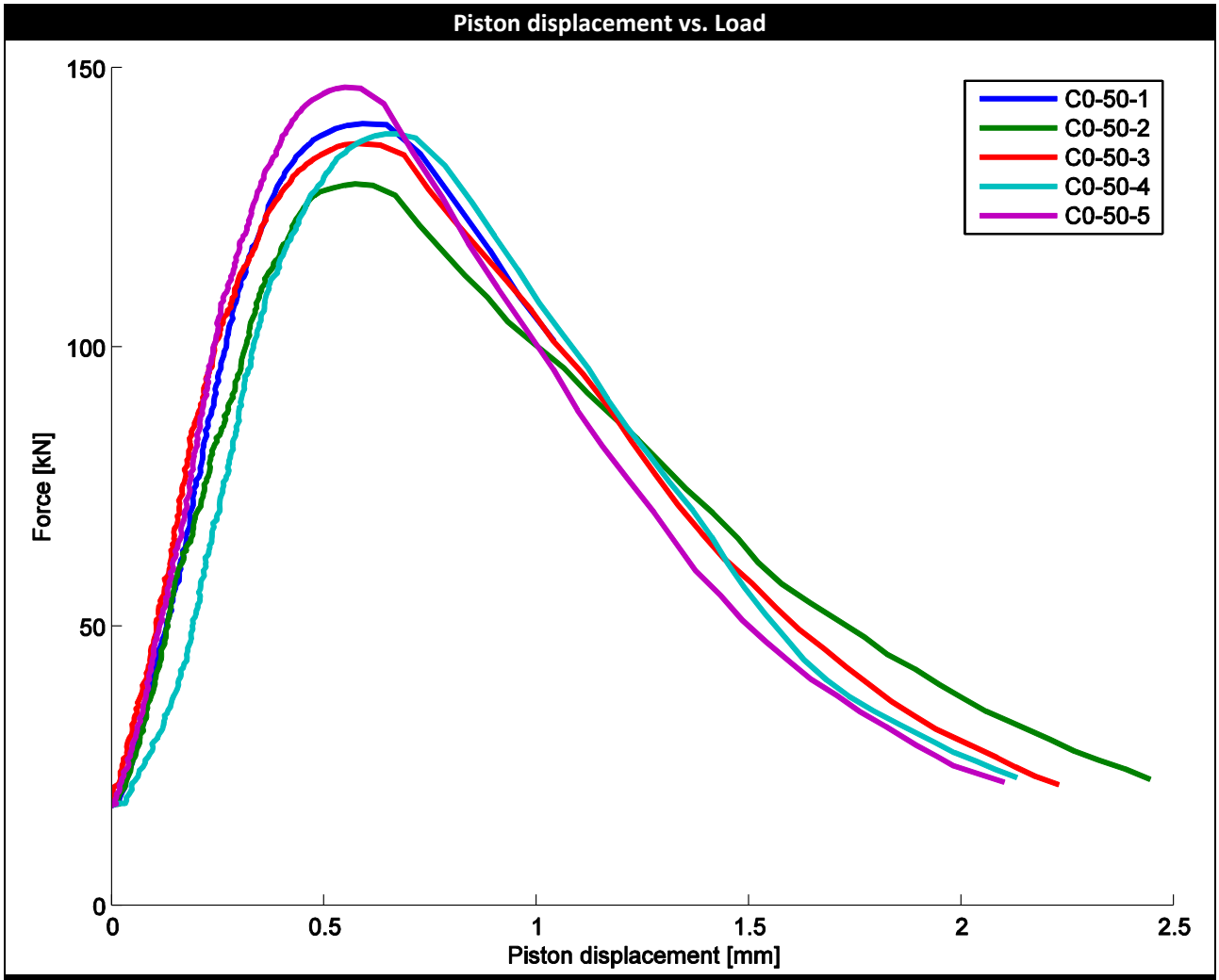
Sample	1	2	3	4	5	Mean	Std. Dev.
f_c $[MPa]$	25.51	26.00	26.00	24.68	20.93	24.62	2.13

C.5 C0-40



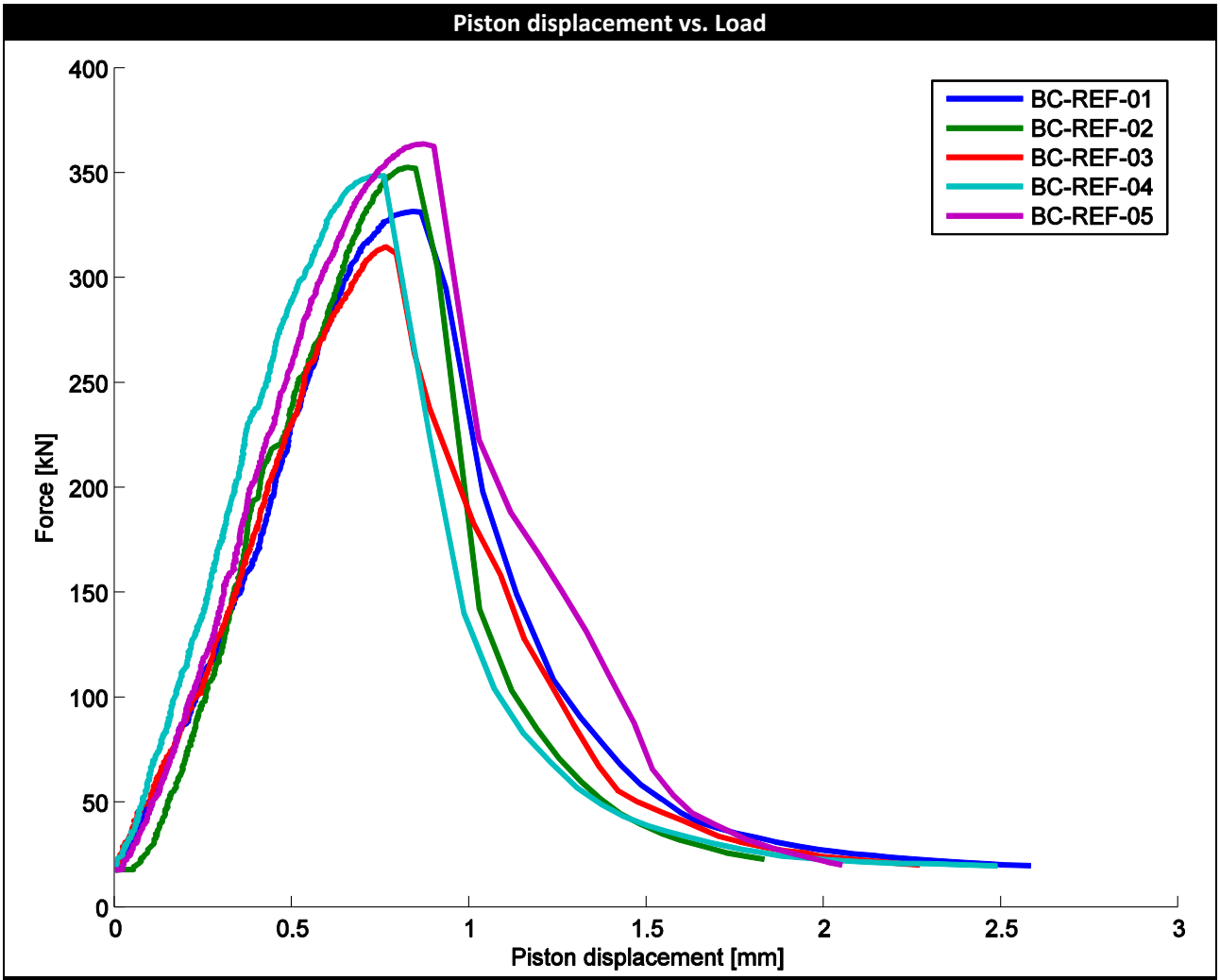
Sample	1	2	3	4	5	Mean	Std. Dev.
f_c $[MPa]$	22.69	22.34	22.83	21.84	23.69	22.68	0.68

C.6 C0-50



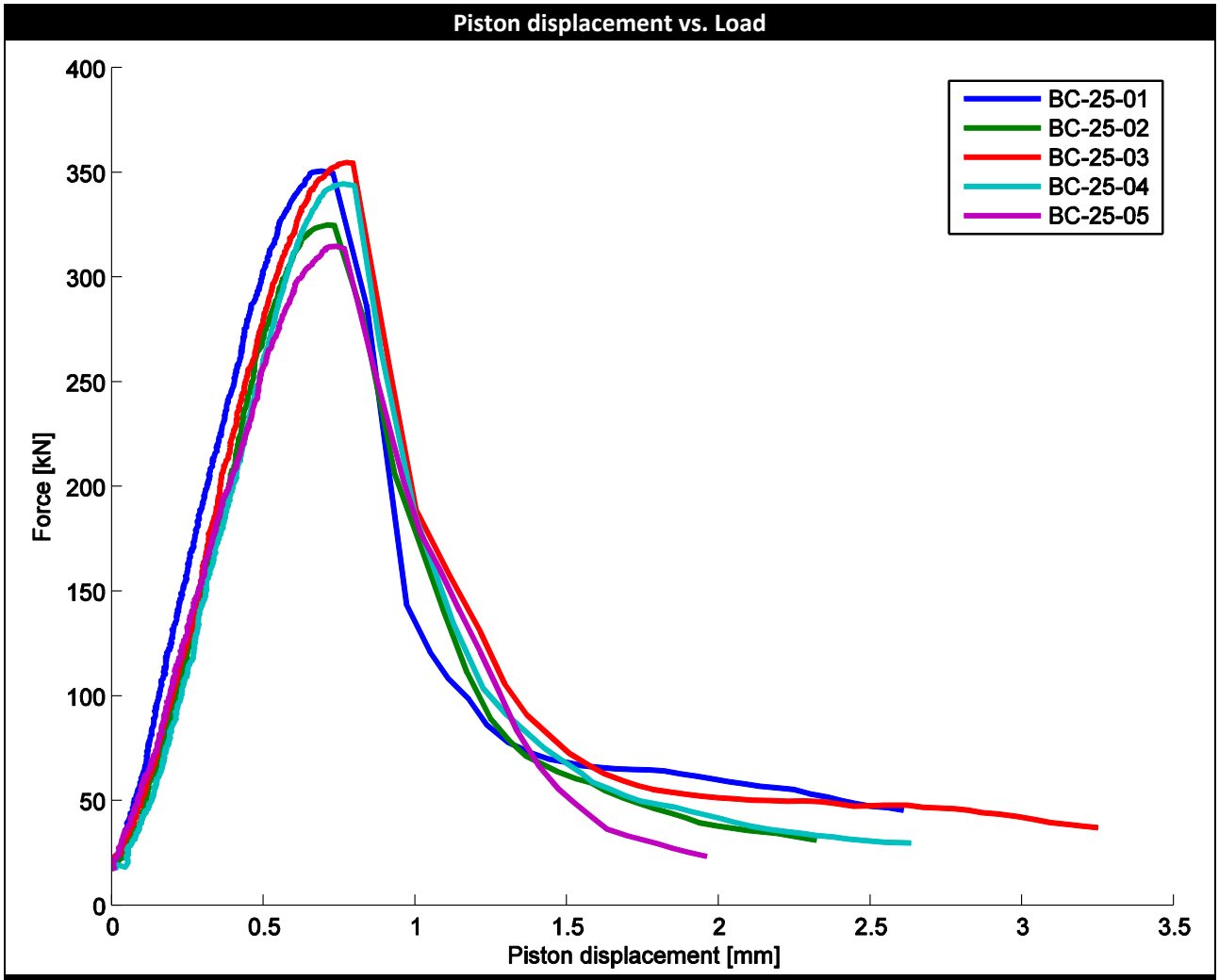
Sample	1	2	3	4	5	Mean	Std. Dev.
f_c $[MPa]$	17.92	16.52	17.46	17.70	18.75	17.67	0.81

C.7 BC-REF



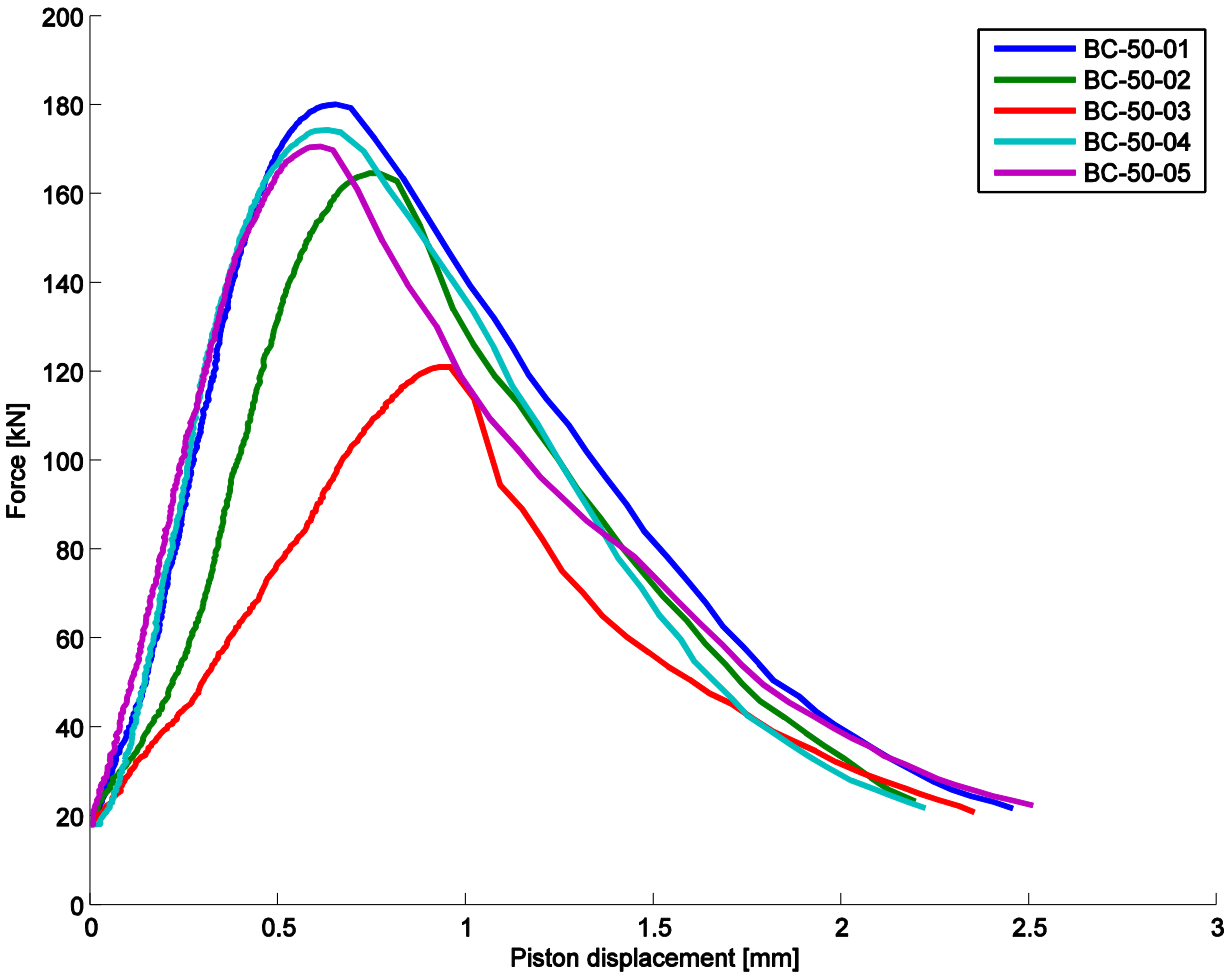
Sample	1	2	3	4	5	Mean	Std. Dev.
f_c $[MPa]$	42.51	45.12	40.29	44.63	46.55	43.82	2.45

C.8 BC-25



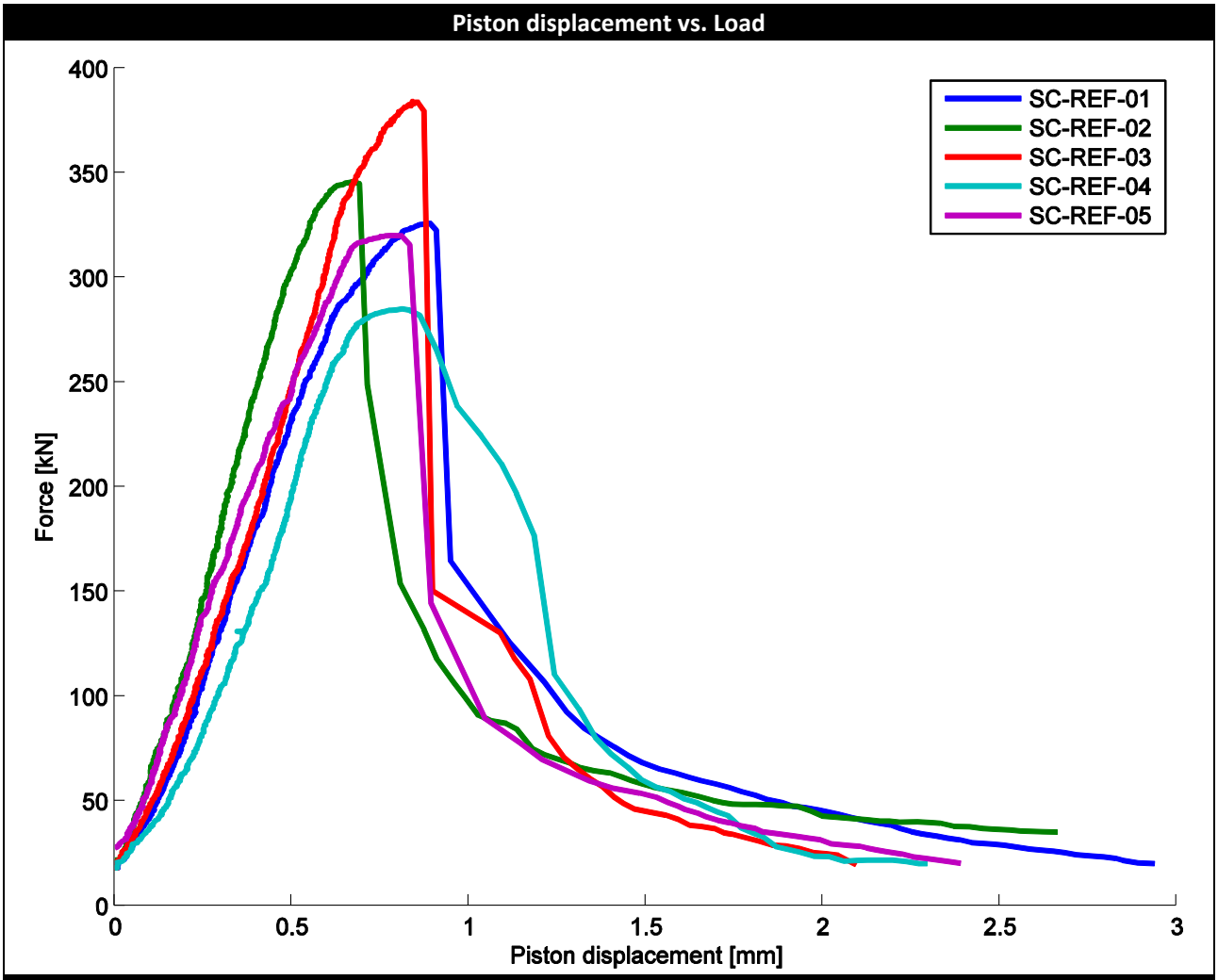
Sample	1	2	3	4	5	Mean	Std. Dev.
f_c $[MPa]$	44.90	41.62	45.59	44.35	40.36	43.34	2.23

C.9 BC-50



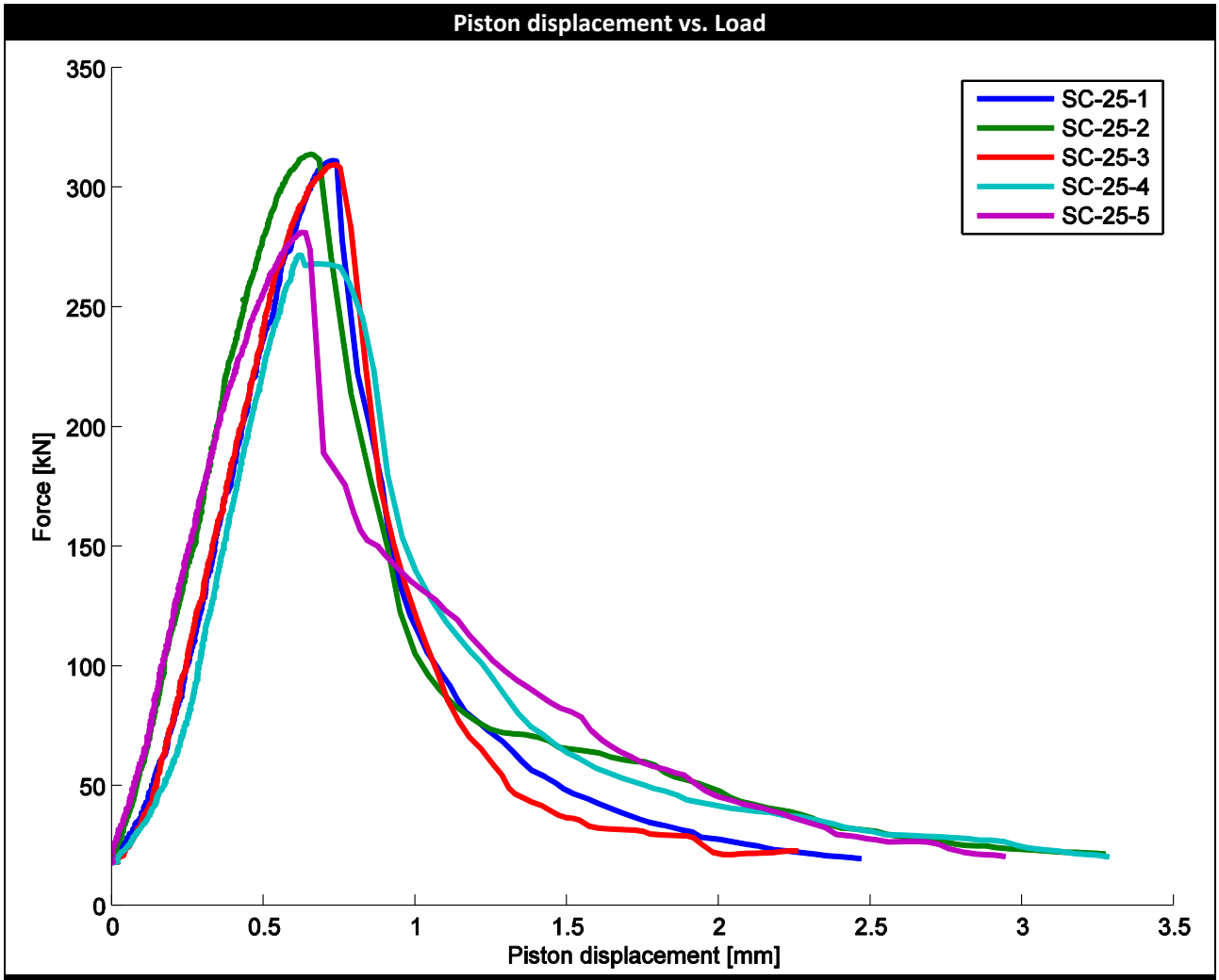
Sample	1	2	3	4	5	Mean	Std. Dev.
f_c $[MPa]$	23.05	21.09	15.49	22.30	21.83	20.75	3.03

C.10 SC-REF



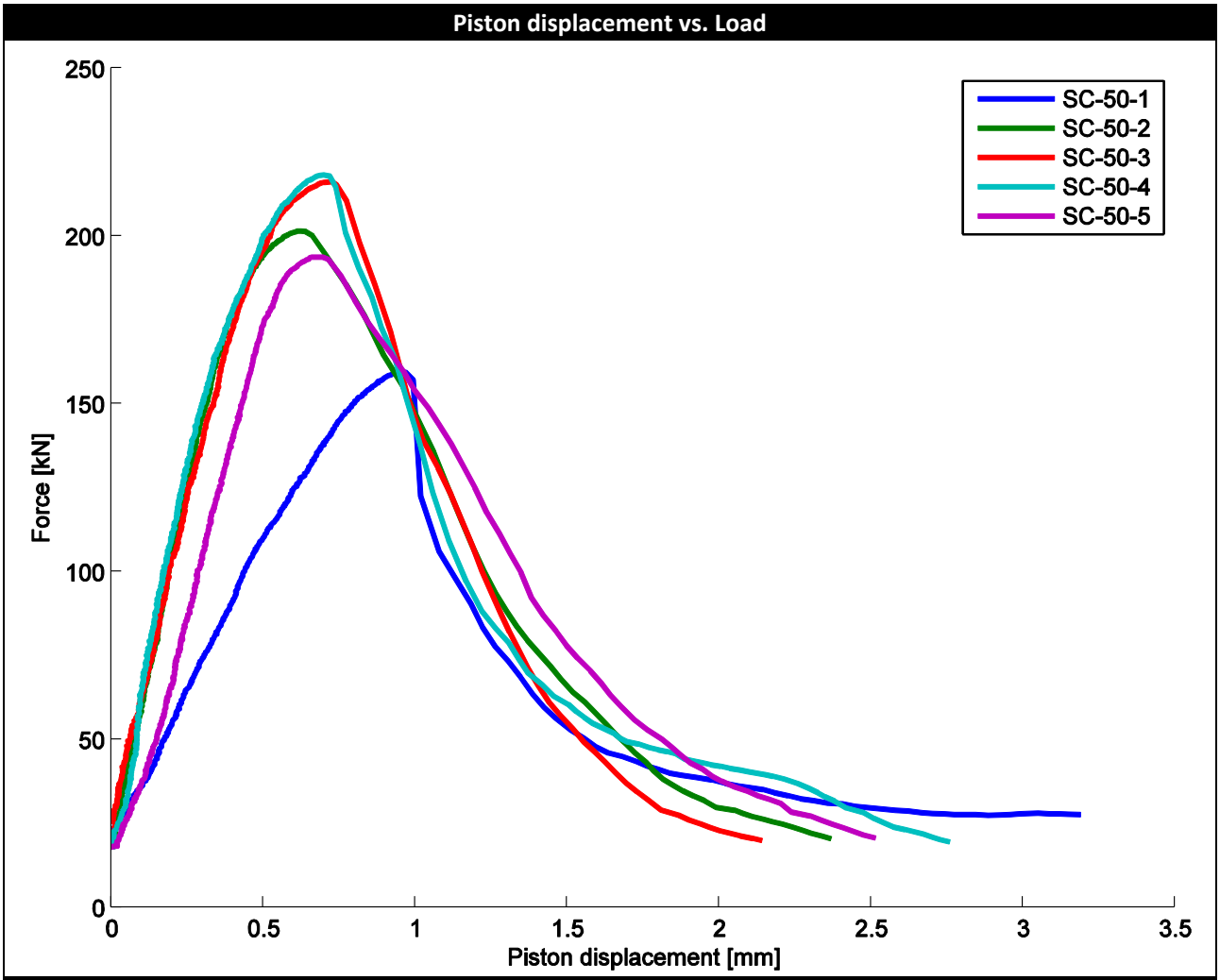
Sample	1	2	3	4	5	Mean	Std. Dev.
f_c $[MPa]$	41.58	44.25	49.09	36.43	40.94	42.46	4.65

C.11 SC-25



Sample	1	2	3	4	5	Mean	Std. Dev.
f_c $[MPa]$	39.72	40.24	39.64	34.71	35.96	38.05	2.53

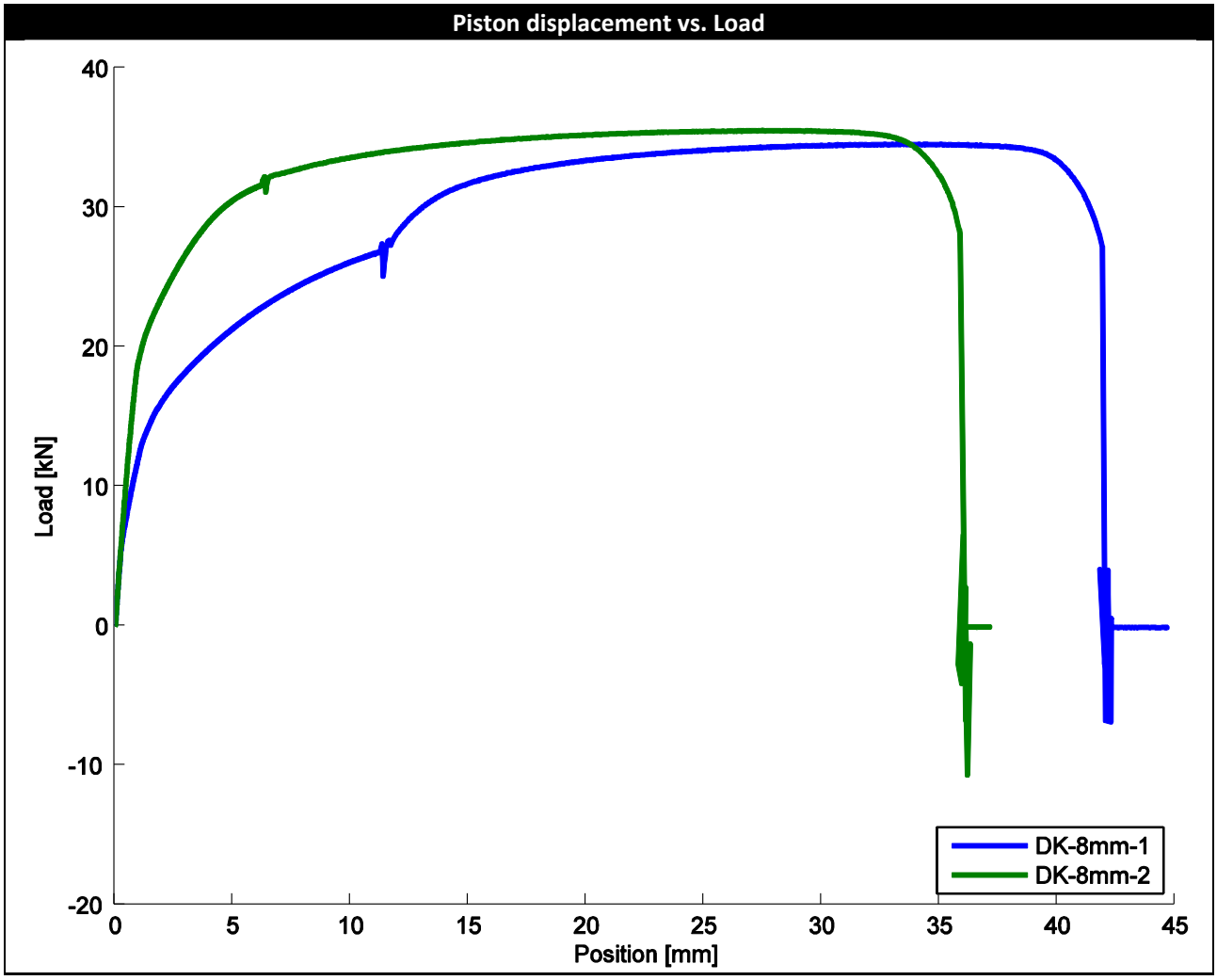
C.12 SC-50

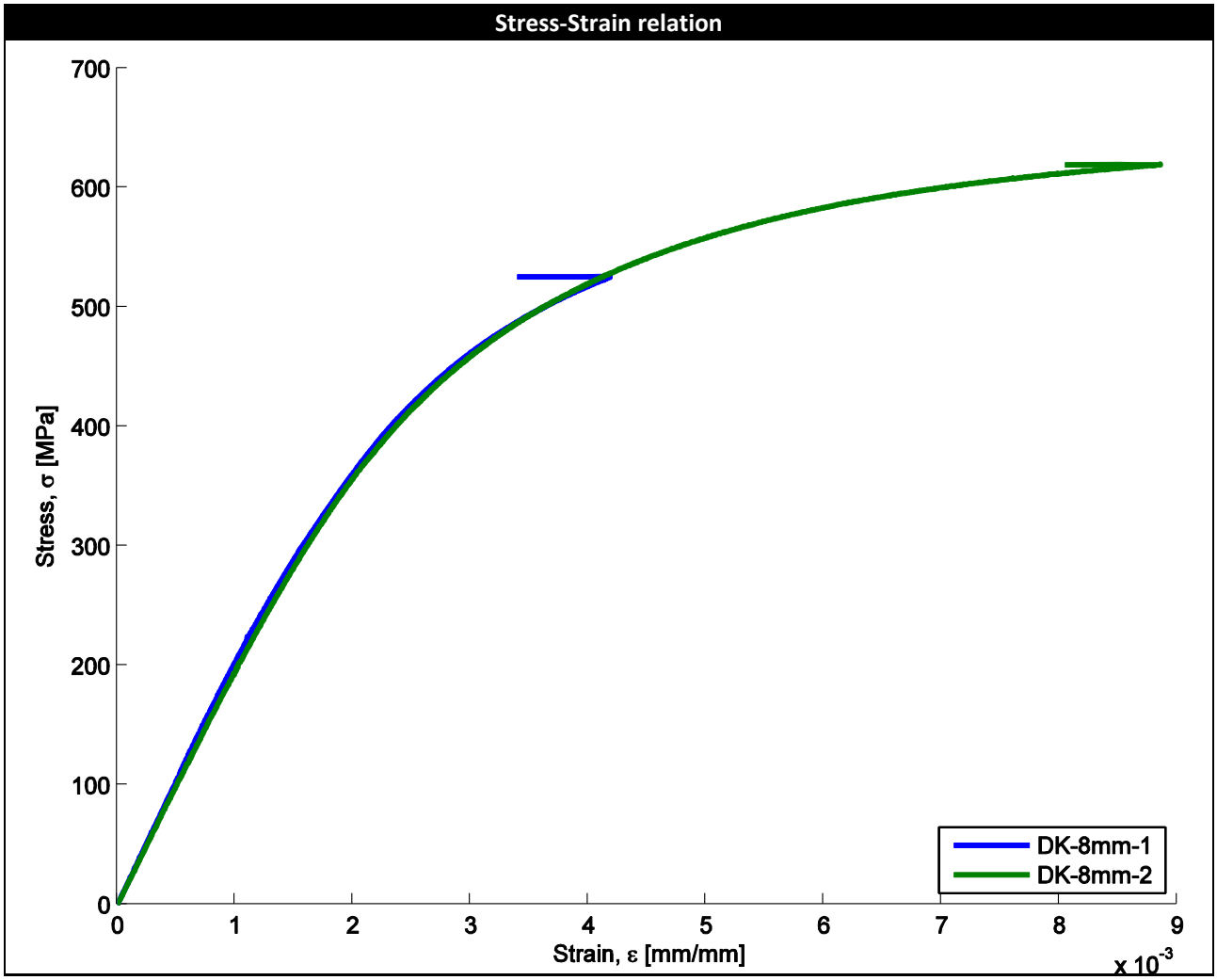


Sample	1	2	3	4	5	Mean	Std. Dev.
f_c $[MPa]$	20.49	25.80	27.67	27.89	24.84	25.34	3.00

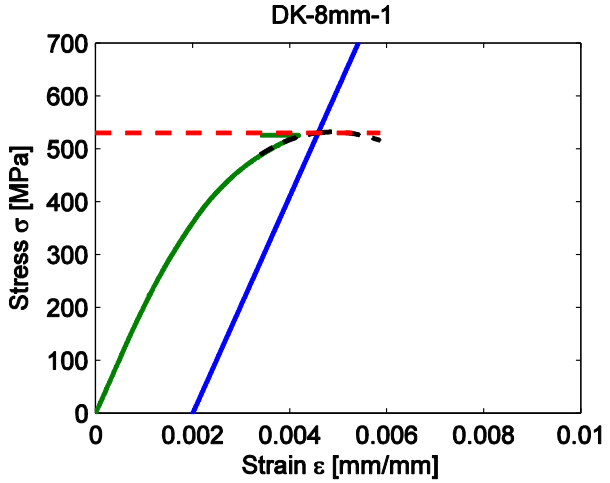
D Steel strengths

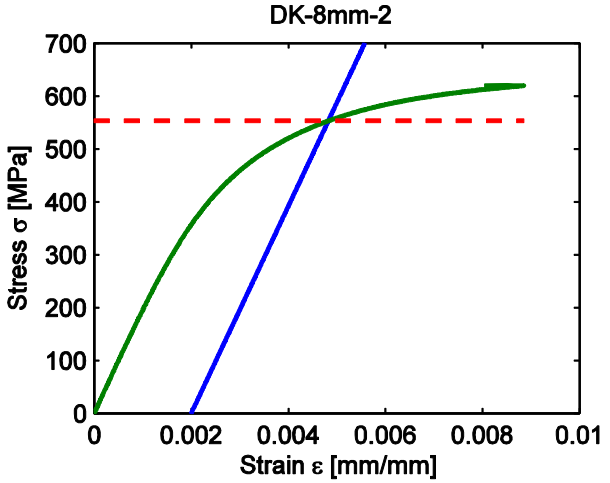
D.1 DK 8 mm




Stress-Strain relation
700
600
500
400
300
200
100
0
Stress, σ [MPa]
0
1
2
3
4
5
6
7
8
9
Strain, ε [mm/mm]
x 10-3
DK-8mm-1
DK-8mm-2

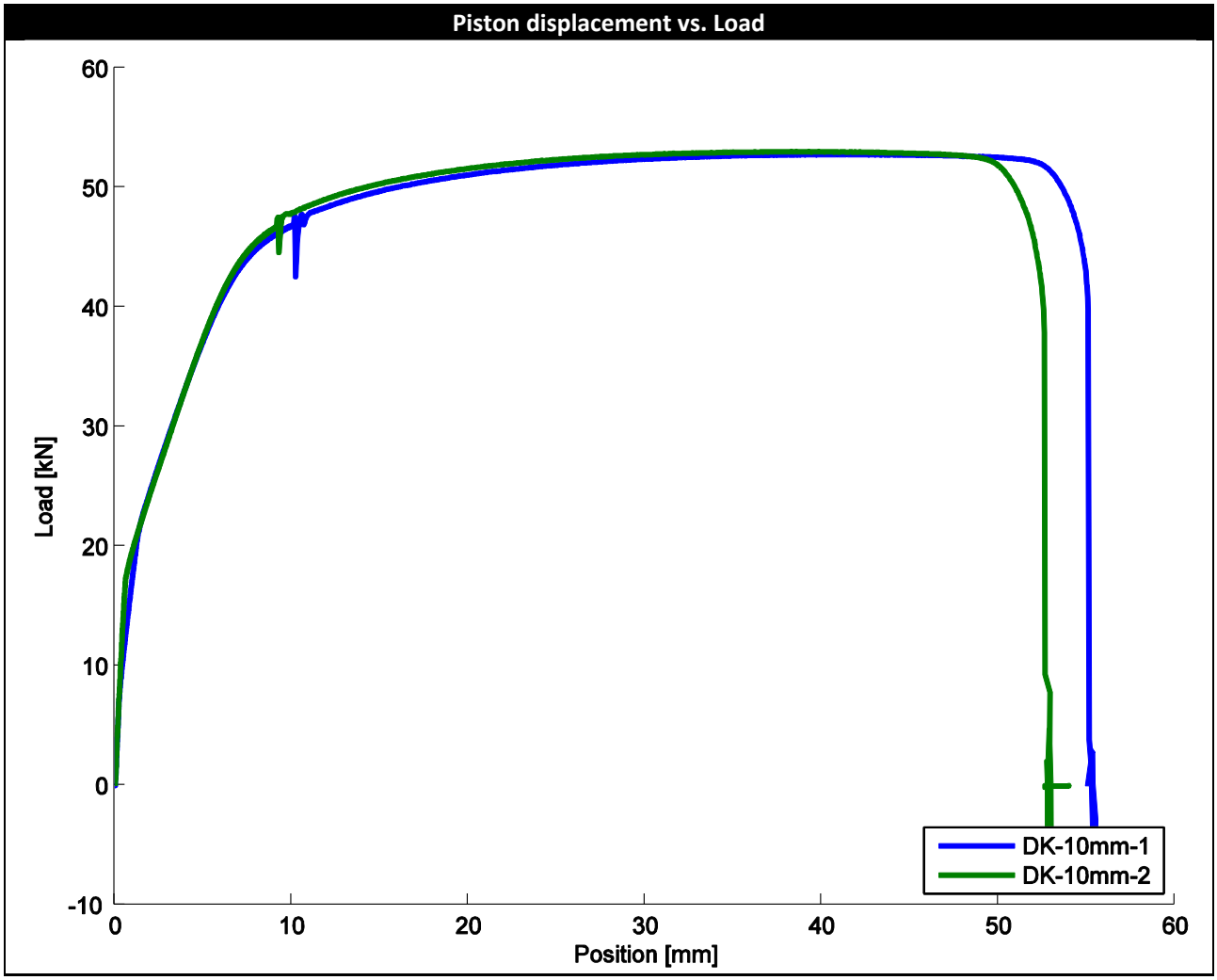
Determination of yield strength

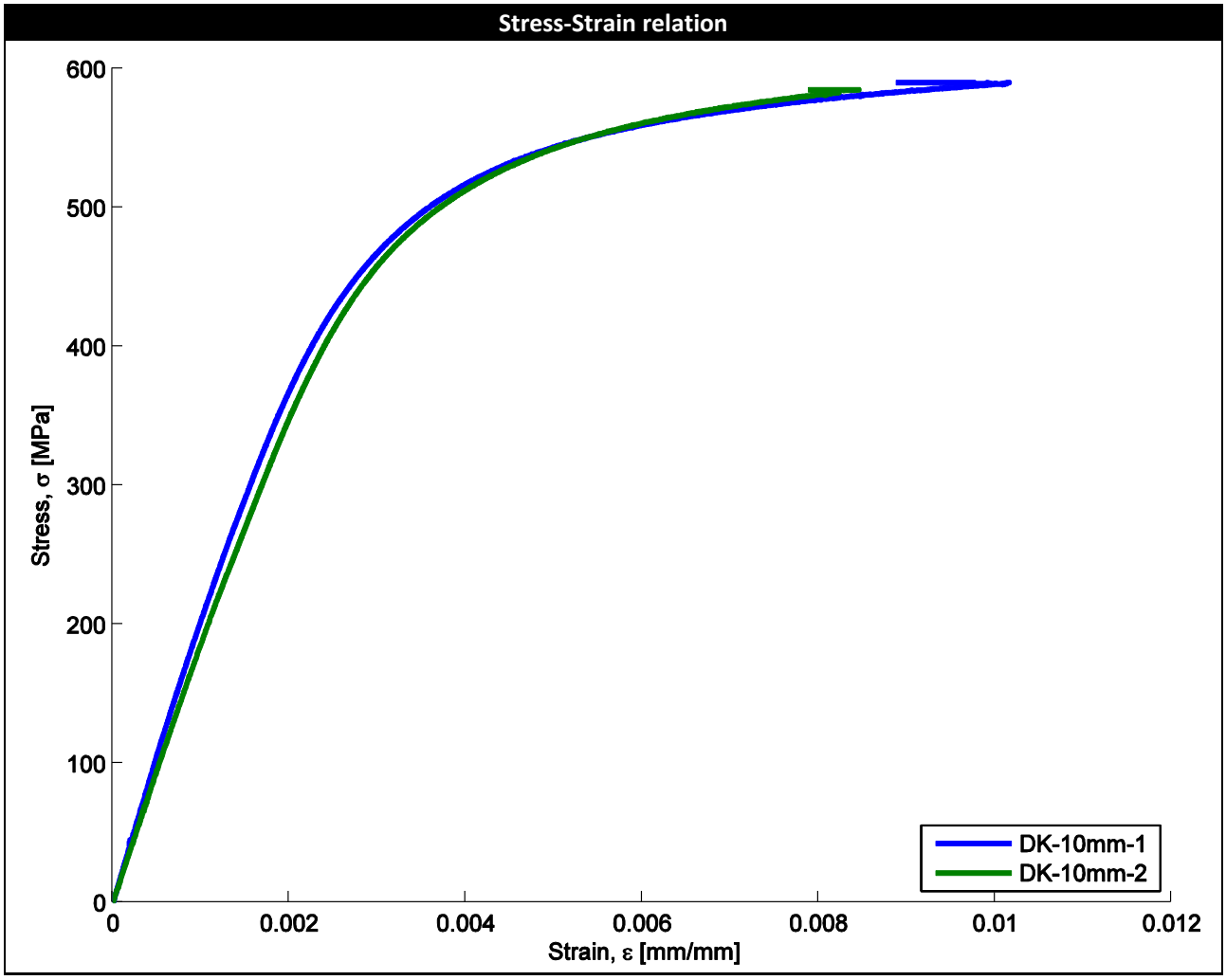




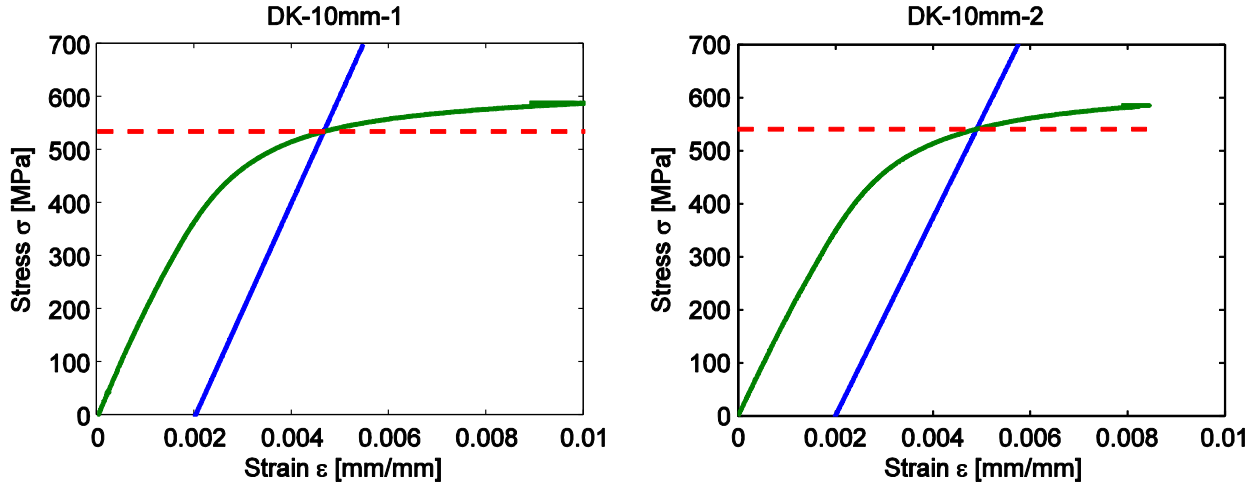
Rod	1	2	Mean	Std Dev
$f_y\ [MPa]$	530.3	553.0	541.6	16.0
$E\ [GPA]$	205.3	195.7	200.5	6.8

D.2 DK 10 mm


Piston displacement vs. Load
Load [kN]
Position [mm]
60
50
40
30
20
10
0
-10
0
10
20
30
40
50
60
DK-10mm-1
DK-10mm-2

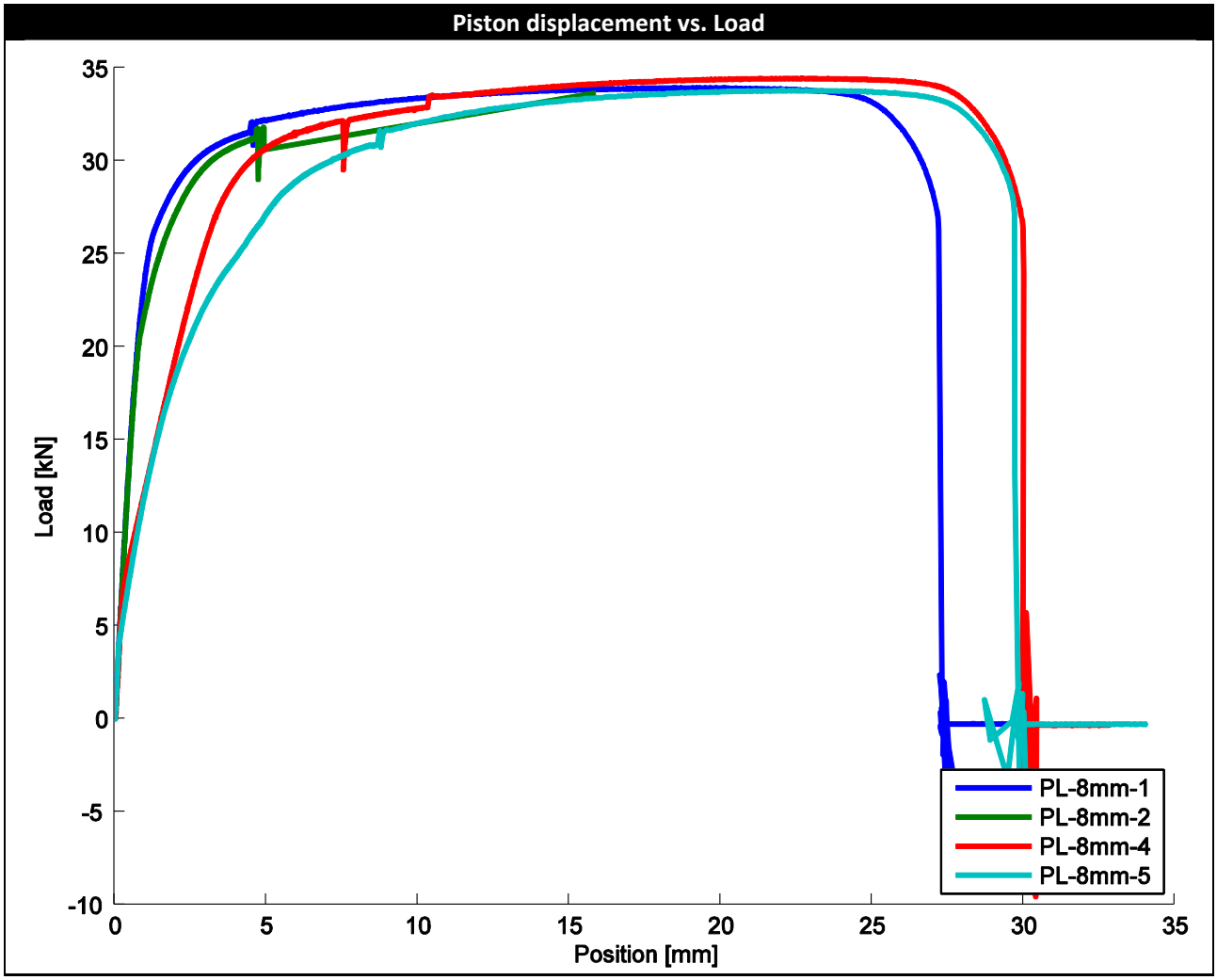

Stress-Strain relation
600
500
400
300
200
100
0
Stress, σ [MPa]
0
0.002
0.004
0.006
0.008
0.01
0.012
Strain, ε [mm/mm]
DK-10mm-1
DK-10mm-2

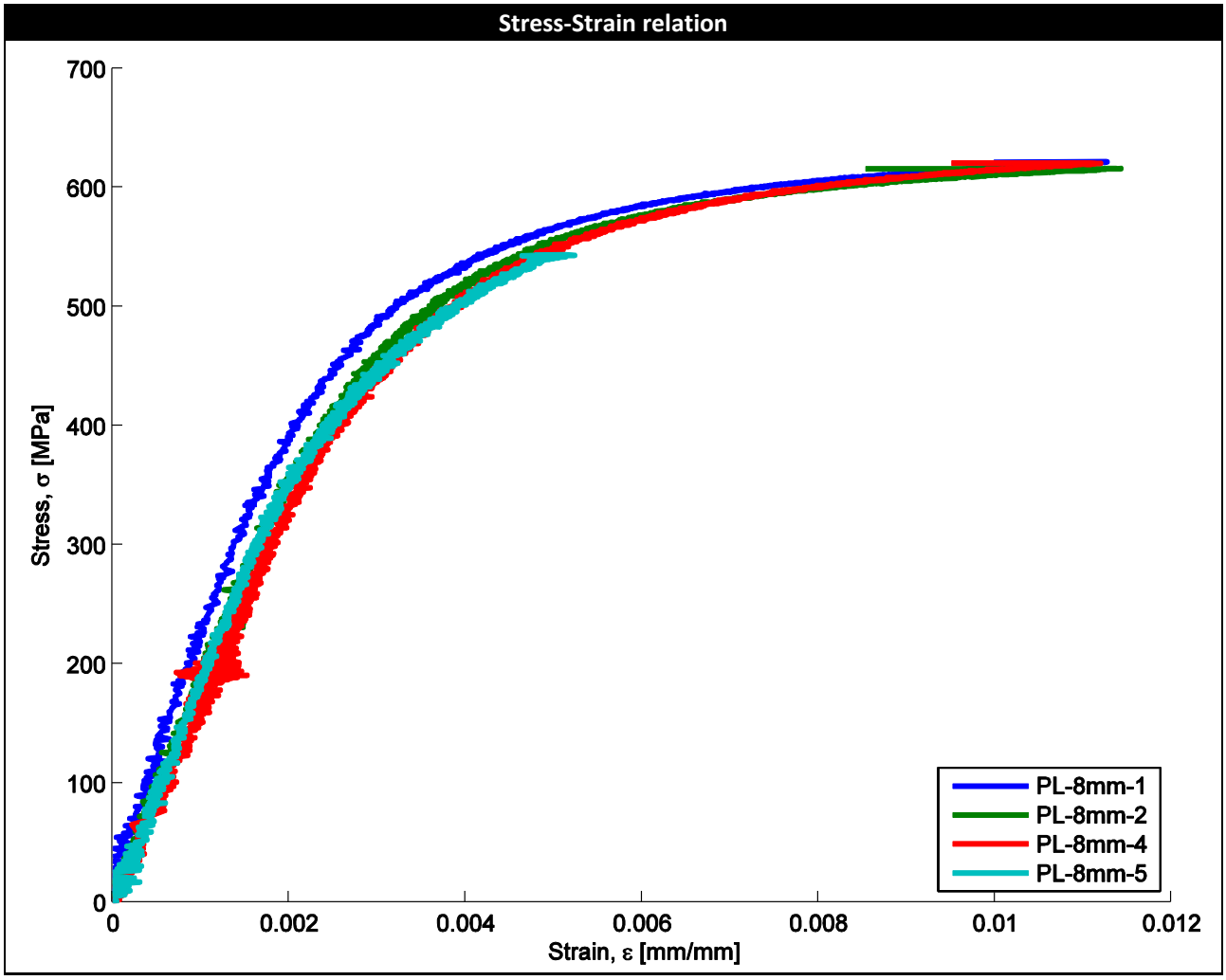
Determination of yield strength



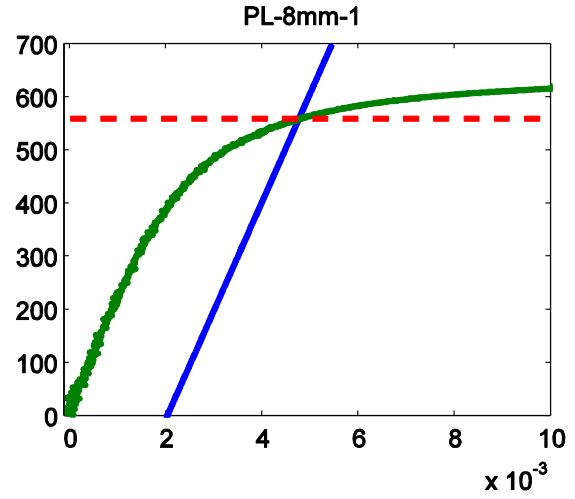
Rod	1	2	Mean	Std Dev
$f_y\ [MPa]$	535.9	540.5	538.2	3.2
$E\ [GPA]$	202.8	186.2	194.5	11.7

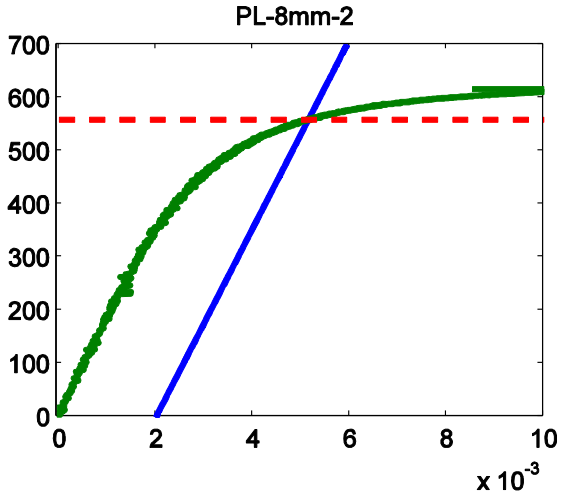
D.3 PL 8mm

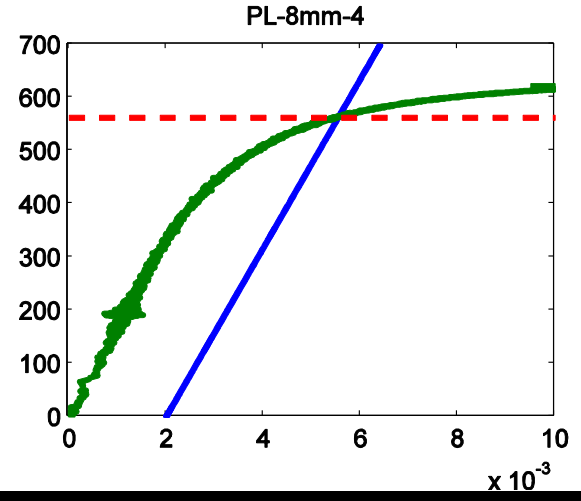

Piston displacement vs. Load
Load [kN]
Position [mm]
35
30
25
20
15
10
5
0
-5
-10
0
5
10
15
20
25
30
35
PL-8mm-1
PL-8mm-2
PL-8mm-4
PL-8mm-5

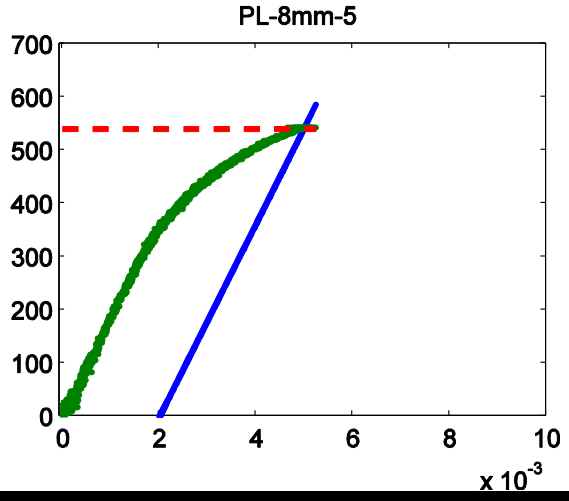

Stress-Strain relation
Stress, σ [MPa]
Strain, ε [mm/mm]
0
100
200
300
400
500
600
700
0
0.002
0.004
0.006
0.008
0.01
0.012
PL-8mm-1
PL-8mm-2
PL-8mm-4
PL-8mm-5

Determination of yield strength



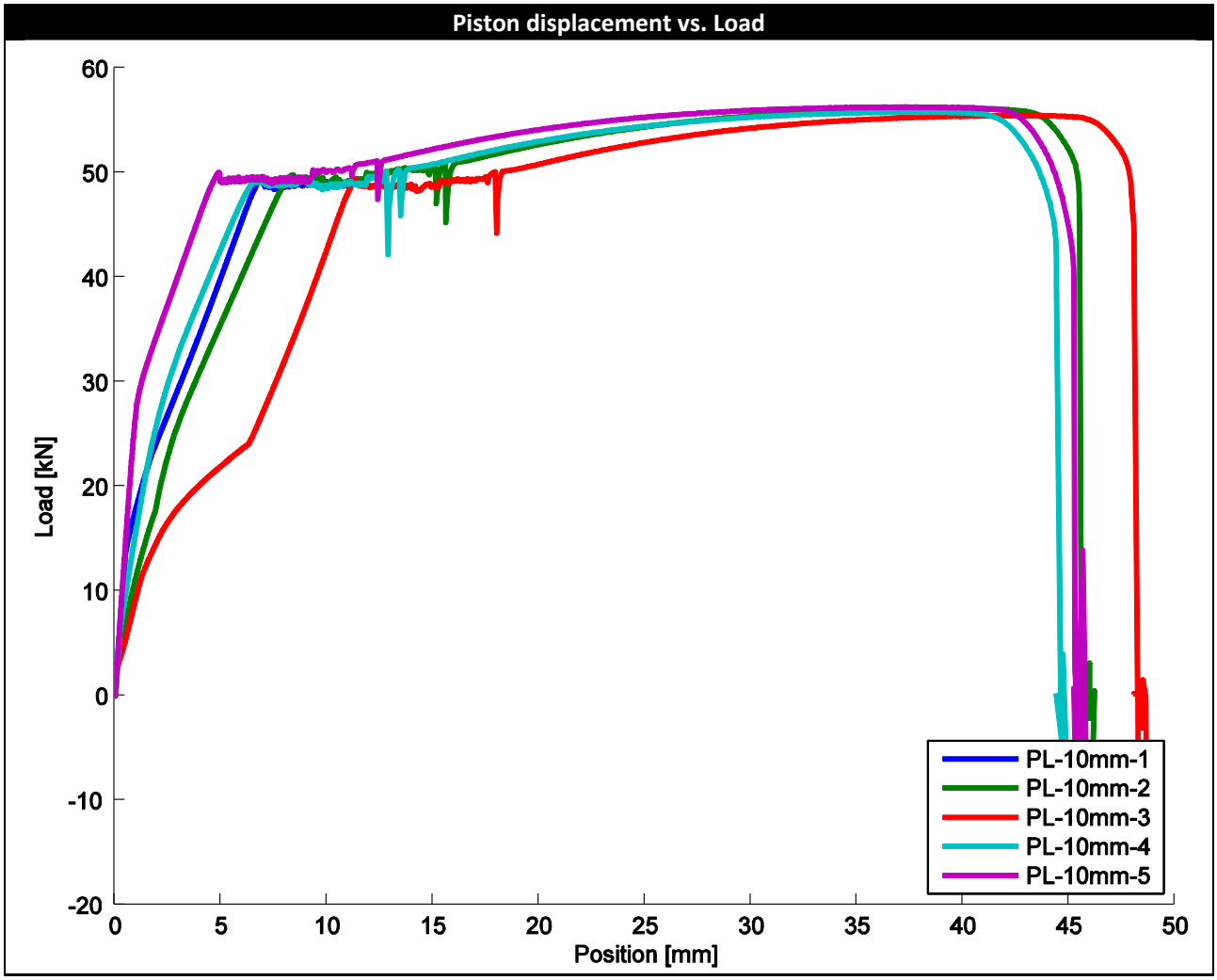


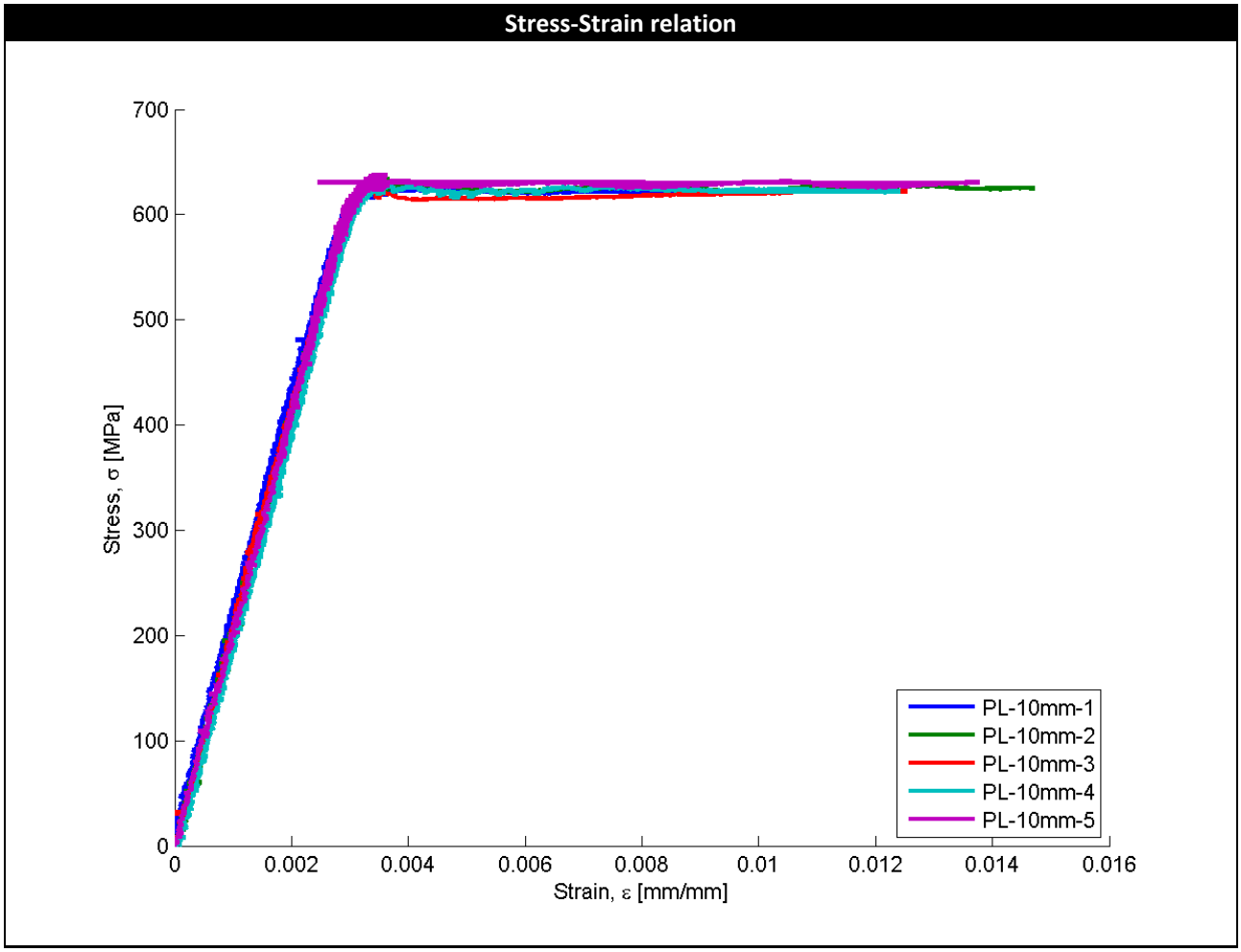




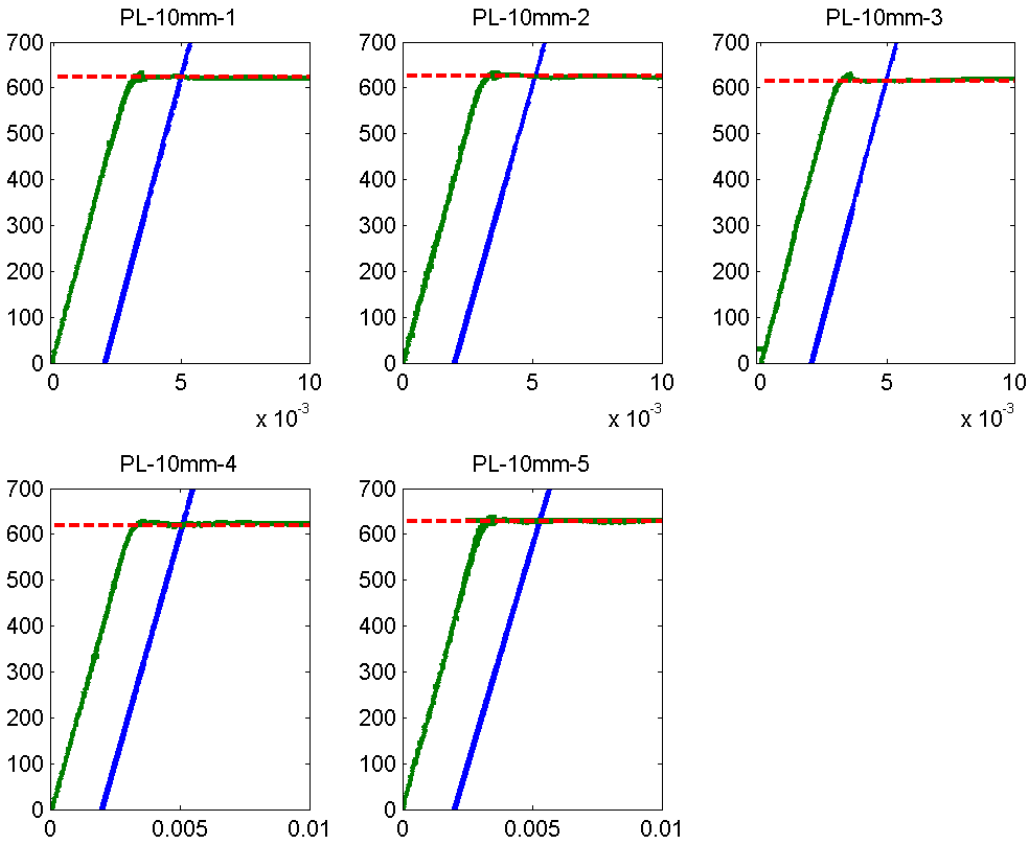
Rod	1	2	4	5	Mean	Std. Dev.
$f_y\ [MPa]$	560.8	559.1	562	541	555.7	7.3
$E\ [GPa]$	204.3	177.8	158.7	181.6	180.6	18.7

D.4 PL 10mm


Piston displacement vs. Load
Load [kN]
Position [mm]
60
50
40
30
20
10
0
-10
-20
0
5
10
15
20
25
30
35
40
45
50
PL-10mm-1
PL-10mm-2
PL-10mm-3
PL-10mm-4
PL-10mm-5


Stress-Strain relation
Stress, σ [MPa]
Strain, ε [mm/mm]
0
100
200
300
400
500
600
700
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
PL-10mm-1
PL-10mm-2
PL-10mm-3
PL-10mm-4
PL-10mm-5

Determination of yield strength



Rod	1	2	3	4	5	Mean	Std. Dev.
$f_y\ [MPa]$	623.9	624.9	615.2	618.4	627.5	622.0	5.0
$E\ [GPa]$	209.0	200.0	207.8	199.7	191.0	201.5	7.3

E Initial theoretical beam results

Resultatoversigt for alle serier

Serie	Bjælke nummer	Momentbæreevne M_R	trykzonehøjde x	ε_s	ε_{sc}	σ_s	σ_{sc}
B-REF	1	20.8	28.2	2.3469%	-0.0846%	622	-171
	2	20.6	25.8	2.6045%	-0.0498%	622	-100
	3	20.4	26.4	2.5025%	-0.0603%	622	-122
B-25	1	20.7	26.4	2.5557%	-0.0541%	622	-109
	2	20.8	26.1	2.6041%	-0.0519%	622	-105
	3	20.5	26.1	2.5616%	-0.0519%	622	-105
B-50	1	19.9	35.8	1.8128%	0.0711%	622	143
	2	19.7	36.2	1.7671%	0.0699%	622	141
	3	16.4	34.0	1.8105%	0.0460%	538	90

Serie	Forskydningsbæreevne V_{Rd} [kN]	$\varepsilon_{s,\%}$	Maksimal revneafstand s_{max}	Revne moment M_{revne} [kNm]	Koresponderende kraft F [kN]	Superposition (samlede udbøjning) $Q_{max\ teori}$
	[kN]	[%]	[mm]	[kNm]	[kN]	[mm]
B-REF	149.9	760%	191.19	4.67	9.33	8.14
	150.6	844%	195.69	4.77	9.70	7.82
	-	-	-	-	-	-
	149.6	811%	196.92	4.75	9.50	7.90
B-25	151.0	828%	190.21	4.65	9.41	7.85
	152.0	844%	195.10	4.76	9.66	7.75
	150.8	830%	194.38	4.66	9.40	7.89
B-50	148.6	587%	187.78	4.83	9.64	8.00
	147.9	572%	191.07	4.84	9.72	8.06
	133.4	654%	194.80	4.62	9.34	7.52

F Sensitivity analysis beam

Input parametre

```
> restart : with(plots) : with(ExcelTools) : with(LinearAlgebra) :
```

Materiale og tværsnitsparametrene defineres:
Bjælke A1 benyttes som eksempel

```
> h := 253.7; b := 125.8; d_sc := 31.8;
```

$$h := 253.7$$
$$b := 125.8$$
$$d_{sc} := 31.8 \qquad \textbf{(1.1.1.1)}$$

```
> f_cmm := 43.82; f_ymm10 := 622; f_ymm8 := 556; E_sm := 201490; E_wm := 180600; d_m
      := 218.4; c_m := 26.8;
```

$$f_{cmm} := 43.82$$
$$f_{ymm10} := 622$$
$$f_{ymm8} := 556$$
$$E_{sm} := 201490$$
$$E_{wm} := 180600$$
$$d_m := 218.4$$
$$c_m := 26.8 \qquad \textbf{(1.1.1.2)}$$

```
> n95 := 1.645
```

$$n95 := 1.645 \qquad \textbf{(1.1.1.3)}$$

```
> svfc := 2.45; svfy10 := 5.02; svfy8 := 9.9; svEl := 7310; svEw := 18680; svd := 1.4;
      svc := 2.8;
```

$$svfc := 2.45$$
$$svfy10 := 5.02$$
$$svfy8 := 9.9$$
$$svEl := 7310$$
$$svEw := 18680$$
$$svd := 1.4$$
$$svc := 2.8 \qquad \textbf{(1.1.1.4)}$$

```
> q1 := 1 :
```

$$f_{cm} := [f_{cmm} - q1 \cdot n95 \cdot svfc, f_{cmm}, f_{cmm} + q1 \cdot n95 \cdot svfc]$$
$$f_{cm} := [39.78975, 43.82, 47.85025] \qquad \textbf{(1.1.1.5)}$$

```
> q2 := 1 :
```

$$\varepsilon_{cu3} := [0.0035 - q2 \cdot 0.0005 , 0.0035 , 0.0035 + q2 \cdot 0.0005]$$
$$\varepsilon_{cu3} := [0.0030, 0.0035, 0.0040] \qquad \textbf{(1.1.1.6)}$$

> $q3 := 1$: $f_{ym,s} := \left[f_{ymm10} - q3 \cdot n95 \cdot svfy10 \;\; f_{ymm10} \;\; f_{ymm10} + q3 \cdot n95 \cdot svfy10 \right]$

$$f_{ym,s} := \left[613.74210 \;\; 622 \;\; 630.25790 \right] \quad \textbf{(1.1.1.7)}$$

> $q5 := 1$: $E_s := \left[E_{sm} - q5 \cdot n95 \cdot svEl, E_{sm}, E_{sm} + n95 \cdot q5 \cdot svEl \right]$

$$E_s := \left[1.89465050\ 10^5, 201490, 2.13514950\ 10^5 \right] \quad \textbf{(1.1.1.8)}$$

> $q7 := 1$: $d := \left[d_m - q7 \cdot n95 \cdot svd, d_m, d_m + q7 \cdot n95 \cdot svd \right]$; $c := \left[c_m + q7 \cdot n95 \cdot svc, c_m, c_m - q7 \cdot n95 \cdot svc \right]$

$$d := [216.0970, 218.4, 220.7030]$$
$$c := [31.4060, 26.8, 22.1940] \quad \textbf{(1.1.1.9)}$$

> $f_{ym,sc} := f_{ym,s}$; $\varnothing_s := 10$; $n_s := 2$; $\varnothing_{sc} := 10$; $n_{sc} := 2$; $E_{sc} := E_s$; $\lambda := 0.8$;; $\varepsilon_{cu2} := 0.002$; $cot\theta := 1.3$; $s := 100$; $vederlag := 280$;

$$f_{ym,sc} := \left[613.74210 \;\; 622 \;\; 630.25790 \right]$$
$$\varnothing_s := 10$$
$$n_s := 2$$
$$\varnothing_{sc} := 10$$
$$n_{sc} := 2$$
$$E_{sc} := \left[1.89465050\ 10^5, 201490, 2.13514950\ 10^5 \right]$$
$$\lambda := 0.8$$
$$\varepsilon_{cu2} := 0.002$$
$$cot\theta := 1.3$$
$$s := 100$$
$$vederlag := 280 \quad \textbf{(1.1.1.10)}$$

> $q4 := 0$: $f_{yw} := \left[f_{ymm8} - q4 \cdot n95 \cdot svfy8 \;\; f_{ymm8} \;\; f_{ymm8} + q4 \cdot n95 \cdot svfy8 \right]$

$$f_{yw} := \left[556 \;\; 556 \;\; 556 \right] \quad \textbf{(1.1.1.11)}$$

> $q6 := 0$: $E_w := \left[E_{wm} - q6 \cdot n95 \cdot svEw, E_{wm}, E_{wm} + q6 \cdot n95 \cdot svEw \right]$

$$E_w := [180600, 180600, 180600] \quad \textbf{(1.1.1.12)}$$

Trækarmeringsarealet beregnes:

> $A_s := n_s \cdot \left(\frac{\varnothing_s}{2} \right)^2 \cdot \pi$

$$A_s := 50\,\pi \quad \textbf{(1.1.1.13)}$$

Trykarmeringsarealet beregnes:

> $A_{sc} := n_{sc} \cdot \left(\frac{\text{ø}_{sc}}{2} \right)^2 \cdot \pi$:

Bøjle armeringarealet beregnes

> $\text{ø}_w := 8$;

$$\text{ø}_w := 8 \qquad \textbf{(1.1.1.14)}$$

> $A_w := 2 \cdot \left(\frac{\text{ø}_w}{2} \right)^2 \cdot \pi$:

Ligningerne for tryk- og træktøjninger, tryk- og trækspændinger, normalkraften der sættes lig nul, og ligningerne løses

>

Moment capcity

Punkt B

> **for** nn **from** 1 **to** 3 **do** $B[nn] := solve\left(\left\{ \varepsilon_s = \frac{\varepsilon_{cu3}[nn] \cdot (d[nn] - x)}{x}, \varepsilon_{sc} = \frac{\varepsilon_{cu3}[nn] \cdot (x - d_{sc})}{x}, \sigma_{sc} = \min\left(\varepsilon_{sc} \cdot E_{sc}[nn], f_{ym,sc}[nn] \right), \sigma_s = \min\left(f_{ym,s}[nn], E_s[nn] \cdot \varepsilon_s \right), 0 = \lambda \cdot x \cdot b \cdot f_{cm}[nn] + A_{sc} \cdot \sigma_{sc} - A_s \cdot \sigma_s, M_{rm} = \lambda \cdot x \cdot b \cdot f_{cm}[nn] \cdot \left(\frac{h}{2} - \frac{\lambda \cdot x}{2} \right) + A_{sc} \cdot \sigma_{sc} \cdot \left(\frac{h}{2} - d_{sc} \right) + A_s \cdot \sigma_s \cdot \left(d[nn] - \frac{h}{2} \right) \right\}, \{x, M_{rm}, \varepsilon_s, \varepsilon_{sc}, \sigma_{sc}, \sigma_s\} \right)$ **end do**:

>

>

> $B[1][2]$

$$\left\{ M_{rm} = 2.005918517\ 10^7, x = 27.53158610, \sigma_s = 613.7421000, \sigma_{sc} = -88.12226572, \varepsilon_s = 0.02054717222, \varepsilon_{sc} = -0.0004651109306 \right\} \qquad \textbf{(1.1.2.1)}$$

>

> $M_{rm} := ([rhs(B[1][2,1]), rhs(B[2][2,1]), rhs(B[3][2,1])])$;

$$M_{rm} := [2.005918517\ 10^7, 2.072379624\ 10^7, 2.139857763\ 10^7] \qquad \textbf{(1.1.2.2)}$$

> $N_{rmB} := [[0], [0], [0]]$:

> $x := ([rhs(B[1][2,1]), rhs(B[2][2,1]), rhs(B[3][2,1])])$;

$$x := [27.53158610, 26.81947068, 26.33684995] \qquad \textbf{(1.1.2.3)}$$

> $\sigma_{st} := \left[rhs(B[1][2,1]) \quad rhs(B[2][2,1]) \quad rhs(B[3][2,1]) \right]$;

$$\sigma_{st} := \left[613.7421000 \quad 622. \quad 630.2579000 \right] \qquad \textbf{(1.1.2.4)}$$

> $\varepsilon_{st} := \left[rhs(B[1][2,3]) \quad rhs(B[2][2,3]) \quad rhs(B[3][2,3]) \right]$;

$$\varepsilon_{st} := \left[0.02054717222 \quad 0.02500168104 \quad 0.02952002996 \right] \qquad \textbf{(1.1.2.5)}$$

Shear capacity

$y := \left[\begin{array}{ccc} 0.8\cdot x[1] & 0.8\cdot x[2] & 0.8\cdot x[3] \end{array}\right];$

$$\left[\begin{array}{ccc} 22.02526888 & 21.45557654 & 21.06947996 \end{array}\right] \quad \textbf{(1.1.3.1)}$$

$z := d - \sim\frac{y}{2}$

$$\left[\begin{array}{ccc} 205.0843656 & 207.6722117 & 210.1682600 \end{array}\right] \quad \textbf{(1.1.3.2)}$$

$n_w := \left[\frac{z[1]\cdot cot\theta}{s}, \frac{z[2]\cdot cot\theta}{s}, \frac{z[3]\cdot cot\theta}{s}\right]$

$$[2.666096753, 2.699738752, 2.732187380] \quad \textbf{(1.1.3.3)}$$

$V_v := \left[\begin{array}{ccc} 0.7 - \frac{f_{cm}[1]}{200} & 0.7 - \frac{f_{cm}[2]}{200} & 0.7 - \frac{f_{cm}[3]}{200} \end{array}\right];$

$$\left[\begin{array}{ccc} 0.5010512500 & 0.4809000000 & 0.4607487500 \end{array}\right] \quad \textbf{(1.1.3.4)}$$

[>

$f_{ctm} := \left[\begin{array}{ccc} 0.3\cdot\left(f_{cm}\left[1\right]\right)^{\left(\frac{2}{3}\right)} & 0.3\cdot\left(f_{cm}\left[2\right]\right)^{\left(\frac{2}{3}\right)} & 0.3\cdot\left(f_{cm}\left[3\right]\right)^{\left(\frac{2}{3}\right)} \end{array}\right];$

$$\left[\begin{array}{ccc} 3.496514994 & 3.728803551 & 3.954067347 \end{array}\right] \quad \textbf{(1.1.3.5)}$$

$l_b := \left[\frac{f_{ym,s}[1]}{9\cdot f_{ctm}[1]}\cdot\phi_s, \frac{f_{ym,s}[2]}{9\cdot f_{ctm}[2]}\cdot\phi_s, \frac{f_{ym,s}[3]}{9\cdot f_{ctm}[3]}\cdot\phi_s\right]$

$$[195.0329593, 185.3439318, 177.1053688] \quad \textbf{(1.1.3.6)}$$

$\sigma_{s,ef} := \left[\min\left(\frac{vederlag}{l_b[1]}\cdot f_{ym,s}\left[1\right], \sigma_{st}\left[1\right]\right), \min\left(\frac{vederlag}{l_b[2]}\cdot f_{ym,s}, \sigma_{st}\left[2\right]\right), \min\left(\frac{vederlag}{l_b[2]}\cdot f_{ym,s}, \sigma_{st}\left[3\right]\right)\right];$

$$\left[\begin{array}{ccc} 613.7421000 & 622. & 630.2579000 \end{array}\right] \quad \textbf{(1.1.3.7)}$$

$V_{Rd,l} := evalf\left(\left[2\cdot\frac{\sigma_{s,ef}[1]\cdot A_s}{cot\theta}\cdot 10^{-3}, 2\cdot\frac{\sigma_{s,ef}[2]\cdot A_s}{cot\theta}\cdot 10^{-3}, 2\cdot\frac{\sigma_{s,ef}[3]\cdot A_s}{cot\theta}\cdot 10^{-3}\right]\right)$

$$[148.3175133, 150.3131254, 152.3087376] \quad \textbf{(1.1.3.8)}$$

$V_{Rd,c} := \left[\frac{V_v[1]\cdot z\left[1\right]\cdot b\cdot f_{cm}\left[1\right]\cdot cot\theta\cdot 10^{-3}}{1+cot\theta}, \frac{V_v[2]\cdot z[2]\cdot b\cdot f_{cm}\left[2\right]\cdot cot\theta\cdot 10^{-3}}{1+cot\theta}, \frac{V_v[3]\cdot z[3]\cdot b\cdot f_{cm}\left[3\right]\cdot cot\theta\cdot 10^{-3}}{1+cot\theta}\right]$

$$\left[\begin{array}{ccc} 290.7247937 & 311.1728488 & 329.4668040 \end{array}\right] \quad \textbf{(1.1.3.9)}$$

$V_{Rd,w} := evalf\left(\left[n_w[1]\cdot A_w\cdot f_{yw}[1]\cdot 10^{-3}, n_w[2]\cdot A_w\cdot f_{yw}[2]\cdot 10^{-3}, n_w[3]\cdot A_w\cdot f_{yw}[3]\cdot 10^{-3}\right]\right)$

$$[149.0220552, 150.9024820, 152.7162051] \quad \textbf{(1.1.3.10)}$$

> $V_{Rd} := [\min(V_{Rd,l}[1], V_{Rd,c}[1], V_{Rd,w}[1]), 0, 0]$

$$V_{Rd} := [148.3175133, 0, 0] \quad \textbf{(1.1.3.11)}$$

> $V_{Rd}[2] := \min(V_{Rd,l}[2], V_{Rd,c}[2], V_{Rd,w}[2])$

$$V_{Rd_2} := 150.3131254 \quad \textbf{(1.1.3.12)}$$

> $V_{Rd}[3] := \min(V_{Rd,l}[3], V_{Rd,c}[3], V_{Rd,w}[3])$

$$V_{Rd_3} := 152.3087376 \quad \textbf{(1.1.3.13)}$$

> V_{Rd}

$$[148.3175133, 150.3131254, 152.3087376] \quad \textbf{(1.1.3.14)}$$

Maximum crack distance

> c

$$[31.4060, 26.8, 22.1940] \quad \textbf{(1.1.4.1)}$$

> svc

$$2.8 \quad \textbf{(1.1.4.2)}$$

>

$$\min\left(\left[5\cdot\left(c[1]+\frac{\varnothing_w}{2}\right), 5\cdot\left(c[2]+\frac{\varnothing_w}{2}\right), 5\cdot\left(c[3]+\frac{\varnothing_w}{2}\right)\right]\right)$$

$$130.9700 \quad \textbf{(1.1.4.3)}$$

$$h_{c,eff} := \left[\min\left(2.5\cdot(h-d[1]), \frac{(h-d[1])}{3}, \frac{h}{2}\right), \min\left(2.5\cdot(h-d[2]), \frac{(h-d[2])}{3}, \frac{h}{2}\right), \min\left(2.5\cdot(h-d[3]), \frac{(h-d[3])}{3}, \frac{h}{2}\right)\right]$$

$$[12.53433333, 11.76666667, 10.99900000] \quad \textbf{(1.1.4.4)}$$

$$A_{c,eff} := b\cdot h_{c,eff}$$

$$[1576.819133, 1480.246667, 1383.674200] \quad \textbf{(1.1.4.5)}$$

$$s_{r,max} := \left[evalf\left(29\cdot c[1]^{\frac{1}{3}} + 0.17\cdot\frac{A_{c,eff}[1]}{A_w}\right), evalf\left(29\cdot c[2]^{\frac{1}{3}} + 0.17\cdot\frac{A_{c,eff}[2]}{A_w}\right), evalf\left(29\cdot c[3]^{\frac{1}{3}} + 0.17\cdot\frac{A_{c,eff}[3]}{A_w}\right)\right]$$

$$[94.16245546, 89.28778118, 83.83711704] \quad \textbf{(1.1.4.6)}$$

Export data

$$R := Transpose\left(Array\left(\left[[M_{rm}[1], M_{rm}[2], M_{rm}[3]], [\varepsilon_{st}[1], \varepsilon_{st}[2], \varepsilon_{st}[3]], [V_{Rd}[1], V_{Rd}[2], V_{Rd}[3]], [s_{r,max}[1], s_{r,max}[2], s_{r,max}[3]]\right]\right)\right)$$

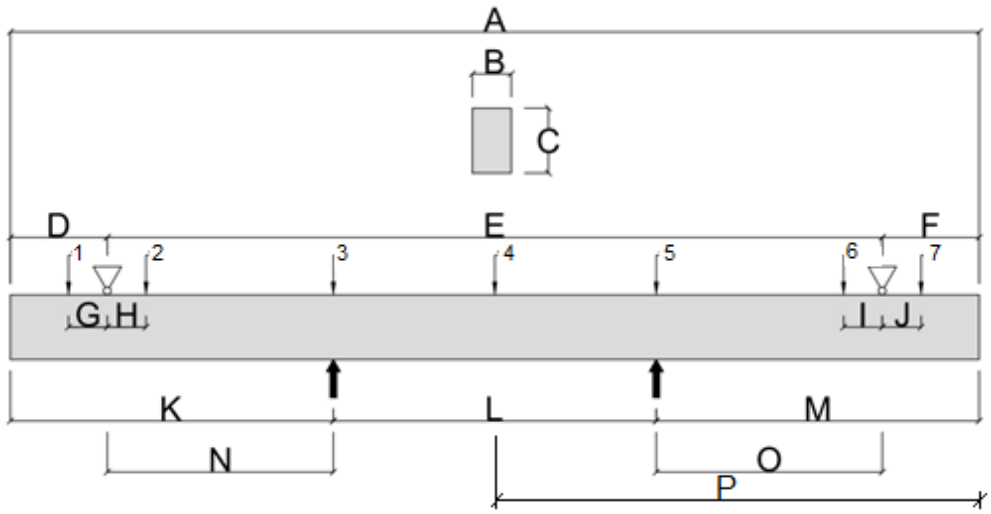
$$\begin{bmatrix} 2.005918517\ 10^{7} & 0.02054717222 & 148.3175133 & 94.16245546 \\ 2.072379624\ 10^{7} & 0.02500168104 & 150.3131254 & 89.28778118 \\ 2.139857763\ 10^{7} & 0.02952002996 & 152.3087376 & 83.83711704 \end{bmatrix} \quad \textbf{(1.1.5.1)}$$

```
fc - D33
εcu3 - L33
fy - T33
Es - AA33
d - AJ33
ALL - AR33

Export(R,"Sensivity.xlsx","Sheet2","AR5");

>
```

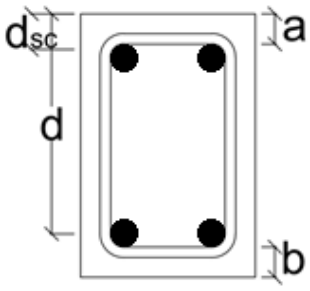
G Beam test results

G.1 B-REF-1

Serie	REF	no.	1		
Test-date	27-4-2015	Test-time	10.30		

Reference	[mm]	Beam dimensions
A	2200	
B	126	
C	251.7	
D	101	
E	1998	
F	101	
G	80	
H	103	
I	80	
J	86	
K	603	
L	996	
M	599	
N	502	
O	498	
P	1100	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	30	30	30	
b	27	32	29.5	
d	-	-	217.2	
d_{sc}	-	-	35	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compresion rebars	10	2	621.98	201.49
Tensile rebars	10	2	621.98	201.49
Stirrups	8	-	546.26	196.71

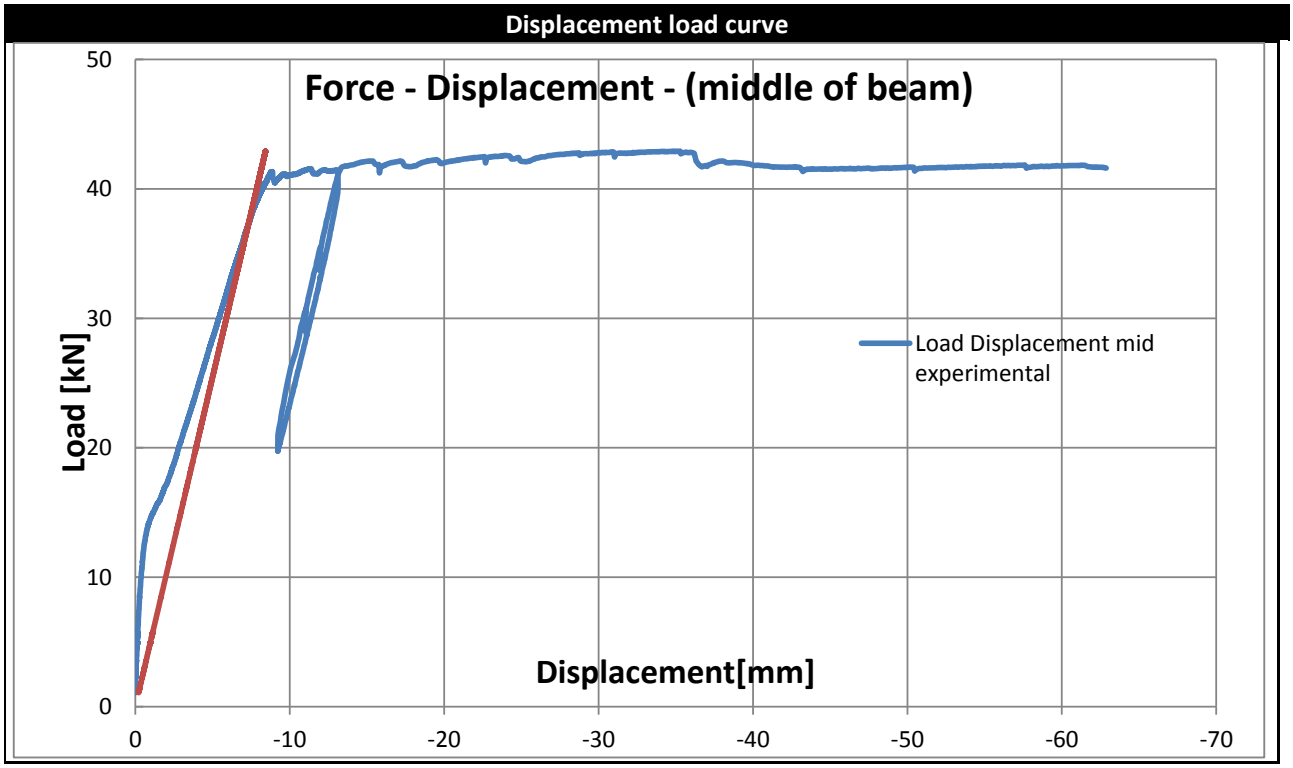
Distance between stirrups is 100 mm, except for the ends of the beam where the distance is 50 mm for the first 300 mm

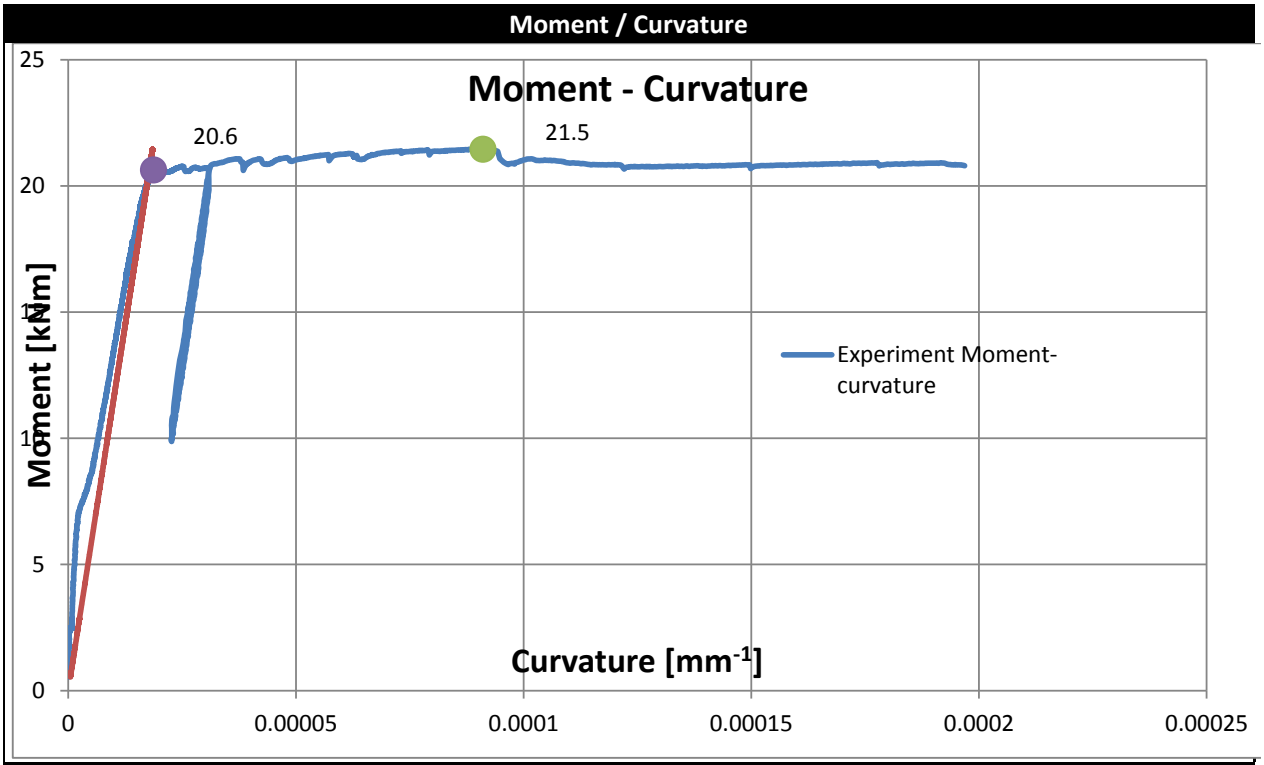
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	43.82	2.45	0

Fracture picture

Displacement load curve





Experiement values	Moment [kNm]	Curvature [mm^{-1}]	Displacement [mm]
M_{u1}	20.6	1.9E-5	-7.2
M_{u2}	21.5	9.1E-5	-35.1
Theoretical values	**Moment capacity [kNm]**	**Shear capacity [kN]**	**Compression zone height (x) [mm]**
M_{Rd}	20.8	149.92	28.2

Mean experimental crack distance [mm]	Experimental Standard deviation [mm]	Characteristic max crack distance (95% percentile) [mm]	Theoretical max crack distance [mm]
101.8	11.2	120.2	191.2

Cracks front										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	130	83	160	100	87	98	115	93	101	105
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]										

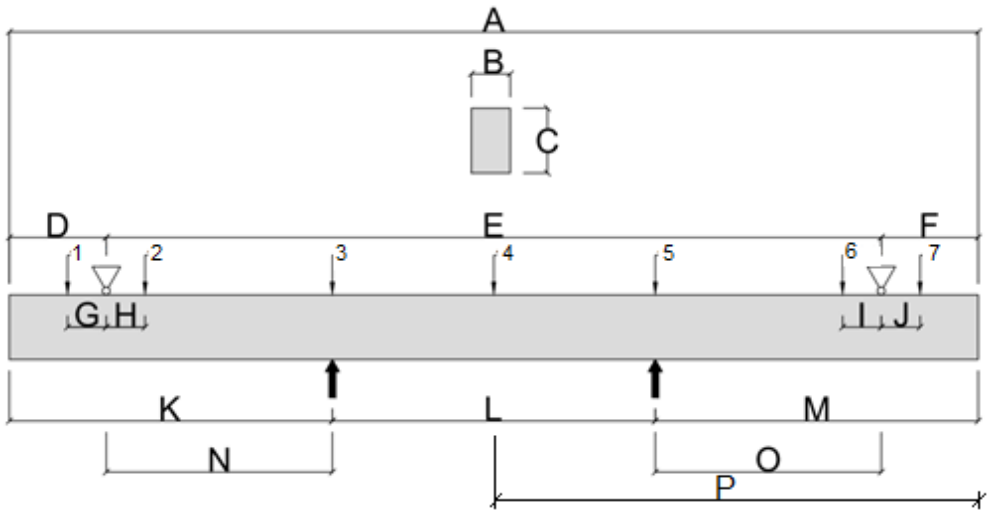
Cracks back										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	90	93	106	102	116	92	117	87	97	110

G.2 B-REF-2

Serie	REF	no.	2
Test-date	27-4-2015	Test-time	14.00

Reference	[mm]
A	2200
B	125.3
C	255
D	104
E	1986.5
F	109.5
G	73
H	89
I	83
J	88
K	599
L	1004
M	598
N	495
O	488.5
P	1100

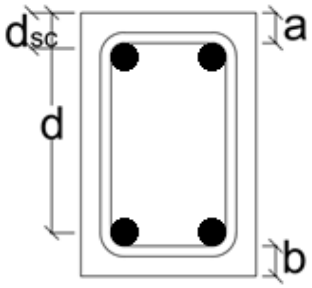
Beam dimensions



B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]
a	24	25	24.5
b	32	32	32
d	-	-	218
d_{sc}	-	-	29.5

Drawing cross section



Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compression rebars	10	2	621.98	201.49
Tensile rebars	10	2	621.98	201.49
Stirrups	8	-	546.26	196.71

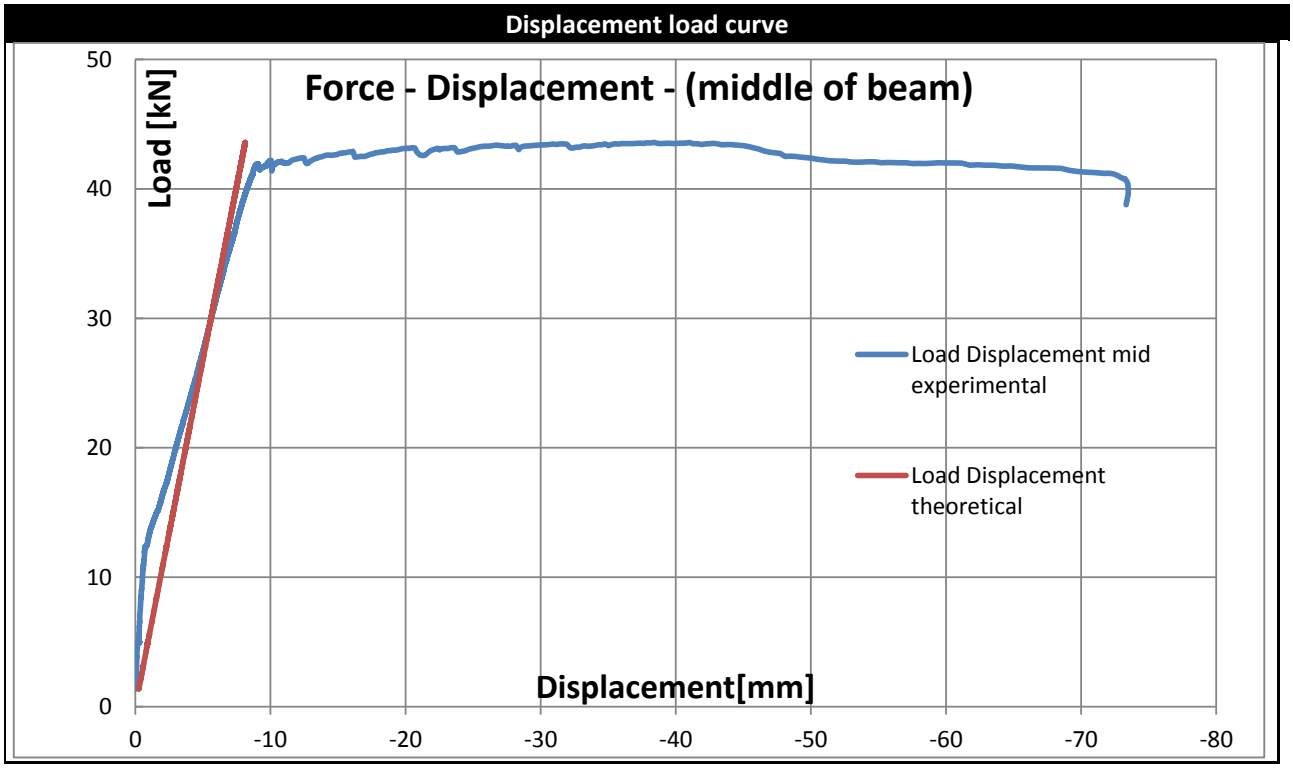
Distance between stirrups is 100 mm, except for the ends of the beam where the distance is 50 mm for the first 300 mm

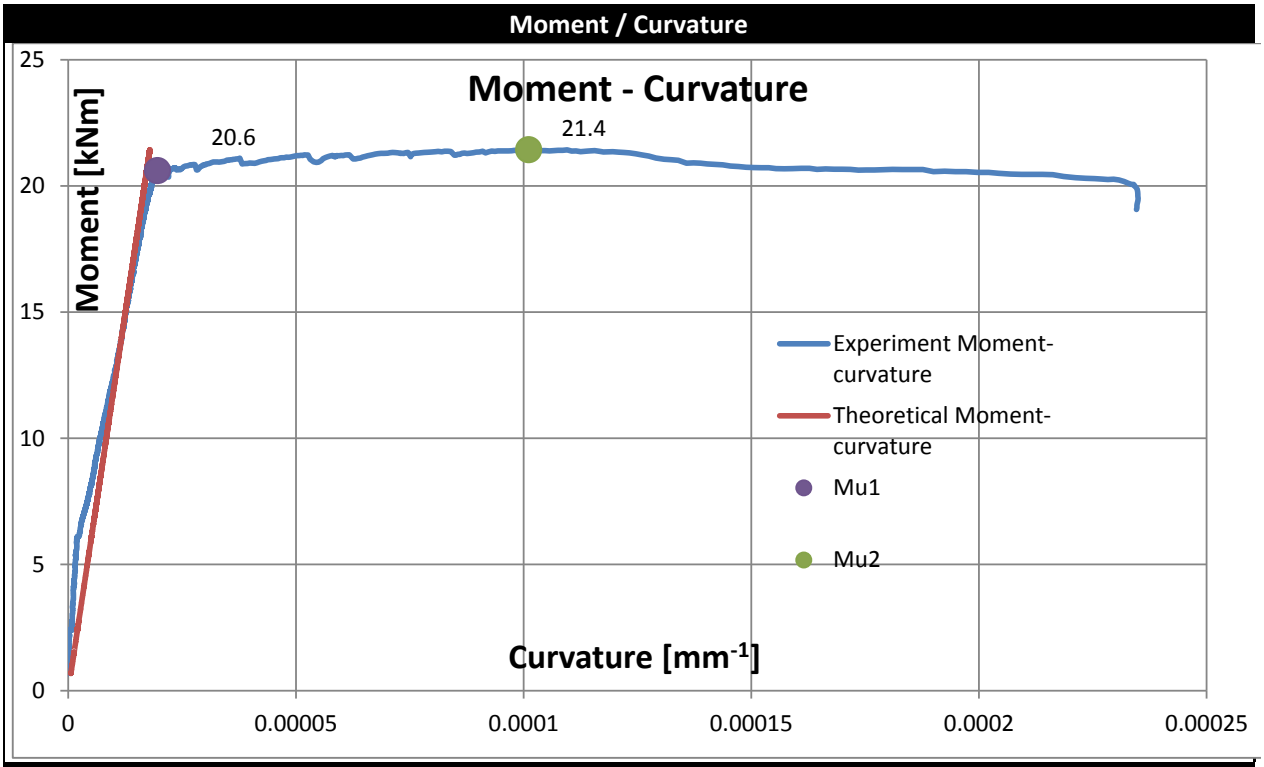
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	43.82	2.45	0

Fracture picture

Displacement load curve





Experiment values	Moment [kNm]	Curvature [mm^{-1}]	Displacement [mm]
M_{u1}	20.6	2.0E-5	-9.0
M_{u2}	21.4	10.1E-5	-38.4
Theoretical values	**Moment capacity [kNm]**	**Shear capacity [kN]**	**Compression zone height (x) [mm]**
M_{Rd}	20.6	150.57	25.82

Mean experimental crack distance [mm]	Experimental Standard deviation [mm]	Characteristic max crack distance (95% percentile) [mm]	Theoretical max crack distance [mm]
103.0	10.8	120.8	195.7

Cracks front										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	90	126	100	98	88	113	103	112	105	100
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]										

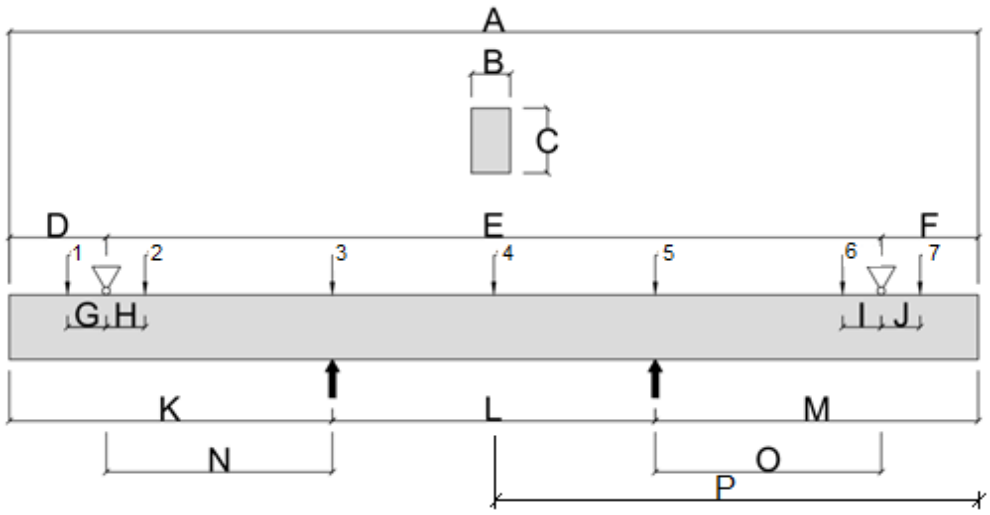
Cracks back										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	95	105	115	89	90	123	100	100	110	98

G.3 B-REF-3

Serie	REF	no.	3
Test-date	28-4-2015	Test-time	9.25

Reference	[mm]
A	2200
B	126
C	254
D	108
E	1984
F	108
G	85
H	83
I	82
J	87
K	597
L	981
M	618
N	489
O	510
P	1100

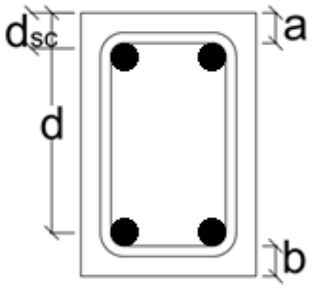
Beam dimensions



B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]
a	28	24	26
b	24	34	29
d	-	-	220
d_{sc}	-	-	31

Drawing cross section



Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compression rebars	10	2	621.98	201.49
Tensile rebars	10	2	621.98	201.49
Stirrups	8	-	546.26	196.71

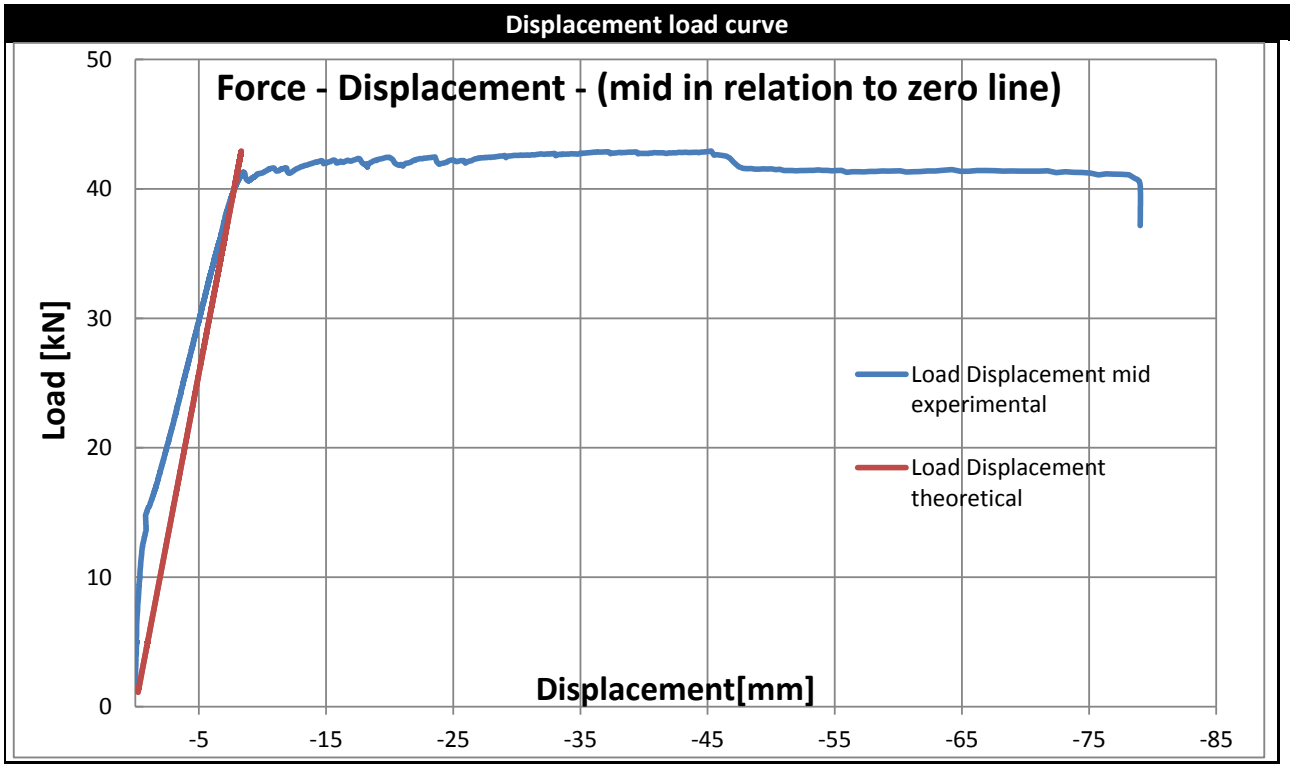
Distance between stirrups is 100 mm, except for the ends of the beam where the distance is 50 mm for the first 300 mm

The cover is measured by manual spalling of the beams

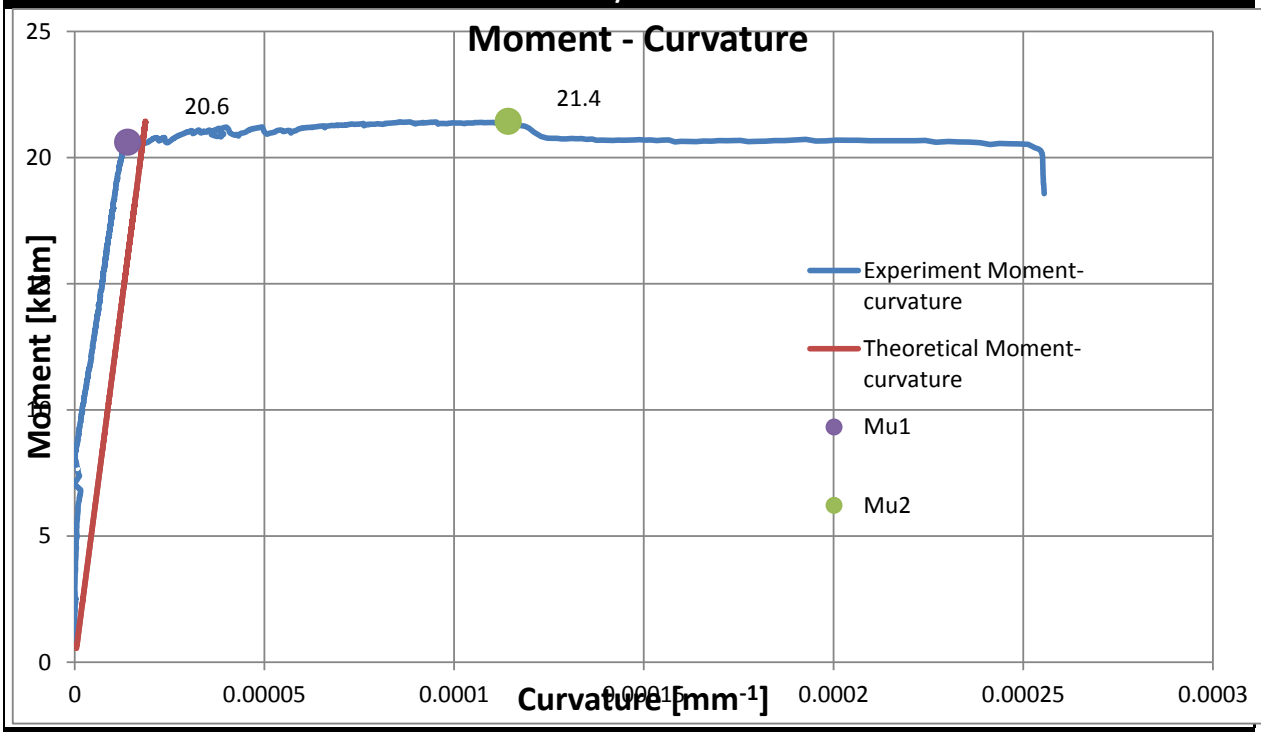
Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	43.82	2.45	0

Fracture picture

Displacement load curve



Moment / Curvature



Experiement values	Moment [kNm]	Curvature [mm^{-1}]	Displacement [mm]
M_{u1}	20.6	1.4E-5	-8.5
M_{u2}	21.4	11.4E-5	-45.3
Theoretical values	**Moment capacity [kNm]**	**Shear capacity [kN]**	**Compression zone height (x) [mm]**
M_{Rd}	40.9	149.59	26.44

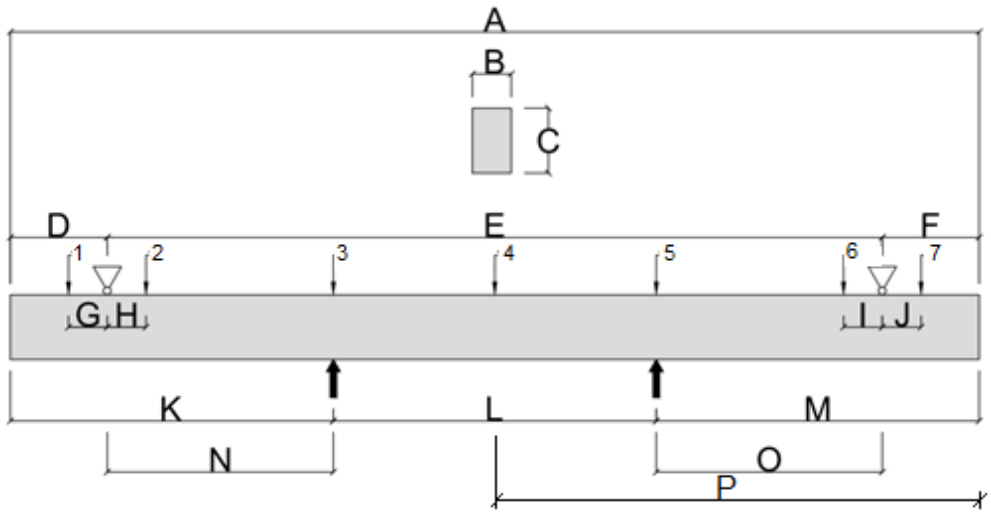
Mean experimental crack distance [mm]	*Experimental Standard deviation [mm]*	*Characteristic max crack distance (95% percentile) [mm]*	*Theoretical max crack distance [mm]*
100.05	12.00	119.8	196.9

Cracks front										
Crack no.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Crack distance [mm]	*90*	*95*	*113*	*113*	*90*	*103*	*102*	*97*	*75*	*110*
Crack no.	*11*	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***
Crack distance [mm]										

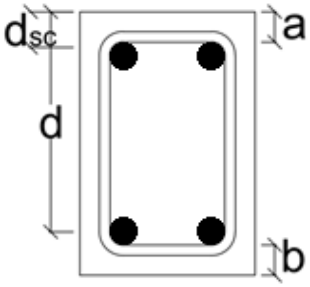
Cracks back										
Crack no.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Crack distance [mm]	*113*	*88*	*114*	*93*	*113*	*90*	*107*	*103*	*80*	*112*
Crack no.	*11*	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***

G.4 B-25-1

Serie	25%	no.	1
Test-date	27-4-2015	Test-time	11.45

Reference	[mm]	Beam dimensions
A	2200	
B	125.3	
C	252.3	
D	105.5	
E	1993.5	
F	101	
G	84.5	
H	85.5	
I	90	
J	80	
K	603	
L	1006	
M	591	
N	497.5	
O	500	
P	1100	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	26	25	25.5	
b	28	28	28	
d	-	-	219.3	
d_{sc}	-	-	30.5	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compresion rebars	10	2	621.98	201.49
Tensile rebars	10	2	621.98	201.49
Stirrups	8	-	546.26	196.71

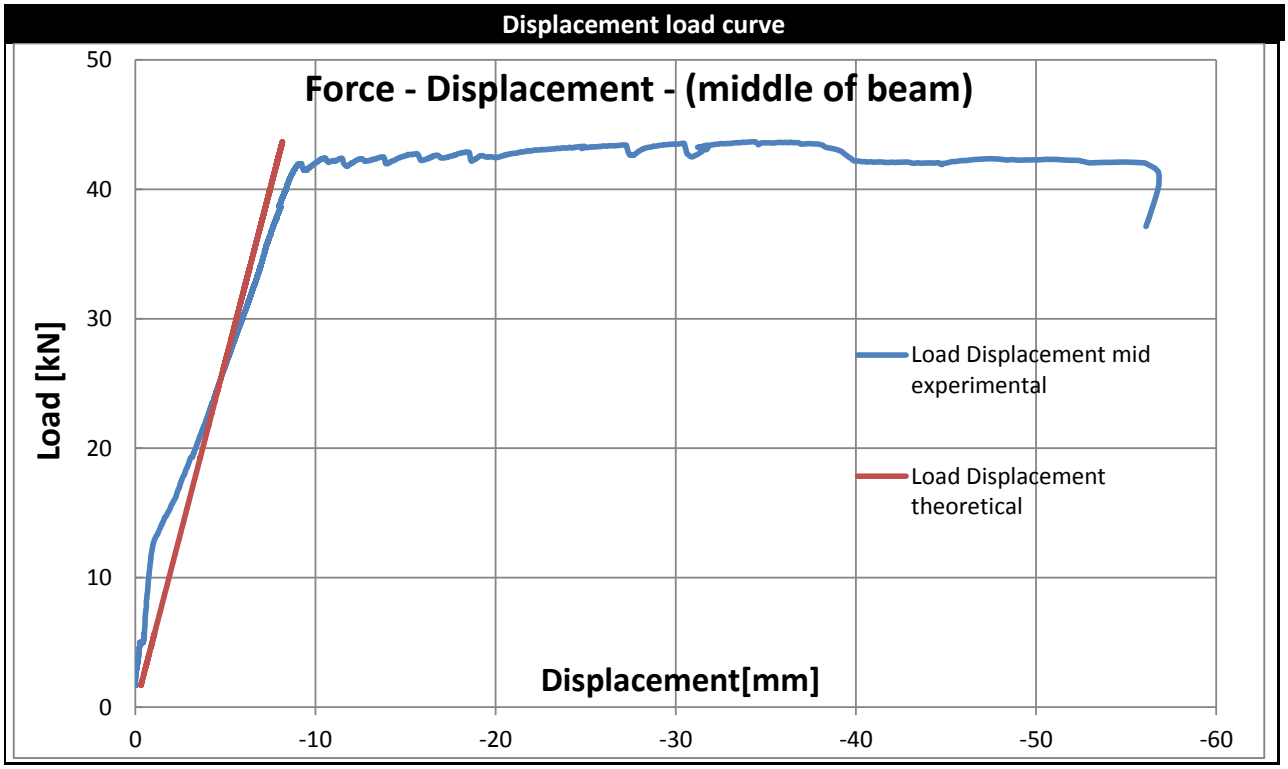
Distance between stirrups is 100 mm, except for the ends of the beam where the distance is 50 mm for the first 300 mm

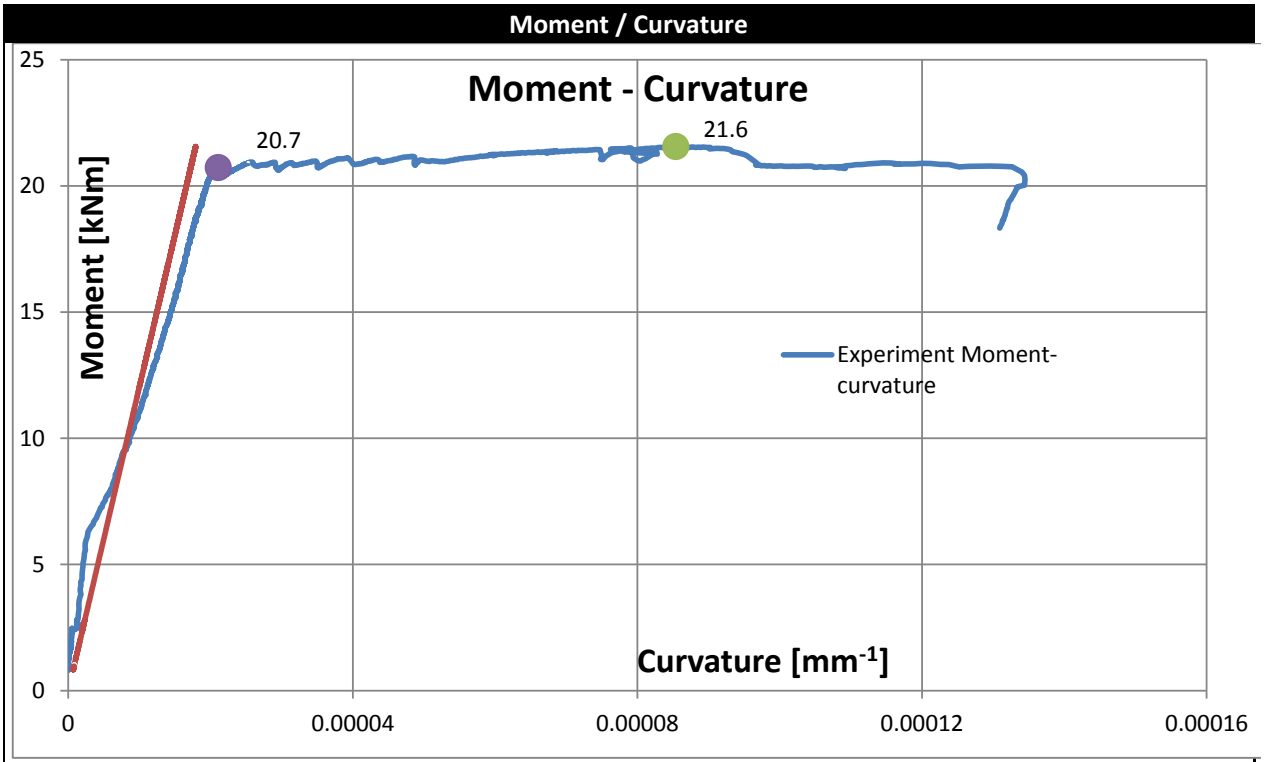
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	43.34	2.45	25

Fracture picture

Displacement load curve





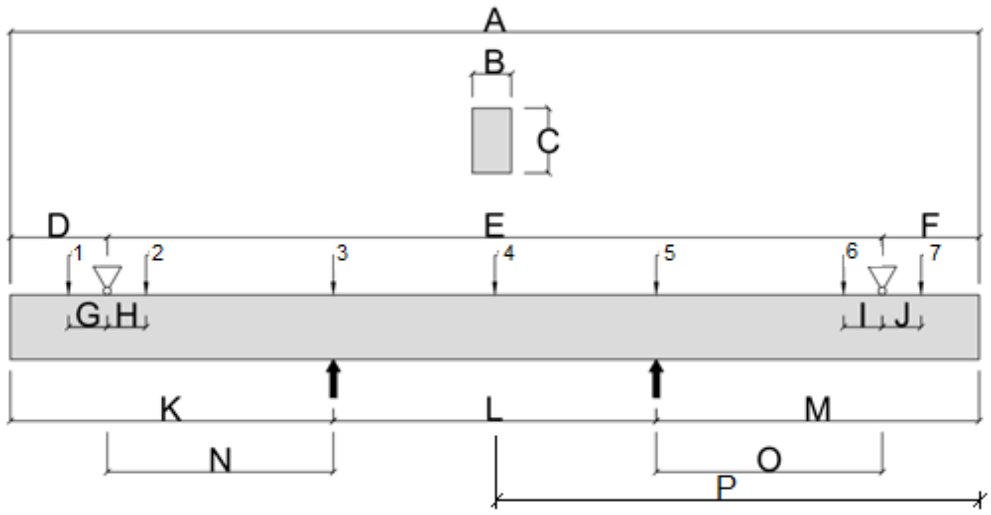
Experiement values	Moment [kNm]	Curvature [mm^{-1}]	Displacement [mm]
M_{u1}	20.7	2.1E-5	-6.6
M_{u2}	21.6	8.5E-5	-34.3
Theoretical values	**Moment capacity [kNm]**	**Shear capacity [kN]**	**Compression zone height (x) [mm]**
M_{Rd}	20.7	149.9	28.2

Mean experimental crack distance [mm]	Experimental Standard deviation [mm]	Characteristic max crack distance (95% percentile) [mm]	Theoretical max crack distance [mm]
99.9	27.7	145.5	190.2

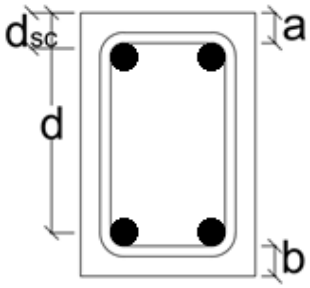
Cracks front										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	130	83	160	100	87	98	115	93	101	105
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]										
Cracks back										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	90	93	106	102	116	92	117	87	97	110

G.5 B-25-2

Serie	25%	no.	2	
Test-date	27-4-2015	Test-time	14.50	

Reference	[mm]	Beam dimensions
A	2200	
B	126	
C	256	
D	102	
E	1989	
F	109	
G	83	
H	90	
I	86	
J	88	
K	592	
L	1004	
M	605	
N	490	
O	496	
P	1100	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	24	26	25	
b	32	29	30.5	
d	-	-	220.5	
d_{sc}	-	-	30	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compression rebars	10	2	621.98	201.49
Tensile rebars	10	2	621.98	201.49
Stirrups	8	-	546.26	196.71

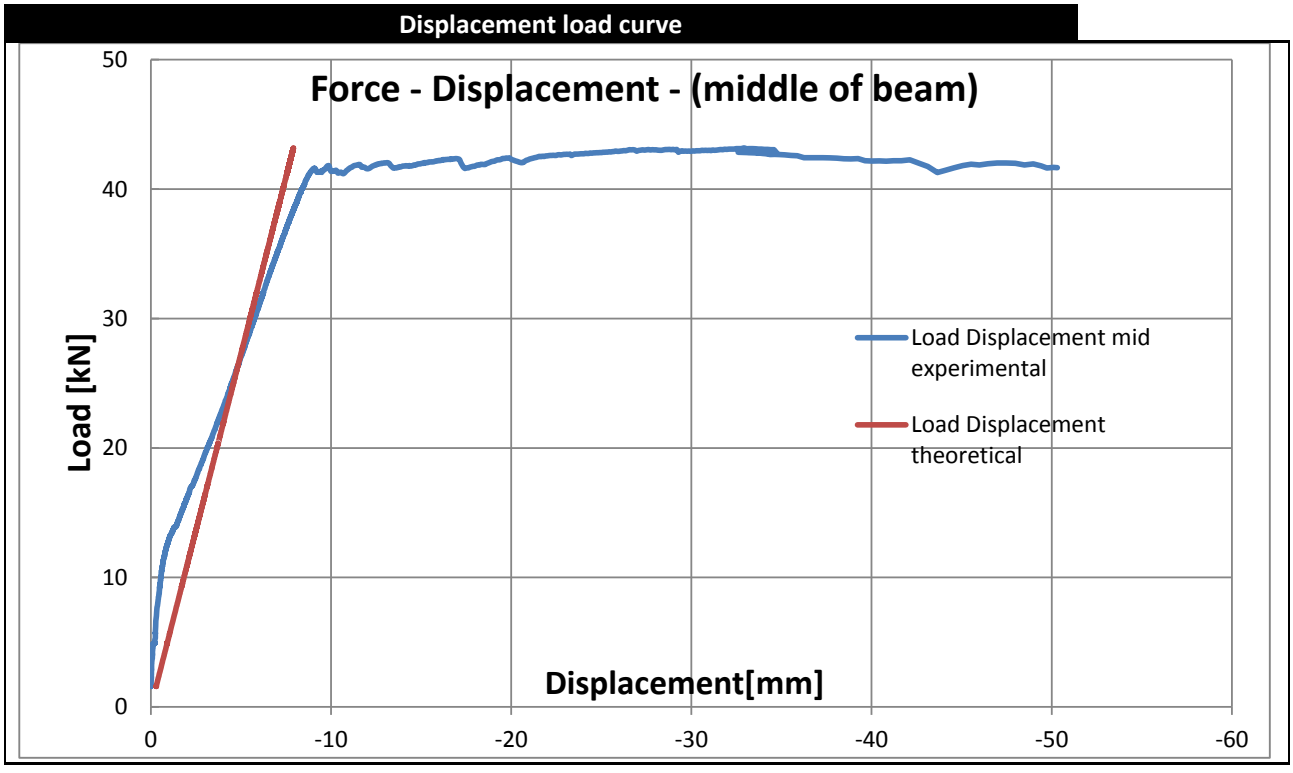
Distance between stirrups is 100 mm, except for the ends of the beam where the distance is 50 mm for the first 300 mm

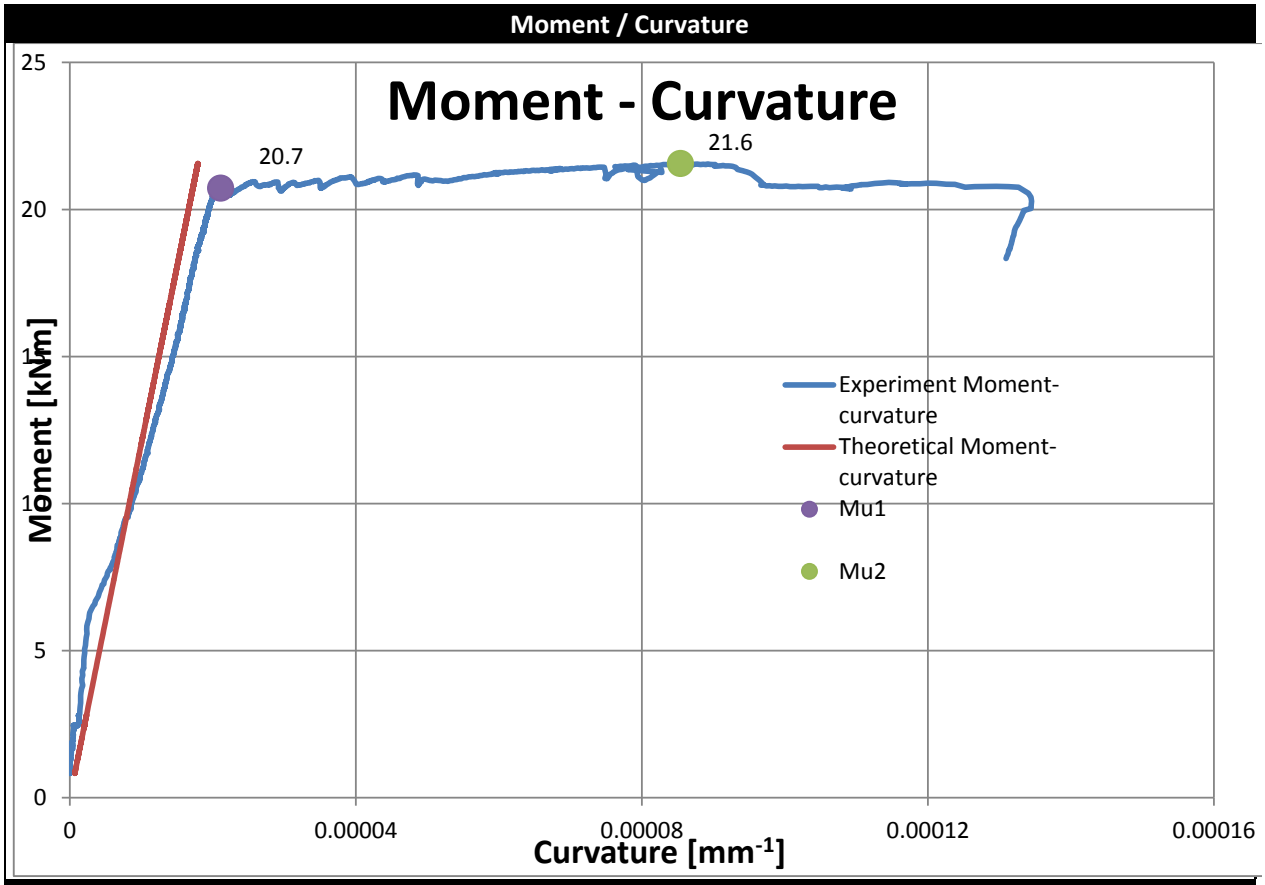
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	43.34	2.45	25

Fracture picture

Displacement load curve



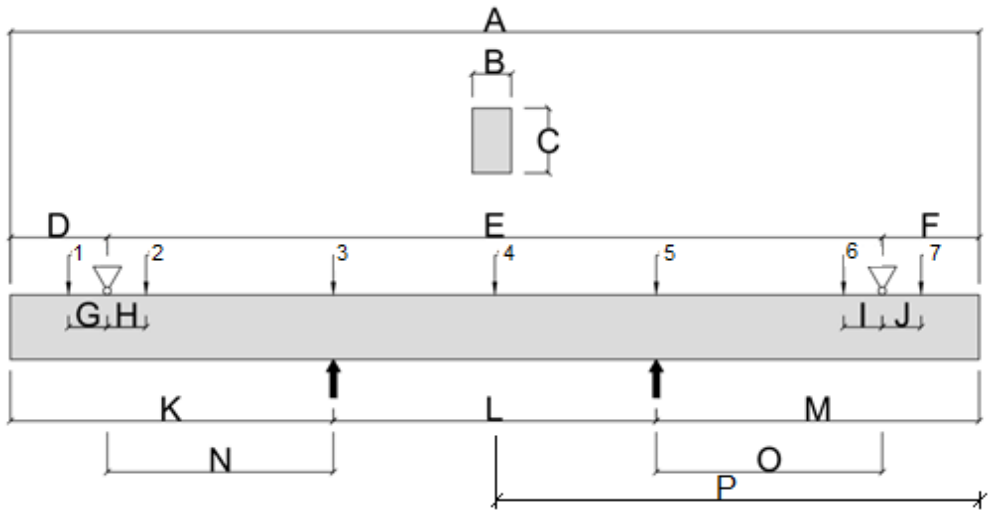


Experimental values	Moment [kNm]	Curvature [mm^{-1}]	Displacement [mm]
M_{u1}	20.6	2.1E-5	-6.4
M_{u2}	21.3	8.4E-5	-32.9
Theoretical values	**Moment capacity [kNm]**	**Shear capacity [kN]**	**Compression zone height (x) [mm]**
M_{Rd}	20.8	152.0	26.2

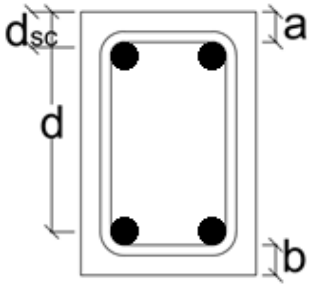
Mean experimental crack distance [mm]	Experimental Standard deviation [mm]			Characteristic max crack distance (95% percentile) [mm]			Theoretical max crack distance [mm]		
101.5	19.6			133.7			195.1		
Cracks front									
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	103	103	98	85	110	106	116	78	58	121
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]										
Cracks back									
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	141	98	108	81	95	100	118	85	85	120
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]										

G.6 B-25-3

Serie	25%	no.	3	
Test-date	28-4-2015	Test-time	10.25	

Reference	[mm]	Beam dimensions
A	2200	
B	126	
C	253.3	
D	99	
E	1993	
F	108	
G	80	
H	89	
I	82	
J	88	
K	600	
L	999	
M	599	
N	501	
O	491	
P	1100	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	26	24	25	
b	31	31	31	
d	-	-	217.3	
d_{sc}	-	-	30	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compression rebars	10	2	621.98	201.49
Tensile rebars	10	2	621.98	201.49
Stirrups	8	-	546.26	196.71

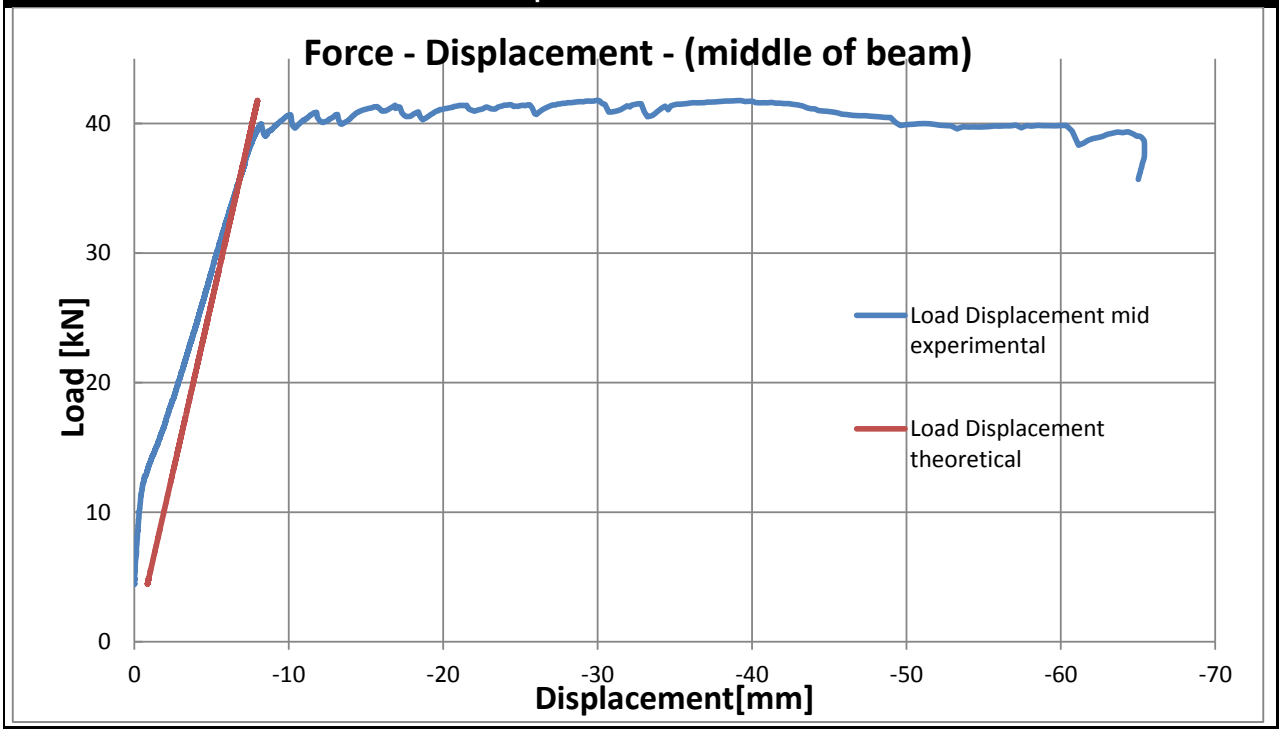
Distance between stirrups is 100 mm, except for the ends of the beam where the distance is 50 mm for the first 300 mm

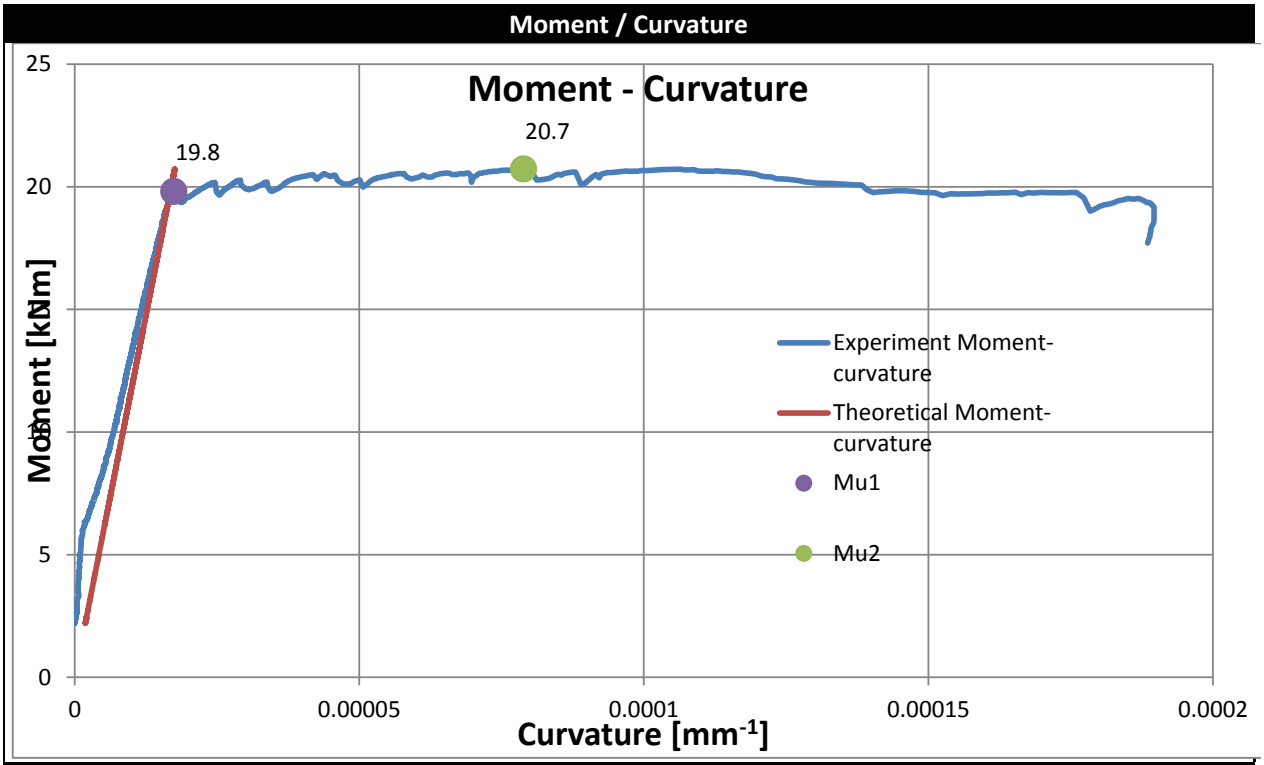
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	43.34	2.45	25

Fracture picture

Displacement load curve



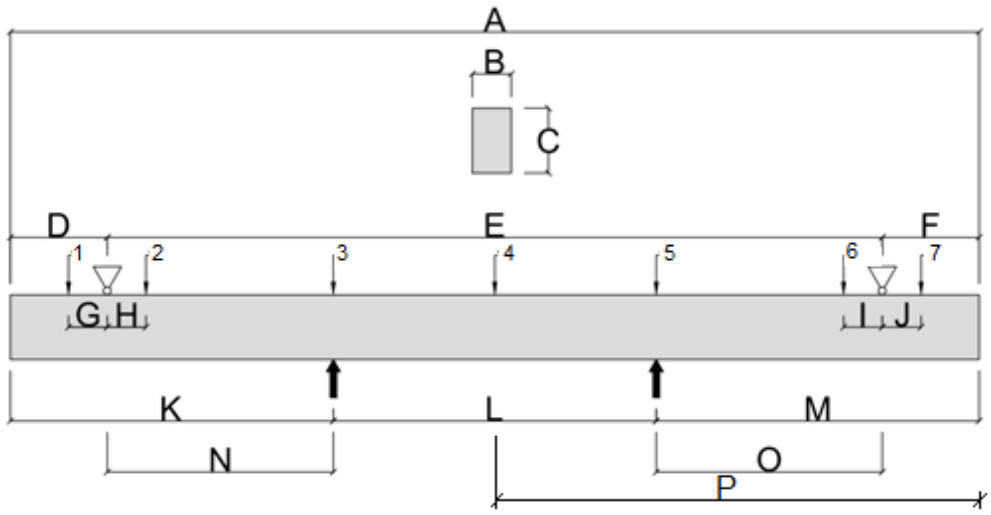


Experimental values	Moment [kNm]	Curvature [mm^{-1}]	Displacement [mm]
M_{u1}	19.8	1.7E-5	-7.5
M_{u2}	20.7	7.9E-5	-29.9
Theoretical values	**Moment capacity [kNm]**	**Shear capacity [kN]**	**Compression zone height (x) [mm]**
M_{Rd}	20.5	150.83	26.12

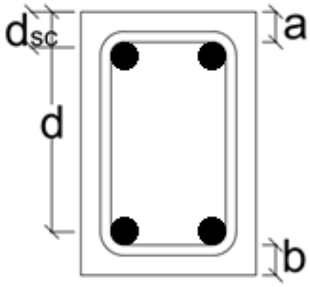
Mean experimental crack distance [mm]	**Experimental Standard deviation [mm]**		**Characteristic max crack distance (95% percentile) [mm]**				**Theoretical max crack distance [mm]**			
99.4	12.6				120.1				194.38	
Cracks front										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	105	87	122	82	110	88	109	80	80	120
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]										
Cracks back										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	108	95	97	105	100	108	93	87	103	108
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]										

G.7 B-50-1

Serie	50%	no.	1	
Test-date	27-4-2015	Test-time	12.50	

Reference	[mm]	Beam dimensions
A	2200	
B	126.7	
C	254	
D	98	
E	2002	
F	100	
G	78	
H	90	
I	90	
J	86	
K	602	
L	999	
M	599	
N	504	
O	499	
P	1100	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	23	24	23.5	
b	28	28	28	
d	-	-	221	
d_{sc}	-	-	28.5	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compression rebars	10	2	621.98	201.49
Tensile rebars	10	2	621.98	201.49
Stirrups	8	-	546.26	196.71

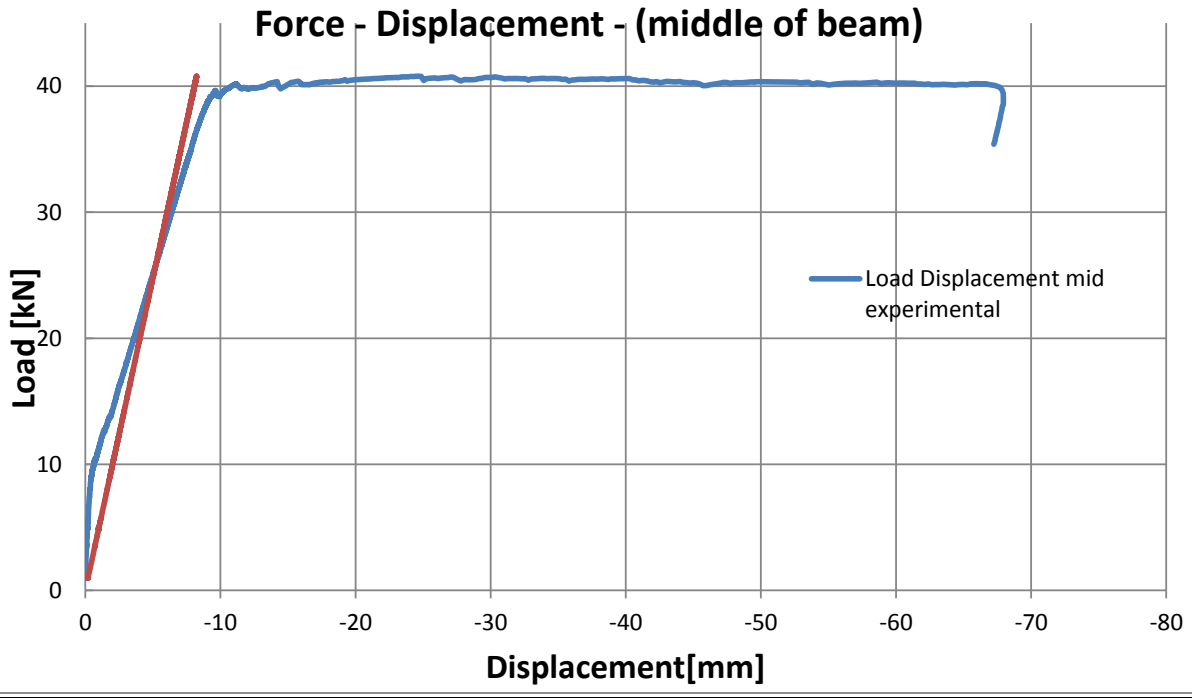
Distance between stirrups is 100 mm, except for the ends of the beam where the distance is 50 mm for the first 300 mm

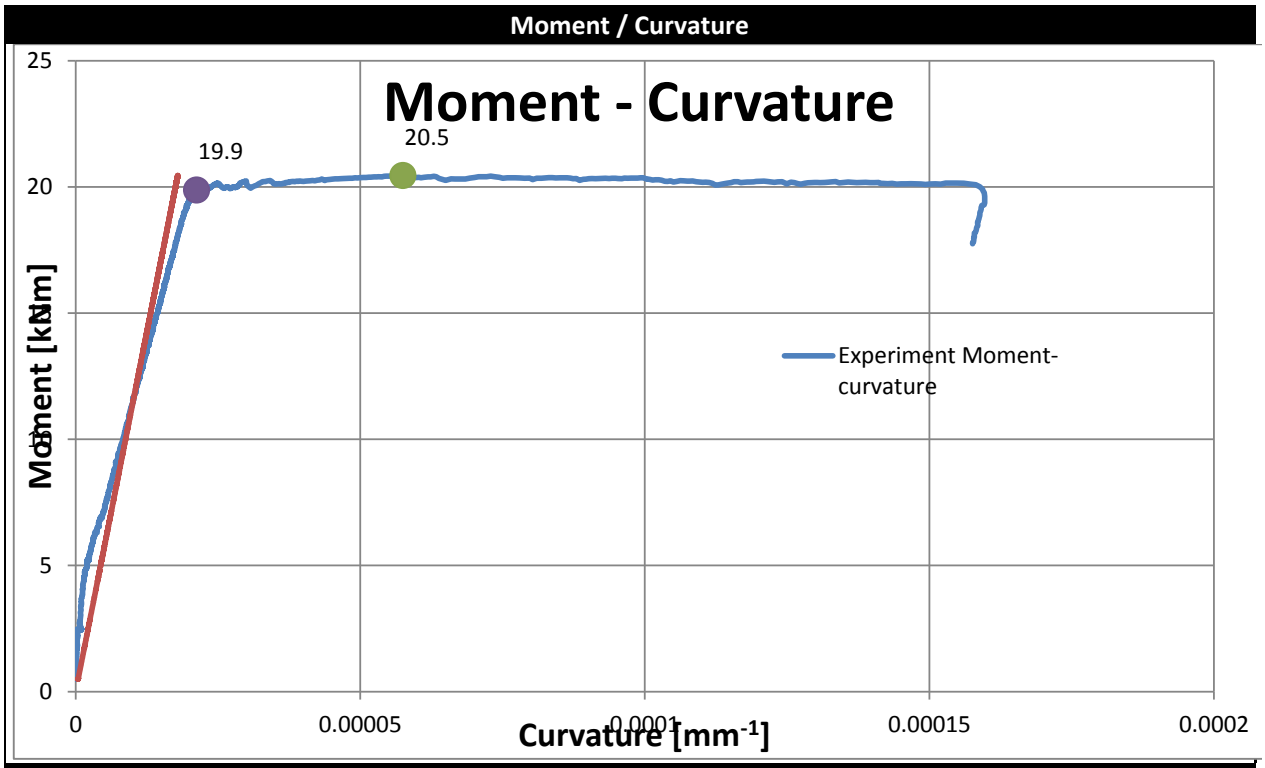
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	20.75	3.03	50

Fracture picture

Displacement load curve



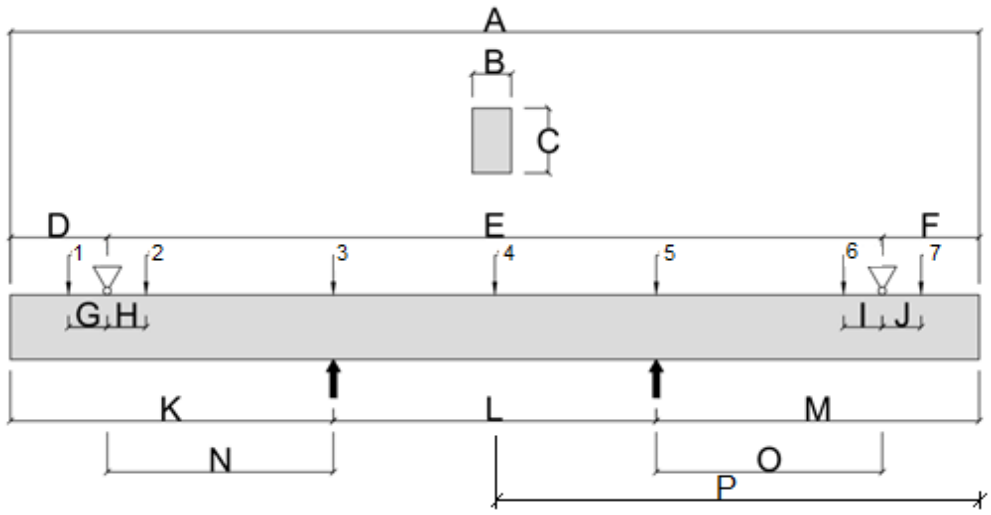


Experimental values	Moment [kNm]	Curvature [mm^{-1}]	Displacement [mm]
M_{u1}	19.9	2.1E-5	-7.2
M_{u2}	20.5	5.7E-5	-24.7
Theoretical values	**Moment capacity [kNm]**	**Shear capacity [kN]**	**Compression zone height (x) [mm]**
M_{Rd}	19.9	157.8	35.76

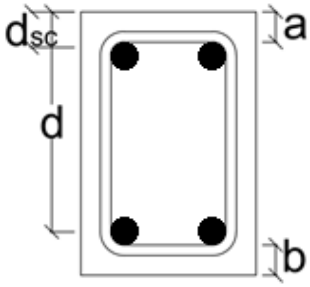
Mean experimental crack distance [mm]	Experimental Standard deviation [mm]			Characteristic max crack distance (95% percentile) [mm]			Theoretical max crack distance [mm]		
99.4	29.2			147.4			187.8		
Cracks front									
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	95	130	93	145	62	87	88	120	100	46
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]	150									
Cracks back									
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	90	120	90	140	50	120	82	110	110	58
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]	100									

G.8 B-50-2

Serie	50%	no.	2	
Test-date	27-4-2015	Test-time	8.30	

Reference	[mm]	Beam dimensions
A	2200	
B	125.7	
C	255.7	
D	100	
E	1999	
F	101	
G	79	
H	89	
I	90	
J	80	
K	590	
L	1000	
M	607	
N	511	
O	406	
P	1100	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	24	24	24	
b	31	32	31.5	
d	-	-	219.2	
d_{sc}	-	-	29	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compression rebars	10	2	621.98	201.49
Tensile rebars	10	2	621.98	201.49
Stirrups	8	-	546.26	196.71

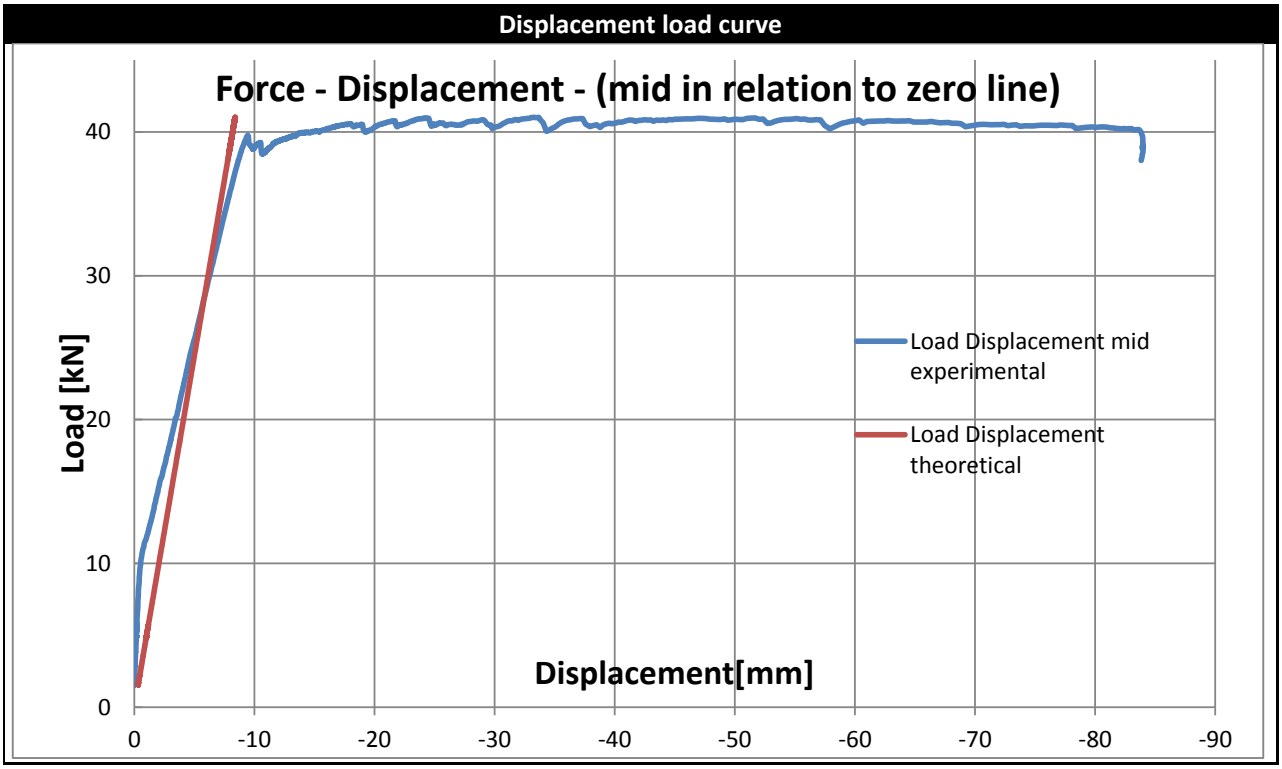
Distance between stirrups is 100 mm, except for the ends of the beam where the distance is 50 mm for the first 300 mm

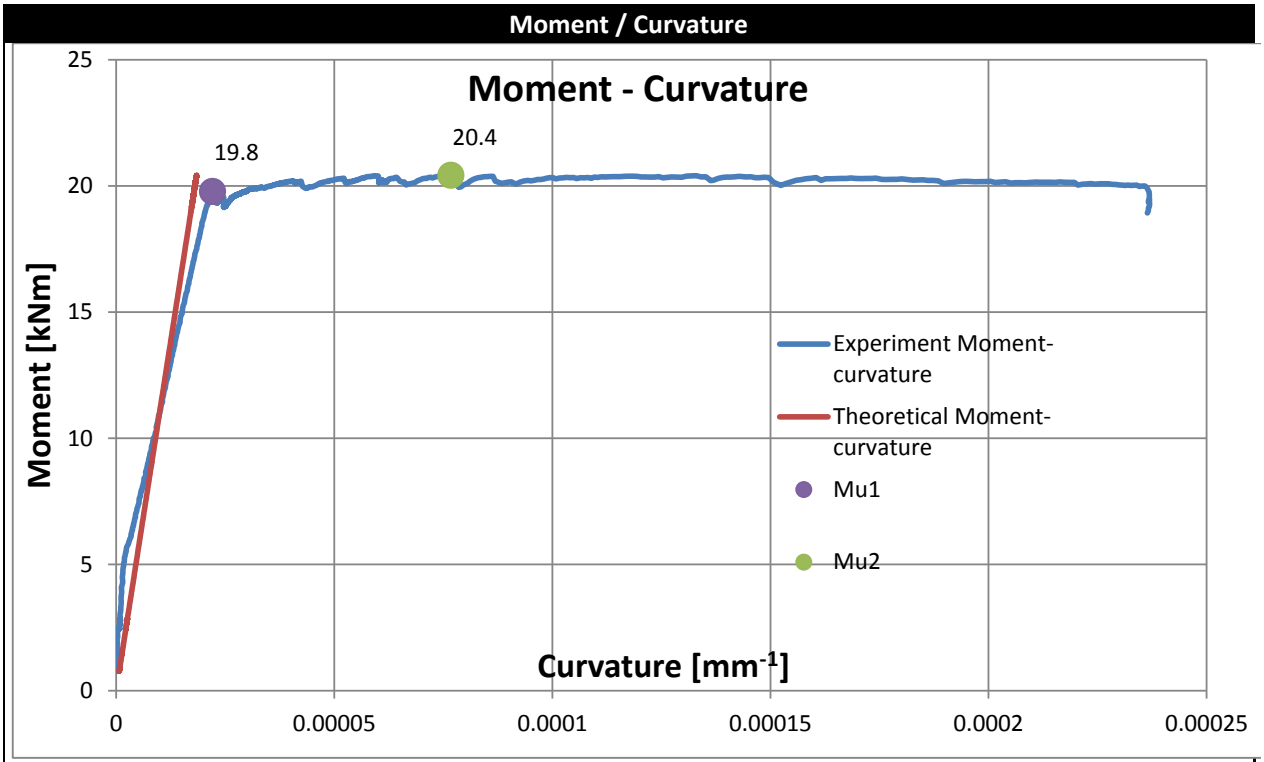
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	20.75	3.03	50

Fracture picture

Displacement load curve



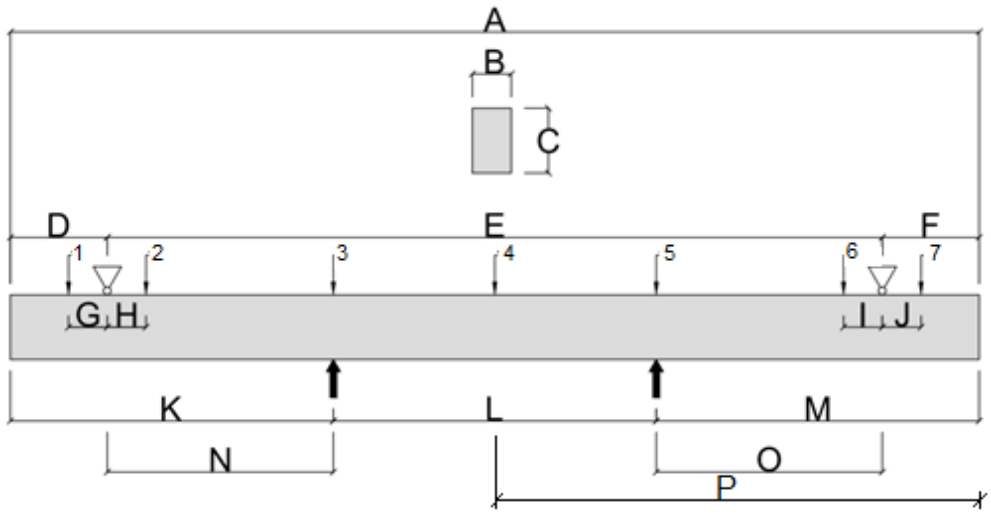


Experimental values	Moment [kNm]	Curvature [mm^{-1}]	Displacement [mm]
M_{u1}	19.8	2.2E-5	-9.4
M_{u2}	20.4	7.6E-5	-33.7
Theoretical values	**Moment capacity [kNm]**	**Shear capacity [kN]**	**Compression zone height (x) [mm]**
M_{Rd}	19.7	142.92	36.23

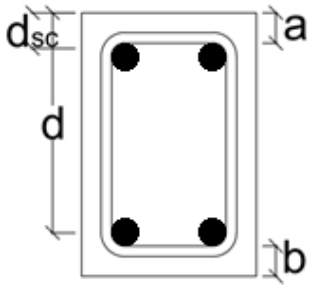
Mean experimental crack distance [mm]	Experimental Standard deviation [mm]			Characteristic max crack distance (95% percentile) [mm]			Theoretical max crack distance [mm]		
93.5	16.6			120.8			191.1		
Cracks front									
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	95	131	73	95	100	88	97	77	75	107
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]	90									
Cracks back									
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	85	125	83	108	93	88	83	75	68	110
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]	110									

G.9 B-50-3

Serie	50%	no.	3	
Test-date	28-4-2015	Test-time	11.20	

Reference	[mm]	Beam dimensions
A	2200	
B	125	
C	251.7	
D	103	
E	1993	
F	104	
G	81	
H	88	
I	87	
J	82	
K	602	
L	1001	
M	595	
N	499	
O	491	
P	1100	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	24	25	24.5	
b	34	40	37	
d	-	-	209.7	
d_{sc}	-	-	29.5	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compression rebars	10	2	538.2	194.5E+3
Tensile rebars	10	2	538.2	194.5E+3
Stirrups	8	-	541.6	200.5E+3

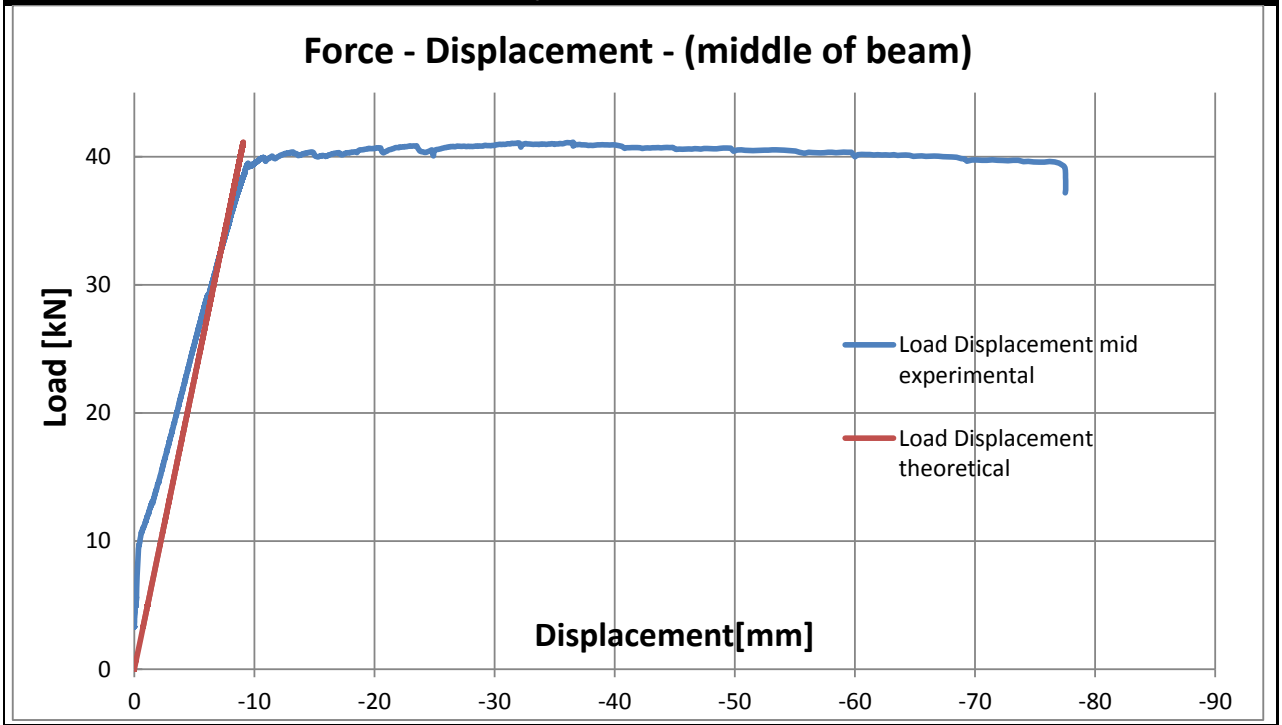
Distance between stirrups is 100 mm, except for the ends of the beam where the distance is 50 mm for the first 300 mm

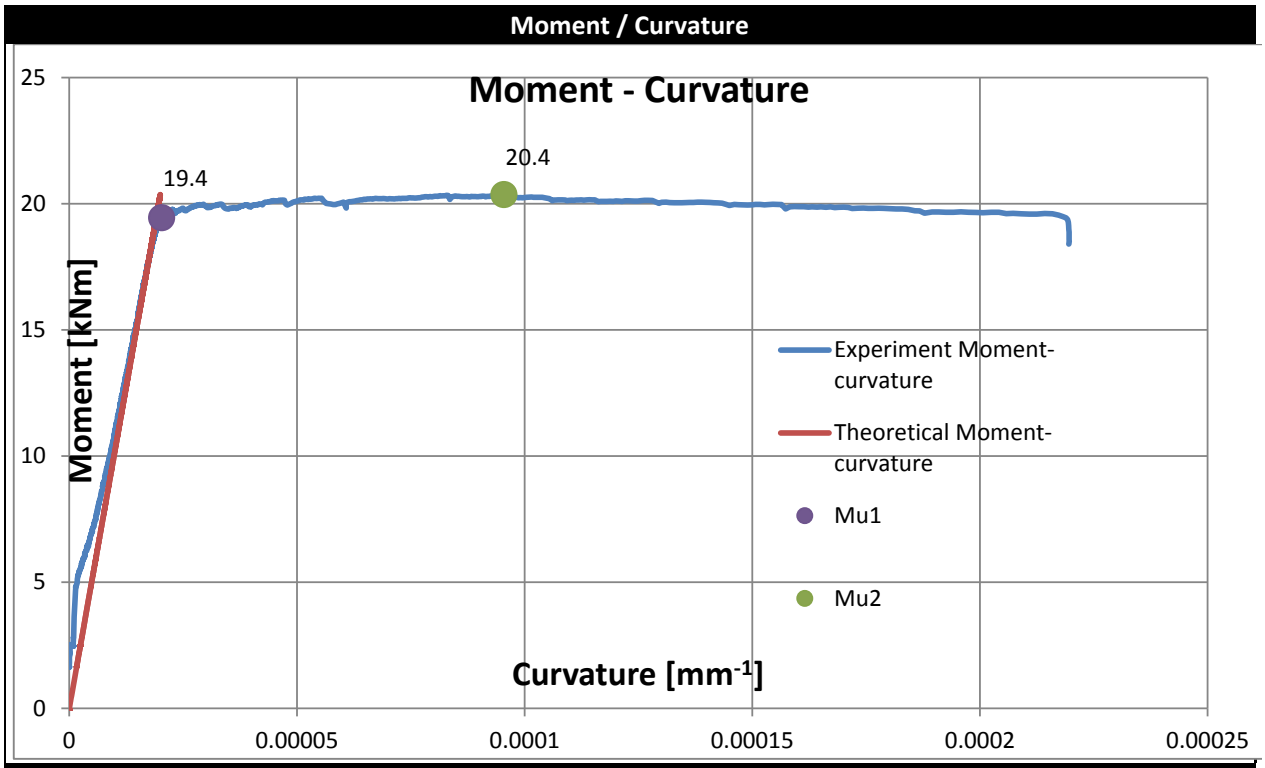
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	20.75	3.03	50

Fracture picture

Displacement load curve





Experimental values	Moment [kNm]	Curvature [mm^{-1}]	Displacement [mm]
M_{u1}	19.4	2.0E-5	-7.0
M_{u2}	20.4.	9.5E-5	-36.5
Theoretical values	**Moment capacity [kNm]**	**Shear capacity [kN]**	**Compression zone height (x) [mm]**
M_{Rd}	16.4	133. 43	33.97

Mean experimental crack distance [mm]	Experimental Standard deviation [mm]	Characteristic max crack distance (95% percentile) [mm]	Theoretical max crack distance [mm]
107.8	22.9	145.5	194.8

Cracks front										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	137	157	90	90	105	97	105	75	98	
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]										

Cracks back										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	139	145	110	97	88	125	98	92	93	
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]										

H Sensitivity analysis column

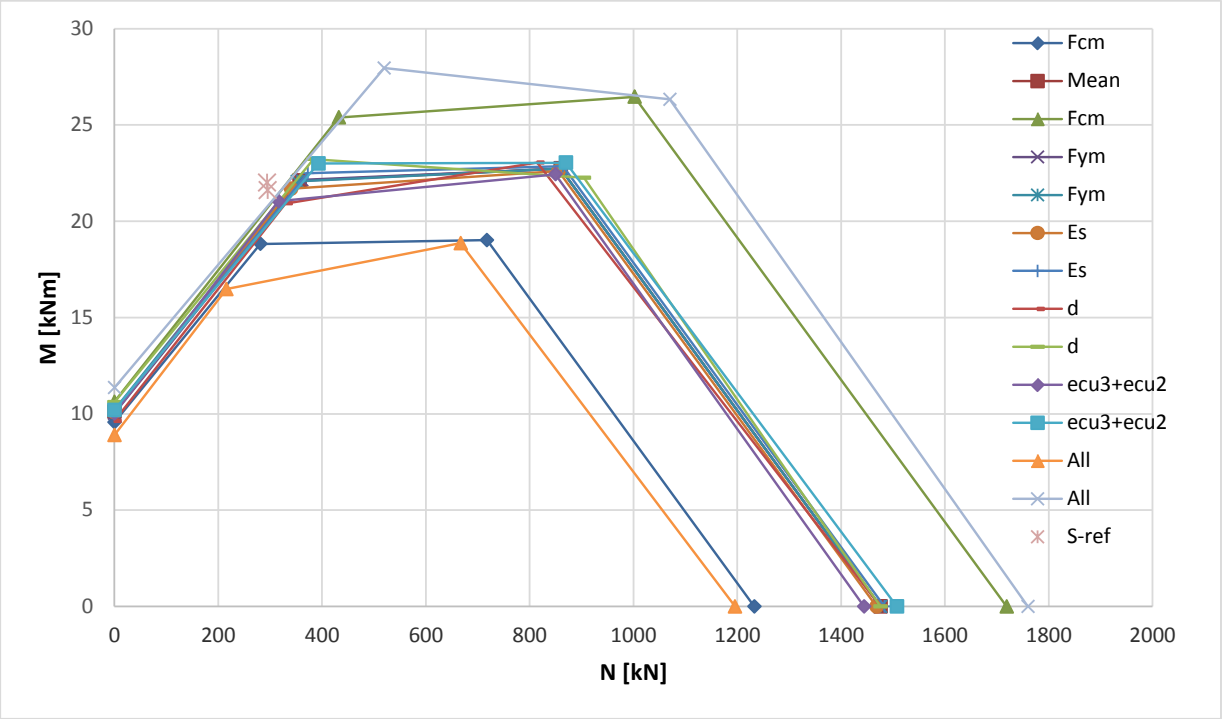


Figure: Sensitiviity analysis for the M-N-diagram for the S-REF-series.

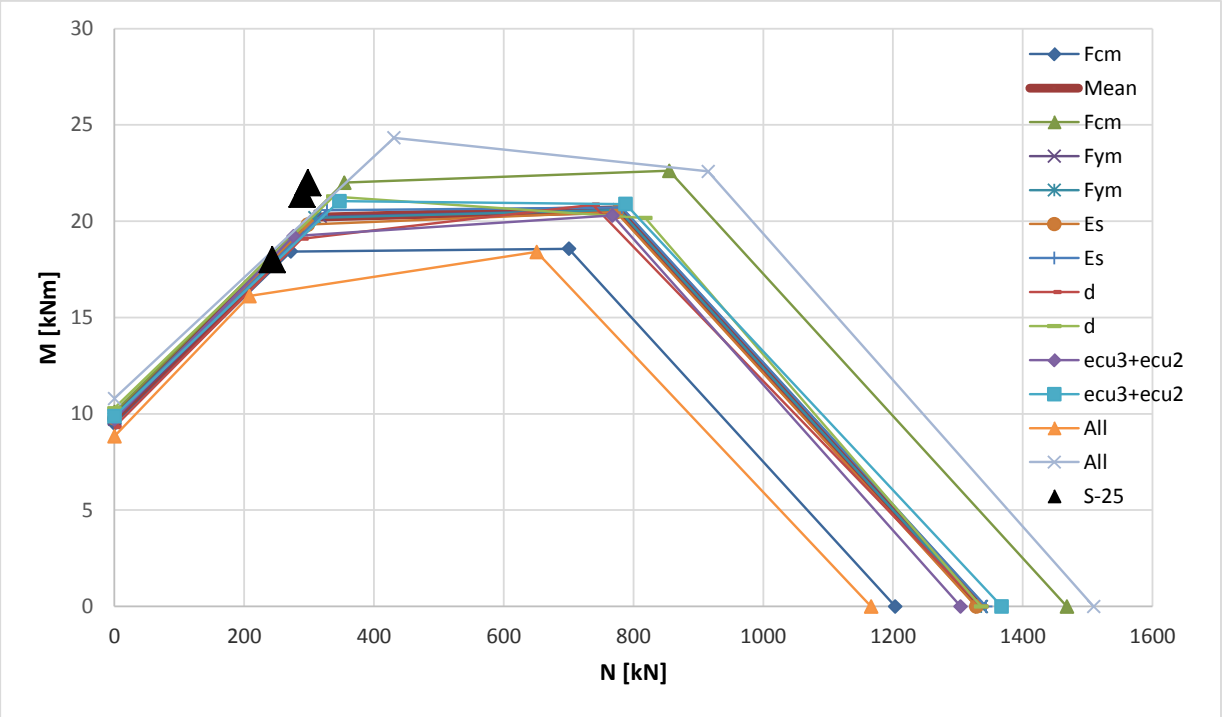


Figure: Sensitiviity analysis for the M-N-diagram for the S-25-series.

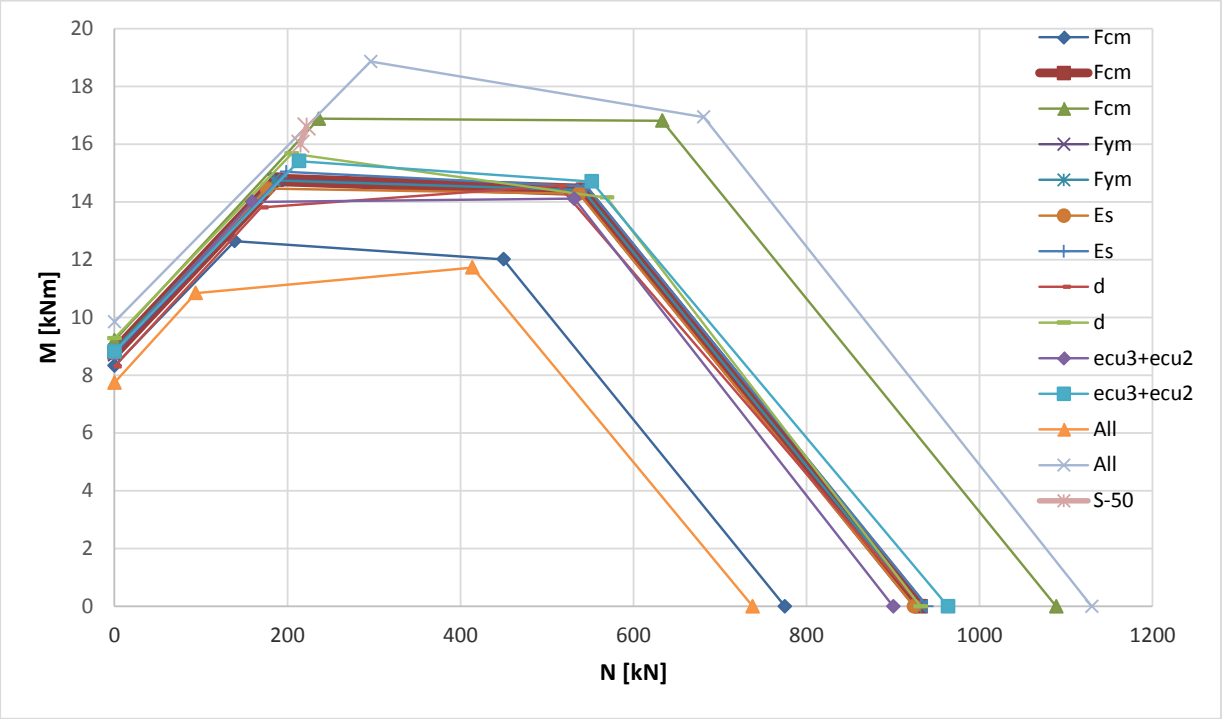
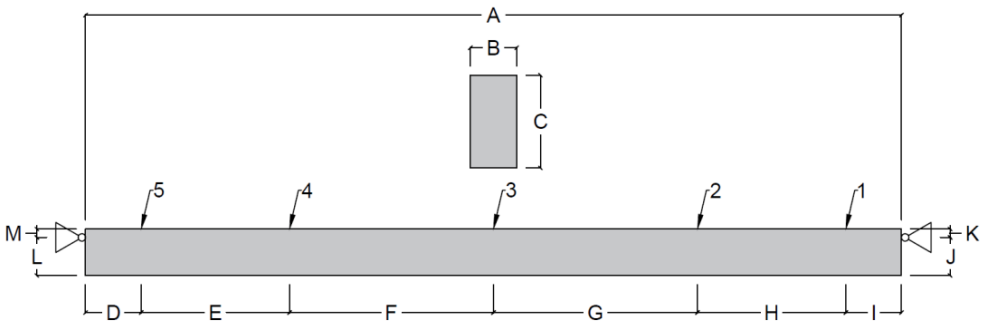


Figure: Sensitiviity analysis for the M-N-diagram for the S-50-series.

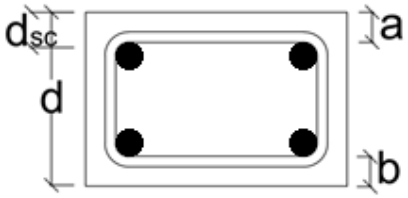
I Column test results

I.1 S-REF-1

Serie	S-REF	no.	1	Eccentricity [mm]
Test-date		20-4-2015		40

Reference	[mm]	Column dimensions
A	2200	
B	125.2	
C	252.0	
D	150	
E	400	
F	550	
G	550	
H	400	
I	150	
J	102,5	
K	22,5	
L	102,5	
M	22,5	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	28.1	27.3	27.7	
b	24.7	29.7	27.2	
d	-	-	92.2	
d_{sc}	-	-	33.5	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compresion rebars	10	2	621,98	201,49
Tensile rebars	10	2	621,98	201,49
Stirrups	8	-	546,26	196,71

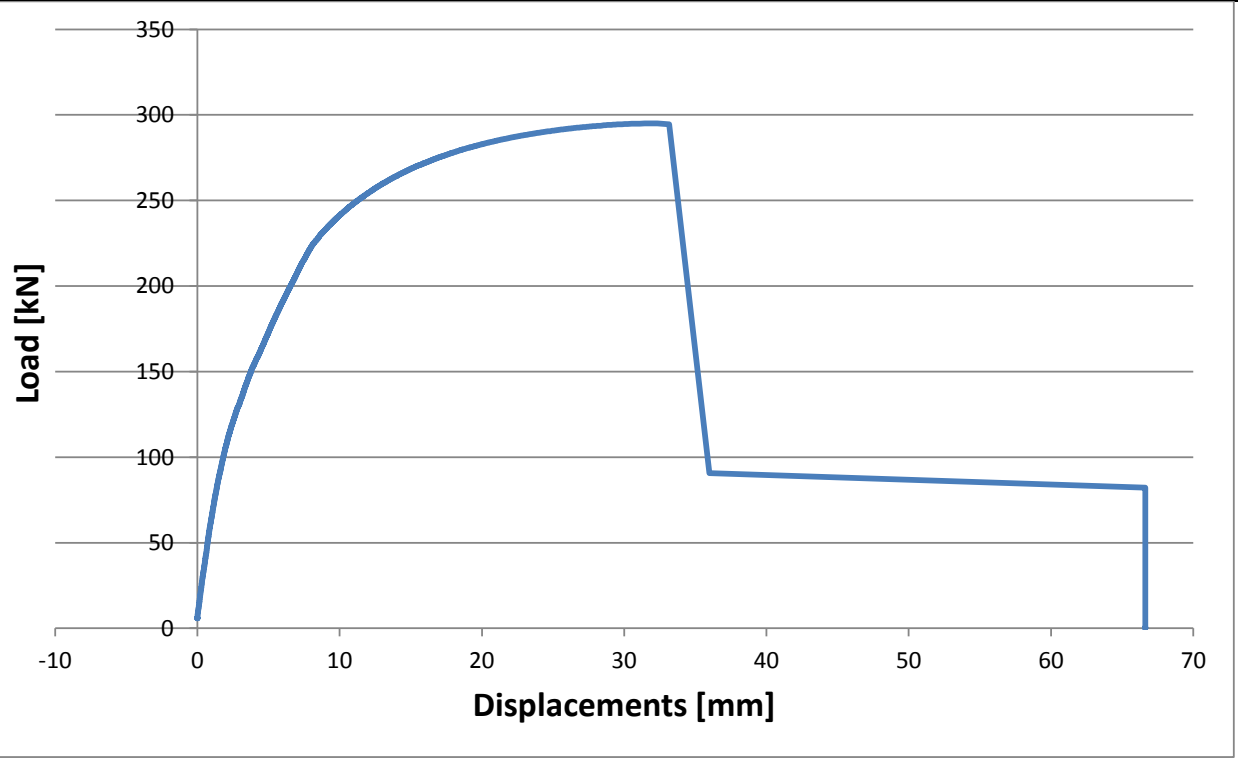
Distance between stirrups is 100 mm, except for the ends of the Column where the distance is 50 mm for the first 300 mm

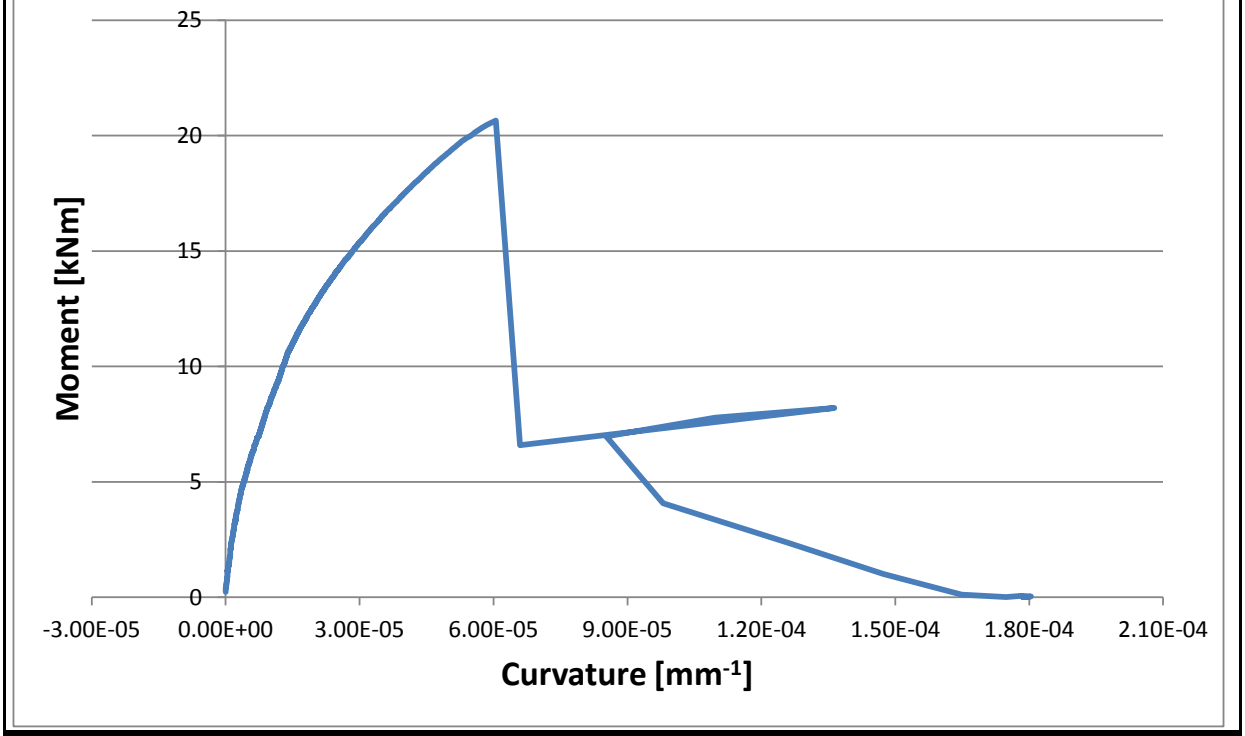
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	42.94	4.65	0

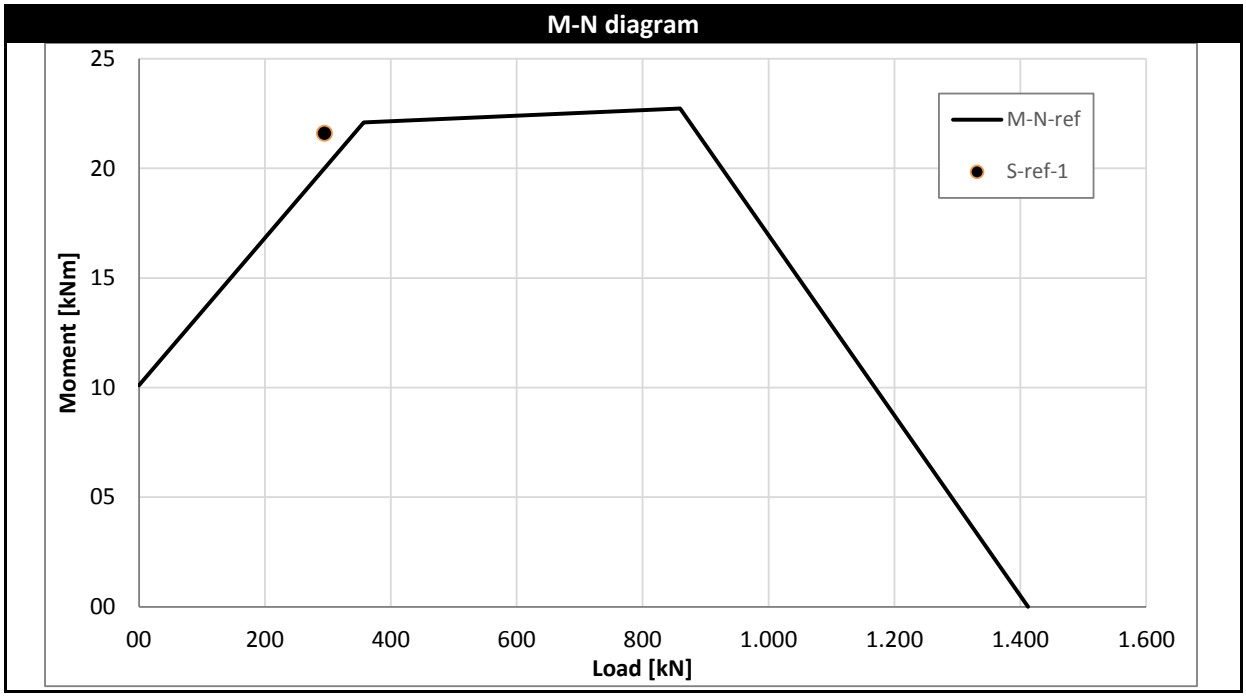
Fracture picture

Displacement load curve





Experimental max values			
Axial Force [kN]	**Moment [kN]**	**Average Curvature [mm^{-1}]**	**Displacement [mm]**
295.0	21.6	6.05E-5	31.8
Theoretical values			
Axial capacity [kN]	Moment capacity [kNm]		**Displacement [mm]**
183	17.3		54.4

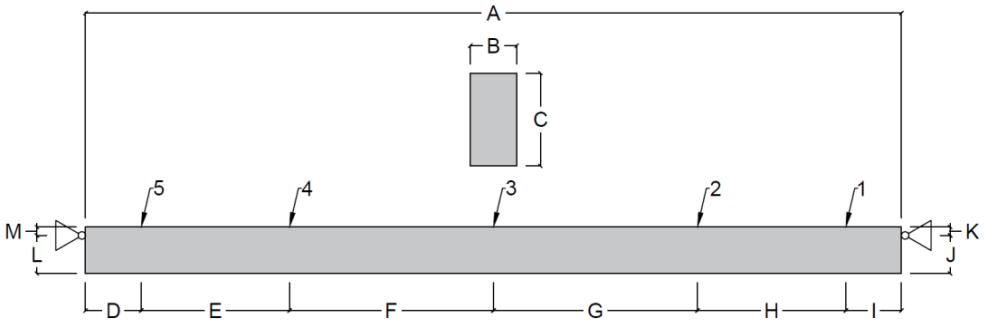


Mean experimental crack distance [mm]	Experimental Standard deviation [mm]	Characteristic max crack distance (95% percentile) [mm]	Theoretical max crack distance [mm]
98.4	19	129.6	185.4

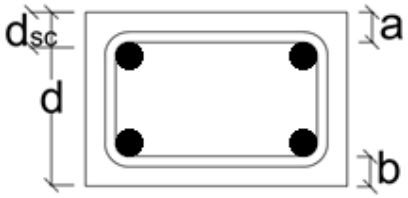
Cracks front										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	107	117	93	73	107	128	112	76	95	100
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]	88	115	60	107	-	-	-	-	-	-

I.2 S-REF-2

Serie S-REF	no. 1	Eccentricity [mm]
Test-date	21-4-2015	40

Reference	[mm]	Column dimensions
A	2201	
B	126.5	
C	250.7	
D	150	
E	400	
F	550	
G	550	
H	400	
I	150	
J	102,5	
K	22,5	
L	102,5	
M	22,5	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	28.2	30.3	29.25	
b	31.5	33.1	32.3	
d	-	-	92.2	
d_{sc}	-	-	33.5	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compresion rebars	10	2	621,98	201,49
Tensile rebars	10	2	621,98	201,49
Stirrups	8	-	546,26	196,71

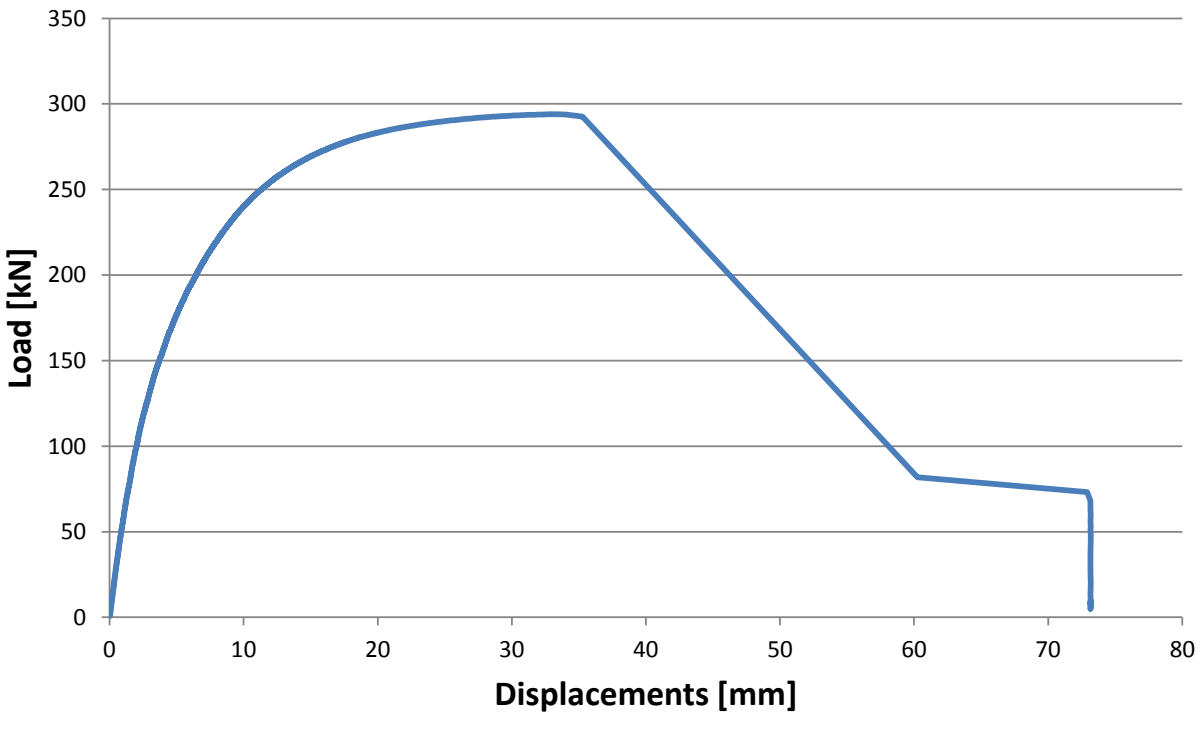
Distance between stirrups is 100 mm, except for the ends of the Column where the distance is 50 mm for the first 300 mm

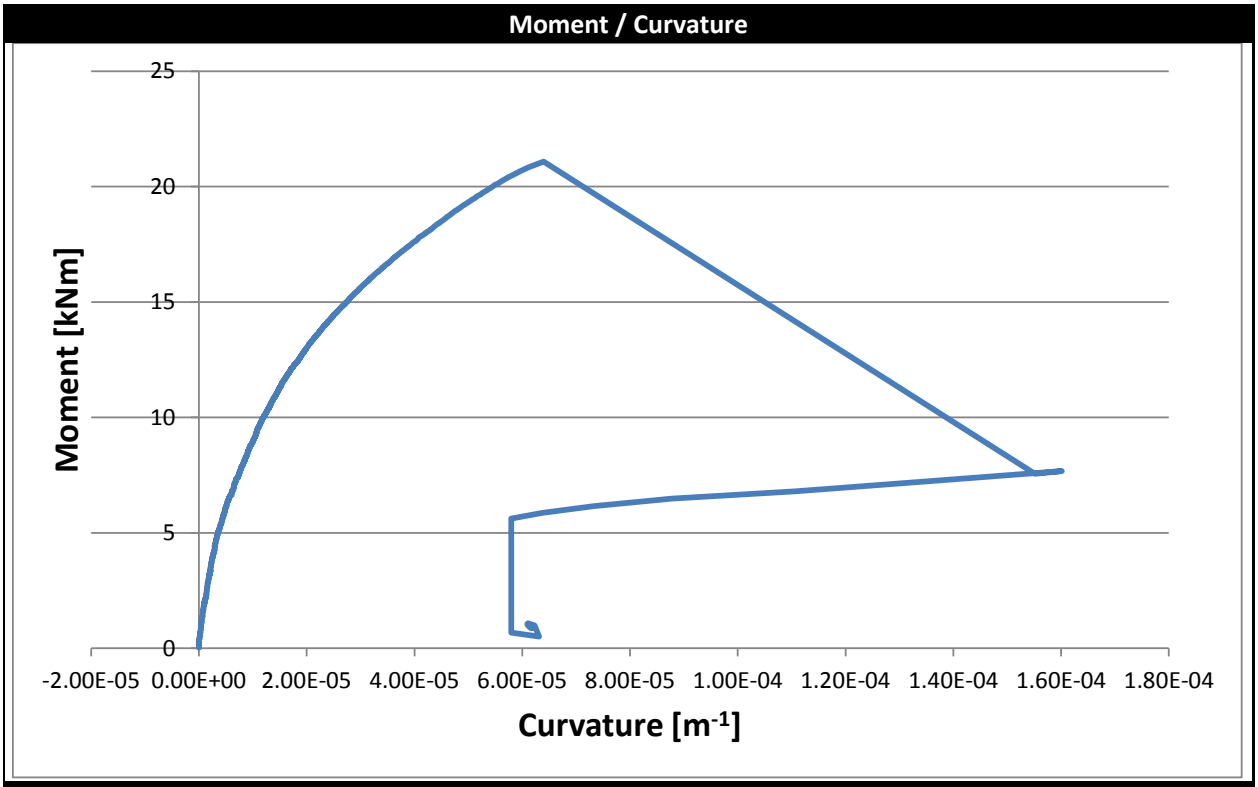
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	42.94	4.65	0

Fracture picture

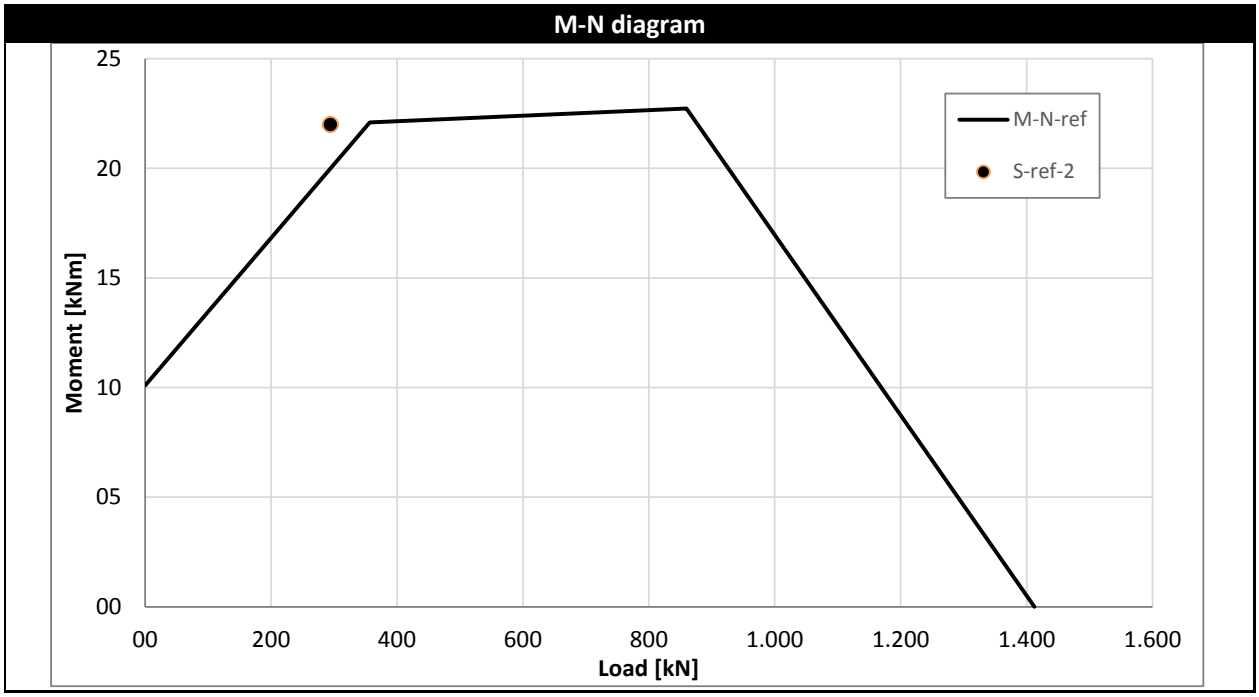
Displacement load curve





Experimental max values			
Axial Force [kN]	**Moment [kN]**	**Average Curvature [mm^{-1}]**	**Displacement [mm]**
293.9	22.0	6.40E-5	33.3

Theoretical values		
Axial capacity [kN]	Moment capacity [kNm]	**Displacement [mm]**
192	17.9	52.8

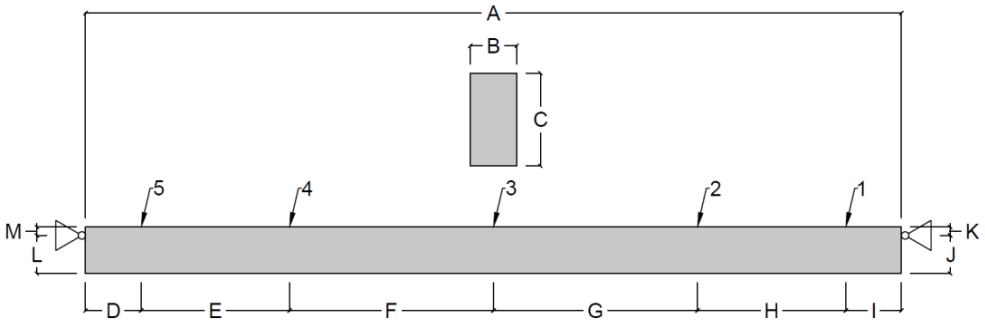


Mean experimental crack distance [mm]	Experimental Standard deviation [mm]	Characteristic max crack distance (95% percentile) [mm]	Theoretical max crack distance [mm]
97.2	24	136.7	185.4

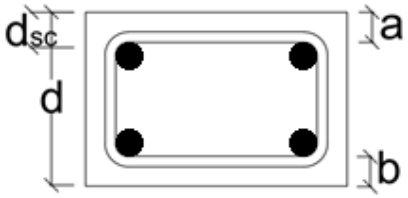
Cracks front										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	90	76	70	115	100	123	92	137	62	107
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]	-	-	-	-	-	-	-	-	-	-

I.3 S-REF-3

Serie S-REF	no. 3	Eccentricity [mm]
Test-date	21-4-2015	40

Reference	[mm]	Column dimensions
A	2200.5	
B	126.5	
C	253.3	
D	150	
E	400	
F	550	
G	550	
H	400	
I	150	
J	102,5	
K	22,5	
L	102,5	
M	22,5	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	22.6	32.3	27.45	
b	30.7	23.7	27.2	
d	-	-	92.2	
d_{sc}	-	-	33.5	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compresion rebars	10	2	621,98	201,49
Tensile rebars	10	2	621,98	201,49
Stirrups	8	-	546,26	196,71

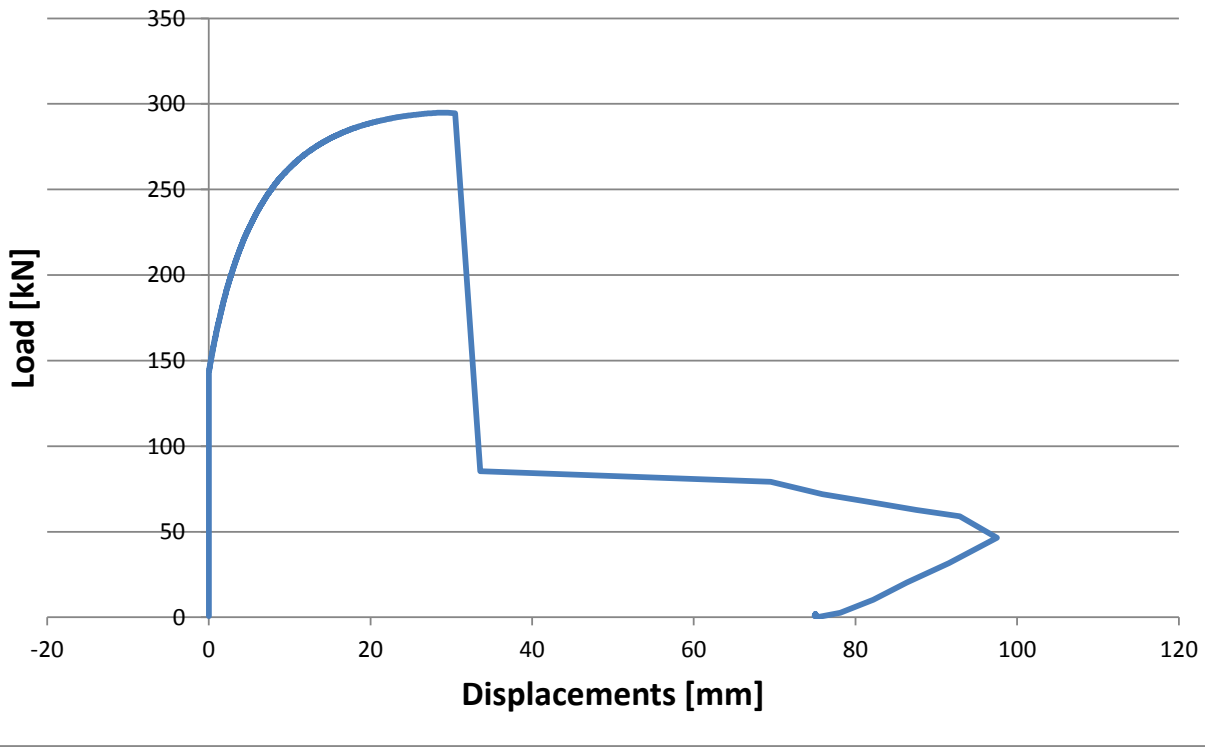
Distance between stirrups is 100 mm, except for the ends of the Column where the distance is 50 mm for the first 300 mm

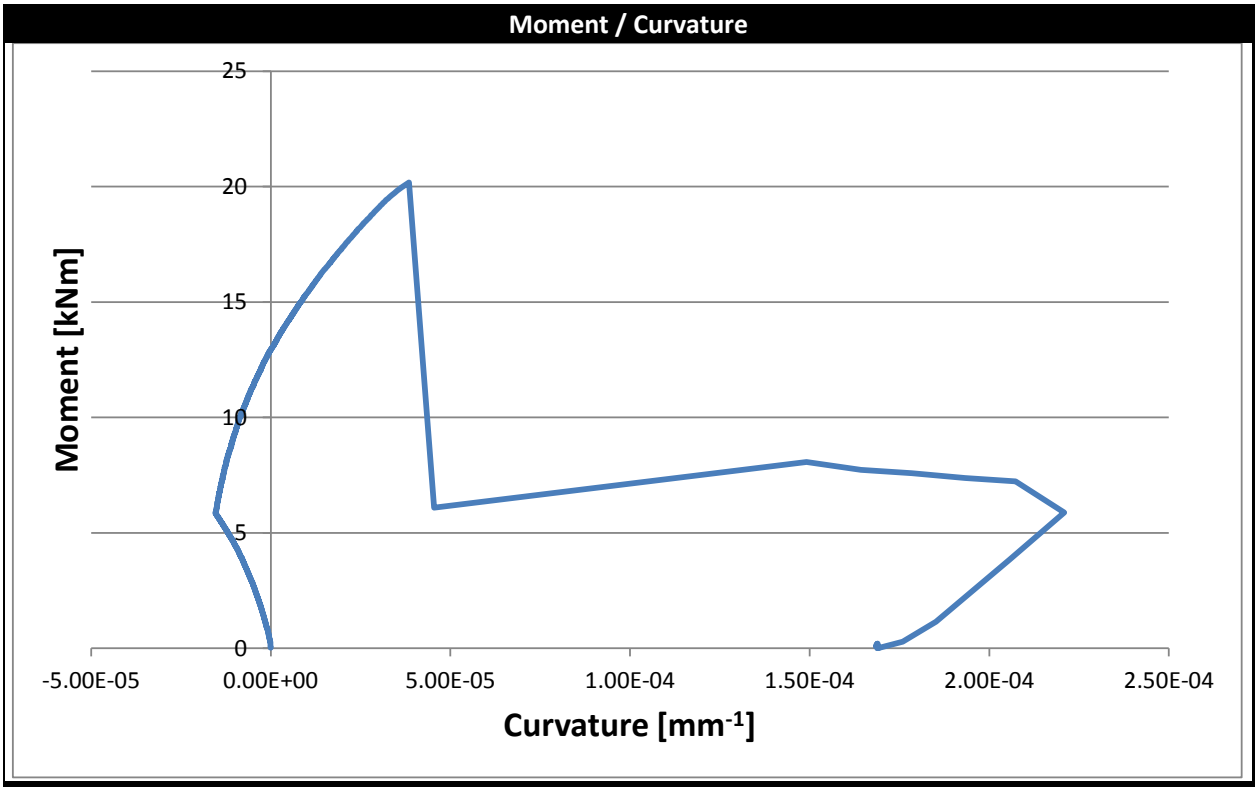
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	42.94	4.65	0

Fracture picture

Displacement load curve





Experimental max values			
Axial Force [kN]	**Moment [kN]**	**Average Curvature [mm^{-1}]**	**Displacement [mm]**
294.9	20.7	3.85E-5	29.0

Theoretical values		
Axial capacity [kN]	Moment capacity [kNm]	**Displacement [mm]**
191	17.8	53.5

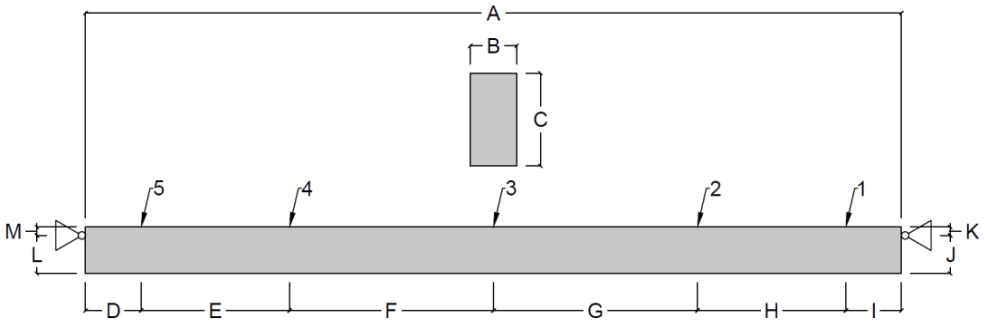
M-N diagram
Not possible dur to flawed data

Mean experimental crack distance [mm]	Experimental Standard deviation [mm]	Characteristic max crack distance (95% percentile) [mm]	Theoretical max crack distance [mm]
79.6	20.3	113.0	185.4

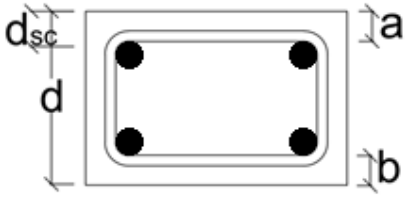
Cracks front										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	105	105	77	55	82	56	75	70	67	67
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]	67	77	62	60	102	110	117	-	-	-

I.4 S-25-1

Serie	S-25	no.	1	Eccentricity [mm]
Test-date	20-4-2015			40

Reference	[mm]	Column dimensions
A	2199	
B	127	
C	252,3	
D	150	
E	400	
F	549	
G	550	
H	400	
I	150	
J	102,5	
K	22,5	
L	102,5	
M	22,5	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	36,1	25,6	30,85	
b	24,5	28,7	26,7	
d	-	-	96.8	
d_{sc}	-	-	35,2	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compresion rebars	10	2	621,98	201,49
Tensile rebars	10	2	621,98	201,49
Stirrups	8	-	546,26	196,71

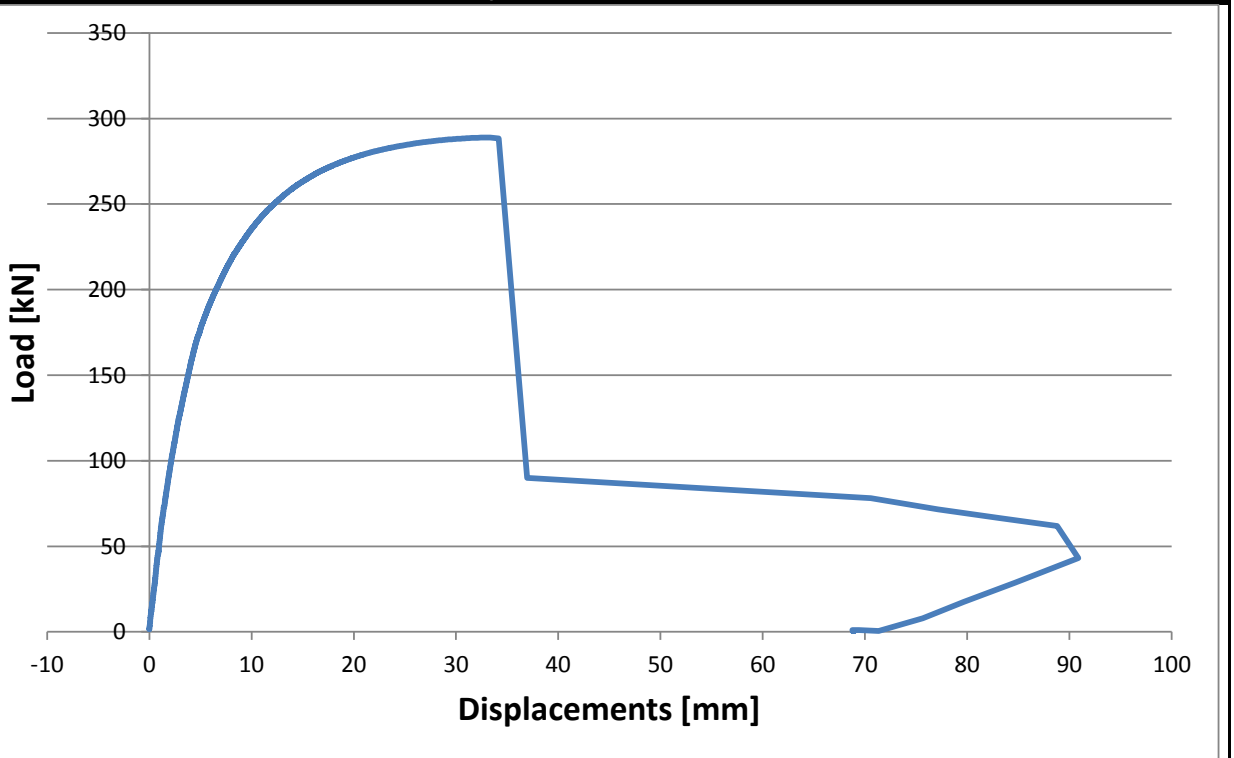
Distance between stirrups is 100 mm, except for the ends of the Column where the distance is 50 mm for the first 300 mm

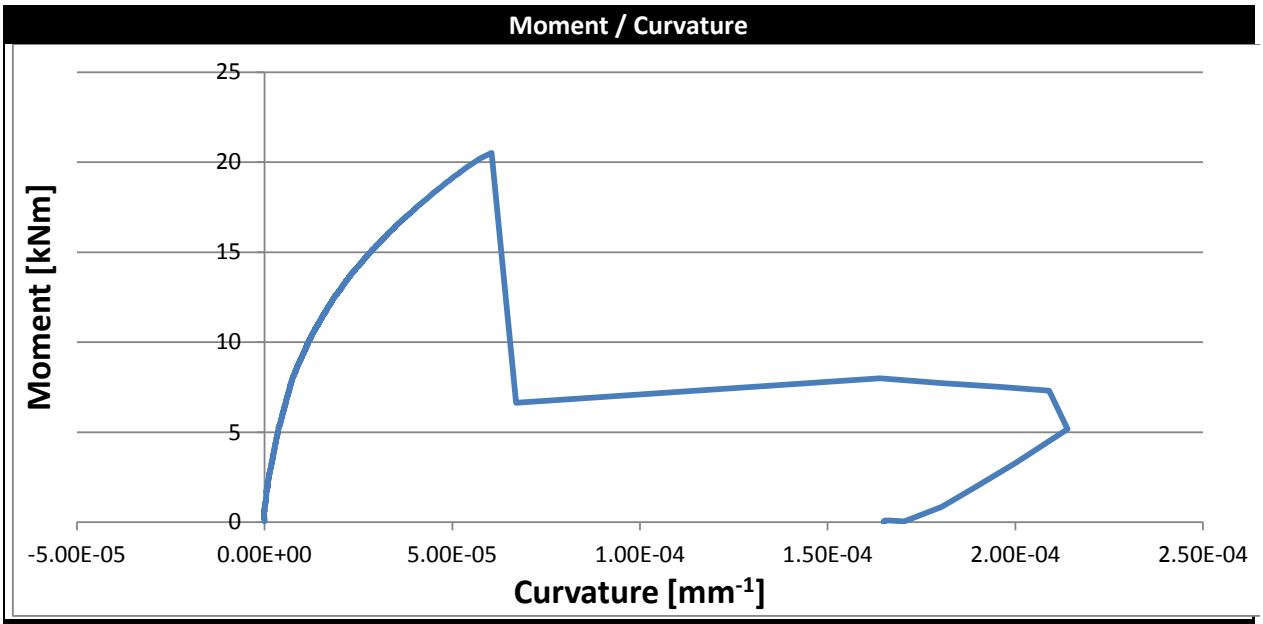
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	38.05	2.53	25

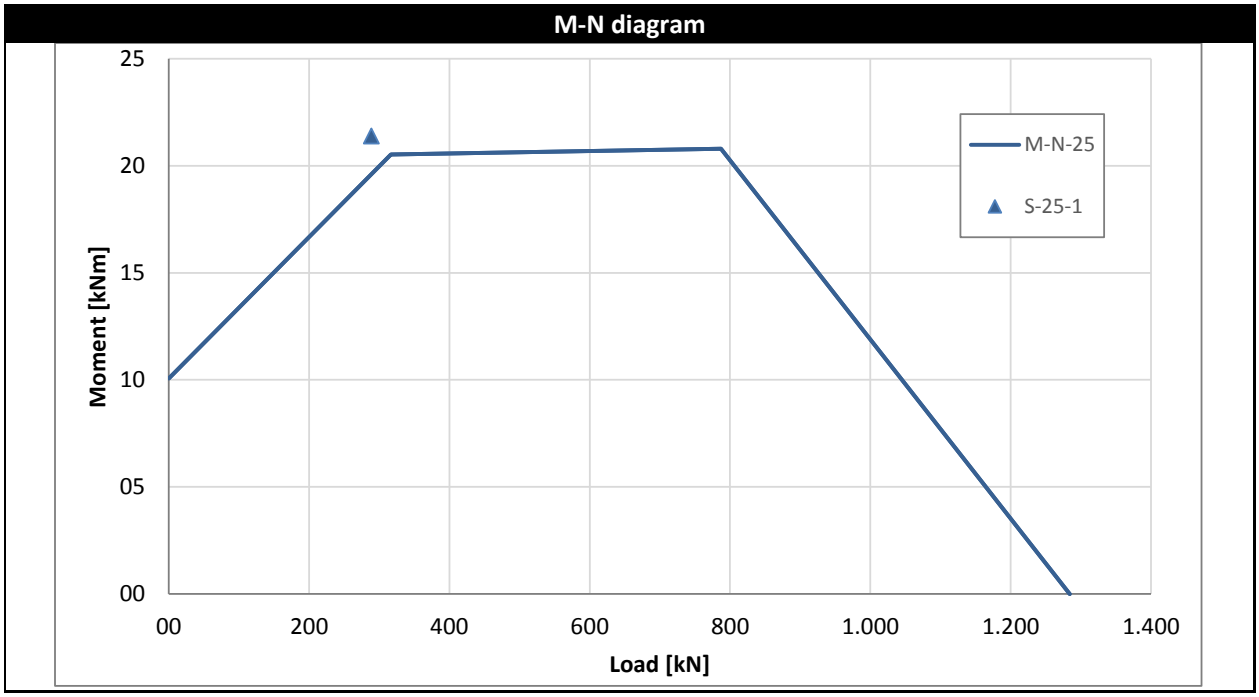
Fracture picture

Displacement load curve





Experimental max values			
Axial Force [kN]	**Moment [kN]**	**Average Curvature [mm^{-1}]**	**Displacement [mm]**
288.9	21.4	6.05E-5	-32.8
Theoretical values			
Axial capacity [kN]	Moment capacity [kNm]		**Displacement [mm]**
212	18.2		46.0

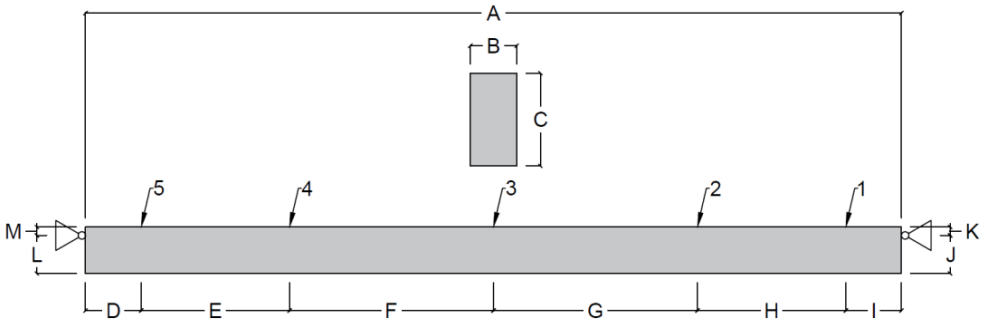


Mean experimental crack distance [mm]	Experimental Standard deviation [mm]	Characteristic max crack distance (95% percentile) [mm]	Theoretical max crack distance [mm]
99.9	17.6	128.9	184.9

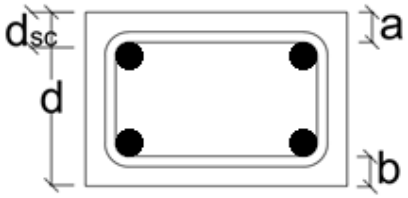
Cracks front										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	118	97	115	95	110	107	105	90	73	57
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]	91	115	115	92	118					

I.5 S-25-2

Serie S-25	no. 2	Eccentricity [mm]
Test-date	21-4-2015	40

Reference	[mm]	Column dimensions
A	2199	
B	127.0	
C	252.3	
D	150	
E	400	
F	550	
G	550	
H	400	
I	150	
J	102,5	
K	22,5	
L	102,5	
M	22,5	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	36,1	25,6	30,85	
b	24,5	28,7	26,7	
d	-	-	96.8	
d_{sc}	-	-	35,2	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compresion rebars	10	2	621,98	201,49
Tensile rebars	10	2	621,98	201,49
Stirrups	8	-	546,26	196,71

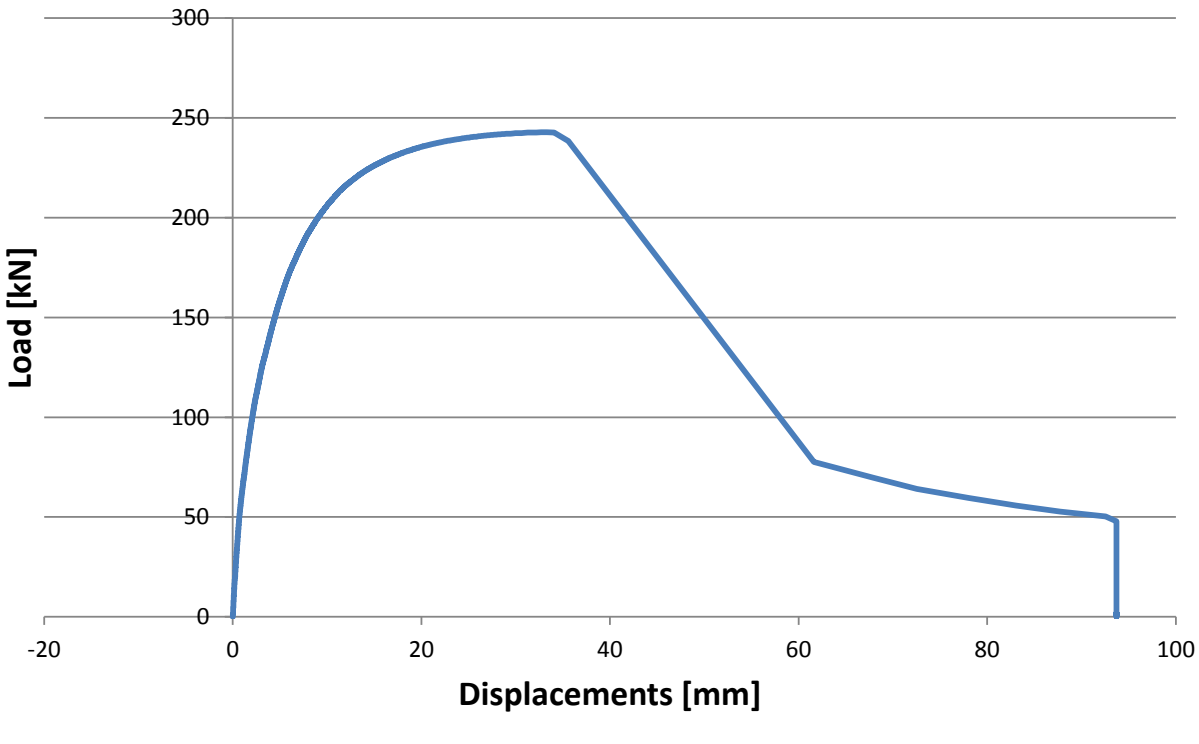
Distance between stirrups is 100 mm, except for the ends of the Column where the distance is 50 mm for the first 300 mm

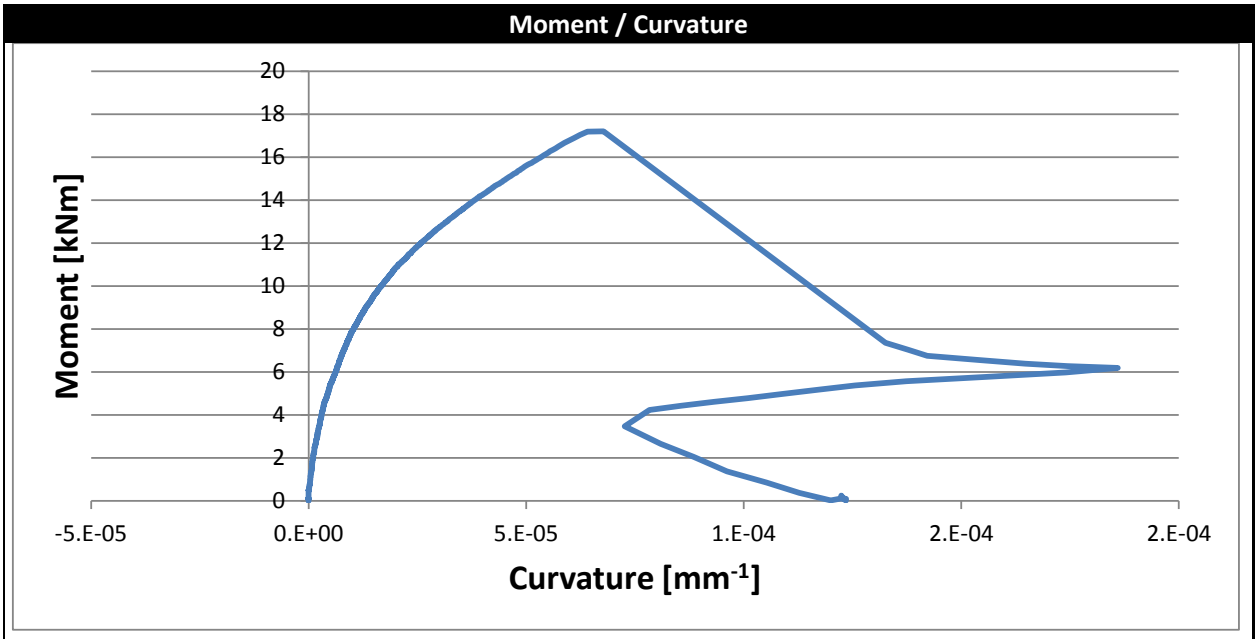
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	38.05	2.53	25

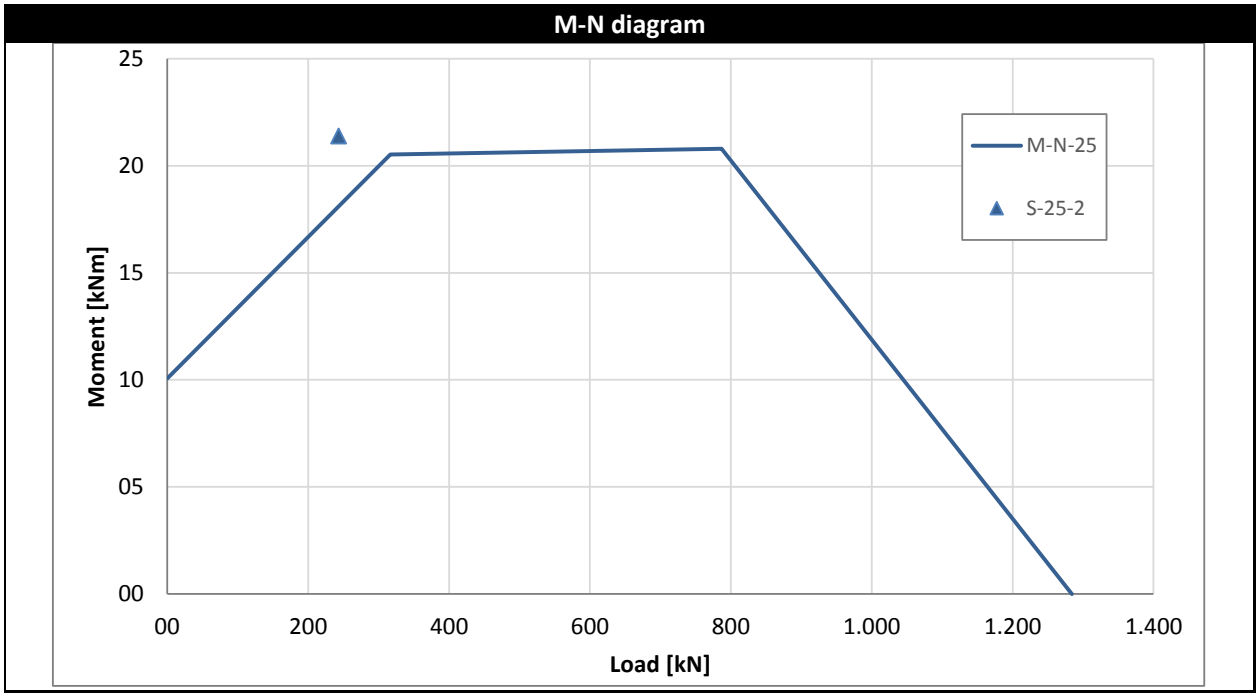
Fracture picture

Displacement load curve





Experimental max values			
Axial Force [kN]	**Moment [kN]**	**Average Curvature [mm^{-1}]**	**Displacement [mm]**
242.7	18.0	6.78E-5	-33
Theoretical values			
Axial capacity [kN]	Moment capacity [kNm]		**Displacement [mm]**
210	18.1		46.2

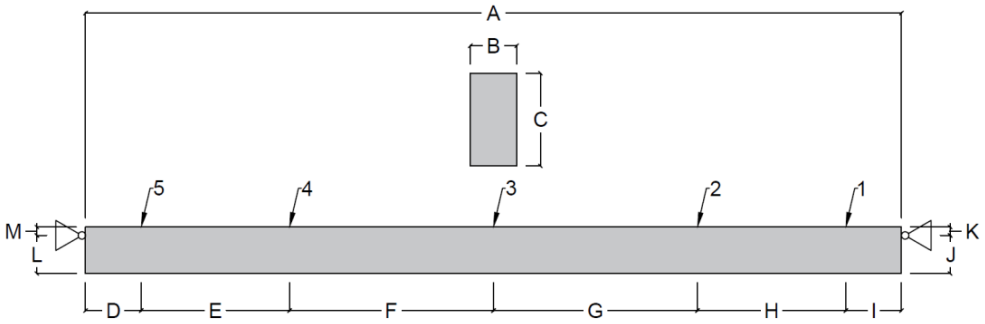


Mean experimental crack distance [mm]	Experimental Standard deviation [mm]	Characteristic max crack distance (95% percentile) [mm]	Theoretical max crack distance [mm]
101.5	20.8	135.8	184.9

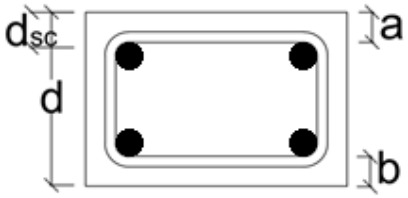
Cracks front										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	120	95	135	100	80	65	85	115	110	-
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]	-	-	-	-	-	-	-	-	-	-

I.6 S-25-3

Serie S-25	no. 3	Eccentricity [mm]
Test-date	21-4-2015	40

Reference	[mm]	Column dimensions
A	2200	
B	126.7	
C	251.7	
D	150	
E	400	
F	550	
G	550	
H	400	
I	150	
J	102,5	
K	22,5	
L	102,5	
M	22,5	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	27.7	30	28.85	
b	32.2	36.2	34.2	
d	-	-	96.8	
d_{sc}	-	-	35,2	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compresion rebars	10	2	621,98	201,49
Tensile rebars	10	2	621,98	201,49
Stirrups	8	-	546,26	196,71

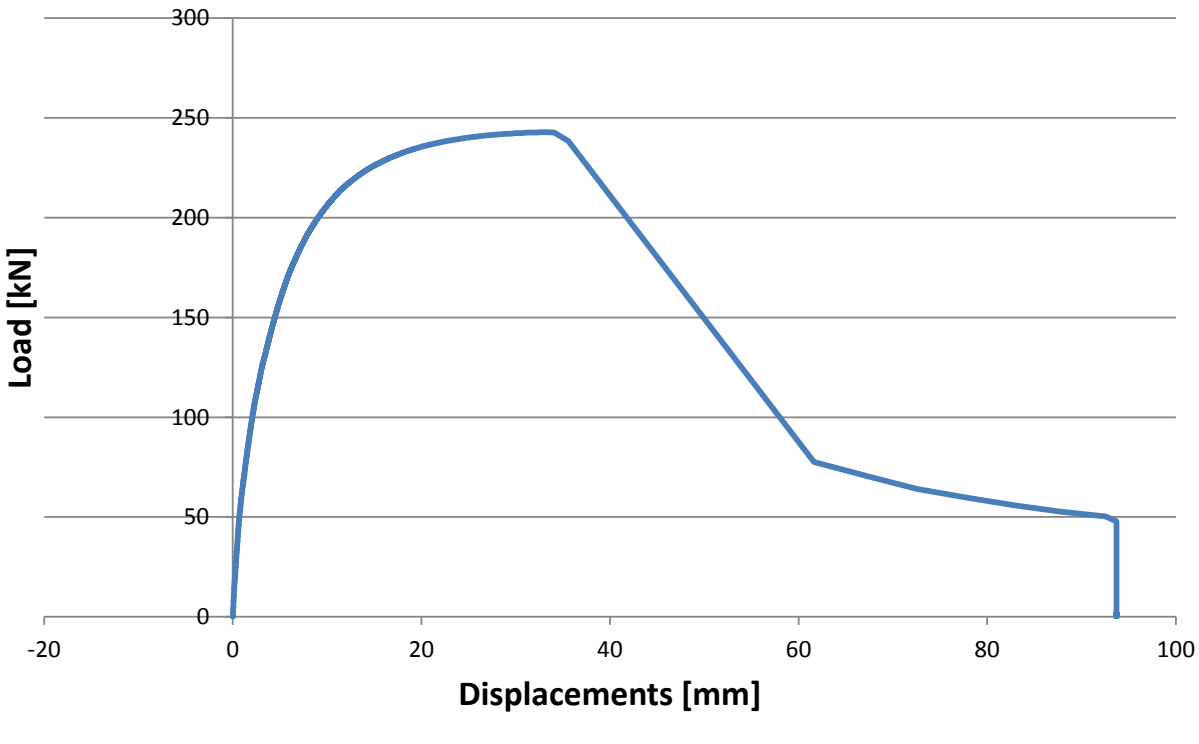
Distance between stirrups is 100 mm, except for the ends of the Column where the distance is 50 mm for the first 300 mm

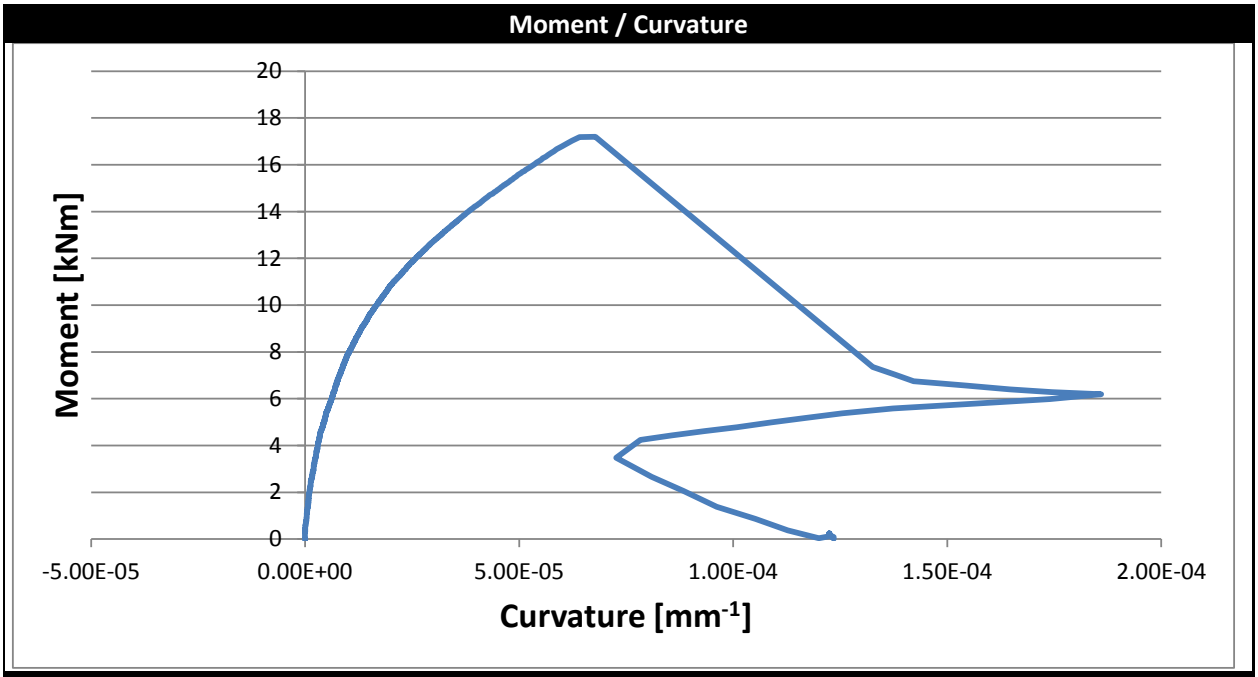
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	38.05	2.53	25

Fracture picture

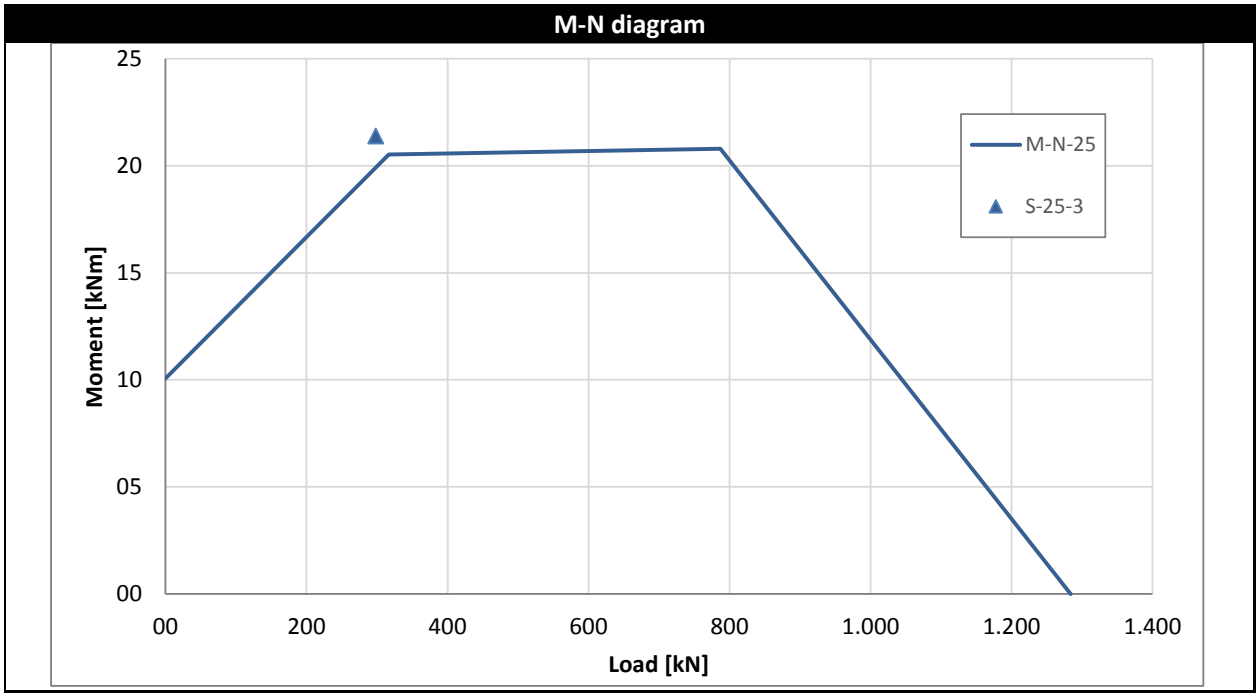
Displacement load curve





Experimental max values			
Axial Force [kN]	**Moment [kNm]**	**Average Curvature [mm^{-1}]**	**Displacement [mm]**
288.9	21.4	6.50E-5	-32.8

Theoretical values		
Axial capacity [kN]	Moment capacity [kNm]	**Displacement [mm]**
217	18.5	45.4

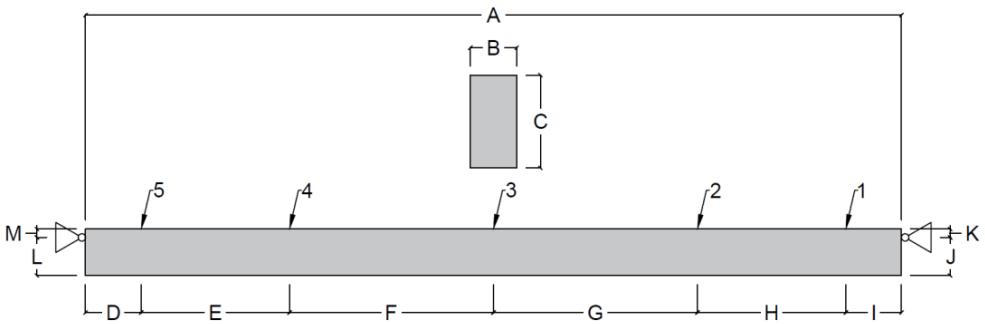


Mean experimental crack distance [mm]	Experimental Standard deviation [mm]	Characteristic max crack distance (95% percentile) [mm]	Theoretical max crack distance [mm]
99.9	17.6	128.9	184.9

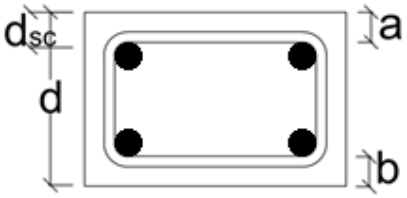
Cracks front										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	118	97	115	95	110	107	105	90	73	57
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]	91	115	115	92	118	-	-	-	-	-

I.7 S-50-1

Serie S-50	no. 1	Eccentricity [mm]
Test-date	20-4-2015	40

Reference	[mm]	Column dimensions
A	2201	
B	126.3	
C	254.0	
D	150	
E	400	
F	550	
G	550	
H	400	
I	150	
J	102,5	
K	22,5	
L	102,5	
M	22,5	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	27.8	26.5	27.15	
b	24.9	33.7	29.3	
d	-	-	92.6	
d_{sc}	-	-	29.5	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compresion rebars	10	2	621,98	201,49
Tensile rebars	10	2	621,98	201,49
Stirrups	8	-	546,26	196,71

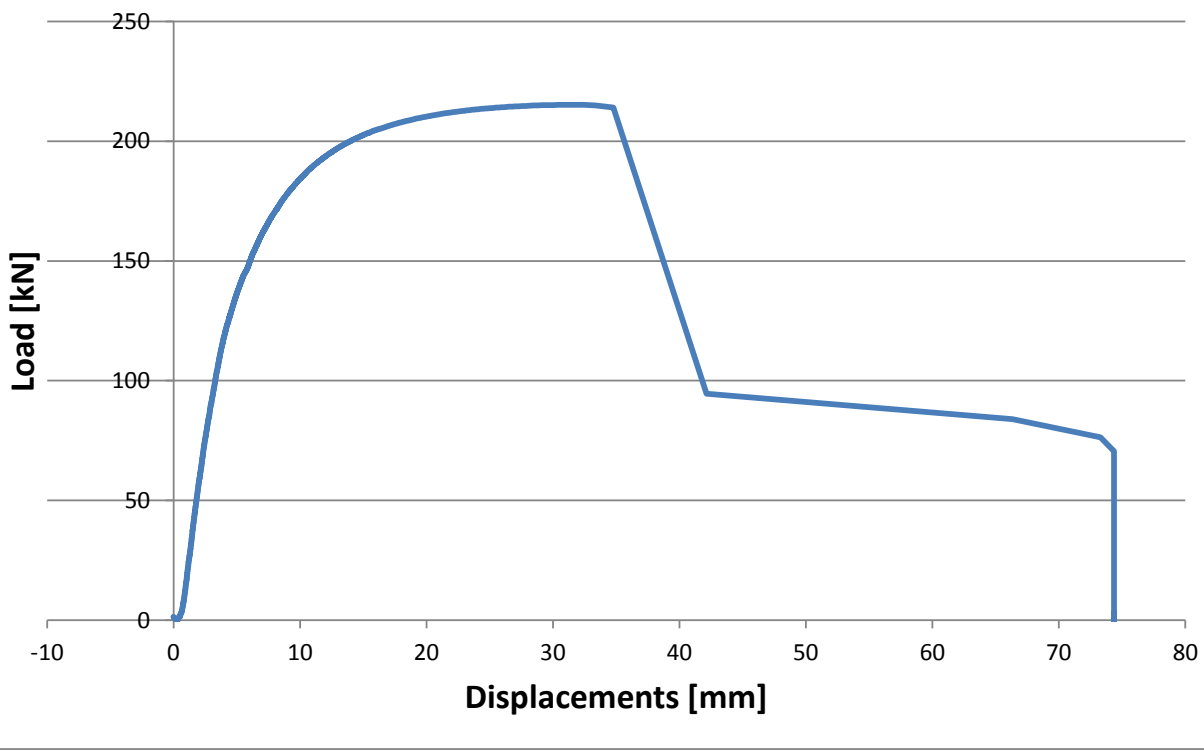
Distance between stirrups is 100 mm, except for the ends of the Column where the distance is 50 mm for the first 300 mm

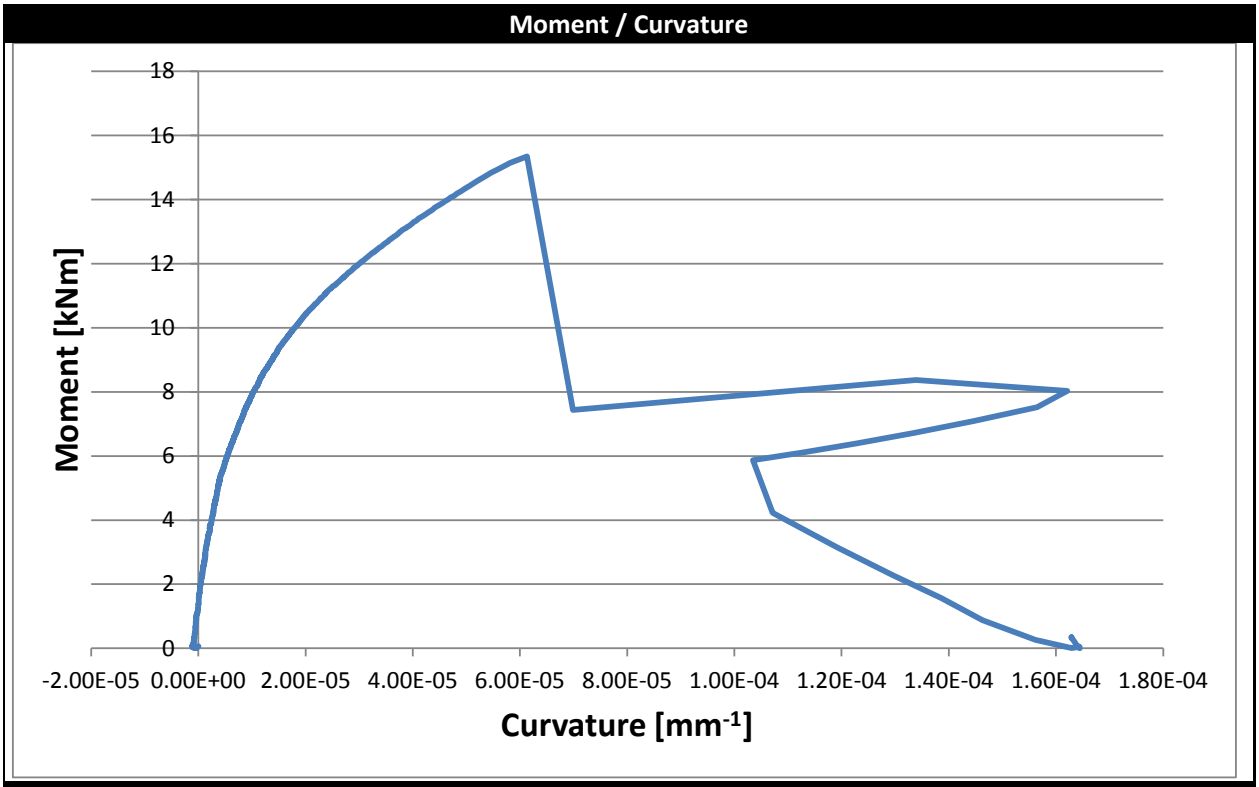
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	25.34	3.00	50

Fracture picture

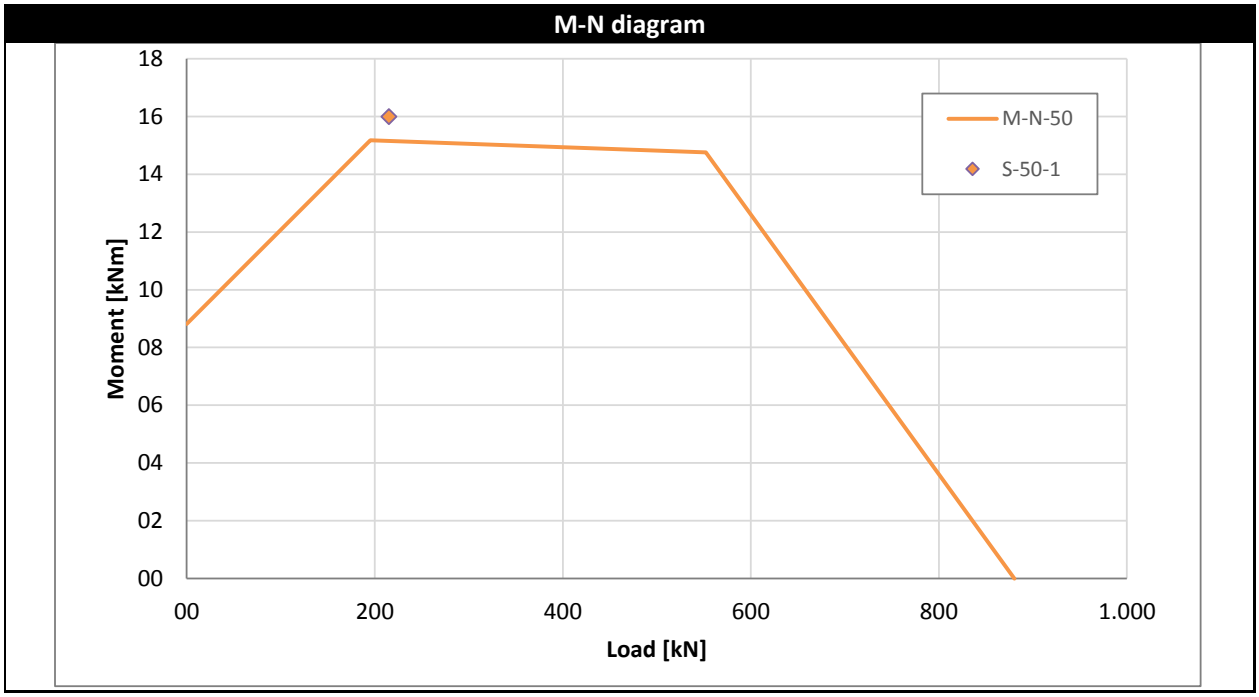
Displacement load curve





Experimental max values			
Axial Force [kN]	**Moment [kNm]**	**Average Curvature [mm^{-1}]**	**Displacement [mm]**
215.2	16.0	6.13E-5	-31.7

Theoretical values		
Axial capacity [kN]	Moment capacity [kNm]	**Displacement [mm]**
231	16.6	31.9

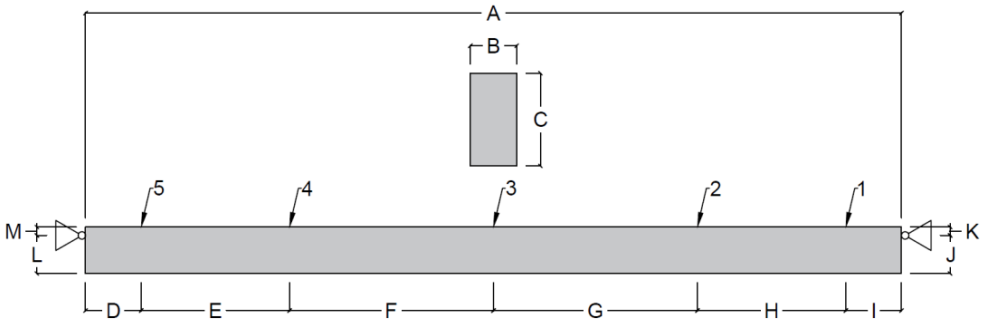


Mean experimental crack distance [mm]	Experimental Standard deviation [mm]	Characteristic max crack distance (95% percentile) [mm]	Theoretical max crack distance [mm]
91.4	20.5	125	181.9

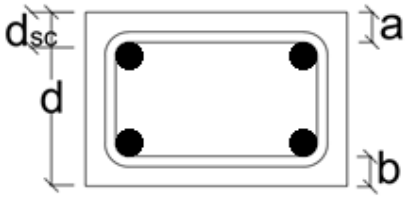
Cracks front										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	105	112	105	98	108	48	63	95	104	90
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]	77	-	-	-	-	-	-	-	-	-

I.8 S-50-2

Serie S-50	no. 2	Eccentricity [mm]
Test-date	21-4-2015	40

Reference	[mm]	Column dimensions
A	2201	
B	126.8	
C	253.7	
D	150	
E	400	
F	550	
G	550	
H	400	
I	150	
J	102,5	
K	22,5	
L	102,5	
M	22,5	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	25.7	29.8	27.75	
b	24.2	30.9	27.55	
d	-	-	92.6	
d_{sc}	-	-	29.5	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compresion rebars	10	2	621,98	201,49
Tensile rebars	10	2	621,98	201,49
Stirrups	8	-	546,26	196,71

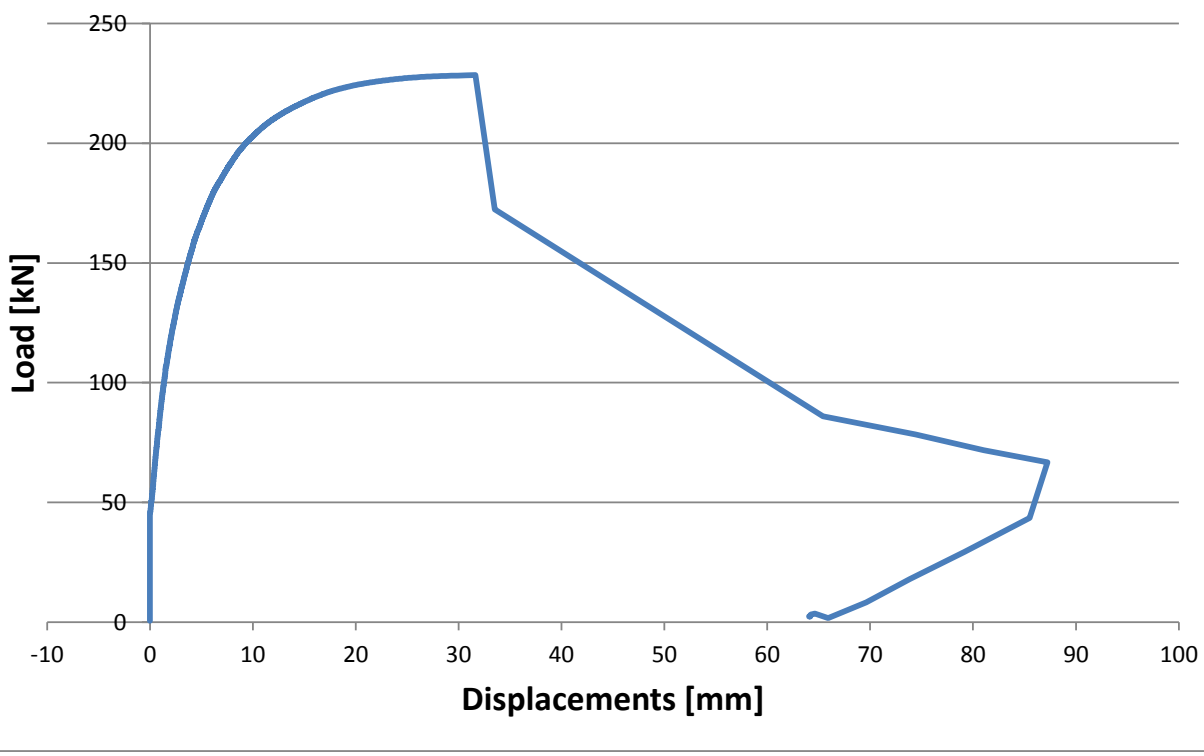
Distance between stirrups is 100 mm, except for the ends of the Column where the distance is 50 mm for the first 300 mm

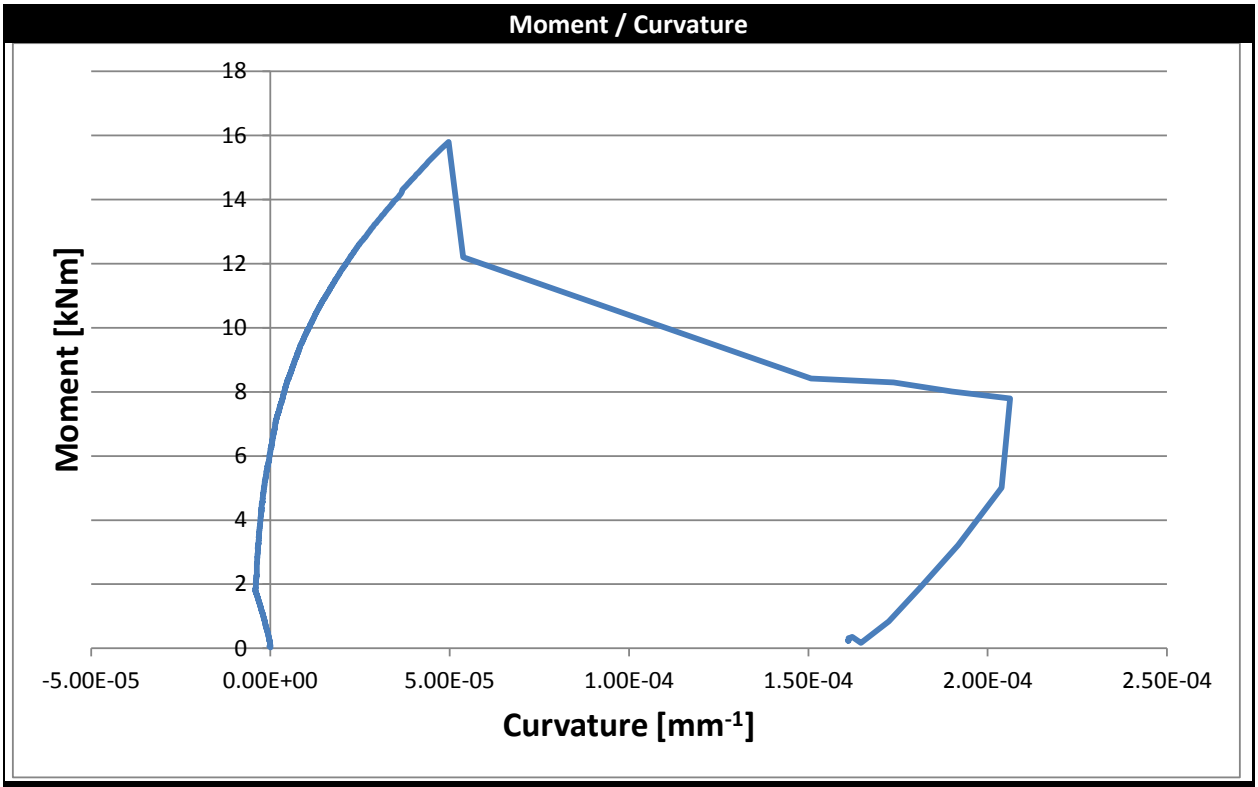
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	25.34	3.00	50

Fracture picture

Displacement load curve





Experimental max values			
Axial Force [kN]	**Moment [kNm]**	**Average Curvature [mm^{-1}]**	**Displacement [mm]**
228.4	16.4	4.97E-5	31.6
Theoretical values			
Axial capacity [kN]	Moment capacity [kNm]		**Displacement [mm]**
234	16.7		31.7

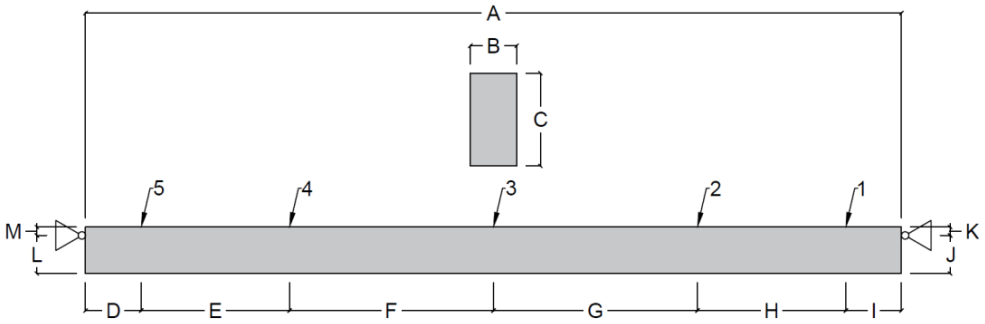
M-N diagram
No graph due to flawed data

Mean experimental crack distance [mm]	Experimental Standard deviation [mm]	Characteristic max crack distance (95% percentile) [mm]	Theoretical max crack distance [mm]
99.4	10.9	117.4	181.9

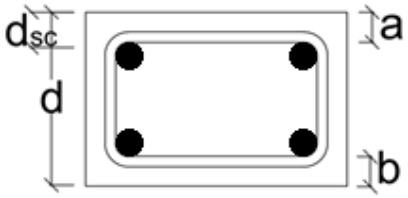
Cracks front										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	83	103	110	95	110	88	107	-	-	-
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]	-	-	-	-	-	-	-	-	-	-

I.9 S-50-3

Serie S-50	no. 3	Eccentricity [mm]
Test-date	21-04-2015	40

Reference	[mm]	Column dimensions
A	2200	
B	126.7	
C	256.3	
D	150	
E	400	
F	550	
G	550	
H	400	
I	150	
J	102,5	
K	22,5	
L	102,5	
M	22,5	

B and C is measured 10 cm from the ends as well as in the middle. The stated values are the averages.

Cover	Left side [mm]	right side [mm]	Average [mm]	Drawing cross section
a	26	23	24.5	
b	24	34	29	
d	-	-	92.6	
d_{sc}	-	-	29.5	

Reinforcement properties	Diameter [mm]	Number of rebars	Yield stress [MPa]	Young's modulus [MPa]
Compresion rebars	10	2	621,98	201,49
Tensile rebars	10	2	621,98	201,49
Stirrups	8	-	546,26	196,71

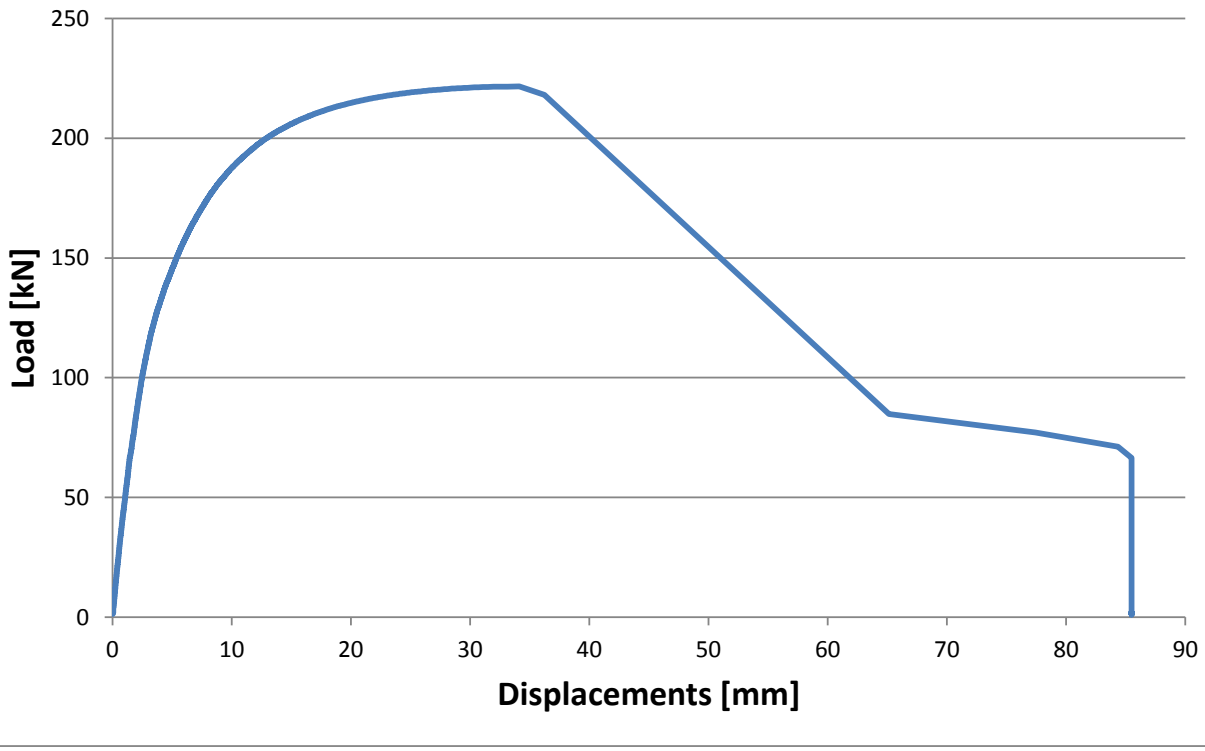
Distance between stirrups is 100 mm, except for the ends of the Column where the distance is 50 mm for the first 300 mm

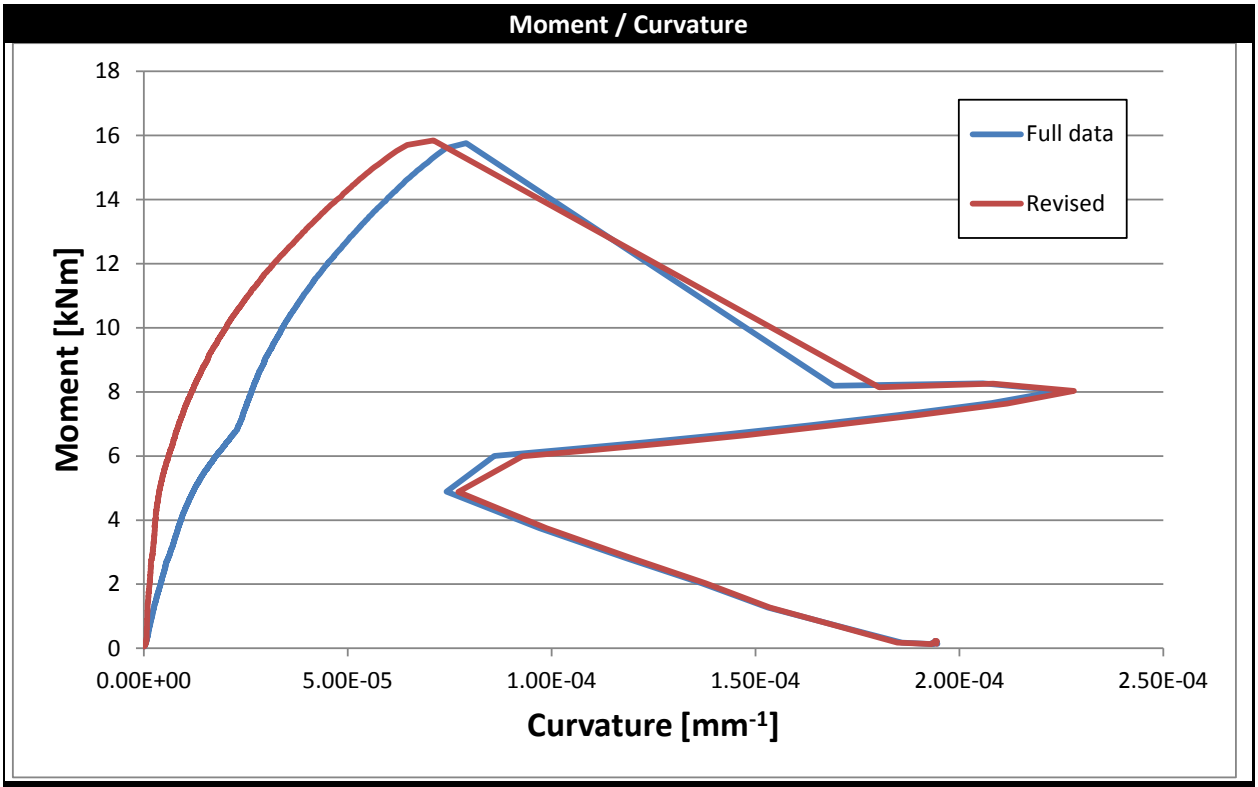
The cover is measured by manual spalling of the beams

Concrete properties	Average [MPa]	Standard deviation [MPa]	SSA content [%]
Compression strength	25.34	3.00	50

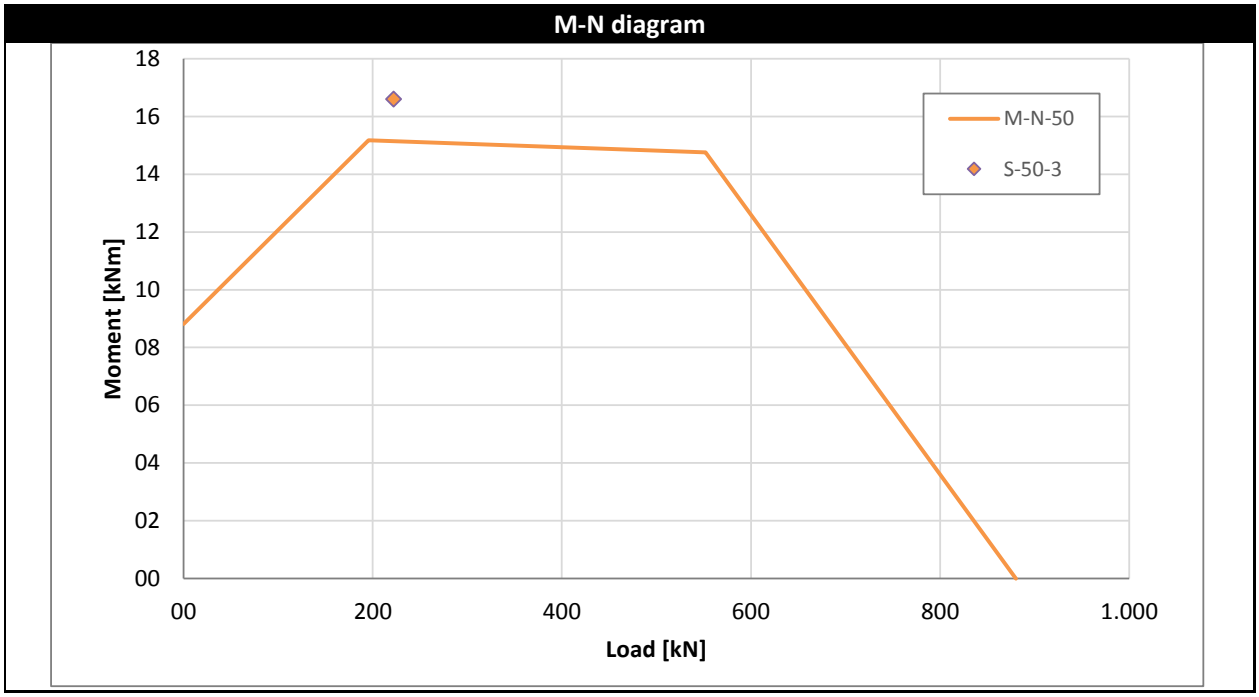
Fracture picture

Displacement load curve





Experimental max values			
Axial Force [kN]	**Moment [kNm]**	**Average Curvature [mm^{-1}]**	**Displacement [mm]**
221.7	16.6	7.90E-5	34.1
Theoretical values			
Axial capacity [kN]	Moment capacity [kNm]		**Displacement [mm]**
234	**16.8**		31.8



Mean experimental crack distance [mm]	Experimental Standard deviation [mm]	Characteristic max crack distance (95% percentile) [mm]	Theoretical max crack distance [mm]
98.1	15.3	123.2	181.9

Cracks front										
Crack no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crack distance [mm]	107	105	80	118	100	113	101	90	98	98
Crack no.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Crack distance [mm]	110	77	65	112	-	-	-	-	-	-