

JULY 2021

M.Sc. in Civil Engineering

İSMAİL ÖZOĞUL

**REPUBLIC OF TURKEY
GAZİANTEP UNIVERSITY
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES**

**FINITE ELEMENT MODELING OF PRESTRESSED
REINFORCED CONCRETE HAUNCHED BEAMS**

**M.Sc. THESIS
IN
CIVIL ENGINEERING**

**BY
İSMAİL ÖZOĞUL
JULY 2021**

**FINITE ELEMENT MODELING OF PRESTRESSED
REINFORCED CONCRETE HAUNCHED BEAMS**

M.Sc.Thesis

in

Civil Engineering

Gaziantep University

Supervisor

Assoc. Prof. Dr. Mehmet Eren GÜLŞAN

by

İsmail ÖZOĞUL

June 2021

©2021[İsmail ÖZOĞUL]

**FINITE ELEMENT MODELING OF PRESTRESSED REINFORCED
CONCRETE HAUNCHED BEAMS**

submitted by **İsmail ÖZOĞUL** in partial fulfillment of the requirements for the
degree of Master of Science in **Civil Engineering, Gaziantep University** is
approved by,

Assoc. Prof. Dr. Mehmet İshak YÜCE
Director of the Graduate School of Natural and Applied Sciences

Prof. Dr. Aytaç GÜVEN
Head of the Department of Civil Engineering

Assoc. Prof. Dr. Mehmet Eren GÜLŞAN
Supervisor, Civil Engineering
Gaziantep University

Graduation Date: 09 July 2021

Examining Committee Members:

Assoc. Prof. Dr. Mehmet Eren GÜLŞAN
Thesis Supervisor, Civil Engineering
Gaziantep University

Prof. Dr. Abdulkadir ÇEVİK
Civil Engineering
Gaziantep University

Asst. Prof. Dr. Nurullah AKBULUT
Civil Engineering
Hasan Kalyoncu University

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

İsmail ÖZOĞUL

ABSTRACT

FINITE ELEMENT MODELING OF PRESTRESSED REINFORCED CONCRETE HAUNCHED BEAMS

ÖZOĞUL, İsmail

M.Sc. in Civil Engineering

Supervisor: Assoc. Prof. Dr. Mehmet Eren GÜLŞAN

July 2021

161 pages

In this study, two types of nonlinear analysis were conducted to examine the behavior of prestressed concrete, which is one of the most important inventions in today's an engineering and architecture field. The first nonlinear analysis is finite element analysis. Considering the properties of a prestressed concrete(PC) haunched beam used in the literature study, it was modeled with the ATENA 2D. As a result of the modeling, it was determined that the experimental model and the analytical model showed similar behaviors. Then, 180 PC haunched beams and 144 PC rectangular beams were modeled with ATENA 2D. These models have changed various parameters: (α / d_m) ratio, prestressing force, concrete compressive strength, and reinforcement ratio were changed for analysis. These models changed various parameters: (α / d_m) ratio, prestress strength, concrete compressive strength, and reinforcement ratio was changed and analyzed. Various findings were reached as a result of these analyzes. With the increase in the reinforcement ratio and compressive strength of the concrete, the load-bearing capacity of the PC haunched beams and RC prismatic beams has increased. The effectiveness of the prestressed reinforcement ratio on the prestressing force was observed. With the increase in (α / d_m) ratio, the effectiveness of the prestress force on the failure load decreased. It was also observed that the prestressing force increased the cracking load of concrete. The second analysis is probabilistic nonlinear analysis(PNA). In this analysis, PNA of 180 PC haunched beams was performed. Reliability, sensitivity and histogram analysis results of all beams were obtained.

Keyword: Prestressed Concrete, Finite Element Analysis, Probabilistic Nonlinear Analysis, Haunched Beam, Reliability of Structures

ÖZET

ÖNGERMELİ PRİZMATİK OLMAYAN BETONARME KİRİŞLERİN SONLU ELEMAN MODELLEMESİ

ÖZOĞUL, İsmail

Yüksek Lisans Tezi, İnşaat Mühendisliği

Danışman: Doç. Dr. Mehmet Eren GÜLŞAN

Temmuz 2021

161 sayfa

Bu çalışmada, günümüz mühendislik ve mimari alanında ön önemli buluşlarından olan öngermeli betonun davranışlarını incelemek için iki çeşit doğrusal olmayan analiz yapılmıştır. Birinci doğrusal olmayan analiz sonlu elemanlar analizidir. Literatür çalışmada kullanılan bir öngermeli beton prizmatik olmayan kirişin özellikleri dikkate alınarak ATENA 2D programı ile modellenmiştir. Modelleme sonucunda deneysel model ve analitik model benzer davranışlar gösterildiği tespit edilmiştir. Daha sonra 180 öngermeli beton prizmatik olmayan kiriş ve 144 öngermeli beton prizmatik kiriş ATENA 2D programı ile modellenmiştir. Bu modeller çeşitli parametreleri değiştirdi: (α / d_m) oranı, ön gerilim dayanımı, beton basınç dayanımı ve donatı oranı değiştirildi ve analiz edildi. Bu analizler sonucunda çeşitli bulgulara ulaşıldı. Betonun donatı oranı ve basınç dayanımının artması ile öngermeli beton prizmatik olmayan kirişlerin ve betonarme prizmatik kirişlerin yük taşıma kapasiteside artmıştır. Öngermeli donatı oranının öngerme kuvveti üzerinde etkinliği gözlemlendi. (α / d_m) oranının artmasıyla öngerme kuvvetinin kırılma yükü üzerinde etkinliği düştü. Ayrıca öngerme kuvvetin betonun çatlama yükünü artırdığı gözlemlenmiş oldu. İkinci analizimiz ise olasılıksal doğrusal olmayan analizidir. Bu analizde 180 öngermeli prizmatik olmayan kirişin olasılıksal doğrusal olmayan analizi yapıldı. Analizler sonucunda tüm kirişlerin güvenilirlik, hassasiyet ve histogram analiz sonuçları çıkarıldı.

Anahtar Kelimeler: Öngermeli Beton, Sonlu Eleman Analiz, Olasılıksal Doğrusal Olmayan Analiz, Prizmatik Olmayan Kiriş, Yapıların Güvenirliği



"Dedicated to my family"

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Assoc. Prof. Dr. Mehmet Eren GÜLŞAN for his guidance and support throughout the study. I am thankful for his encouragement and motivation.

I deeply offer my gratefulness to all staff and students of engineering school, whom direct or indirect contribution in academic or administrative levels has been helpful to accomplishment of this research.

Here I once again express my deep gratefulness to my family who has always been an encourager and supportive of my educational studies and efforts.

TABLE OF CONTENTS	Page
ABSTRACT	v
ÖZET.....	vi
ACKNOWLEDGEMENTS.....	viii
TABLE OF CONTENTS.....	ix
LIST OF TABLES	xii
LIST OF FIGURES	xiii
LIST OF SYMBOLS	xxi
LIST OF ABBREVIATIONS	xxii
CHAPTER I.....	1
INTRODUCTION.....	1
1.1 General.....	1
1.2 Thesis Aims.....	2
1.3 Thesis Layout.....	3
CHAPTER II	4
LITERATURE REVIEW.....	4
2.1 General	4
CHAPTER III	7
EXPERIMENTAL STUDY AND ANALYTICAL MODELING	7
3.1 Experimental Study.....	7
3.2.1 Program of Experimental Study.....	8
3.2.2 Crackings in Tapered Prestressed Beams	9
3.2 Analytical Modeling.....	10
3.2.1 Program of Analytical Modeling	10

3.2.2 ATENA 2D Finite Element Program	10
3.2.3 Steps of Analysis with ATENA 2D Program	11
3.2.3.1 Material Parameters	12
3.2.3.2 Modelling Geometrical (Topology)	13
3.2.3.3 Introduce Macro Element and Reinforcement	13
3.2.3.4 Mesh Generation	14
3.2.3.5 Supports and Loads	14
3.2.3.6 Assigning Load Cases	14
3.2.3.7 Run	15
3.2.3.8 Comparison of Experimental Study and Analytical Modeling	16
CHAPTER IV	20
PARAMETRIC WORK AND EVALUATION	20
4.1 Compressive Strength of Concrete Effect	26
4.2 Prestressing Force Effect	40
4.2.1 Effect of Prestressing Force on Failure Load	50
4.2.2 Effect of Prestressing Force on Cracking Load	58
4.3 Area of Tensile Bars Effect	66
4.4 Taper Slope of Beams Effect	75
4.5 Effect of α/d_m Ratio	84
4.6 PC Haunched Beams & PC Rectangular Beams	93
CHAPTER V	114
PROBABILISTIC NONLINEAR ANALYSIS OF PC HAUNCHED BEAMS	114
5.1 SARA Studio	114
5.2 Application of Probabilistic Nonlinear Analysis of Haunched Beams	116
5.2.1 Stochastic Model	116
5.2.2 Random Variables	116

5.2.3 Statistical Correlation.....	117
5.2.4 Latin Hypercube Sampling	117
5.2.4.1 General Data.....	118
5.2.4.2 Check Samples	118
5.2.4.3 Model Analysis	118
5.2.5 Simulation Result Assessment	118
CHAPTER VI.....	154
CONCLUSIONS	154
REFERENCES.....	158
CV.....	161

LIST OF TABLES

	Page
Table 3.1 Detail of specimens and material properties [1]	7
Table 3.2 The element types used in ATENA 2D	13
Table 3.3 Comparison of failure load and displacement of TB3-3 beam.....	19
Table 4.1 HB beams detail and loading	21
Table 5.1 Random variables of compressive strength of concrete.	117
Table 5.2 Random variables of tensile bars and compressive bars.....	117
Table 5.3 Statistical correlation of parameters	117
Table 5.4 LHS general data adjustment.....	118
Table 5.5 HB beams' histogram, sensitivity, and reliability analysis	118
Table 5.6 Distribution of HB beams.....	152

LIST OF FIGURES

	Page
Figure 3.1 The geometric detail and loading of the TB3-3 beam [1].....	8
Figure 3.2 Four-point loading application in tapered prestressed beams.....	9
Figure 3.3 Crack pattern of TB3-3 beam[1].....	9
Figure 3.4 Symmetric half of TB3-3 beam.	10
Figure 3.5 ATENA 2D software window.	11
Figure 3.6 Steps of analysis with ATENA 2D finite element program.	12
Figure 3.7 Supports and Loads applications in the analytical model.....	15
Figure 3.8 Load-displacement plot of TB3-3 beam	16
Figure 3.9 Just before peak of TB3-3 beam in EXP[1].....	17
Figure 3.10 Just before peak of TB3-3 beam with mesh in ATENA.....	17
Figure 3.11 Just before peak of TB3-3 beam without mesh in ATENA.....	17
Figure 3.12 After peak of TB3-3 beam in EXP[1].....	18
Figure 3.13 Just after peak of TB3-3 beam with mesh in ATENA.....	18
Figure 3.14 Just after peak of TB3-3 beam without mesh in ATENA.....	18
Figure 3.15 Stress of TB3-3 beam	19
Figure 4.1 Naming the beams.....	20
Figure 4.3 Load-Displacement plot of HB-(30, 50.5)-0.10-3-2-18.43.	27
Figure 4.4 Load-Displacement plot of HB-(30, 50.5)-0.10-6-2-18.43.	28
Figure 4.5 Load-Displacement plot of HB-(30, 50.5)-0.15-0-2-18.43.	28
Figure 4.6 Load-Displacement plot of HB-(30, 50.5)-0.015-3-2-18.43.	29
Figure 4.7 Load-Displacement plot of HB-(30, 50.5)-0.015-6-2-18.43.	29

Figure 4.8 Load-Displacement plot of HB-(30, 50.5)-0.020-0-2-18.43.	30
Figure 4.9 Load-Displacement plot of HB-(30, 50.5)-0.020-6-2-18.43.	30
Figure 4.10 Load-Displacement plot of HB-(30, 50.5)-0.020-3-2-18.43.	31
Figure 4.11 Load-Displacement plot of HB-(30, 50.5)-0.010-3-4-8.97.	31
Figure 4.12 Load-Displacement plot of HB-(30, 50.5)-0.010-6-4-8.97.	32
Figure 4.13 Load-Displacement plot of HB-(30, 50.5)-0.015-0-4-8.97.	32
Figure 4.14 Load-Displacement plot of HB-(30, 50.5)-0.015-3-4-8.97.	33
Figure 4.15 Load-Displacement plot of HB-(30, 50.5)-0.015-6-4-8.97.	33
Figure 4.16 Load-Displacement plot of HB-(30, 50.5)-0.020-0-4-8.97.	34
Figure 4.17 Load-Displacement plot of HB-(30, 50.5)-0.020-3-4-8.97.	34
Figure 4.18 Load-Displacement plot of HB-(30, 50.5)-0.020-6-4-8.97.	35
Figure 4.19 Load-Displacement plot of HB-(30, 50.5)-0.010-0-6-5.91.	35
Figure 4.20 Load-Displacement plot of HB-(30, 50.5)-0.010-3-6-5.91.	36
Figure 4.21 Load-Displacement plot of HB-(30, 50.5)-0.010-6-6-5.91.	36
Figure 4.22 Load-Displacement plot of HB-(30, 50.5)-0.015-0-6-5.91.	37
Figure 4.23 Load-Displacement plot of HB-(30, 50.5)-0.015-3-6-5.91.	37
Figure 4.24 Load-Displacement plot of HB-(30, 50.5)-0.015-6-6-5.91.	38
Figure 4.25 Load-Displacement plot of HB-(30, 50.5)-0.020-0-6-5.91.	38
Figure 4.26 Load-Displacement plot of HB-(30, 50.5)-0.020-3-6-5.91.	39
Figure 4.27 Load-Displacement plot of HB-(30, 50.5)-0.020-6-6-5.91.	39
Figure 4.28 Load-Displacement plot of HB-30-0.010-(0, 3, 6)-2-18.43.	41
Figure 4.29 Load-Displacement plot of HB-30-0.015-(0, 3, 6)-2-18.43.	41
Figure 4.30 Load-Displacement plot of HB-30-0.020-(0, 3, 6)-2-18.43.	42
Figure 4.31 Load-Displacement plot of HB-50.5-0.010-(0, 3, 6)-2-18.43.	42
Figure 4.32 Load-Displacement plot of HB-50.5-0.015-(0, 3, 6)-2-18.43.	43
Figure 4.33 Load-Displacement plot of HB-50.5-0.020-(0, 3, 6)-2-18.43.	43

Figure 4.34 Load-Displacement plot of HB-30-0.010-(0, 3, 6)-4-8.97.	44
Figure 4.35 Load-Displacement plot of HB-30-0.015-(0, 3, 6)-4-8.97.	44
Figure 4.36 Load-Displacement plot of HB-30-0.020-(0, 3, 6)-4-8.97.	45
Figure 4.37 Load-Displacement plot of HB-50.5-0.010-(0, 3, 6)-4-8.97.	45
Figure 4.38 Load-Displacement plot of HB-50.5-0.015-(0, 3, 6)-4-8.97.	46
Figure 4.39 Load-Displacement plot of HB-50.5-0.020-(0, 3, 6)-4-8.97.	46
Figure 4.40 Load-Displacement plot of HB-30-0.015-(0, 3, 6)-6-5.91.	47
Figure 4.41 Load-Displacement plot of HB-30-0.020-(0, 3, 6)-6-5.91.	47
Figure 4.42 Load-Displacement plot of HB-50.5-0.010-(0, 3, 6)-6-5.91.	48
Figure 4.43 Load-Displacement plot of HB-50.5-0.015-(0, 3, 6)-6-5.91.	48
Figure 4.44 Load-Displacement plot of HB-50.5-0.020-(0, 3, 6)-6-5.91.	49
Figure 4.45 FLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=2$	50
Figure 4.46 FLG of beams with concrete strength of 50.5 (N/mm ²) and $\alpha/d_m=2$	50
Figure 4.47 FLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=3$	51
Figure 4.48 FLG of beams with concrete strength of 50.5 (N/mm ²) and $\alpha/d_m=3$	51
Figure 4.49 FLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=4$	52
Figure 4.50 FLG of beams with concrete strength of 50.5 (N/mm ²) and $\alpha/d_m=4$	52
Figure 4.51 FLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=5$	53
Figure 4.52 FLG of beams with concrete strength of 50.5 (N/mm ²) and $\alpha/d_m=5$	53
Figure 4.53 FLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=6$	54
Figure 4.54 FLG of beams with concrete strength of 50.5 (N/mm ²) and $\alpha/d_m=6$	54
Figure 4.55 FLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=7$	55
Figure 4.56 FLG of beams with concrete strength of 50.5 (N/mm ²) and $\alpha/d_m=7$	55
Figure 4.57 FLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=8$	56
Figure 4.58 FLG of beams with concrete strength of 50.5 (N/mm ²) and $\alpha/d_m=8$	56
Figure 4.59 FLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=9$	57

Figure 4.60	FLG of beams with concrete strength of 50.5 (N/mm ²) and $\alpha/d_m=9$	57
Figure 4.61	CLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=2$	58
Figure 4.62	CLG of beams with concrete strength of 50.5 (N/mm ²) and $\alpha/d_m=2$	58
Figure 4.63	CLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=3$	59
Figure 4.64	CLG of beams with concrete strength of 50.5 (N/mm ²) and $\alpha/d_m=3$	59
Figure 4.65	CLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=4$	60
Figure 4.66	CLG of beams with concrete strength of 50.5 (N/mm ²) and $\alpha/d_m=4$	60
Figure 4.67	CLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=5$	61
Figure 4.68	CLG of beams with concrete strength of 50.5 (N/mm ²) $\alpha/d_m=5$	61
Figure 4.69	CLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=6$	62
Figure 4.70	CLG of beams with concrete strength of 50.5 (N/mm ²) and $\alpha/d_m=6$	62
Figure 4.71	CLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=7$	63
Figure 4.72	CLG of beams with concrete strength of 50.5 (N/mm ²) and $\alpha/d_m=7$	63
Figure 4.73	CLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=8$	64
Figure 4.74	CLG of beams with concrete strength of 50.5 (N/mm ²) and $\alpha/d_m=8$	64
Figure 4.75	CLG of beams with concrete strength of 30 (N/mm ²) and $\alpha/d_m=9$	65
Figure 4.76	CLG of beams with concrete strength of 50.5 (N/mm ²) and α/d_m	65
Figure 4.77	Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-0-2-18.43. ...	66
Figure 4.78	Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-3-2-18.43. ...	66
Figure 4.79	Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-6-2-18.43. ...	67
Figure 4.80	Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-0-2-18.43. ...	67
Figure 4.81	Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-3-2-18.43. ...	68
Figure 4.82	Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-6-2-18.43. ...	68
Figure 4.83	Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-0-4-8.97.	69
Figure 4.84	Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-3-4-8.97.	69
Figure 4.85	Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-6-4-8.97.	70

Figure 4.86	Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-0-4-8.97. ..	70
Figure 4.87	Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-3-4-8.97. ..	71
Figure 4.88	Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-6-4-8.97. ..	71
Figure 4.89	Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-0-6-5.91.	72
Figure 4.90	Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-3-6-5.91.	72
Figure 4.91	Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-6-6-5.91.	73
Figure 4.92	Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-0-6-5.91. ..	73
Figure 4.93	Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-3-6-5.91. ..	74
Figure 4.94	Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-6-6-5.91. ..	74
Figure 4.95	Load-Displacement plot of HB-30-0.010-0-5-(5, 7.13, 10).	75
Figure 4.96	Load-Displacement plot of HB-30-0.010-3-5-(5, 7.13, 10).	75
Figure 4.97	Load-Displacement plot of HB-30-0.010-6-5-(5, 7.13, 10).	76
Figure 4.98	Load-Displacement plot of HB-30-0.015-0-5-(5, 7.13, 10).	76
Figure 4.99	Load-Displacement plot of HB-30-0.015-3-5-(5, 7.13, 10).	77
Figure 4.100	Load-Displacement plot of HB-30-0.015-6-5-(5, 7.13, 10).	77
Figure 4.101	Load-Displacement plot of HB-30-0.020-0-5-(5, 7.13, 10).	78
Figure 4.102	Load-Displacement plot of HB-30-0.020-3-5-(5, 7.13, 10).	78
Figure 4.103	Load-Displacement plot of HB-30-0.020-6-5-(5, 7.13, 10).	79
Figure 4.104	Load-Displacement plot of HB-50.5-0.010-0-5-(5, 7.13, 10).	79
Figure 4.105	Load-Displacement plot of HB-50.5-0.010-3-5-(5, 7.13, 10).	80
Figure 4.106	Load-Displacement plot of HB-50.5-0.010-6-5-(5, 7.13, 10).	80
Figure 4.107	Load-Displacement plot of HB-50.5-0.015-0-5-(5, 7.13, 10).	81
Figure 4.108	Load-Displacement plot of HB-50.5-0.015-3-5-(5, 7.13, 10).	81
Figure 4.109	Load-Displacement plot of HB-50.5-0.015-6-5-(5, 7.13, 10).	82
Figure 4.110	Load-Displacement plot of HB-50.5-0.020-0-5-(5, 7.13, 10).	82
Figure 4.111	Load-Displacement plot of HB-50.5-0.020-3-5-(5, 7.13, 10).	83

Figure 4.112 Load-Displacement plot of HB-50.5-0.020-6-5-(5, 7.13, 10).	83
Figure 4.113 L-D plot of HB-30-0.010-0-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	84
Figure 4.114 L-D plot of HB-30-0.010-3-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	84
Figure 4.115 L-D plot of HB-30-0.010-6-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	85
Figure 4.116 L-D plot of HB-30-0.015-0-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	85
Figure 4.117 L-D plot of HB-30-0.015-3-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	86
Figure 4.118 L-D plot of HB-30-0.015-6-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	86
Figure 4.119 L-D plot of HB-30-0.020-0-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	87
Figure 4.120 L-D plot of HB-30-0.020-3-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	87
Figure 4.121 L-D plot of HB-30-0.020-6-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	88
Figure 4.122 L-D plot of HB-50.5-0.010-0-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	88
Figure 4.123 L-D plot of HB-50.5-0.010-3-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	89
Figure 4.124 L-D plot of HB-50.5-0.010-6-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	89
Figure 4.125 L-D plot of HB-50.5-0.015-0-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	90
Figure 4.126 L-D plot of HB-50.5-0.015-3-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	90
Figure 4.127 L-D plot of HB-50.5-0.015-6-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	91
Figure 4.128 L-D plot of HB-50.5-0.020-0-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	91
Figure 4.129 L-D plot of HB-50.5-0.020-3-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	92
Figure 4.130 L-D plot of HB-50.5-0.020-6-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).	92
Figure 4.131 L-D plot of RB-30-0.010-0-2-0 and HB-30-0.010-0-2-18.43.	93
Figure 4.132 L-D plot of RB-30-0.010-3-2-0 and HB-30-0.010-0-3-18.43.	93
Figure 4.133 L-D plot of RB-30-0.010-6-2-0 and HB-30-0.010-6-2-18.43.	94
Figure 4.134 L-D plot of RB-30-0.010-0-3-0 and HB-30-0.010-0-3-12.09.	94
Figure 4.135 L-D plot of RB-30-0.010-3-3-0 and HB-30-0.010-3-3-12.09.	95
Figure 4.136 L-D plot of RB-30-0.010-6-3-0 and HB-30-0.010-6-3-12.09.	95
Figure 4.137 L-D plot of RB-30-0.010-0-4-0 and HB-30-0.010-0-4-8.97.	96

Figure 4.138 L-D plot of RB-30-0.010-3-4-0 and HB-30-0.010-3-4-8.97.	96
Figure 4.139 L-D plot of RB-30-0.010-6-4-0 and HB-30-0.010-6-4-8.97.	97
Figure 4.140 L-D plot of RB-30-0.010-0-5-0 and HB-30-0.010-0-5-7.13.	97
Figure 4.141 L-D plot of RB-30-0.010-3-5-0 and HB-30-0.010-3-5-7.13.	98
Figure 4.142 L-D plot of RB-30-0.010-6-5-0 and HB-30-0.010-6-5-7.13.	98
Figure 4.143 L-D plot of RB-30-0.010-0-6-0 and HB-30-0.010-0-6-5.91.	99
Figure 4.144 L-D plot of RB-30-0.010-3-6-0 and HB-30-0.010-3-6-5.91.	99
Figure 4.145 L-D plot of RB-30-0.010-6-6-0 and HB-30-0.010-6-6-5.91.	100
Figure 4.146 L-D plot of RB-30-0.010-0-7-0 and HB-30-0.010-0-7-5.04.	100
Figure 4.147 L-D plot of RB-30-0.010-3-7-0 and HB-30-0.010-3-7-5.04.	101
Figure 4.148 L-D plot of RB-30-0.010-6-7-0 and HB-30-0.010-6-7-5.04.	101
Figure 4.149 L-D plot of RB-30-0.010-0-8-0 and HB-30-0.010-0-8-4.40.	102
Figure 4.150 L-D plot of RB-30-0.010-3-8-0 and HB-30-0.010-3-8-4.40.	102
Figure 4.151 L-D plot of RB-30-0.010-6-8-0 and HB-30-0.010-6-8-4.40.	103
Figure 4.152 L-D plot of RB-30-0.010-0-9-0 and HB-30-0.010-0-9-3.90.	104
Figure 4.153 L-D plot of RB-30-0.010-3-9-0 and HB-30-0.010-3-9-3.90.	104
Figure 4.154 L-D plot of RB-30-0.010-6-9-0 and HB-30-0.010-6-9-3.90.	105
Figure 4.155 L-D plot of RB-30-0.015-0-9-0 and HB-30-0.015-0-9-3.90.	105
Figure 4.156 L-D plot of RB-30-0.015-3-9-0 and HB-30-0.015-3-9-3.90.	106
Figure 4.157 L-D plot of RB-30-0.015-6-9-0 and HB-30-0.015-6-9-3.90.	106
Figure 4.158 L-D plot of RB-30-0.020-0-9-0 and HB-30-0.020-0-9-3.90.	107
Figure 4.159 L-D plot of RB-30-0.020-3-9-0 and HB-30-0.020-3-9-3.90.	107
Figure 4.160 L-D plot of RB-30-0.020-6-9-0 and HB-30-0.020-6-9-3.90.	108
Figure 4.161 L-D plot of RB-50.5-0.010-0-9-0 and HB-50.5-0.010-0-9-3.90.	108
Figure 4.162 L-D plot of RB-50.5-0.010-3-9-0 and HB-50.5-0.010-3-9-3.90.	109
Figure 4.163 L-D plot of RB-50.5-0.010-6-9-0 and HB-50.5-0.010-6-9-3.90.	109

Figure 4.164	L-D plot of RB-50.5-0.015-0-9-0 and HB-50.5-0.015-0-9-3.90.	110
Figure 4.165	L-D plot of RB-50.5-0.015-3-9-0 and HB-50.5-0.015-3-9-3.90.	110
Figure 4.166	L-D plot of RB-50.5-0.015-6-9-0 and HB-50.5-0.015-6-9-3.90.	111
Figure 4.167	L-D plot of RB-50.5-0.020-0-9-0 and HB-50.5-0.020-0-9-3.90.	111
Figure 4.168	L-D plot of RB-50.5-0.020-3-9-0 and HB-50.5-0.020-3-9-3.90.	112
Figure 4.169	L-D plot of RB-50.5-0.020-6-9-0 and HB-50.5-0.020-6-9-3.90.	112
Figure 5.1	The relationship of SARA Studio, FReET and ATENA 2D	115
Figure 5.2	Distribution plot of sensitivity factors.	153



LIST OF SYMBOLS

α_c	Taper slop
f_c	Compressive strength of concrete
f_t	Tensile strength of concrete
E	Elastisite m of concrete
α	Shear span
d_s	Effective depth at support
d_m	Effective depth at mid-span
c	Length of the tapered part
σ_{pc}	Average prestress level at the cross section of loading point
A_1	Cross section area of tensile reinforcement bars
A_2	Cross section area of compression reinforcement bars
b_w	Width of the beam
V_{exp}	Shear capacity from the experiments.
f_{ty}	Yield strength of tensile bar
G_f	Fracture energy

LIST OF ABBREVIATIONS

FEM	Finite Element Model
SARA	Structural Analysis and Reliability Assessment
FReET	Feasible Reliability Engineering Tool
PNA	Probabilistic Nonlinear Analysis
JSCE	Japan Society of Civil Engineers
HB	Haunched Beam
LHS	Latin Hypercube Sampling
L-D	Load-Displacement
CLG	Cracking Load Graph
FLG	Failure Load Graph

CHAPTER I

INTRODUCTION

1.1 General

In today's world where technology and science are on the rise, new ways are an important issue in many projects. For this reason, with the increasing cost of materials and labor, obtaining the conditions has started to gain importance in the field of engineering. Modeling is the study of the behavior and properties of a real system by creating it in a computer environment. Many modeling made in computer environment provides insight on many issues. For example, future mishaps allow us to foresee. Thus, measures to make it easier to take. Modeling studies are carried out in many fields such as engineering, medicine, space, transportation, and astronomy.

The most important elements in a building element are its safety and economy. However, it is necessary to know in advance what such effects may occur in order to ensure that the building element is suitable for the place of construction and the purpose of use and to prevent future errors in the building. The importance of modeling work is revealed here.

Building behavior can be observed under various load conditions by modeling the building element in computer. With modeling, it is possible to examine the parts that may cause problems in the building in more detail and to make changes if deemed necessary. With these studies, the most economical sections for the building are determined. Modeling studies are more economical than experimental studies. They also take less time.

Complex engineering problems involve solutions of the same complexity. This confusion also distracts the solution phase from sensitivity. The solution of complex problems in the shortest way and closest to the correct result has led to the use of the finite element method.

The basic logic in the finite element method is to solve a complex problem by simplifying it. In this method, the solution region is divided into a large number of simple, small, interconnected, subregions called finite elements. In short, the solution of the problem, which is divided into parts connected by many nodes, can be easily done.

The finite element method has found its place in many fields today. This method is used for solving engineering problems related to heat conduction, fluid mechanics, electric and magnetic fields, as well as structural mechanics problems. One of the reasons why the method finds so many applications is the similarities between different engineering problems.

1.2 Thesis Aims

Since classical concrete could not meet the needs of modern architecture, prestressed concrete started to gain importance. With the increasing importance of prestressed concrete, its movements under load have been studied. Behavior of prestressed concrete under load depending on different parameters has been started to be investigated.

Within the scope of the thesis, the modeling of a prestressed reinforced concrete tapered beam sample, which has been experimentally studied, will be modeled in order to examine the behavior and properties of the prestressed reinforced concrete tapered beam under load. Nonlinear analysis will be made due to the properties of the materials. For analysis, ATENA 2D, a finite element program that contains nonlinear elements and can perform nonlinear analysis, will be used. After observing that the behavior of the experimental beam is similar in the computer, new models will be derived by making changes in various parameters on this beam. These models have been analyzed and their behavior will be compared. In this way, 180 PC haunched and 144 PC rectangular beams were modeled together with the experimental sample and were compared.

After evaluating the nonlinear analyzes, the probabilistic nonlinear analysis of these beams will be done with the SARA package program. The results of the beams with probabilistic nonlinear analysis will be compared.

1.3 Thesis Layout

Chapter one : In this section, information was given about the subject and then the aims of the subject were mentioned.

Chapter two: In this section, prestressed reinforced concrete is introduced in general, and provides the literature review for the prestressed concrete.

Chapter three: The experimental model was described in detail. PC tapered beams, which were later made experimental model, was modeled in the computer. Nonlinear finite element analysis was performed with the ATENA 2D program. The plot load-displacement of the experimental study and the plot load-displacement of the analytical model were compared. Both load-displacement plots have been observed to behave similarly.

Chapter four: In this chapter, the nonlinear analysis of 180 prestressed concrete tapered beams and 144 prestressed concrete rectangular beams with different parameters were been performed. The effect of different parameters of beams that were analyzed nonlinear FEM was investigated.

Chapter five: In this chapter, a probabilistic nonlinear analysis of prestressed concrete (PC) tapered beams have been performed. Probabilistic nonlinear analysis of PC tapered beams was performed by using the SARA (Structural Analysis and Reliability Assessment) Studio version 2.1.1.1 program. Histograms, sensitivity analysis, and reliability results of analyzed beams were evaluated.

Chapter six: The results of the probabilistic nonlinear analysis and the nonlinear finite element analysis were deduced. These results are explained in detail in this chapter.

CHAPTER II

LITERATURE REVIEW

2.1 General

Prestressed concrete experiments started at the end of the 19th century. Made from low to high-quality steel, then high-quality steel. These trials were unsuccessful due to the losses incurred in the pretension. First pre-tensioning with high-strength steel in 1928. Made by French Eugen Freyssinet. Thus, the first step of post-tensioning was taken.

There are many studies on prestressed concrete beams in the literature. Some of these studies are mentioned below.

Chenwei et al. study goals to clarify the shear resistance mechanism of reinforced concrete and prestressed tapered beams without stirrups. In this study, experiments were carried out on 7 beams. These beams have been tested with different parameters. In this study, the displacement-load graph of the beams whose experimental study was carried out was drawn. Then, these beams were modeled in computer environment and nonlinear analyzes were made. The experimental results and the results of the computer studies were compared [1].

Barr et al. made an evaluation of load distribution factors for prestressed concrete beams in their study. For this process, a bridge behavior determined by measuring the results of static loading tests was used to determine the reliability of the finite element method. He also investigated how various characteristics of the bridge superstructure affect the load distribution coefficients using the finite element method. They compared their results with the load distribution coefficients presented in various regulations on bridge design [2].

Sixteen beams were tested by Adheim. The analysis results of these beams were found in accordance with the load-displacement behavior obtained as a result of the experimental study. The graphs of three prestressed reinforced concrete beams in different geometries and different prestressed reinforced concrete beams, which were discussed in the study, were examined up to the nonlinear maximum load carrying point under increased load. In the experimental study, the behavior of 16 prestressed reinforced concrete beams loaded with 4-point loading process exposed to bending moment has been handled [3].

In the study conducted by Akgül and Frangopol, performance analysis of existing prestressed concrete bridges throughout their lifetime has been made. Only the superstructure elements have been considered in the study. The study was established by defining four separate categories. These are boundary state equations, random variables, real determining parameters, and constant coefficients. The results of this study were developed and applied on seven bridges [4].

Fanning tested reinforced concrete and post-tensioned beams in the laboratory and modeled them with the ANSYS finite element program. Within the scope of the study, 2 rectangular reinforced concrete beams and a T-section post-tensioned beam were used. The nonlinear analysis of the beams was done with the ANSYS 5.5 program. The experiments were carried out with displacement control under four-point loading. Fracture tests of post-tensioned beams were carried out under rotation and strain control. In the modeling, the concrete element showing the nonlinear bending behavior of the reinforced concrete system until the collapse has been used. In this element, the smeared crack model that allows cracks in the concrete is used when the reinforcement is modeled as discrete or dispersed. It was understood that the optimum strategy in modeling was controlling the mesh density and initially placing the reinforcement in its place in the beam with split modeling. As a result, it has been understood that the split crack model is a suitable numerical model in modeling reinforced concrete systems that collapse without bending [5].

Lehký et al. used three types of sensitivity analysis to provide optimum selection of the dominant random variables of concrete structures. The first method is the nonparametric statistical correlation of rank order between basic methods. The second is sensitivity analysis in terms of the coefficient of variation and the last of

them is neural network ensemble-based sensitivity analysis. All methods were used and compared for two selected concrete structures: a prestressed concrete bridge made of MPD beams and a T-shaped prestressed concrete roof beam. It was used to determine selected uncertain design parameters and then to assess load carrying capacity and reliability [18].

Leandro had worked on a finite element model for physically and geometrically nonlinear analysis of prestressed concrete beams with unbonded inner tendons under short-term loading. The reinforced concrete beam is modeled with Euler-Bernoulli nonlinear plane frame elements and total Lagrange approximation. The prestress tendon was modeled by a single polygonal element embedded in a certain subset of frame members. Geometric and material nonlinearities were taken into account for both reinforced concrete beams and prestressing tendons. Under large displacements, the internal force vector of each element and the corresponding tangent stiffness matrix was consistently derived and new expressions for the tangent stiffness operator were developed that provide the convergence ratios of the Newton-Raphson scheme [20].

CHAPTER III

EXPERIMENTAL STUDY AND ANALYTICAL MODELING

3.1 Experimental Study

The experimental study part of this thesis is taken from the article shear behavior of reinforced concrete and prestressed concrete tapered beams without stirrups. In this experimental study, prestressed and non-prestressed beams are used. The analysis results of these beams have been found in accordance with the load-displacement behavior obtained as a result of the experimental study. In the thesis study, 1 prestressed reinforced concrete beam has been used with different parameters (concrete, reinforcement ratio, different prestressing load). In the experimental study, the behavior of 7 beams loaded with a 4-point loading process, which is subjected to bending moment, is handled [1].

The details and material properties of the beams used in the experimental study are shown in Table 3.1.

Table 3.1 Detail of specimens and material properties [1].

Name	α_c (°)	f_c (N/mm ²)	α (mm)	d _s (mm)	d _m (mm)	α / d _m	c (mm)	σ_{pc} (N/mm ²)	A ₁ (mm ²)	b _w (mm)	V _{exp} (kN)
TB1	23.22	40.2	650	214	450	1.44	550	0	760.2	150	149.0
RB2	0	38.8		240	240	2.71	-			200	68.8
TB2	10.39	34.4		130			600				75.8
RB3-0	0	50.5	1250	250	250	5.00	-	3			63.3
TB3-0	7.13			100			1200				56.2
RB3-3	0			250			-				95.5
TB3-3	7.13			100			1200				106.6

TB3-3 tapered beam was used for thesis work. High strength concrete was used in the experimental study ($f_c=50.5\text{MPa}$). In this beam, D22 bars ($A_1=760.2\text{ mm}^2$) with a yield strength of 930 N/mm^2 were used as tensile longitudinal bars. Two D6 bars ($A_2=31.67\text{mm}^2$) with the yield strength of 328 N/mm^2 were used as compression bars and D6 bars (31.67 mm^2) with the yield strength of 322 N/mm^2 were used as stirrups. Moreover, the sheath and grouting were used for the prestressed beam to reduce the difference in casting procedures. The grouting used in the experiments had a compressive strength of 81 N/mm^2 .

The geometric detail and loading of the TB3-3beam were shown in Figure 3.1.

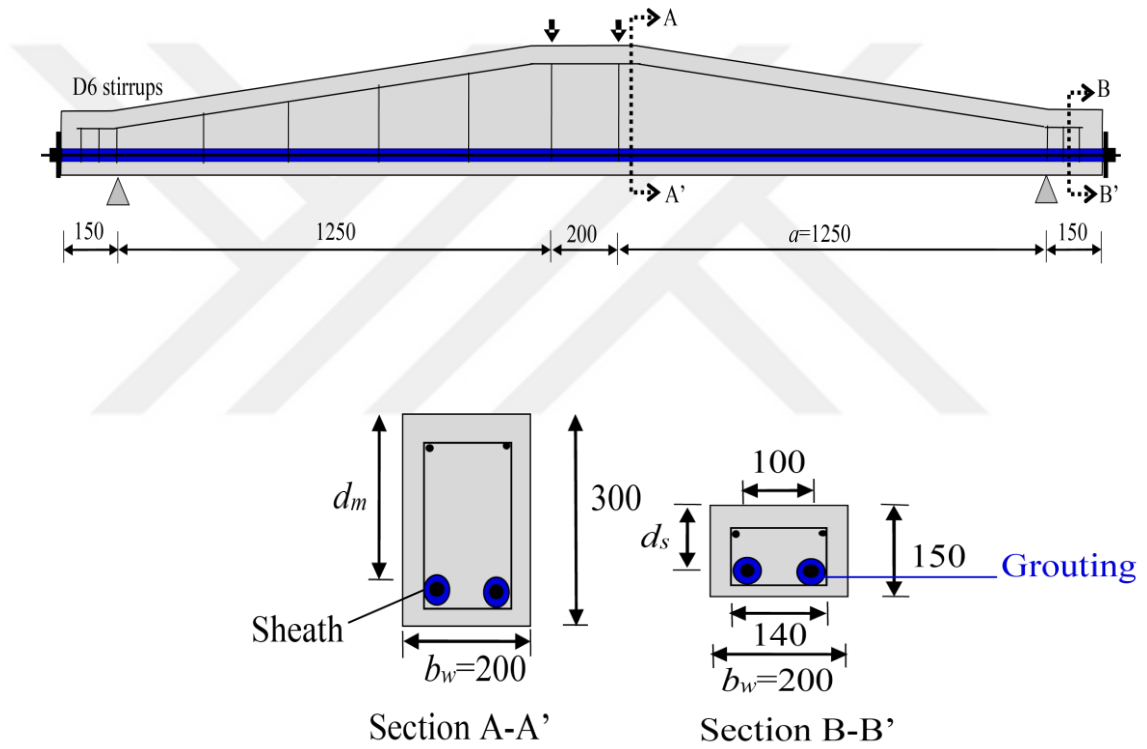


Figure 3.1 The geometric detail and loading of the TB3-3 beam [1].

3.2.1 Program of Experimental Study

A total of four prestressed beams with tapered cross-sections and rectangular cross-sections were used. Simple support was used in these beams. The test procedure of these beams was taken according to the regulation of JSCE (Japan Society of Civil Engineers) [6]. These beams are tested under 2 symmetrical loads (four point loading). The loading process of the beam used in the thesis is shown in Figure 3.2.

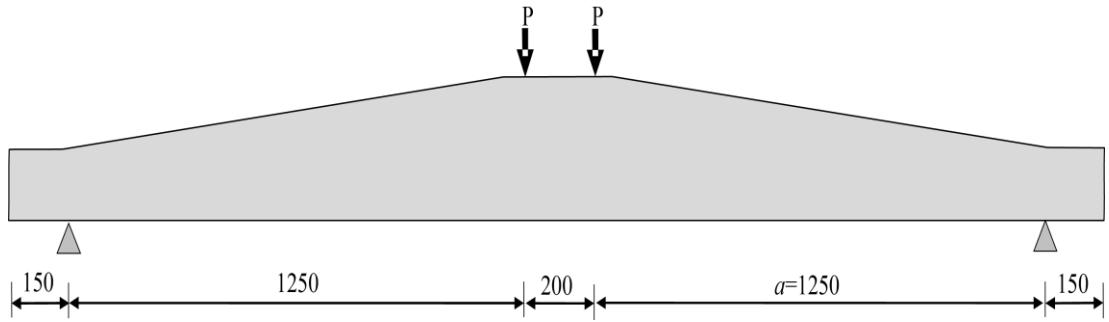


Figure 3.2 Four-point loading application in tapered prestressed beams.

3.2.2 Crackings in Tapered Prestressed Beams

In order to observe the formation of cracks in prestressed reinforced concrete beams, beam samples are painted white before testing. Cracks are marked with a pencil. As the loading process progresses, the width of the cracks is determined after each load increase. TB3-3 beam exposed to bending moment creates cracks like shown in Figure 3.3.



a) Just before peak



b) Just after peak

Figure 3.1 Crack pattern of TB3-3 beam [1].

3.2 Analytical Modeling

TB3-3 beam was used in the thesis study. The length of TB3-3 beam is 3000mm and its width is 200mm. In this beam, D22 bars ($A_s=760.2\text{mm}^2$) with yield strength of 930 N/mm^2 were used as tensile longitudinal bars. Two D6 bars ($A_s=31.67\text{mm}^2$) with yield strength of 328 N/mm^2 were used as a compression bars. And, the D6 stirrups ($A_s=31.67\text{mm}^2$) with yield strength of 322 N/mm^2 were used as a stirrups bar. The properties of TB3-3 beam used in the experimental study are given in Table 3.1.

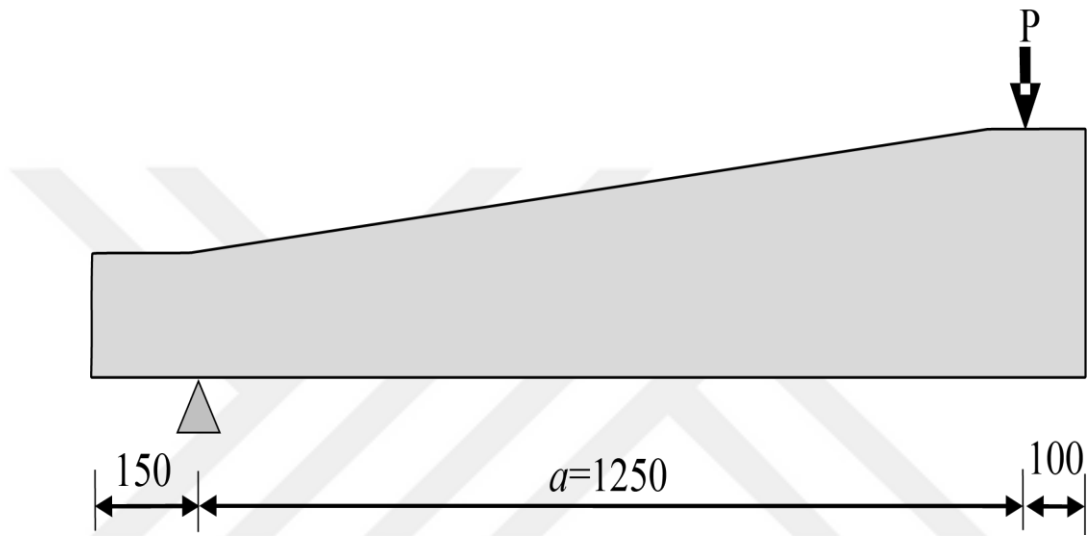


Figure 3.2 Symmetric half of TB3-3 beam.

3.2.1 Program of Analytical Modeling

The beam is symmetric around its vertical axis, therefore, only one symmetric half of the beam was analyzed.

3.2.2 ATENA 2D Finite Element Program

ATENA 2D is a package program widely used in the solution of various mechanical problems with the finite element method. The ATENA program, determined for nonlinear finite element analysis of structures, has tools specially designed for computer simulation of concrete and reinforced concrete structure behavior.

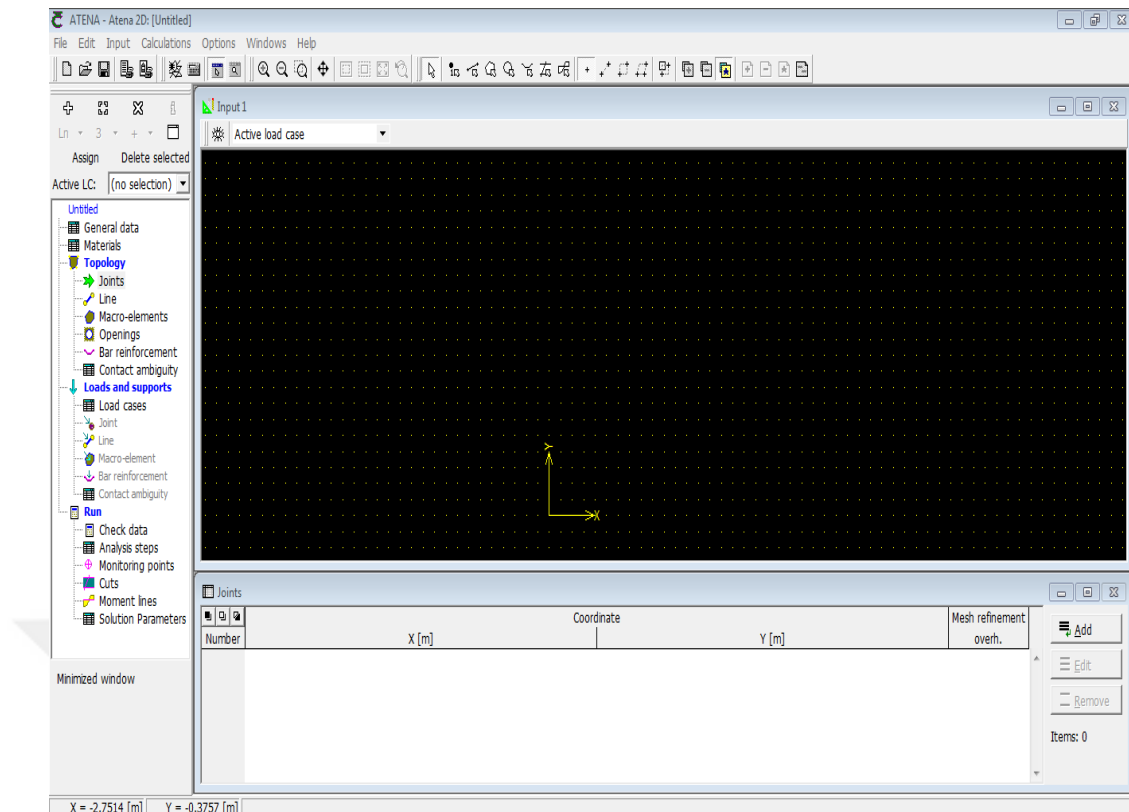


Figure 3.3 ATENA 2D software window.

3.2.3 Steps of Analysis with ATENA 2D Program

While analyzing with a finite element program, firstly the model geometry is created and the model is divided into a finite number of elements. These elements are like small units that have the characteristics of the physical environment. After the acceptance of the element and material models for these elements, boundary conditions are created, loads are applied to the necessary points and the results are obtained by analyzing. However, one of the most important points to note here is that the finite element method is a method based on nodes. In other words, the loads to be affected by the structural element are applied to the nodes and the stress and displacement values obtained as a result of the analysis are the values at the nodes. In the ATENA 2D finite element program, the steps of analysis were schematized as shown in Figure 3.5.

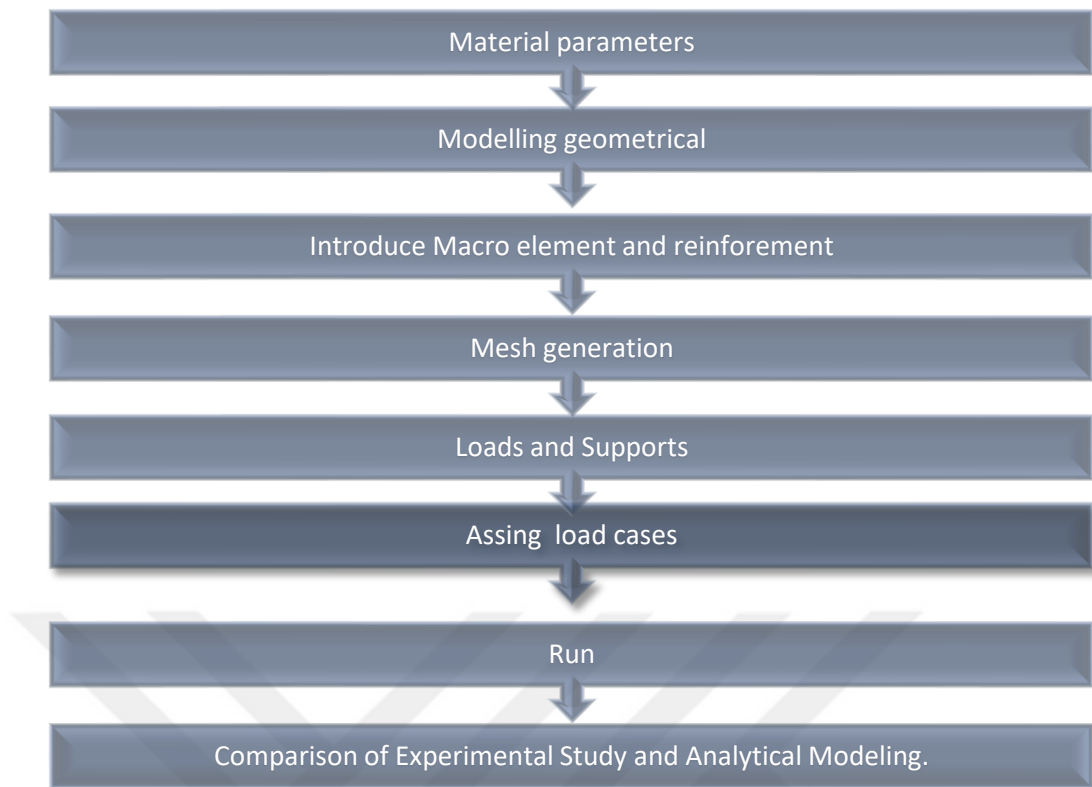


Figure 3.4 Steps of analysis with ATENA 2D finite element program.

3.2.3.1 Material Parameters

There are more than 20 element types in the ATENA 2D library. SBeta Material element is used in ATENA 2D to model concrete. In the study, the Reinforcement element was used for top reinforcement, prestressing steel, and stirrups. In addition, since the loading on the beam is 4 points, the loading plates and the supports at the ends of the beam are modeled. Plane Stress Elastic Isotropic element was used for the loading plate and supports.

Introduction of the element types used in the model

SBeta Material

The SBeta Material element is an element that is used in the modeling of concrete, can break under stress crack pressure, and has freedom at each node. Both reinforced and unreinforced concrete are modeled with this element. One of the most important properties of the element has a nonlinear material behavior.

Reinforcement

Reinforcement can be modeled in two distinct forms: discrete and smeared. Discrete reinforcement is in form of reinforcing bars and is modeled by truss elements. The smeared reinforcement is a component of composite material and can be considered either as a single (only one-constituent) material in the element under consideration or as one of the more such constituents.

Plane Stress Elastic Isotropic

It is an element that does not have crushing and cracking properties. Within the scope of the work, loading plates and beam supports were created to prevent local stress concentrations and cracks that may occur during loading on the beams. These are also modeled with the Plane Stress Elastic Isotropic element.

The element types used in ATENA 2D in the thesis study are given in Table 3.2.

Table 3.2 The element types used in ATENA 2D

Material types	ATENA 2D element
Concrete	SBeta Material
Compressive bar, tensile bar and stirrup	Reinforcement
Support and loading plate	Plane Stress Elastic Isotropic

3.2.3.2 Modelling Geometrical (Topology)

When creating the geometry of the building element to be analyzed, it is important to consider the dimension of the problem. In the analysis for which a two-dimensional solution is sufficient, it is sufficient to create lines from points and to create areas from lines.

3.2.3.3 Introduce Macro Element and Reinforcement

In this study, first, the joints were taken according to geometry and the joints were connected by lines according to geometry. After the definition of geometrical lines, the next step is to connect these lines to form areas. In ATENA 2D areas are called macro- elements. Concrete and steel plates were created with these areas. After the

concrete and steel plates were formed with these areas, the reinforcements were assigned. In the ATENA 2D reinforcements are called Bar Reinforcement.

3.2.3.4 Mesh Generation

The process of dividing an interval into intervals smaller than itself is called mesh. An important point to be considered in the meshing process is that it creates a mesh density. Because mesh density is very important for the precision of the results. In addition, keeping the mesh density high causes the analysis time to be too long and the computer capacity to be strained. Another important point in the meshing process is that there should be harmony between the dimensions of the elements formed as a result of the mesh [7]. The finite element mesh quality has a very important influence on the quality of the analysis results, the speed, and memory requirements. Refining only the important parts can save a lot of processor time and disk space [8].

The meshing in ATENA 2D is fully automatic. Depending on the size of the macro elements defined, a finite element mesh is automatically created [8].

3.2.3.5 Supports and Loads

This section describes the definition of supports and loads for TB3-3beam.

3.2.3.6 Assing Load Cases

Support load

The analyzed beam was supported at the bottom steel plate in the vertical direction. Point and line support were used in the TB3-3 beam. Simple support was used in the experimental study. These boundary conditions were taken into consideration while creating the beam models. At one end of the beam, it is constant in the x-direction and free in the y-direction. The other end is constant in the x-direction and free in the y-direction. In addition, since the beam was geometrically symmetrical, half of the beam was modeled. To define the symmetrical axis of the model, the nodes passing through this axis were kept fixed displacement in the x-direction, and they also were kept free displacement in the y-direction.

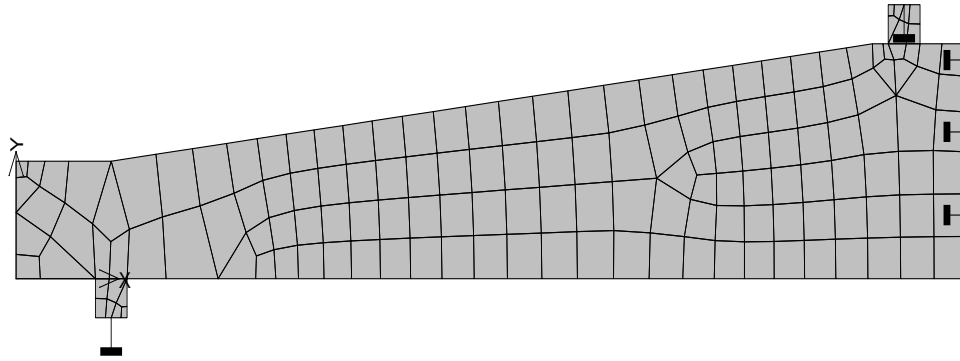


Figure 3.5 Supports and Loads applications in the analytical model.

Prescribed load

The beam is loaded at the top steel plate. Since this is related to the maximum load-carrying capacity of the beam, it means that the structural response must also be observed in the post-peak regime. The easiest method to accomplish this is by loading the beam by prescribed displacements at the top steel plate. It is possible to apply the loading by vertical forces, which will be increased in each load step.

Prestressing Load

The first load step corresponds to prestressing. In this step, total prestressing force of reinforcement 0.18 MN is applied to reinforcement.

3.2.3.7 Run

In this section, the number of steps, monitoring points, and method of analysis were determined.

A load step number was determined for analysis according to the model geometry and loading conditions.

Newton-Raphson Method

Newton-Raphson method was used for ATENA 2D nonlinear analysis. In the Newton-Raphson method, the load applied to the element is divided into load steps. These load steps consist of load increments [9].

3.2.3.8 Comparison of Experimental Study and Analytical Modeling

After analytical modeling was run, the analysis results were compared with the experimental study. The properties of the beam used in the experimental study were modeled in the computer environment. Both load-displacement graphs have similar behaviors. As seen in TB3-3, the load-displacement curve of TB3-3 was found to be at almost the same slope as the load-displacement curve of the experimental study from the initial stages of load application to reaching the failure load. The comparison of the analysis and experimental results of the beam is shown in Figure 3.8.

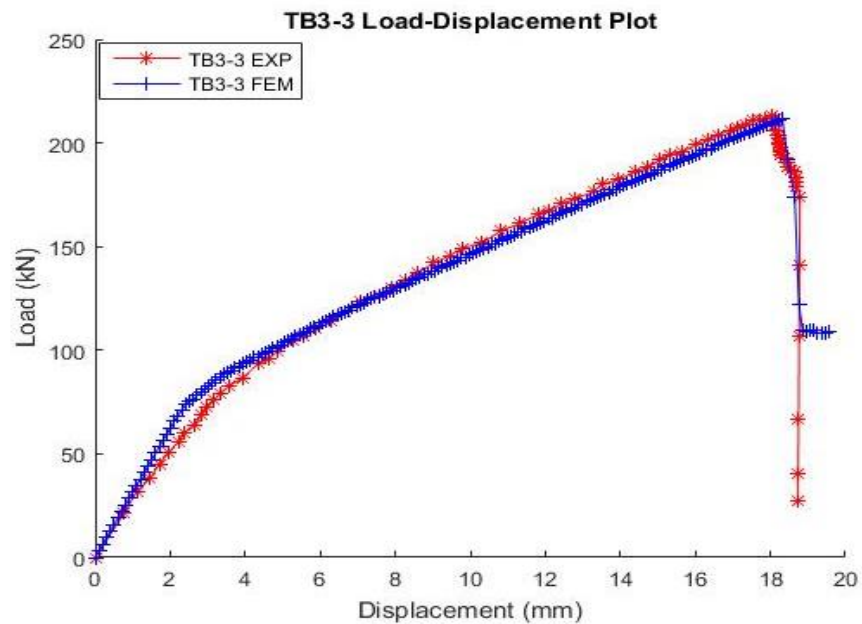


Figure 3.6 Load-displacement plot of TB3-3 beam



Figure 3.7 Just before peak of TB3-3 beam in EXP [1].

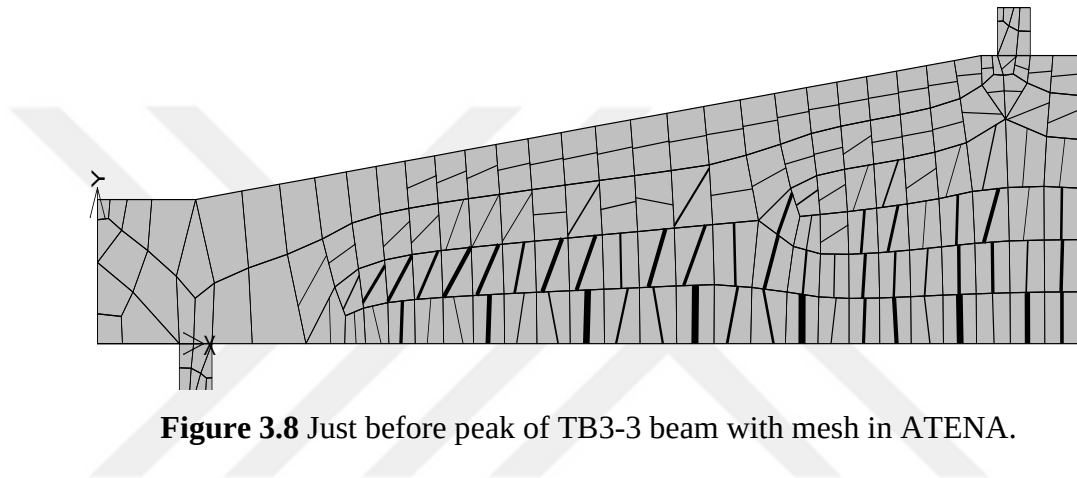


Figure 3.8 Just before peak of TB3-3 beam with mesh in ATENA.

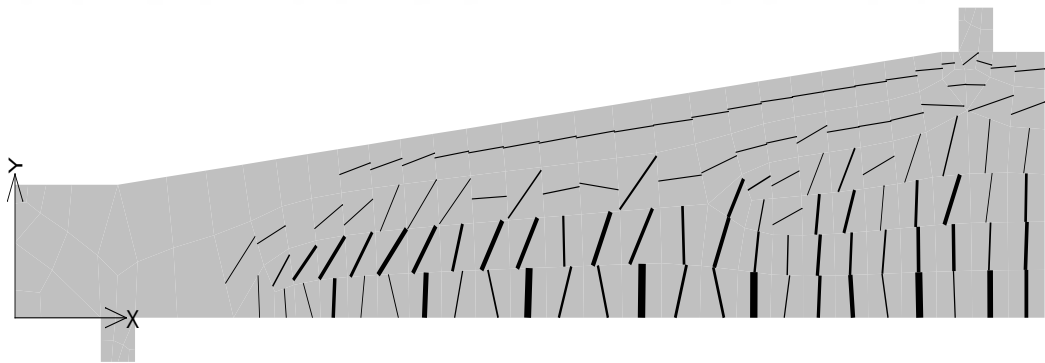


Figure 3.9 Just before peak of TB3-3 beam without mesh in ATENA.



Figure 3.10 After peak of TB3-3 beam in EXP [1].

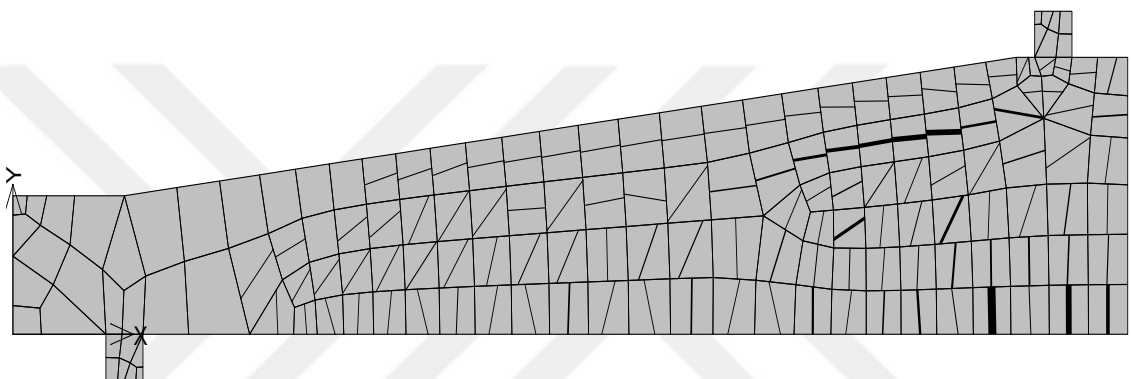


Figure 3.11 Just after peak of TB3-3 beam with mesh in ATENA.

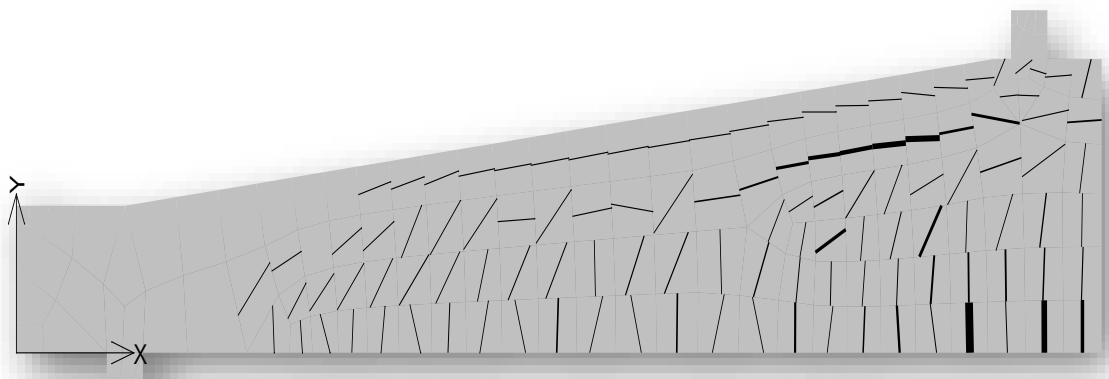


Figure 3.12 Just after peak of TB3-3 beam without mesh in ATENA.

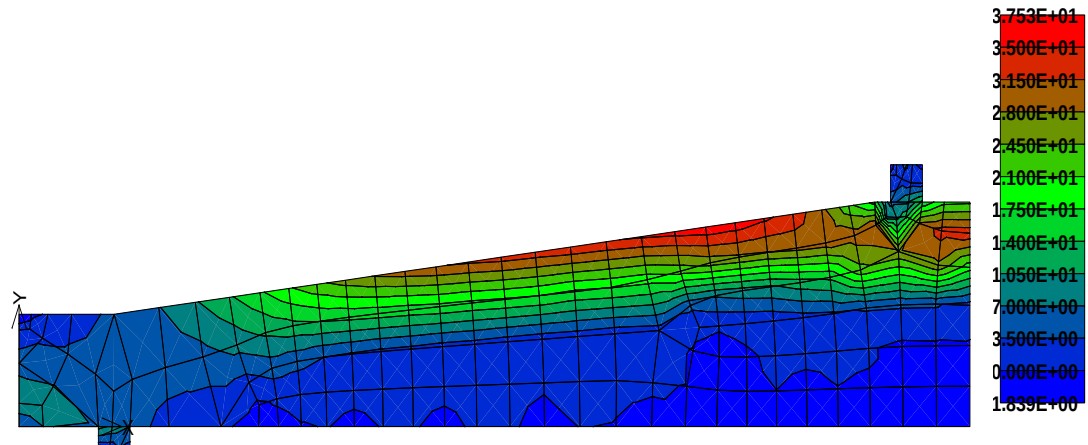


Figure 3.13 Stress of TB3-3 beam

As seen in Figure 3.8, the load-displacement curve of the TB3-3 beam continued at almost the same slope with the load-displacement curve of the experimental study from the first stages of application to the failure load.

Table 3.3 Comparison of failure load and displacement of TB3-3 beam.

Beam	Experimental Failure Load (kN)	Analysis Failure Load (kN)	Error Rate	Experimental Displacement Load (mm)	Analysis Displacement Load (mm)	Error Rate
TB3-3	213.2	211.4	0.8%	18	18	0%

It was observed that there was a displacement of about 0.8% in the failure load value obtained in the analytical result and around 0% in the maximum displacement values. And these results were determined within acceptable limits in terms of the finite element method. In addition, when the cracking behaviors were examined, it was observed that they behaved similarly.

CHAPTER IV

PARAMETRIC WORK AND EVALUATION

In this chapter, the nonlinear analysis of 180 prestressed concrete tapered beams and 144 prestressed concrete rectangular beams with different parameters were been performed. The effect of different parameters of beams that were analyzed nonlinear FEM was investigated.

The parameters examined are as follows:

- Prestressing force
- Tensile bars ratio
- Taper slop
- α/d_m ratio
- compressive strength of concrete

All beams were named as in Figure 4.1 below.

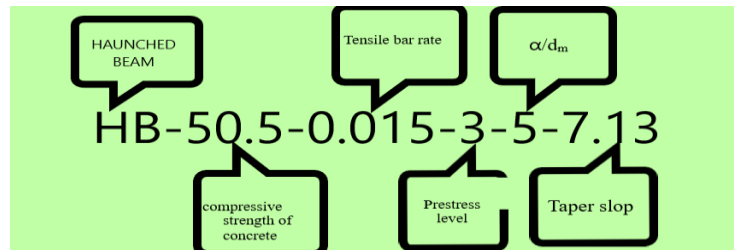


Figure 4.1 Naming the beams

Taper angle, compressive strength of concrete, prestress level, tensile reinforcement bars area cracking load, and failure load were shown in Table 4.1

Table 4.1 HB beams detail and loading

Name	α_c (°)	f_c' (N/mm ²)	α (mm)	d_s (mm)	d_m (mm)	α/d	c (mm)	σ_{pc} (N/mm ²)	A_s (mm ²)	b_w (mm)	p_{cr} (kN)	p_{ult} (kN)
HB-30-0.010-0-2-18.43	18.43	30	500	100	250	2	450	0	500	200	42	237
HB-30-0.010-3-2-18.43	18.43	30	500	100	250	2	450	3	500	200	162	288
HB-30-0.010-6-2-18.43	18.43	30	500	100	250	2	450	6	500	200	259	374
HB-30-0.015-0-2-18.43	18.43	30	500	100	250	2	450	0	760.2	200	43	278
HB-30-0.015-3-2-18.43	18.43	30	500	100	250	2	450	3	760.2	200	165	338
HB-30-0.015-6-2-18.43	18.43	30	500	100	250	2	450	6	760.2	200	268	382
HB-30-0.020-0-2-18.43	18.43	30	500	100	250	2	450	0	1000	200	49	283
HB-30-0.020-3-2-18.43	18.43	30	500	100	250	2	450	3	1000	200	169	348
HB-30-0.020-6-2-18.43	18.43	30	500	100	250	2	450	6	1000	200	275	371
HB-50.5-0.010-0-2-18.43	18.43	50.5	500	100	250	2	450	0	500	200	58	346
HB-50.5-0.010-3-2-18.43	18.43	50.5	500	100	250	2	450	3	500	200	182	379
HB-50.5-0.010-6-2-18.43	18.43	50.5	500	100	250	2	450	6	500	200	278	437
HB-50.5-0.015-0-2-18.43	18.43	50.5	500	100	250	2	450	0	760.2	200	59	397
HB-50.5-0.015-3-2-18.43	18.43	50.5	500	100	250	2	450	3	760.2	200	185	418
HB-50.5-0.015-6-2-18.43	18.43	50.5	500	100	250	2	450	6	760.2	200	300	504
HB-50.5-0.020-0-2-18.43	18.43	50.5	500	100	250	2	450	0	1000	200	60	347
HB-50.5-0.020-3-2-18.43	18.43	50.5	500	100	250	2	450	3	1000	200	198	425
HB-50.5-0.020-6-2-18.43	18.43	50.5	500	100	250	2	450	6	1000	200	297	517
HB-30-0.010-0-3-12.09	12.09	30	750	100	250	3	700	0	500	200	30	191
HB-30-0.010-3-3-12.09	12.09	30	750	100	250	3	700	3	500	200	109	240
HB-30-0.010-6-3-12.09	12.09	30	750	100	250	3	700	6	500	200	171	263
HB-30-0.015-0-3-12.09	12.09	30	750	100	250	3	700	0	760.2	200	32	219
HB-30-0.015-3-3-12.09	12.09	30	750	100	250	3	700	3	760.2	200	110	263
HB-30-0.015-6-3-12.09	12.09	30	750	100	250	3	700	6	760.2	200	181	285
HB-30-0.020-0-3-12.09	12.09	30	750	100	250	3	700	0	1000	200	32	239
HB-30-0.020-3-3-12.09	12.09	30	750	100	250	3	700	3	1000	200	105	268
HB-30-0.020-6-3-12.09	12.09	30	750	100	250	3	700	6	1000	200	178	294
HB-50.5-0.010-0-3-12.09	12.09	50.5	750	100	250	3	700	0	500	200	31	253
HB-50.5-0.010-3-3-12.09	12.09	50.5	750	100	250	3	700	3	500	200	115	293
HB-50.5-0.010-6-3-12.09	12.09	50.5	750	100	250	3	700	6	500	200	192	291
HB-50.5-0.015-0-3-12.09	12.09	50.5	750	100	250	3	700	0	760.2	200	39	301
HB-50.5-0.015-3-3-12.09	12.09	50.5	750	100	250	3	700	3	760.2	200	120	336
HB-50.5-0.015-6-3-12.09	12.09	50.5	750	100	250	3	700	6	760.2	200	199	374
HB-50.5-0.020-0-3-12.09	12.09	50.5	750	100	250	3	700	0	1000	200	40	323
HB-50.5-0.020-3-3-12.09	12.09	50.5	750	100	250	3	700	3	1000	200	125	365
HB-50.5-0.020-6-3-12.09	12.09	50.5	750	100	250	3	700	6	1000	200	200	387
HB-30-0.010-0-4-8.97	8.97	30	1000	100	250	4	950	0	500	200	20	142
HB-30-0.010-3-4-8.97	8.97	30	1000	100	250	4	950	3	500	200	79	187
HB-30-0.010-6-4-8.97	8.97	30	1000	100	250	4	950	6	500	200	135	196
HB-30-0.015-0-4-8.97	8.97	30	1000	100	250	4	950	0	760.2	200	21	157
HB-30-0.015-3-4-8.97	8.97	30	1000	100	250	4	950	3	760.2	200	82	210
HB-30-0.015-6-4-8.97	8.97	30	1000	100	250	4	950	6	760.2	200	136	218
HB-30-0.020-0-4-8.97	8.97	30	1000	100	250	4	950	0	1000	200	22	174
HB-30-0.020-3-4-8.97	8.97	30	1000	100	250	4	950	3	1000	200	82	220
HB-30-0.020-6-4-8.97	8.97	30	1000	100	250	4	950	6	1000	200	148	224
HB-50.5-0.010-0-4-8.97	8.97	50.5	1000	100	250	4	950	0	500	200	23	204
HB-50.5-0.010-3-4-8.97	8.97	50.5	1000	100	250	4	950	3	500	200	86	214
HB-50.5-0.010-6-4-8.97	8.97	50.5	1000	100	250	4	950	6	500	200	150	219
HB-50.5-0.015-0-4-8.97	8.97	50.5	1000	100	250	4	950	0	760.2	200	27	229
HB-50.5-0.015-3-4-8.97	8.97	50.5	1000	100	250	4	950	3	760.2	200	88	259
HB-50.5-0.015-6-4-8.97	8.97	50.5	1000	100	250	4	950	6	760.2	200	152	282
HB-50.5-0.020-0-4-8.97	8.97	50.5	1000	100	250	4	950	0	1000	200	29	248
HB-50.5-0.020-3-4-8.97	8.97	50.5	1000	100	250	4	950	3	1000	200	96	278
HB-50.5-0.020-6-4-8.97	8.97	50.5	1000	100	250	4	950	6	1000	200	156	298
HB-30-0.010-0-5-7.13	7.13	30	1250	100	250	5	1200	0	500	200	16	115
HB-30-0.010-3-5-7.13	7.13	30	1250	100	250	5	1200	3	500	200	66	155
HB-30-0.010-6-5-7.13	7.13	30	1250	100	250	5	1200	6	500	200	108	159
HB-30-0.015-0-5-7.13	7.13	30	1250	100	250	5	1200	0	760.2	200	18	133
HB-30-0.015-3-5-7.13	7.13	30	1250	100	250	5	1200	3	760.2	200	69	169
HB-30-0.015-6-5-7.13	7.13	30	1250	100	250	5	1200	6	760.2	200	110	180
HB-30-0.020-0-5-7.13	7.13	30	1250	100	250	5	1200	0	1000	200	19	146
HB-30-0.020-3-5-7.13	7.13	30	1250	100	250	5	1200	3	1000	200	70	181
HB-30-0.020-6-5-7.13	7.13	30	1250	100	250	5	1200	6	1000	200	115	189

Table 4.1 Cont.

HB-50.5-0.010-0-5-7.13	7.13	50.5	1250	100	250	5	1200	0	500	200	22	167
HB-50.5-0.010-3-5-7.13	7.13	50.5	1250	100	250	5	1200	3	500	200	72	174
HB-50.5-0.010-6-5-7.13	7.13	50.5	1250	100	250	5	1200	6	500	200	118	176
HB-50.5-0.015-0-5-7.13	7.13	50.5	1250	100	250	5	1200	0	760.2	200	22	190
HB-50.5-0.015-3-5-7.13	7.13	50.5	1250	100	250	5	1200	3	760.2	200	73	211
HB-50.5-0.015-6-5-7.13	7.13	50.5	1250	100	250	5	1200	6	760.2	200	122	232
HB-50.5-0.020-0-5-7.13	7.13	50.5	1250	100	250	5	1200	0	1000	200	23	210
HB-50.5-0.020-3-5-7.13	7.13	50.5	1250	100	250	5	1200	3	1000	200	75	228
HB-50.5-0.020-6-5-7.13	7.13	50.5	1250	100	250	5	1200	6	1000	200	125	245
HB-30-0.010-0-6-5.91	5.91	30	1500	100	250	6	1450	0	500	200	14	97
HB-30-0.010-3-6-5.91	5.91	30	1500	100	250	6	1450	3	500	200	54	129
HB-30-0.010-6-6-5.91	5.91	30	1500	100	250	6	1450	6	500	200	91	132
HB-30-0.015-0-6-5.91	5.91	30	1500	100	250	6	1450	0	760.2	200	15	112
HB-30-0.015-3-6-5.91	5.91	30	1500	100	250	6	1450	3	760.2	200	58	142
HB-30-0.015-6-6-5.91	5.91	30	1500	100	250	6	1450	6	760.2	200	93	146
HB-30-0.020-0-6-5.91	5.91	30	1500	100	250	6	1450	0	1000	200	16	122
HB-30-0.020-3-6-5.91	5.91	30	1500	100	250	6	1450	3	1000	200	59	152
HB-30-0.020-6-6-5.91	5.91	30	1500	100	250	6	1450	6	1000	200	94	153
HB-50.5-0.010-0-6-5.91	5.91	50.5	1500	100	250	6	1450	0	500	200	19	140
HB-50.5-0.010-3-6-5.91	5.91	50.5	1500	100	250	6	1450	3	500	200	59	145
HB-50.5-0.010-6-6-5.91	5.91	50.5	1500	100	250	6	1450	6	500	200	99	147
HB-50.5-0.015-0-6-5.91	5.91	50.5	1500	100	250	6	1450	0	760.2	200	19	160
HB-50.5-0.015-3-6-5.91	5.91	50.5	1500	100	250	6	1450	3	760.2	200	63	176
HB-50.5-0.015-6-6-5.91	5.91	50.5	1500	100	250	6	1450	6	760.2	200	100	201
HB-50.5-0.020-0-6-5.91	5.91	50.5	1500	100	250	6	1450	0	1000	200	20	176
HB-50.5-0.020-3-6-5.91	5.91	50.5	1500	100	250	6	1450	3	1000	200	63	190
HB-50.5-0.020-6-6-5.91	5.91	50.5	1500	100	250	6	1450	6	1000	200	102	207
HB-30-0.010-0-7-5.04	5.04	30	1750	100	250	7	1700	0	500	200	10	85
HB-30-0.010-3-7-5.04	5.04	30	1750	100	250	7	1700	3	500	200	46	111
HB-30-0.010-6-7-5.04	5.04	30	1750	100	250	7	1700	6	500	200	79	113
HB-30-0.015-0-7-5.04	5.04	30	1750	100	250	7	1700	0	760.2	200	12	97
HB-30-0.015-3-7-5.04	5.04	30	1750	100	250	7	1700	3	760.2	200	47	121
HB-30-0.015-6-7-5.04	5.04	30	1750	100	250	7	1700	6	760.2	200	81	128
HB-30-0.020-0-7-5.04	5.04	30	1750	100	250	7	1700	0	1000	200	14	106
HB-30-0.020-3-7-5.04	5.04	30	1750	100	250	7	1700	3	1000	200	48	130
HB-30-0.020-6-7-5.04	5.04	30	1750	100	250	7	1700	6	1000	200	82	134
HB-50.5-0.010-0-7-5.04	5.04	50.5	1750	100	250	7	1700	0	500	200	15	119
HB-50.5-0.010-3-7-5.04	5.04	50.5	1750	100	250	7	1700	3	500	200	52	124
HB-50.5-0.010-6-7-5.04	5.04	50.5	1750	100	250	7	1700	6	500	200	58	124
HB-50.5-0.015-0-7-5.04	5.04	50.5	1750	100	250	7	1700	0	760.2	200	17	140
HB-50.5-0.015-3-7-5.04	5.04	50.5	1750	100	250	7	1700	3	760.2	200	52	154
HB-50.5-0.015-6-7-5.04	5.04	50.5	1750	100	250	7	1700	6	760.2	200	89	172
HB-50.5-0.020-0-7-5.04	5.04	50.5	1750	100	250	7	1700	0	1000	200	18	153
HB-50.5-0.020-3-7-5.04	5.04	50.5	1750	100	250	7	1700	3	1000	200	52	164
HB-50.5-0.020-6-7-5.04	5.04	50.5	1750	100	250	7	1700	6	1000	200	87	179
HB-30-0.010-0-8-4.40	4.40	30	2000	100	250	8	1950	0	500	200	10	79
HB-30-0.010-3-8-4.40	4.40	30	2000	100	250	8	1950	3	500	200	41	96
HB-30-0.010-6-8-4.40	4.40	30	2000	100	250	8	1950	6	500	200	67	99
HB-30-0.015-0-8-4.40	4.40	30	2000	100	250	8	1950	0	760.2	200	10	89
HB-30-0.015-3-8-4.40	4.40	30	2000	100	250	8	1950	3	760.2	200	41	106
HB-30-0.015-6-8-4.40	4.40	30	2000	100	250	8	1950	6	760.2	200	67	109
HB-30-0.020-0-8-4.40	4.40	30	2000	100	250	8	1950	0	1000	200	11	95
HB-30-0.020-3-8-4.40	4.40	30	2000	100	250	8	1950	3	1000	200	42	114
HB-30-0.020-6-8-4.40	4.40	30	2000	100	250	8	1950	6	1000	200	68	113
HB-50.5-0.010-0-8-4.40	4.40	50.5	2000	100	250	8	1950	0	500	200	13	108
HB-50.5-0.010-3-8-4.40	4.40	50.5	2000	100	250	8	1950	3	500	200	44	108
HB-50.5-0.010-6-8-4.40	4.40	50.5	2000	100	250	8	1950	6	500	200	72	109
HB-50.5-0.015-0-8-4.40	4.40	50.5	2000	100	250	8	1950	0	760.2	200	14	124
HB-50.5-0.015-3-8-4.40	4.40	50.5	2000	100	250	8	1950	3	760.2	200	44	137
HB-50.5-0.015-6-8-4.40	4.40	50.5	2000	100	250	8	1950	6	760.2	200	73	151
HB-50.5-0.020-0-8-4.40	4.40	50.5	2000	100	250	8	1950	0	1000	200	14	136
HB-50.5-0.020-3-8-4.40	4.40	50.5	2000	100	250	8	1950	3	1000	200	45	146
HB-50.5-0.020-6-8-4.40	4.40	50.5	2000	100	250	8	1950	6	1000	200	76	158
HB-30-0.010-0-9-3.90	3.90	30	2250	100	250	9	2200	0	500	200	9	70
HB-30-0.010-3-9-3.90	3.90	30	2250	100	250	9	2200	3	500	200	36	85
HB-30-0.010-6-9-3.90	3.90	30	2250	100	250	9	2200	6	500	200	60	88

Table 4.1. Cont.

HB-30-0.015-0-9-3.90	3.90	30	2250	100	250	9	2200	0	760.2	200	9	78
HB-30-0.015-3-9-3.90	3.90	30	2250	100	250	9	2200	3	760.2	200	38	94
HB-30-0.015-6-9-3.90	3.90	30	2250	100	250	9	2200	6	760.2	200	61	98
HB-30-0.020-0-9-3.90	3.90	30	2250	100	250	9	2200	0	1000	200	9	85
HB-30-0.020-3-9-3.90	3.90	30	2250	100	250	9	2200	3	1000	200	38	101
HB-30-0.020-6-9-3.90	3.90	30	2250	100	250	9	2200	6	1000	200	62	99
HB-50.5-0.010-0-9-3.90	3.90	50.5	2250	100	250	9	2200	0	500	200	11	96
HB-50.5-0.010-3-9-3.90	3.90	50.5	2250	100	250	9	2200	3	500	200	39	96
HB-50.5-0.010-6-9-3.90	3.90	50.5	2250	100	250	9	2200	6	500	200	63	97
HB-50.5-0.015-0-9-3.90	3.90	50.5	2250	100	250	9	2200	0	760.2	200	11	111
HB-50.5-0.015-3-9-3.90	3.90	50.5	2250	100	250	9	2200	3	760.2	200	41	124
HB-50.5-0.015-6-9-3.90	3.90	50.5	2250	100	250	9	2200	6	760.2	200	64	129
HB-50.5-0.020-0-9-3.90	3.90	50.5	2250	100	250	9	2200	0	1000	200	13	123
HB-50.5-0.020-3-9-3.90	3.90	50.5	2250	100	250	9	2200	3	1000	200	41	132
HB-50.5-0.020-6-9-3.90	3.90	50.5	2250	100	250	9	2200	6	1000	200	67	141
HB-30-0.010-0-5-5	5	30	1250	100	250	5	1200	0	500	200	15	112
HB-30-0.010-3-5-5	5	30	1250	100	250	5	1200	3	500	200	68	153
HB-30-0.010-6-5-5	5	30	1250	100	250	5	1200	6	500	200	117	159
HB-30-0.015-0-5-5	5	30	1250	100	250	5	1200	0	760.2	200	18	130
HB-30-0.015-3-5-5	5	30	1250	100	250	5	1200	3	760.2	200	69	166
HB-30-0.015-6-5-5	5	30	1250	100	250	5	1200	6	760.2	200	116	181
HB-30-0.020-0-5-5	5	30	1250	100	250	5	1200	0	1000	200	21	143
HB-30-0.020-3-5-5	5	30	1250	100	250	5	1200	3	1000	200	69	175
HB-30-0.020-6-5-5	5	30	1250	100	250	5	1200	6	1000	200	117	187
HB-50.5-0.010-0-5-5	5	50.5	1250	100	250	5	1200	0	500	200	22	167
HB-50.5-0.010-3-5-5	5	50.5	1250	100	250	5	1200	3	500	200	73	174
HB-50.5-0.010-6-5-5	5	50.5	1250	100	250	5	1200	6	500	200	120	175
HB-50.5-0.015-0-5-5	5	50.5	1250	100	250	5	1200	0	760.2	200	25	186
HB-50.5-0.015-3-5-5	5	50.5	1250	100	250	5	1200	3	760.2	200	74	206
HB-50.5-0.015-6-5-5	5	50.5	1250	100	250	5	1200	6	760.2	200	122	242
HB-50.5-0.020-0-5-5	5	50.5	1250	100	250	5	1200	0	1000	200	25	202
HB-50.5-0.020-3-5-5	5	50.5	1250	100	250	5	1200	3	1000	200	74	228
HB-50.5-0.020-6-5-5	5	50.5	1250	100	250	5	1200	6	1000	200	122	246
HB-30-0.010-0-5-10	10	30	1250	100	250	5	1200	0	500	200	12	100
HB-30-0.010-3-5-10	10	30	1250	100	250	5	1200	3	500	200	65	123
HB-30-0.010-6-5-10	10	30	1250	100	250	5	1200	6	500	200	104	150
HB-30-0.015-0-5-10	10	30	1250	100	250	5	1200	0	760.2	200	14	109
HB-30-0.015-3-5-10	10	30	1250	100	250	5	1200	3	760.2	200	64	125
HB-30-0.015-6-5-10	10	30	1250	100	250	5	1200	6	760.2	200	104	150
HB-30-0.020-0-5-10	10	30	1250	100	250	5	1200	0	1000	200	15	115
HB-30-0.020-3-5-10	10	30	1250	100	250	5	1200	3	1000	200	65	128
HB-30-0.020-6-5-10	10	30	1250	100	250	5	1200	6	1000	200	104	148
HB-50.5-0.010-0-5-10	10	50.5	1250	100	250	5	1200	0	500	200	16	156
HB-50.5-0.010-3-5-10	10	50.5	1250	100	250	5	1200	3	500	200	70	174
HB-50.5-0.010-6-5-10	10	50.5	1250	100	250	5	1200	6	500	200	116	175
HB-50.5-0.015-0-5-10	10	50.5	1250	100	250	5	1200	0	760.2	200	20	171
HB-50.5-0.015-3-5-10	10	50.5	1250	100	250	5	1200	3	760.2	200	71	186
HB-50.5-0.015-6-5-10	10	50.5	1250	100	250	5	1200	6	760.2	200	117	207
HB-50.5-0.020-0-5-10	10	50.5	1250	100	250	5	1200	0	1000	200	20	182
HB-50.5-0.020-3-5-10	10	50.5	1250	100	250	5	1200	3	1000	200	70	190
HB-50.5-0.020-6-5-10	10	50.5	1250	100	250	5	1200	6	1000	200	116	209
RB-30-0.010-0-5-0	0	30	1250	100	250	5	1200	0	500	200	19	107
RB-30-0.010-3-5-0	0	30	1250	100	250	5	1200	3	500	200	67	145
RB-30-0.010-6-5-0	0	30	1250	100	250	5	1200	6	500	200	112	157
RB-30-0.015-0-5-0	0	30	1250	100	250	5	1200	0	760.2	200	19	118
RB-30-0.015-3-5-0	0	30	1250	100	250	5	1200	3	760.2	200	69	163
RB-30-0.015-6-5-0	0	30	1250	100	250	5	1200	6	760.2	200	114	162
RB-30-0.020-0-5-0	0	30	1250	100	250	5	1200	0	1000	200	22	133
RB-30-0.020-3-5-0	0	30	1250	100	250	5	1200	3	1000	200	71	170
RB-30-0.020-6-5-0	0	30	1250	100	250	5	1200	6	1000	200	114	179
RB-50.5-0.010-0-5-0	0	50.5	1250	100	250	5	1200	0	500	200	24	151
RB-50.5-0.010-3-5-0	0	50.5	1250	100	250	5	1200	3	500	200	74	172
RB-50.5-0.010-6-5-0	0	50.5	1250	100	250	5	1200	6	500	200	121	175
RB-50.5-0.015-0-5-0	0	50.5	1250	100	250	5	1200	0	500	200	24	168
RB-50.5-0.015-3-5-0	0	50.5	1250	100	250	5	1200	3	500	200	75	203

RB-50.5-0.015-6-5-0	0	50.5	1250	100	250	5	1200	6	500	200	121	211
RB-50.5-0.020-0-5-0	0	50.5	1250	100	250	5	1200	0	500	200	27	179
RB-50.5-0.020-3-5-0	0	50.5	1250	100	250	5	1200	3	500	200	77	213
RB-50.5-0.020-6-5-0	0	50.5	1250	100	250	5	1200	6	500	200	122	231
RB-30-0.010-0-2-0	0	30	500	100	250	2	450	0	500	200	45	221
RB-30-0.010-3-2-0	0	30	500	100	250	2	450	3	500	200	162	305
RB-30-0.010-6-2-0	0	30	500	100	250	2	450	6	500	200	250	340
RB-30-0.015-0-2-0	0	30	500	100	250	2	450	0	760.2	200	46	237
RB-30-0.015-3-2-0	0	30	500	100	250	2	450	3	760.2	200	177	318
RB-30-0.015-6-2-0	0	30	500	100	250	2	450	6	760.2	200	252	341
RB-30-0.020-0-2-0	0	30	500	100	250	2	450	0	1000	200	48	257
RB-30-0.020-3-2-0	0	30	500	100	250	2	450	3	1000	200	170	332
RB-30-0.020-6-2-0	0	30	500	100	250	2	450	6	1000	200	253	348
RB-50.5-0.010-0-2-0	0	50.5	500	100	250	2	450	0	500	200	61	287
RB-50.5-0.010-3-2-0	0	50.5	500	100	250	2	450	3	500	200	174	414
RB-50.5-0.010-6-2-0	0	50.5	500	100	250	2	450	6	500	200	289	418
RB-50.5-0.015-0-2-0	0	50.5	500	100	250	2	450	0	760.2	200	64	356
RB-50.5-0.015-3-2-0	0	50.5	500	100	250	2	450	3	760.2	200	177	451
RB-50.5-0.015-6-2-0	0	50.5	500	100	250	2	450	6	760.2	200	280	449
RB-50.5-0.020-0-2-0	0	50.5	500	100	250	2	450	0	1000	200	66	368
RB-50.5-0.020-3-2-0	0	50.5	500	100	250	2	450	3	1000	200	187	462
RB-50.5-0.020-6-2-0	0	50.5	500	100	250	2	450	6	1000	200	295	483
RB-30-0.010-0-3-0	0	30	750	100	250	3	700	0	500	200	29	159
RB-30-0.010-3-3-0	0	30	750	100	250	3	700	3	500	200	110	212
RB-30-0.010-6-3-0	0	30	750	100	250	3	700	6	500	200	181	239
RB-30-0.015-0-3-0	0	30	750	100	250	3	700	0	760.2	200	29	173
RB-30-0.015-3-3-0	0	30	750	100	250	3	700	3	760.2	200	113	229
RB-30-0.015-6-3-0	0	30	750	100	250	3	700	6	760.2	200	174	242
RB-30-0.020-0-3-0	0	30	750	100	250	3	700	0	1000	200	30	182
RB-30-0.020-3-3-0	0	30	750	100	250	3	700	3	1000	200	116	232
RB-30-0.020-6-3-0	0	30	750	100	250	3	700	6	1000	200	183	242
RB-50.5-0.010-0-3-0	0	50.5	750	100	250	3	700	0	500	200	35	239
RB-50.5-0.010-3-3-0	0	50.5	750	100	250	3	700	3	500	200	119	283
RB-50.5-0.010-6-3-0	0	50.5	750	100	250	3	700	6	500	200	196	290
RB-50.5-0.015-0-3-0	0	50.5	750	100	250	3	700	0	760.2	200	36	262
RB-50.5-0.015-3-3-0	0	50.5	750	100	250	3	700	3	760.2	200	122	315
RB-50.5-0.015-6-3-0	0	50.5	750	100	250	3	700	6	760.2	200	194	324
RB-50.5-0.020-0-3-0	0	50.5	750	100	250	3	700	0	1000	200	49	279
RB-50.5-0.020-3-3-0	0	50.5	750	100	250	3	700	3	1000	200	124	337
RB-50.5-0.020-6-3-0	0	50.5	750	100	250	3	700	6	1000	200	202	331
RB-30-0.010-0-4-0	0	30	1000	100	250	4	950	0	500	200	20	123
RB-30-0.010-3-4-0	0	30	1000	100	250	4	950	3	500	200	79	166
RB-30-0.010-6-4-0	0	30	1000	100	250	4	950	6	500	200	135	185
RB-30-0.015-0-4-0	0	30	1000	100	250	4	950	0	760.2	200	21	132
RB-30-0.015-3-4-0	0	30	1000	100	250	4	950	3	760.2	200	87	175
RB-30-0.015-6-4-0	0	30	1000	100	250	4	950	6	760.2	200	134	192
RB-30-0.020-0-4-0	0	30	1000	100	250	4	950	0	1000	200	27	143
RB-30-0.020-3-4-0	0	30	1000	100	250	4	950	3	1000	200	89	118
RB-30-0.020-6-4-0	0	30	1000	100	250	4	950	6	1000	200	146	193
RB-50.5-0.010-0-4-0	0	50.5	1000	100	250	4	950	0	500	200	29	157
RB-50.5-0.010-3-4-0	0	50.5	1000	100	250	4	950	3	500	200	88	210
RB-50.5-0.010-6-4-0	0	50.5	1000	100	250	4	950	6	500	200	149	217
RB-50.5-0.015-0-4-0	0	50.5	1000	100	250	4	950	0	760.2	200	33	201
RB-50.5-0.015-3-4-0	0	50.5	1000	100	250	4	950	3	760.2	200	90	240
RB-50.5-0.015-6-4-0	0	50.5	1000	100	250	4	950	6	760.2	200	148	253
RB-50.5-0.020-0-4-0	0	50.5	1000	100	250	4	950	0	1000	200	33	214
RB-50.5-0.020-3-4-0	0	50.5	1000	100	250	4	950	3	1000	200	98	249
RB-50.5-0.020-6-4-0	0	50.5	1000	100	250	4	950	6	1000	200	151	255
RB-30-0.010-0-6-0	0	30	1500	100	250	6	1450	0	500	200	15	77
RB-30-0.010-3-6-0	0	30	1500	100	250	6	1450	3	500	200	52	114
RB-30-0.010-6-6-0	0	30	1500	100	250	6	1450	6	500	200	88	128
RB-30-0.015-0-6-0	0	30	1500	100	250	6	1450	0	760.2	200	15	96
RB-30-0.015-3-6-0	0	30	1500	100	250	6	1450	3	760.2	200	55	122
RB-30-0.015-6-6-0	0	30	1500	100	250	6	1450	6	760.2	200	86	134
RB-30-0.020-0-6-0	0	30	1500	100	250	6	1450	0	1000	200	16	103
RB-30-0.020-3-6-0	0	30	1500	100	250	6	1450	3	1000	200	57	124
RB-30-0.020-6-6-0	0	30	1500	100	250	6	1450	6	1000	200	96	139

RB-50.5-0.010-0-6-0	0	50.5	1500	100	250	6	1450	0	500	200	19	126
RB-50.5-0.010-3-6-0	0	50.5	1500	100	250	6	1450	3	500	200	60	142
RB-50.5-0.010-6-6-0	0	50.5	1500	100	250	6	1450	6	500	200	93	144
RB-50.5-0.015-0-6-0	0	50.5	1500	100	250	6	1450	0	760.2	200	19	138
RB-50.5-0.015-3-6-0	0	50.5	1500	100	250	6	1450	3	760.2	200	60	169
RB-50.5-0.015-6-6-0	0	50.5	1500	100	250	6	1450	6	760.2	200	97	182
RB-50.5-0.020-0-6-0	0	50.5	1500	100	250	6	1450	0	1000	200	20	150
RB-50.5-0.020-3-6-0	0	50.5	1500	100	250	6	1450	3	1000	200	65	180
RB-50.5-0.020-6-6-0	0	50.5	1500	100	250	6	1450	6	1000	200	100	182
RB-30-0.010-0-7-0	0	30	1750	100	250	7	1700	0	500	200	12	68
RB-30-0.010-3-7-0	0	30	1750	100	250	7	1700	3	500	200	47	97
RB-30-0.010-6-7-0	0	30	1750	100	250	7	1700	6	500	200	78	105
RB-30-0.015-0-7-0	0	30	1750	100	250	7	1700	0	760.2	200	14	82
RB-30-0.015-3-7-0	0	30	1750	100	250	7	1700	3	760.2	200	49	105
RB-30-0.015-6-7-0	0	30	1750	100	250	7	1700	6	760.2	200	79	116
RB-30-0.020-0-7-0	0	30	1750	100	250	7	1700	0	1000	200	12	90
RB-30-0.020-3-7-0	0	30	1750	100	250	7	1700	3	1000	200	50	112
RB-30-0.020-6-7-0	0	30	1750	100	250	7	1700	6	1000	200	79	124
RB-50.5-0.010-0-7-0	0	50.5	1750	100	250	7	1700	0	500	200	17	107
RB-50.5-0.010-3-7-0	0	50.5	1750	100	250	7	1700	3	500	200	54	120
RB-50.5-0.010-6-7-0	0	50.5	1750	100	250	7	1700	6	500	200	82	124
RB-50.5-0.015-0-7-0	0	50.5	1750	100	250	7	1700	0	760.2	200	17	112
RB-50.5-0.015-3-7-0	0	50.5	1750	100	250	7	1700	3	760.2	200	52	152
RB-50.5-0.015-6-7-0	0	50.5	1750	100	250	7	1700	6	760.2	200	82	147
RB-50.5-0.020-0-7-0	0	50.5	1750	100	250	7	1700	0	1000	200	21	121
RB-50.5-0.020-3-7-0	0	50.5	1750	100	250	7	1700	3	1000	200	56	157
RB-50.5-0.020-6-7-0	0	50.5	1750	100	250	7	1700	6	1000	200	82	170
RB-30-0.010-0-8-0	0	30	2000	100	250	8	1950	0	500	200	11	66
RB-30-0.010-3-8-0	0	30	2000	100	250	8	1950	3	500	200	46	85
RB-30-0.010-6-8-0	0	30	2000	100	250	8	1950	6	500	200	68	97
RB-30-0.015-0-8-0	0	30	2000	100	250	8	1950	0	760.2	200	12	67
RB-30-0.015-3-8-0	0	30	2000	100	250	8	1950	3	760.2	200	46	93
RB-30-0.015-6-8-0	0	30	2000	100	250	8	1950	6	760.2	200	68	104
RB-30-0.020-0-8-0	0	30	2000	100	250	8	1950	0	1000	200	12	81
RB-30-0.020-3-8-0	0	30	2000	100	250	8	1950	3	1000	200	45	99
RB-30-0.020-6-8-0	0	30	2000	100	250	8	1950	6	1000	200	71	108
RB-50.5-0.010-0-8-0	0	50.5	2000	100	250	8	1950	0	500	200	14	96
RB-50.5-0.010-3-8-0	0	50.5	2000	100	250	8	1950	3	500	200	48	105
RB-50.5-0.010-6-8-0	0	50.5	2000	100	250	8	1950	6	500	200	75	108
RB-50.5-0.015-0-8-0	0	50.5	2000	100	250	8	1950	0	760.2	200	14	98
RB-50.5-0.015-3-8-0	0	50.5	2000	100	250	8	1950	3	760.2	200	47	129
RB-50.5-0.015-6-8-0	0	50.5	2000	100	250	8	1950	6	760.2	200	78	134
RB-50.5-0.020-0-8-0	0	50.5	2000	100	250	8	1950	0	1000	200	18	109
RB-50.5-0.020-3-8-0	0	50.5	2000	100	250	8	1950	3	1000	200	50	137
RB-50.5-0.020-6-8-0	0	50.5	2000	100	250	8	1950	6	1000	200	78	138
RB-30-0.010-0-9-0	0	30	2250	100	250	9	2200	0	500	200	10	65
RB-30-0.010-3-9-0	0	30	2250	100	250	9	2200	3	500	200	38	84
RB-30-0.010-6-9-0	0	30	2250	100	250	9	2200	6	500	200	59	87
RB-30-0.015-0-9-0	0	30	2250	100	250	9	2200	0	760.2	200	11	72
RB-30-0.015-3-9-0	0	30	2250	100	250	9	2200	3	760.2	200	41	90
RB-30-0.015-6-9-0	0	30	2250	100	250	9	2200	6	760.2	200	61	97
RB-30-0.020-0-9-0	0	30	2250	100	250	9	2200	0	1000	200	11	79
RB-30-0.020-3-9-0	0	30	2250	100	250	9	2200	3	1000	200	40	97
RB-30-0.020-6-9-0	0	30	2250	100	250	9	2200	6	1000	200	61	101
RB-50.5-0.010-0-9-0	0	50.5	2250	100	250	9	2200	0	500	200	13	91
RB-50.5-0.010-3-9-0	0	50.5	2250	100	250	9	2200	3	500	200	42	96
RB-50.5-0.010-6-9-0	0	50.5	2250	100	250	9	2200	6	500	200	66	97
RB-50.5-0.015-0-9-0	0	50.5	2250	100	250	9	2200	0	760.2	200	14	106
RB-50.5-0.015-3-9-0	0	50.5	2250	100	250	9	2200	3	760.2	200	41	121
RB-50.5-0.015-6-9-0	0	50.5	2250	100	250	9	2200	6	760.2	200	69	125
RB-50.5-0.020-0-9-0	0	50.5	2250	100	250	9	2200	0	1000	200	14	114
RB-50.5-0.020-3-9-0	0	50.5	2250	100	250	9	2200	3	1000	200	42	132
RB-50.5-0.020-6-9-0	0	50.5	2250	100	250	9	2200	6	1000	200	68	132

Parameter effects can be examined under the following headings:

- **Effect of compressive strength of concrete**
- **Effect of prestress level**
- **Effect of taper slope**
- **Effect of the prestressed reinforcement bars area (A_1)**
- **Effect of a/d_m**
- **Cracking effect**

4.1 Compressive Strength of Concrete Effect

The concrete used in prestressed concrete has a higher strength than the concrete used in reinforced concrete. The design should take into account the differences in strength, elongation capacity, and elastic modulus. There are also many other reasons for using high-strength concrete in prestressed concrete. Since concrete is under the influence of great forces, there are economic results with quality concrete. Beams with larger spans can be used. The use of high-strength concrete minimizes the element cross-sections. In addition, another advantage of high-strength concrete is that the loss of elastic shortening in prestressing is less than normal concrete due to its high elasticity modulus [10].

To understand the effect of compressive strength on prestressed concrete, concrete with two different compressive strengths was used. The behavior of two different compressive strength concretes on prestressed concrete is shown in Fig. 4.(2-17) below.

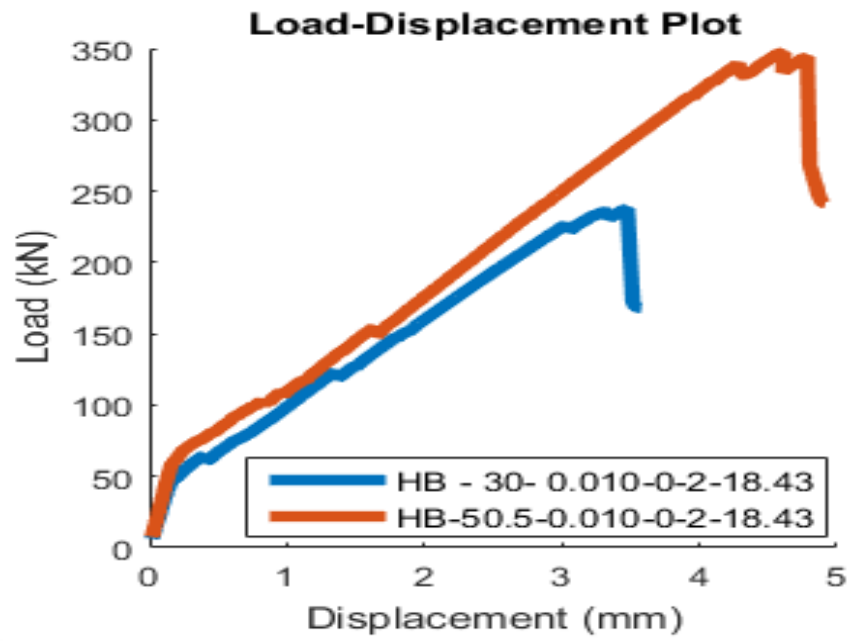


Figure 4.2 Load-Displacement plot of HB-(30, 50.5)-0.10-0-2-18.43.

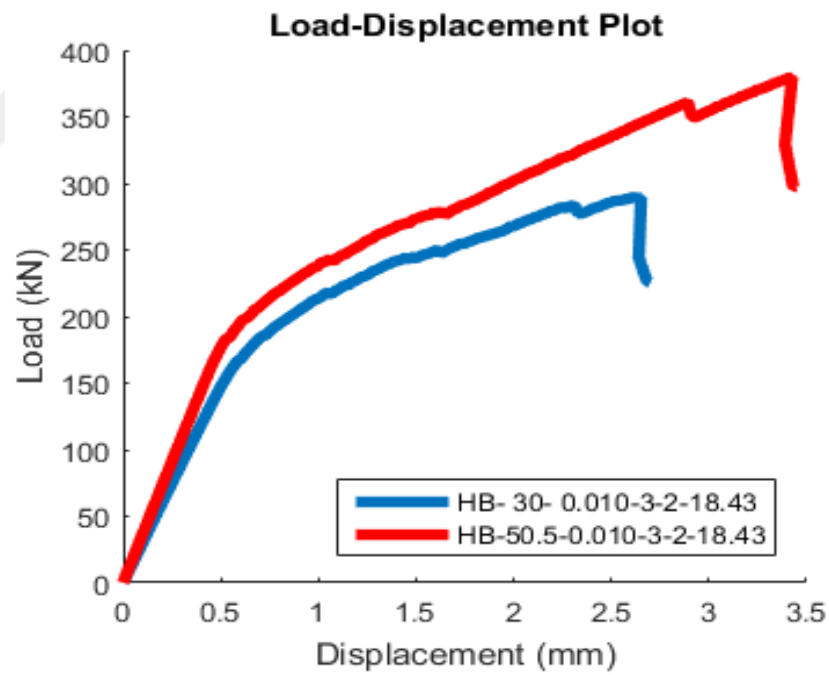


Figure 4.2 Load-Displacement plot of HB-(30, 50.5)-0.10-3-2-18.43.

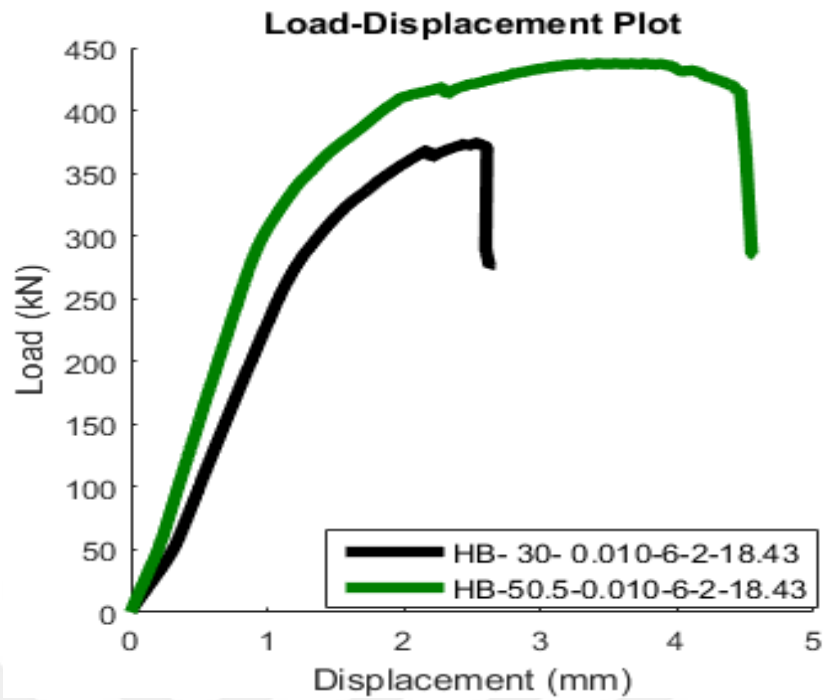


Figure 4.3 Load-Displacement plot of HB-(30, 50.5)-0.10-6-2-18.43.

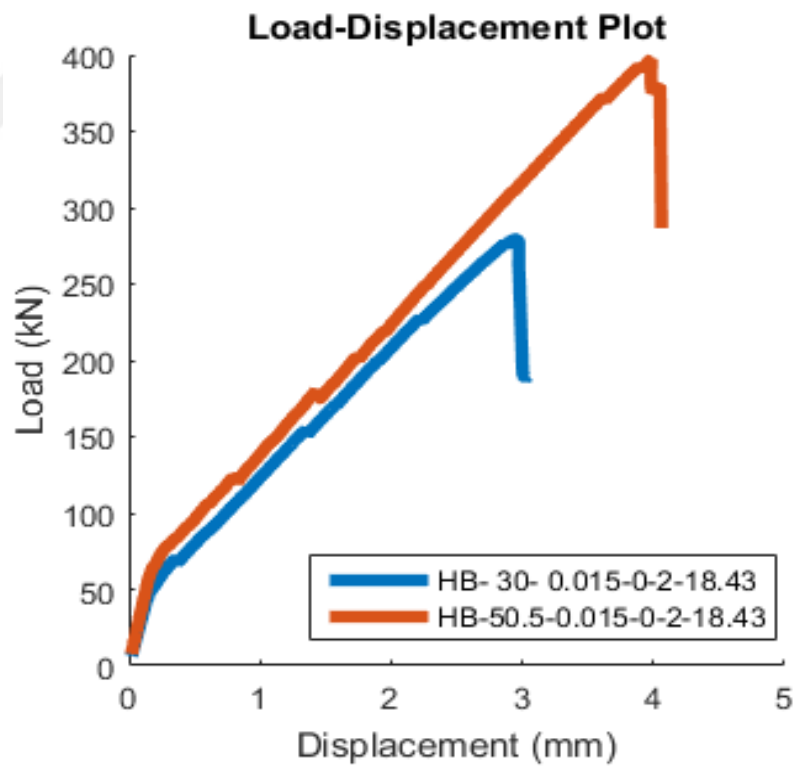


Figure 4.4 Load-Displacement plot of HB-(30, 50.5)-0.15-0-2-18.43.

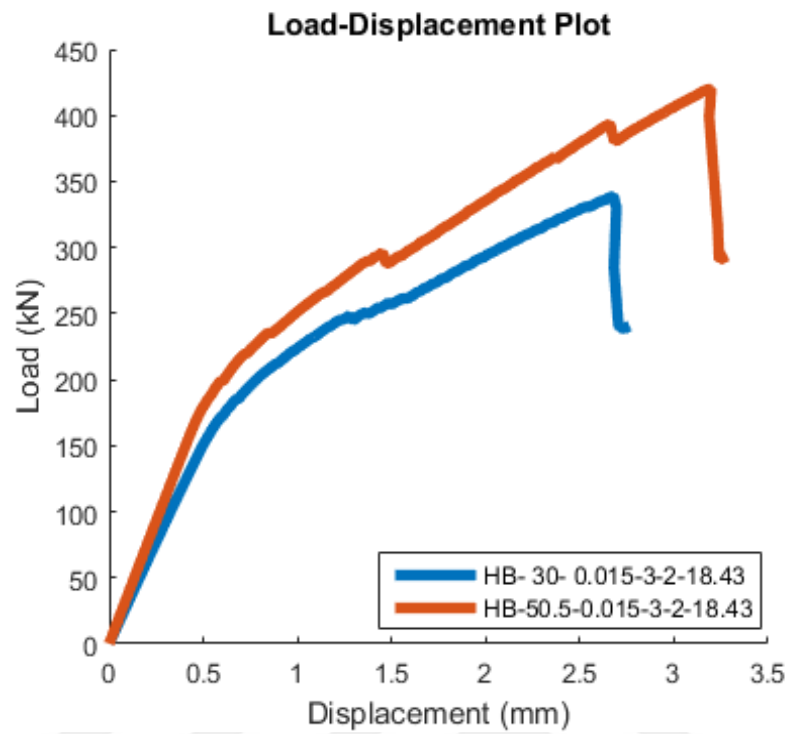


Figure 4.5 Load-Displacement plot of HB-(30, 50.5)-0.015-3-2-18.43.

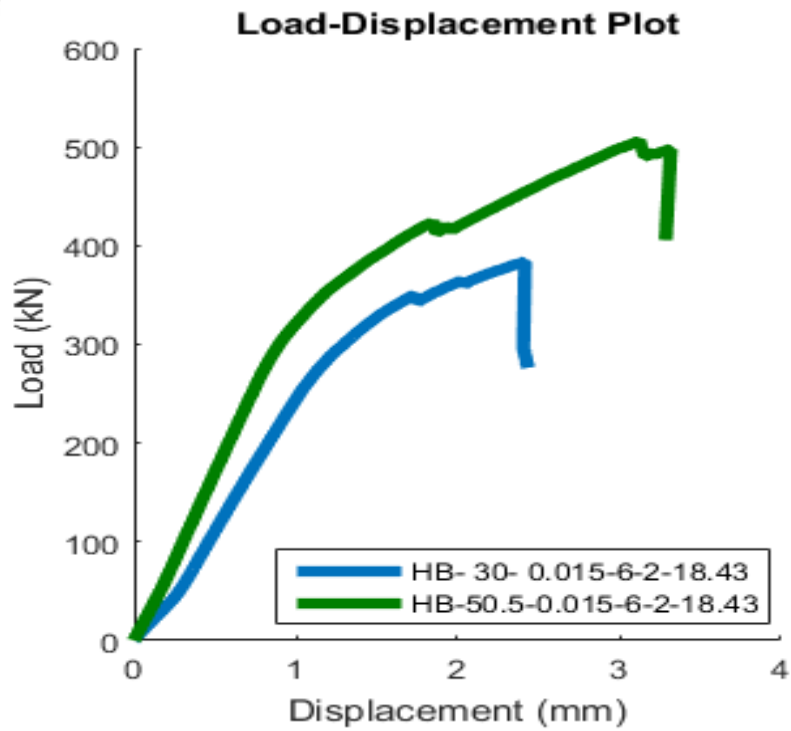


Figure 4.6 Load-Displacement plot of HB-(30, 50.5)-0.015-6-2-18.43.

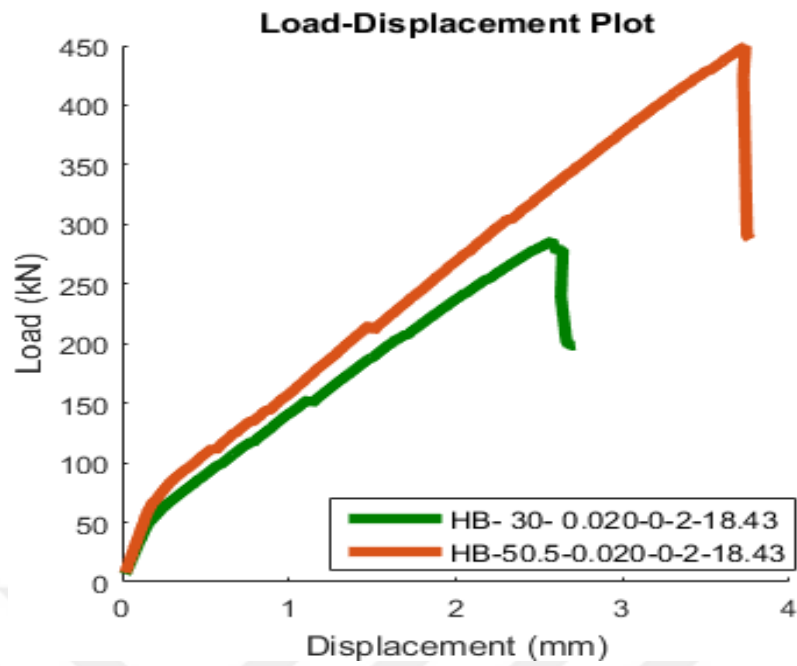


Figure 4.7 Load-Displacement plot of HB-(30, 50.5)-0.020-0-2-18.43.

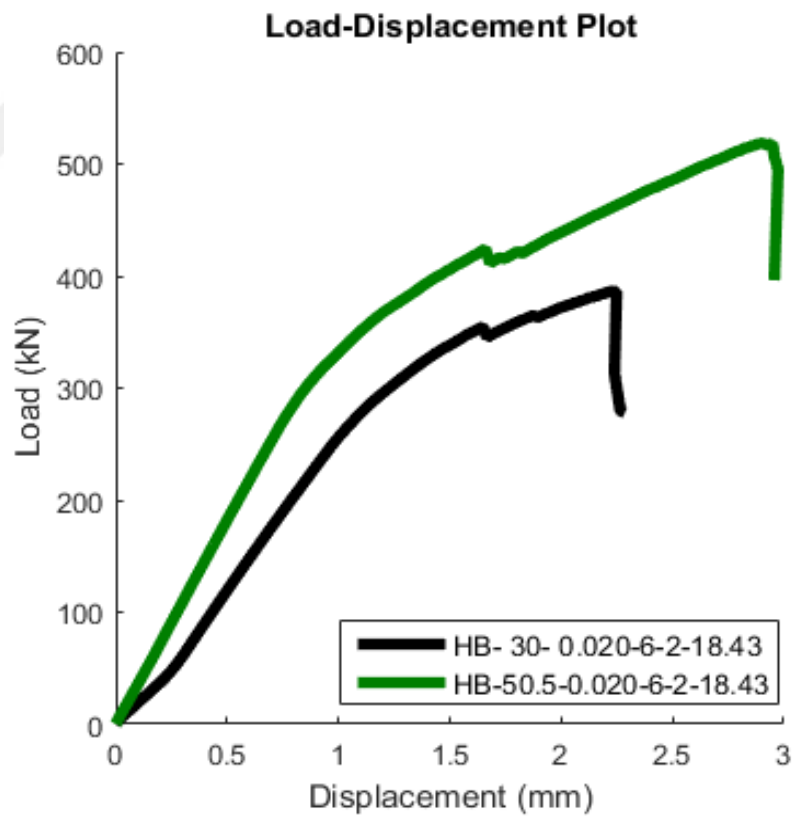


Figure 4.8 Load-Displacement plot of HB-(30, 50.5)-0.020-6-2-18.43.

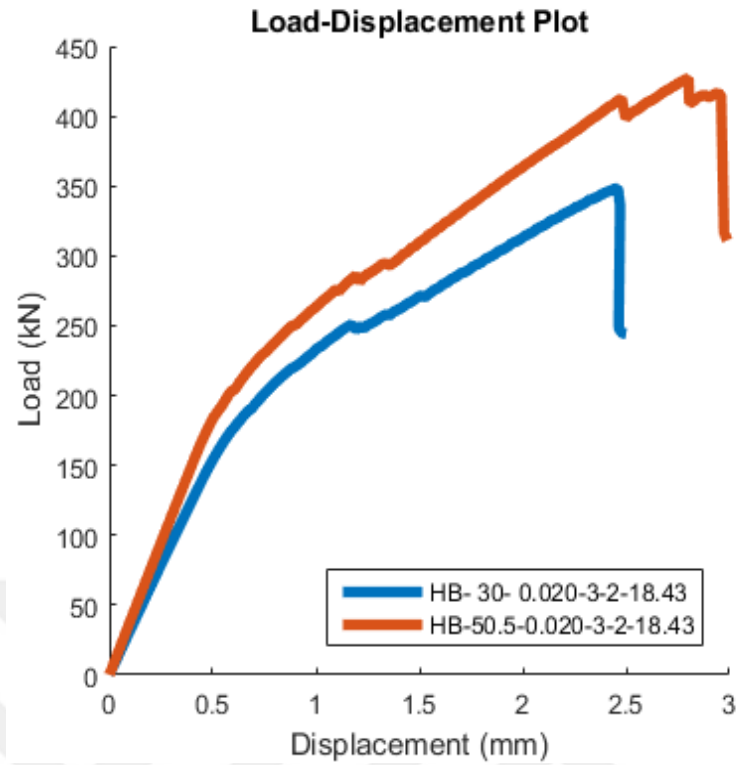


Figure 4.9 Load-Displacement plot of HB-(30, 50.5)-0.020-3-2-18.43.

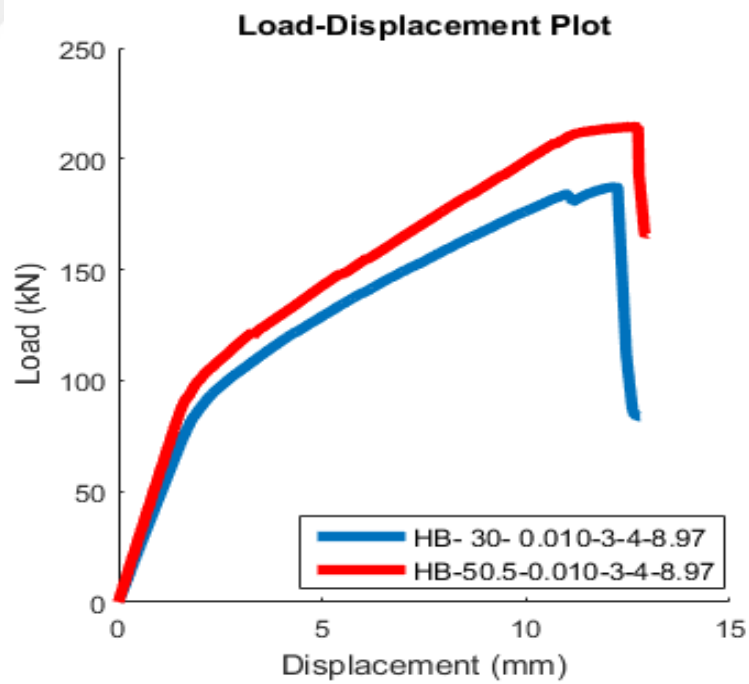


Figure 4.10 Load-Displacement plot of HB-(30, 50.5)-0.010-3-4-8.97.

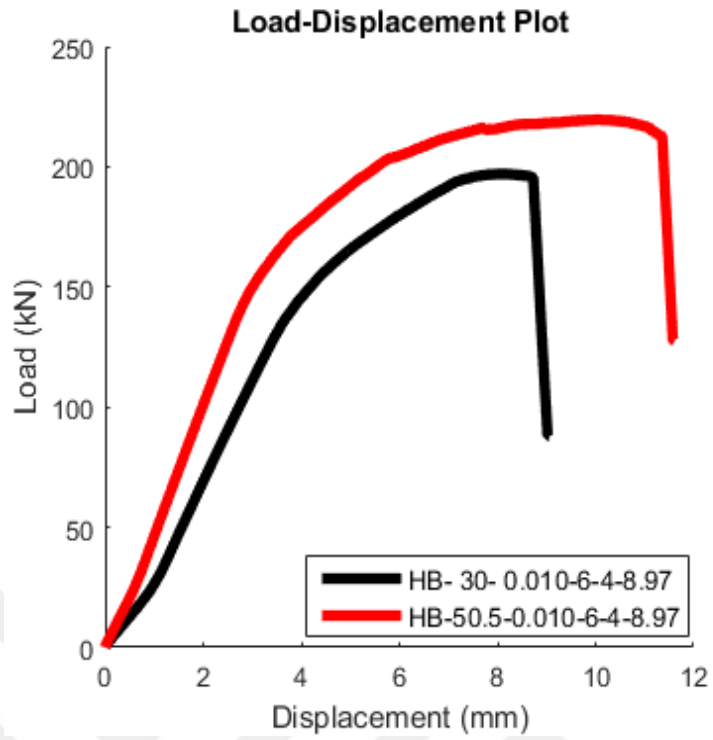


Figure 4.11 Load-Displacement plot of HB-(30, 50.5)-0.010-6-4-8.97.

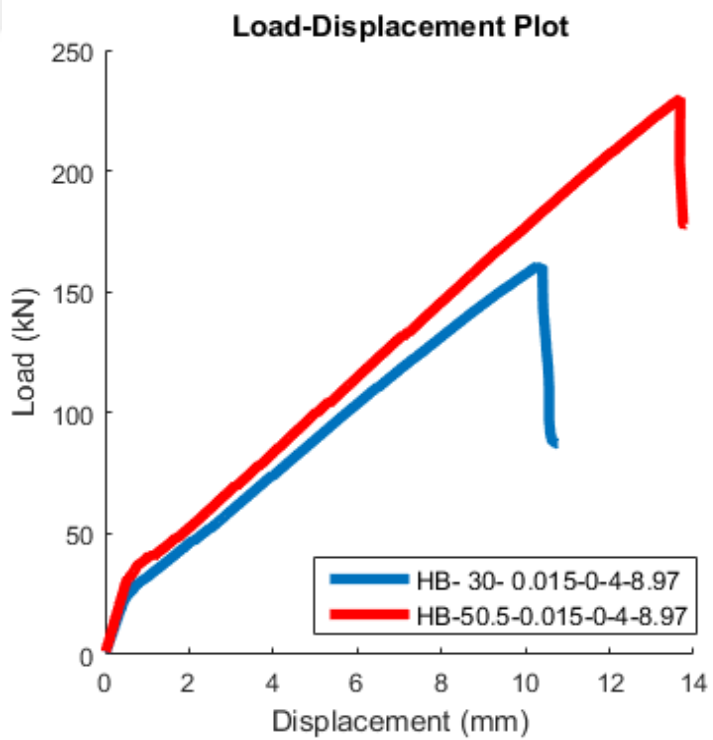


Figure 4.12 Load-Displacement plot of HB-(30, 50.5)-0.015-0-4-8.97.

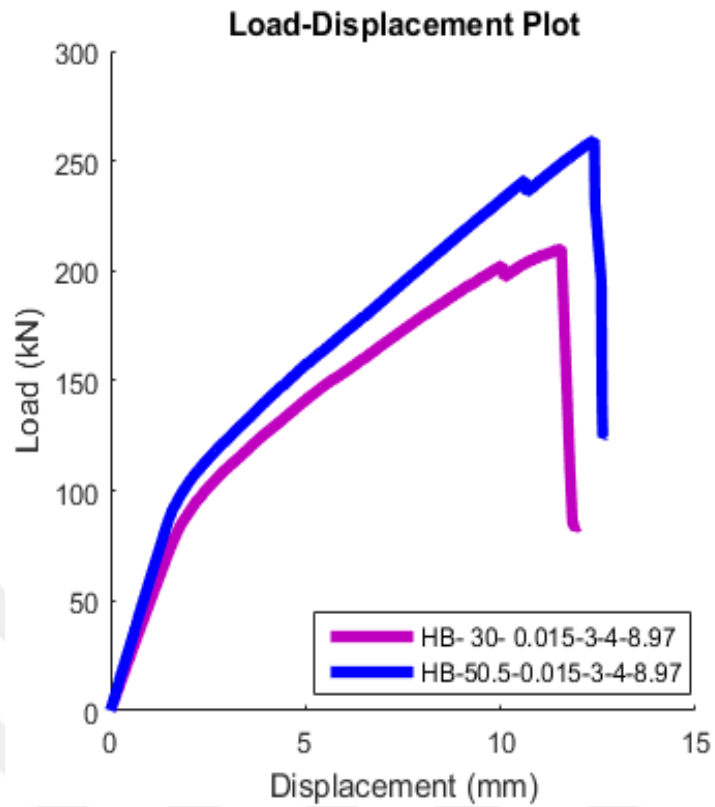


Figure 4.13 Load-Displacement plot of HB-(30, 50.5)-0.015-3-4-8.97.

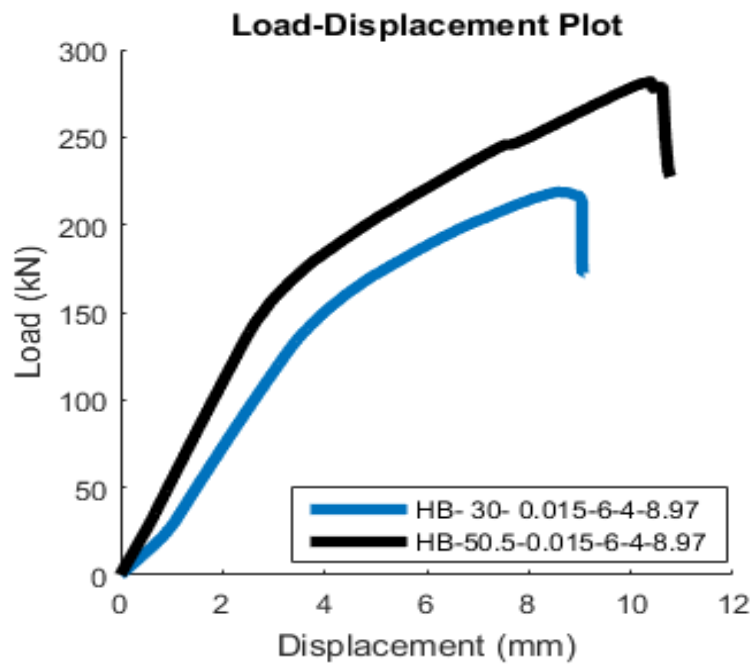


Figure 4.14 Load-Displacement plot of HB-(30, 50.5)-0.015-6-4-8.97.

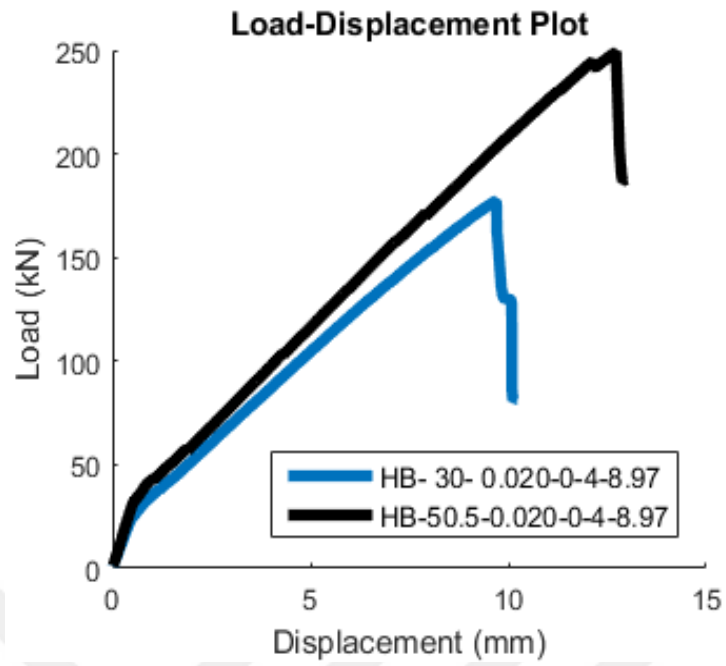


Figure 4.15 Load-Displacement plot of HB-(30, 50.5)-0.020-0-4-8.97.

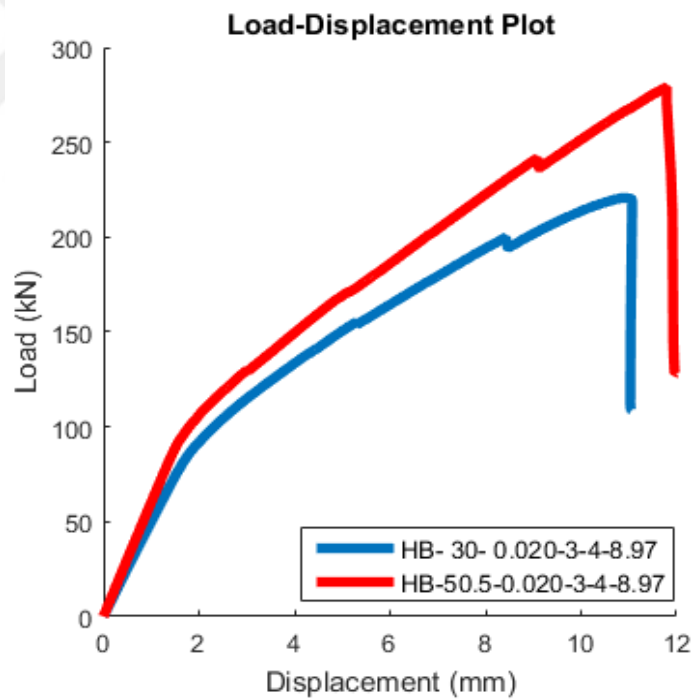


Figure 4.16 Load-Displacement plot of HB-(30, 50.5)-0.020-3-4-8.97.

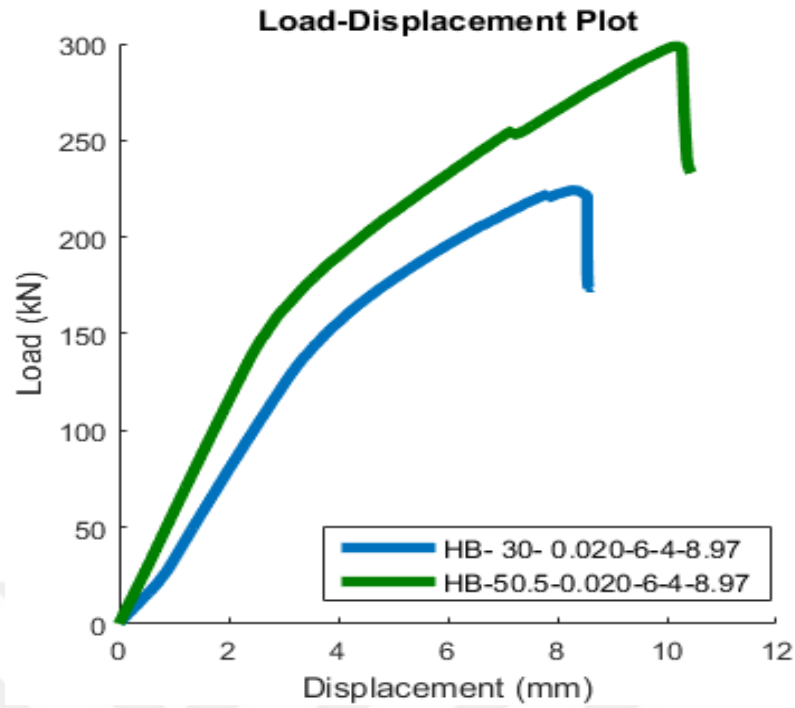


Figure 4.17 Load-Displacement plot of HB-(30, 50.5)-0.020-6-4-8.97

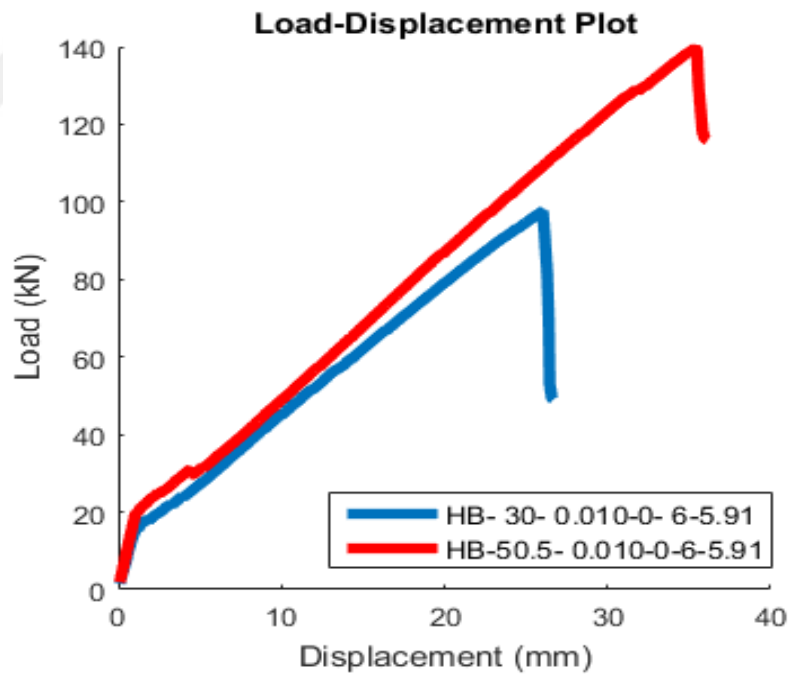


Figure 4.18 Load-Displacement plot of HB-(30, 50.5)-0.010-0-6-5.91.

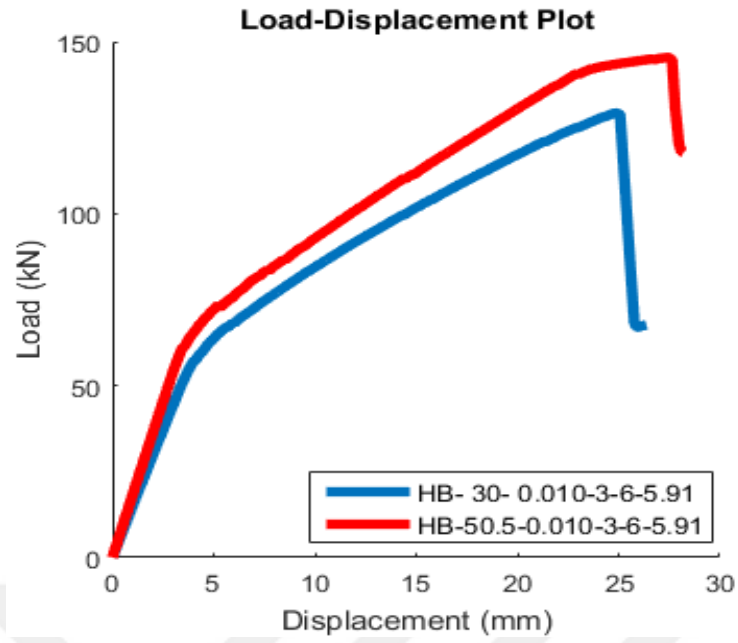


Figure 4.19 Load-Displacement plot of HB-(30, 50.5)-0.010-3-6-5.91.

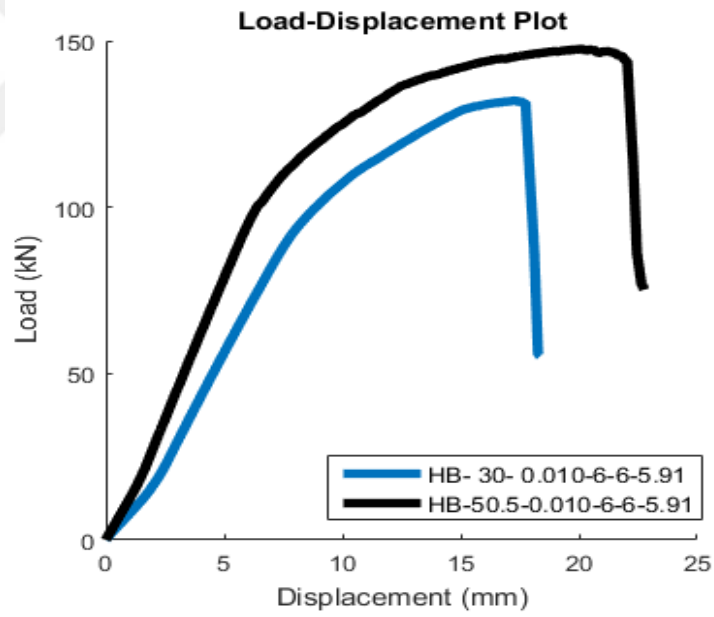


Figure 4.20 Load-Displacement plot of HB-(30, 50.5)-0.010-6-6-5.91.

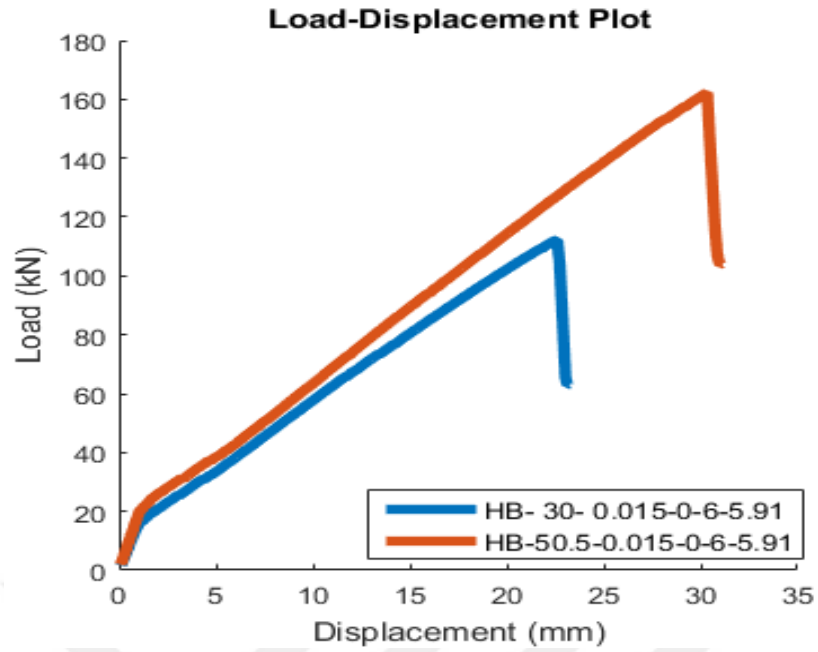


Figure 4.21 Load-Displacement plot of HB-(30, 50.5)-0.015-0-6-5.91.

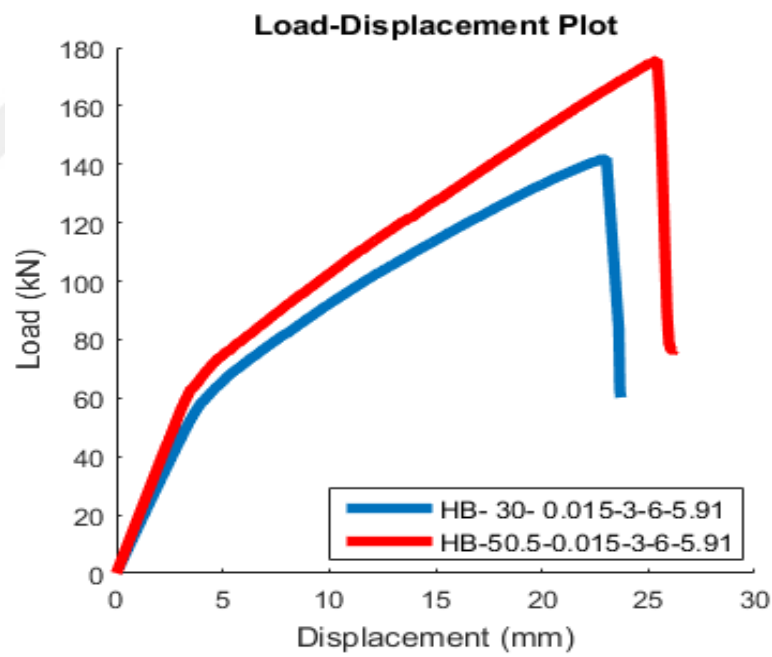


Figure 4.22 Load-Displacement plot of HB-(30, 50.5)-0.015-3-6-5.91.

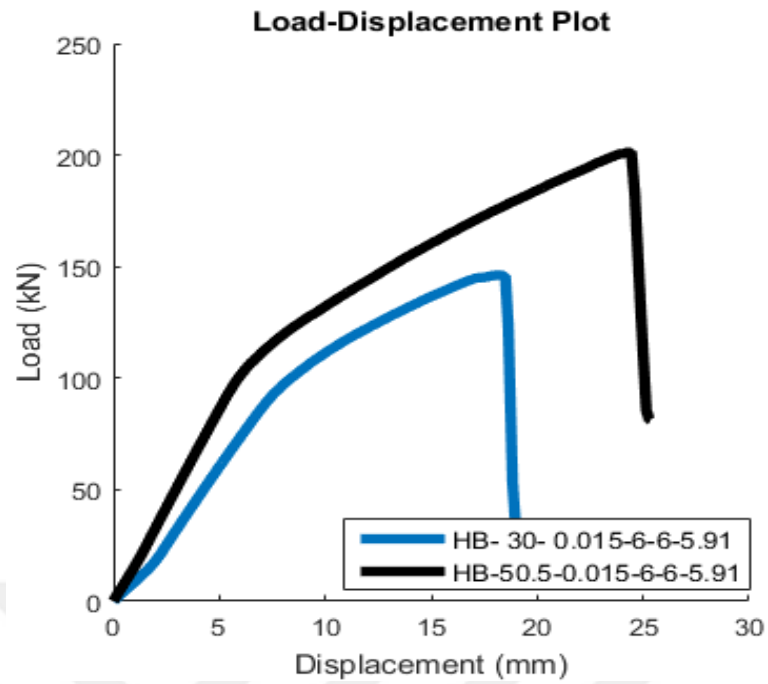


Figure 4.23 Load-Displacement plot of HB-(30, 50.5)-0.015-6-6-5.91.

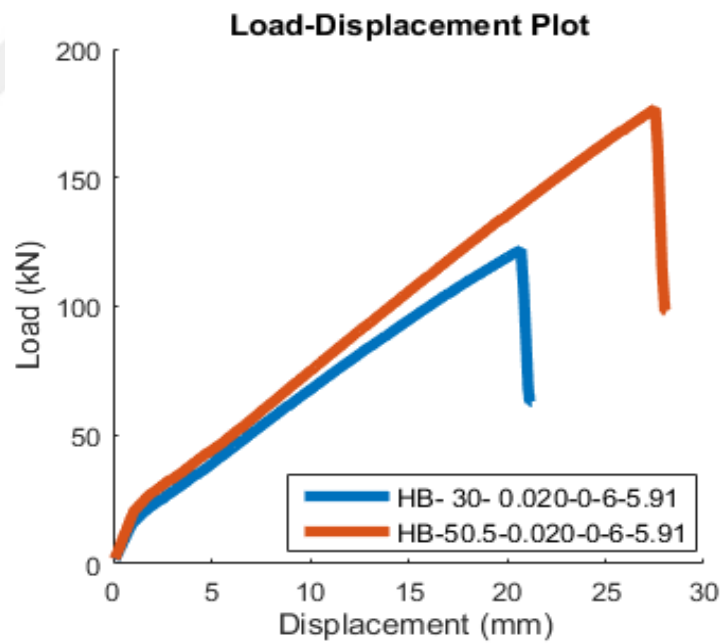


Figure 4.24 Load-Displacement plot of HB-(30, 50.5)-0.020-0-6-5.91.

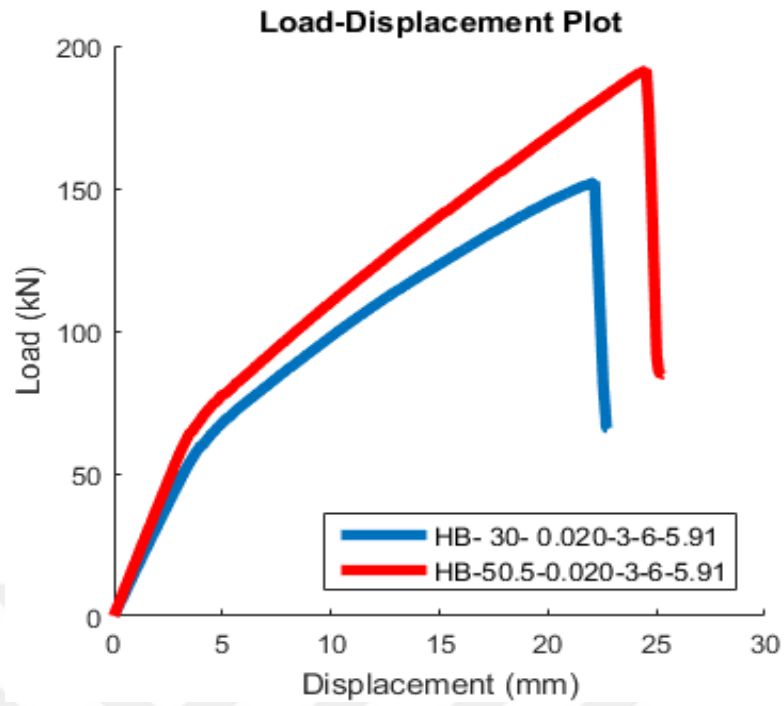


Figure 4.25 Load-Displacement plot of HB-(30, 50.5)-0.020-3-6-5.91.

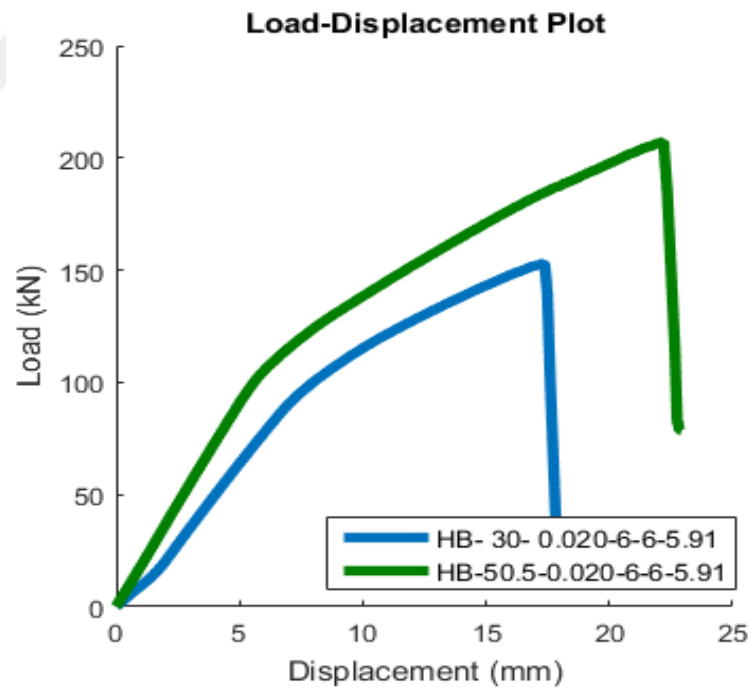


Figure 4.26 Load-Displacement plot of HB-(30, 50.5)-0.020-6-6-5.91.

Looking at the Fig.4.(2-27), while the average prestress level at the cross-section of the loading point was 3 (N/mm²), there was no break in both concretes at the time of the prestressing application. However, when the average prestress level was 6 (N / mm²) in the cross-section of the loading point, it had been observed that cracking occurs when prestress was applied low compressive strength concrete, but no cracking in high strength concrete. These results prove why high strength concrete is used in prestressed concrete.

4.2 Prestressing Force Effect

Whether post-tensioned or pre-stressed, a wire on the neutral axis without any eccentricity inside the area (A) section provides a uniform pressure stress distribution when the prestressing effect is applied. If the prestressing force is P, this stress is calculated by the formula below [11].

$$\sigma_{pc} = \frac{P}{A}$$

In the plots below, the effect of prestressing force on concrete has been investigated. These plots were used different prestress forces and were compared.

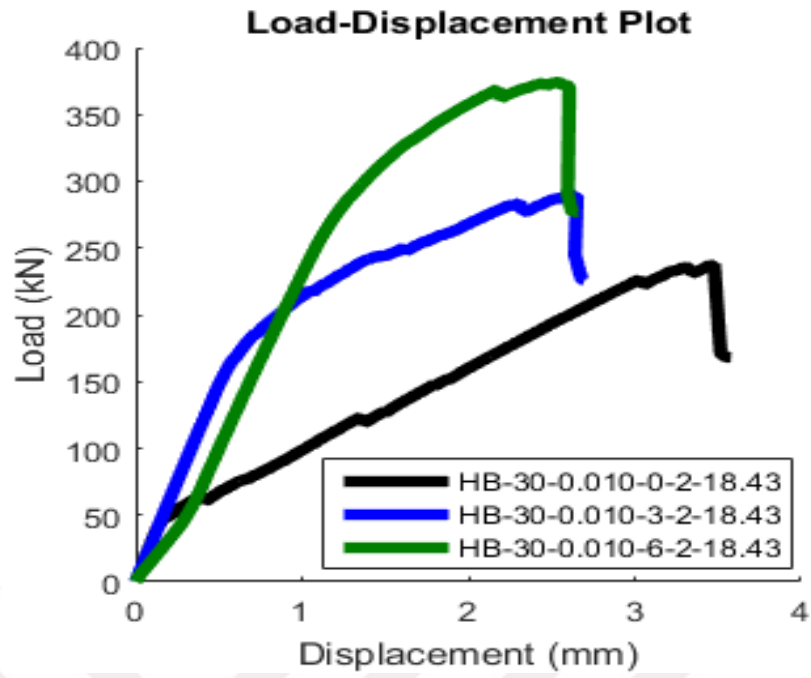


Figure 4.27 Load-Displacement plot of HB-30-0.010-(0, 3, 6)-2-18.43.

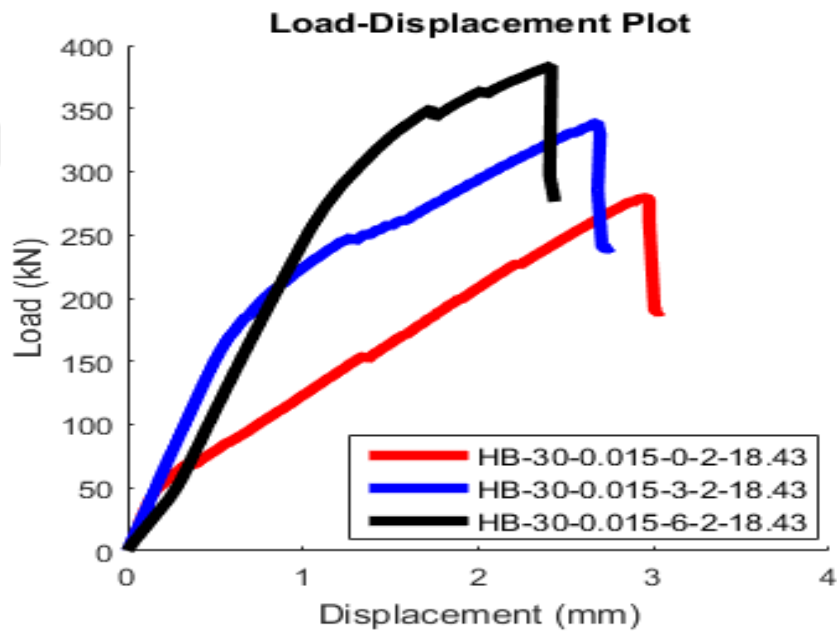


Figure 4.28 Load-Displacement plot of HB-30-0.015-(0, 3, 6)-2-18.43.

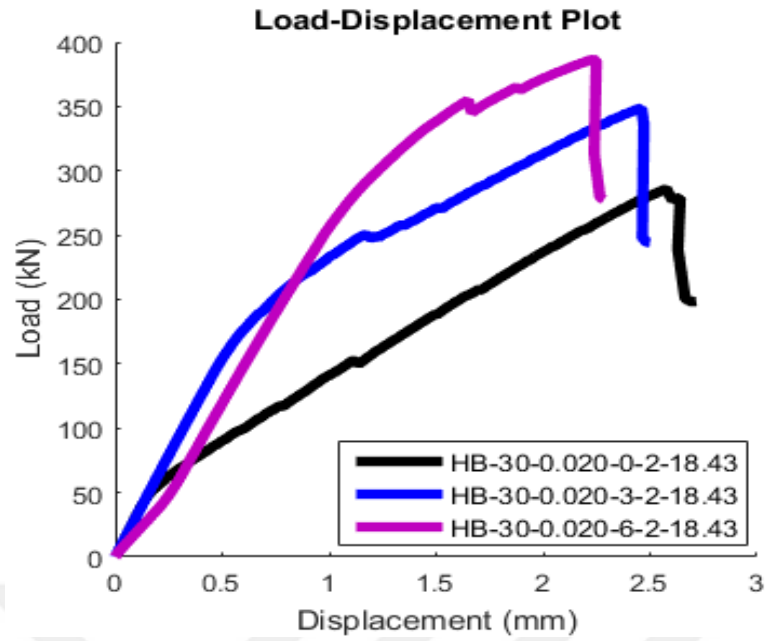


Figure 4.29 Load-Displacement plot of HB-30-0.020-(0, 3, 6)-2-18.43.

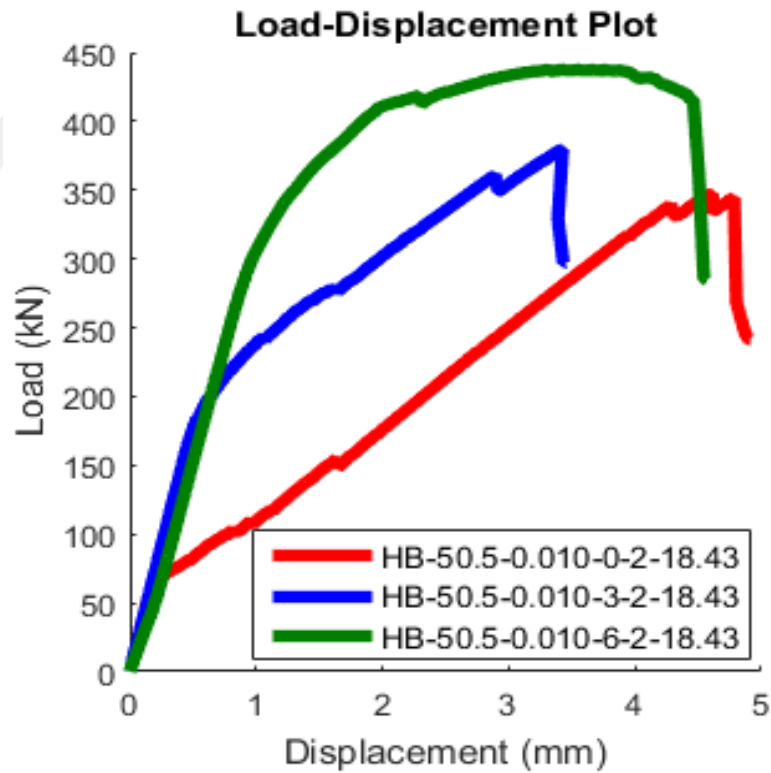


Figure 4.30 Load-Displacement plot of HB-50.5-0.010-(0, 3, 6)-2-18.43.

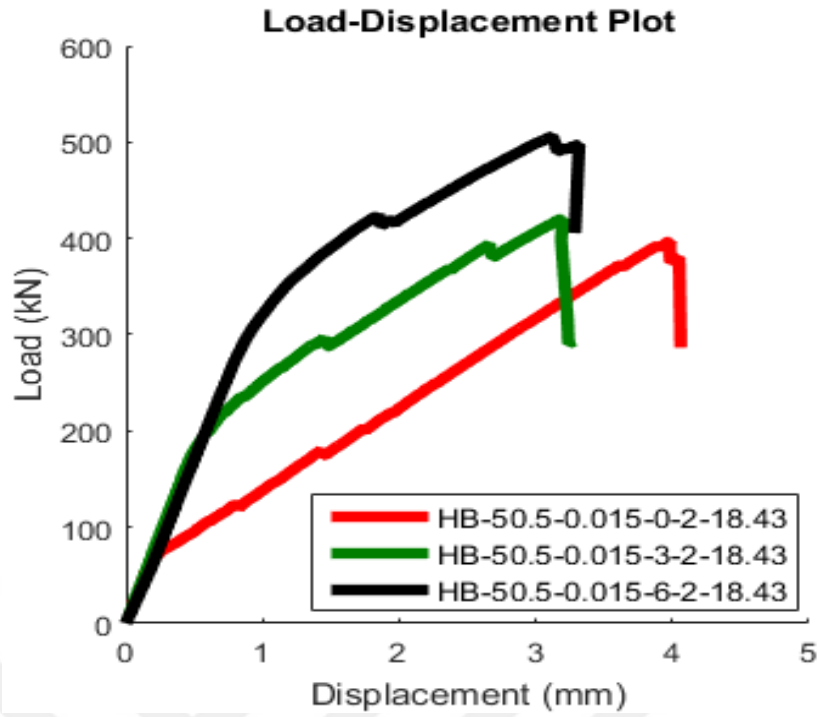


Figure 4.31 Load-Displacement plot of HB-50.5-0.015-(0, 3, 6)-2-18.43.

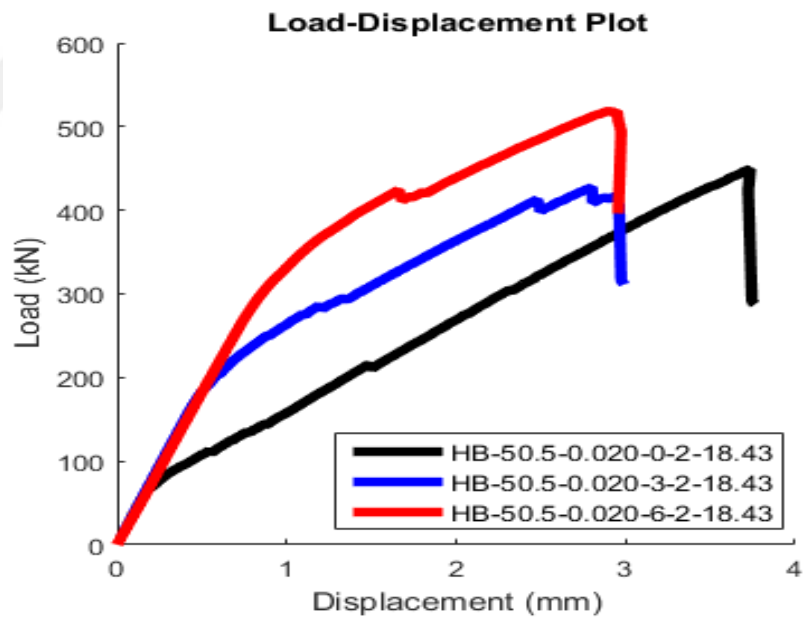


Figure 4.32 Load-Displacement plot of HB-50.5-0.020-(0, 3, 6)-2-18.43.

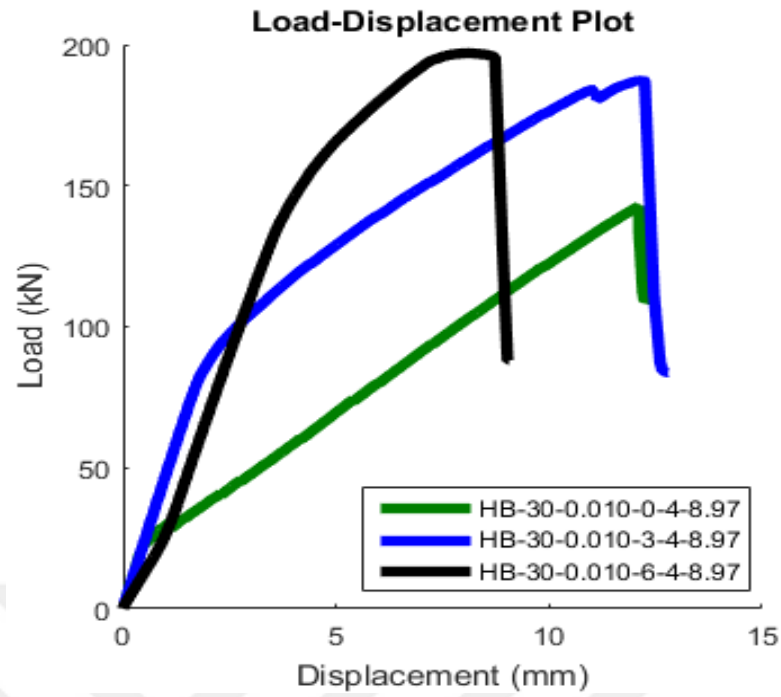


Figure 4.33 Load-Displacement plot of HB-30-0.010-(0, 3, 6)-4-8.97.

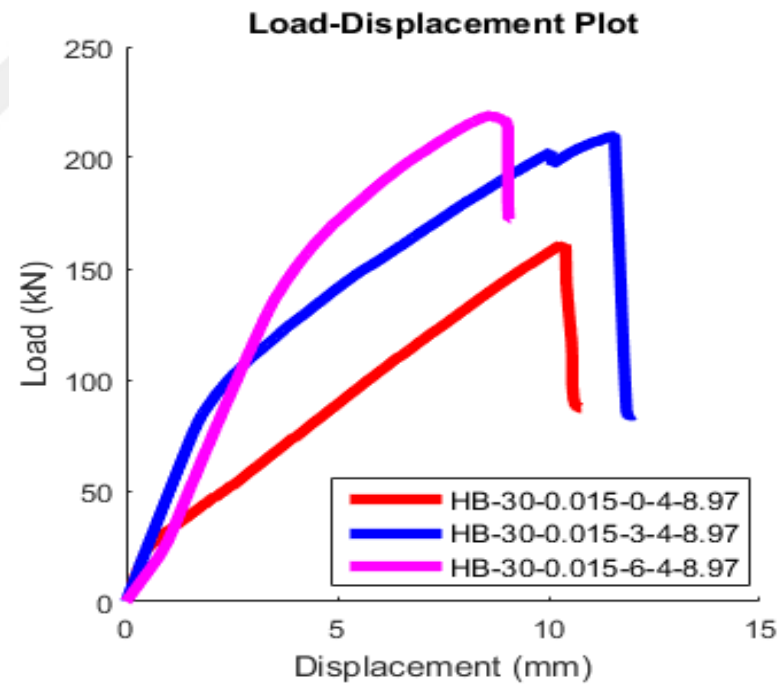


Figure 4.34 Load-Displacement plot of HB-30-0.015-(0, 3, 6)-4-8.97.

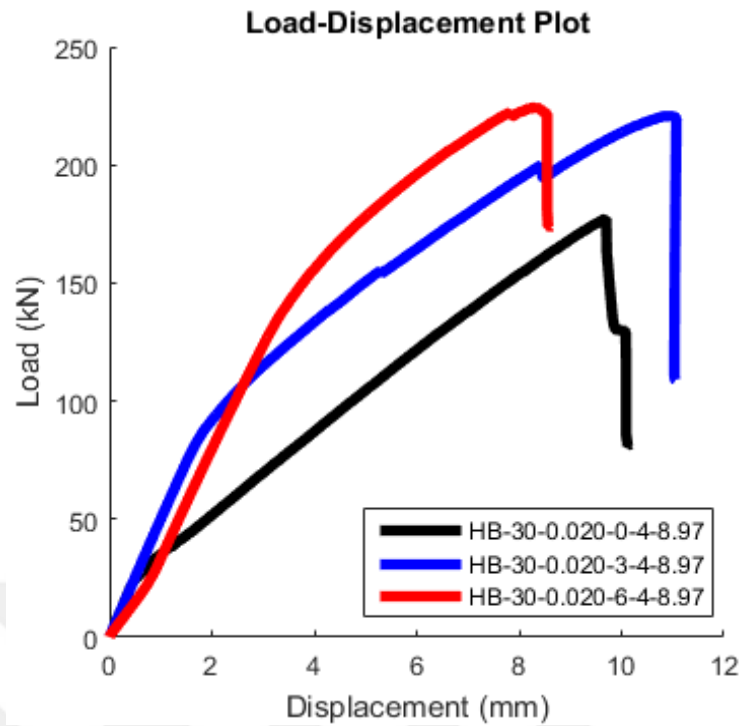


Figure 4.35 Load-Displacement plot of HB-30-0.020-(0, 3, 6)-4-8.97.

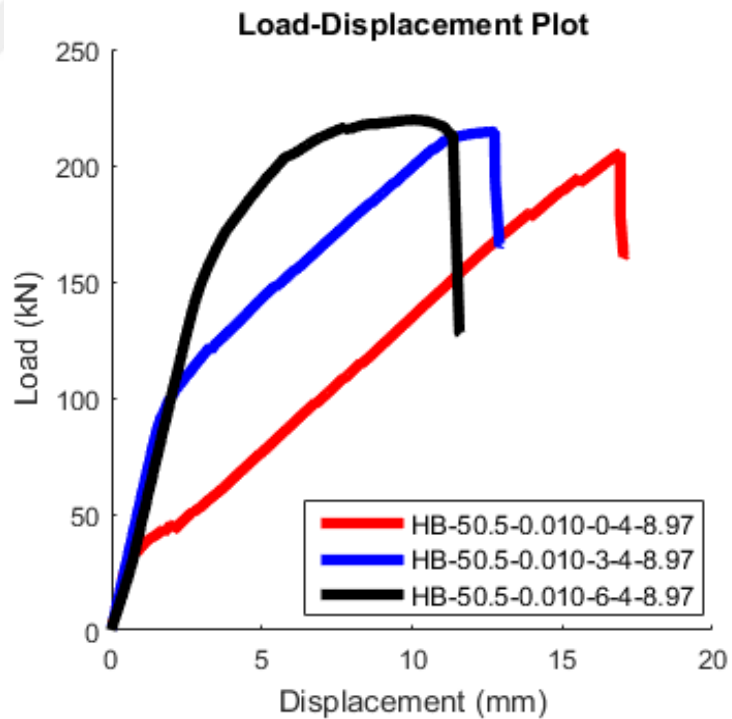


Figure 4.36 Load-Displacement plot of HB-50.5-0.010-(0, 3, 6)-4-8.97.

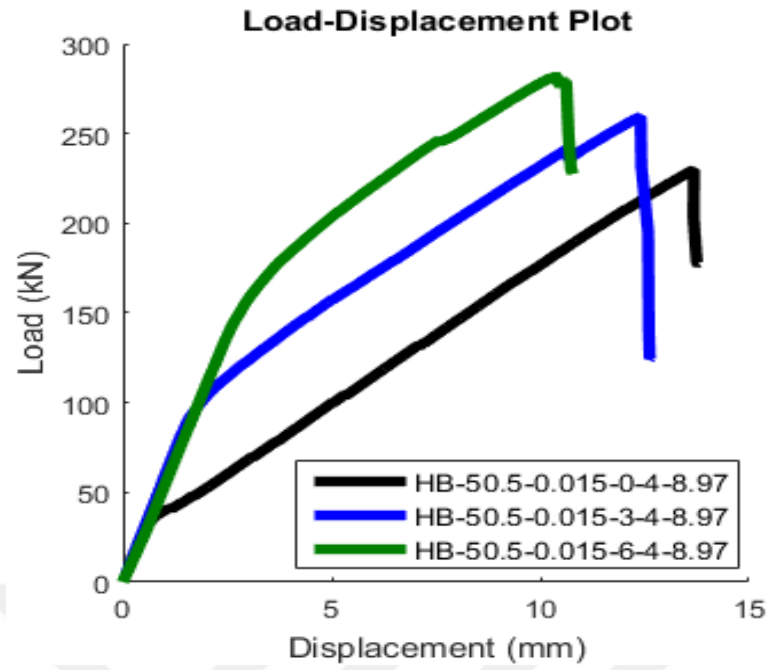


Figure 4.37 Load-Displacement plot of HB-50.5-0.015-(0, 3, 6)-4-8.97.

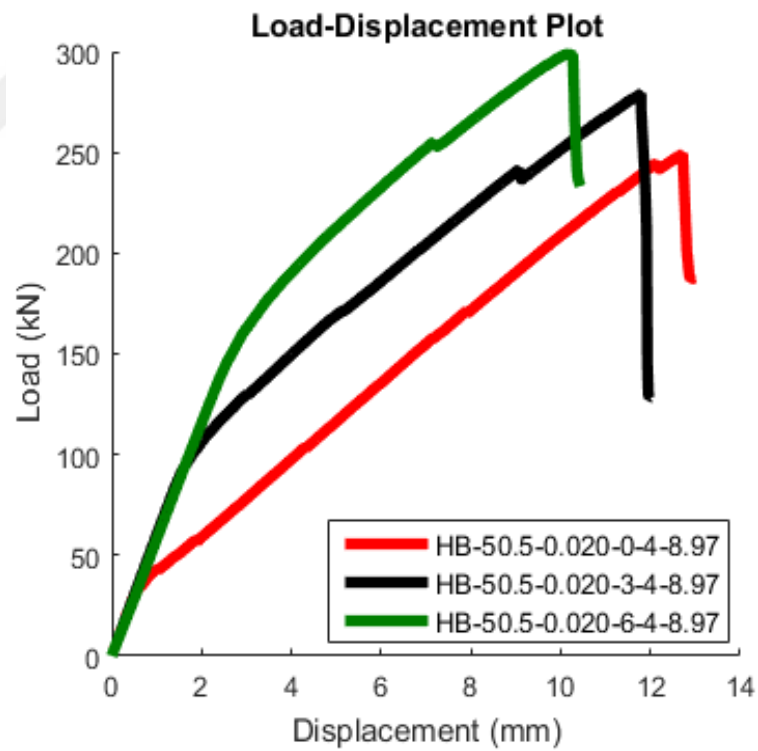


Figure 4.38 Load-Displacement plot of HB-50.5-0.020-(0, 3, 6)-4-8.97.

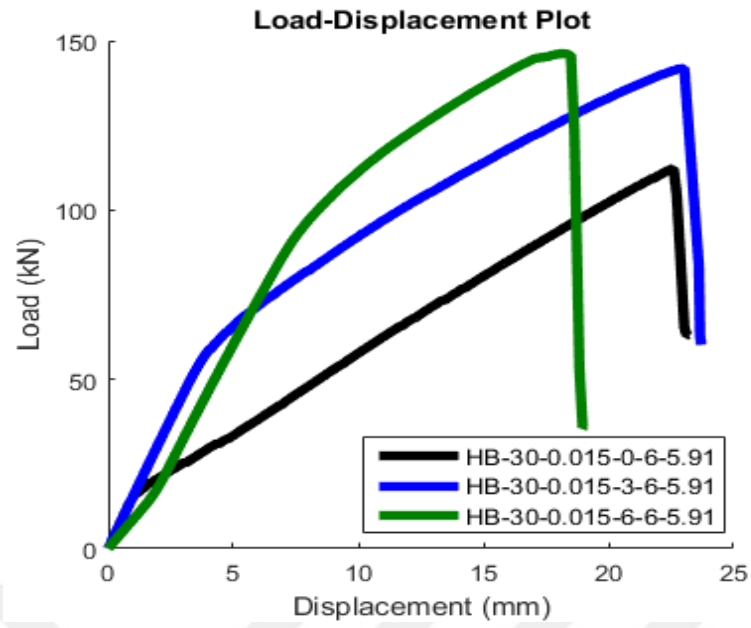


Figure 4.39 Load-Displacement plot of HB-30-0.015-(0, 3, 6)-6-5.91.

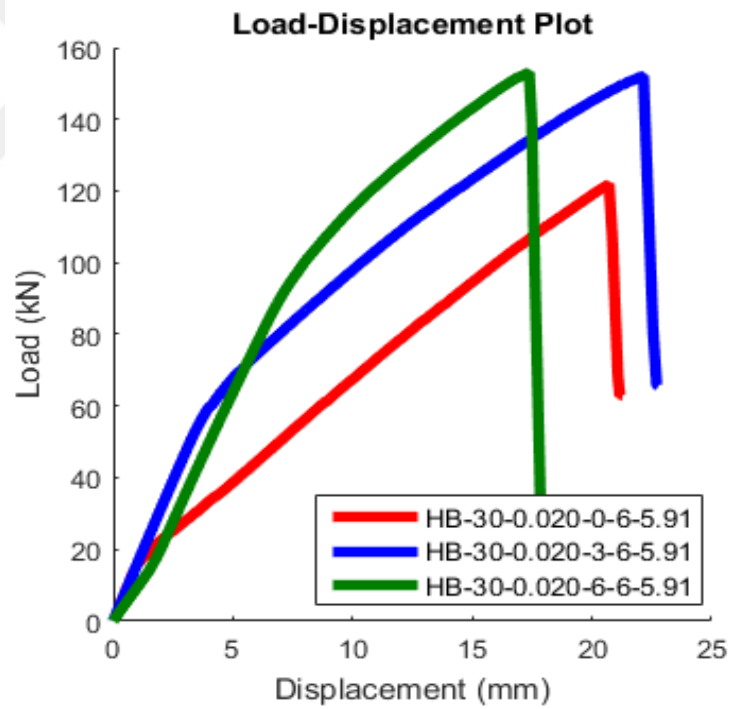


Figure 4.40 Load-Displacement plot of HB-30-0.020-(0, 3, 6)-6-5.91.

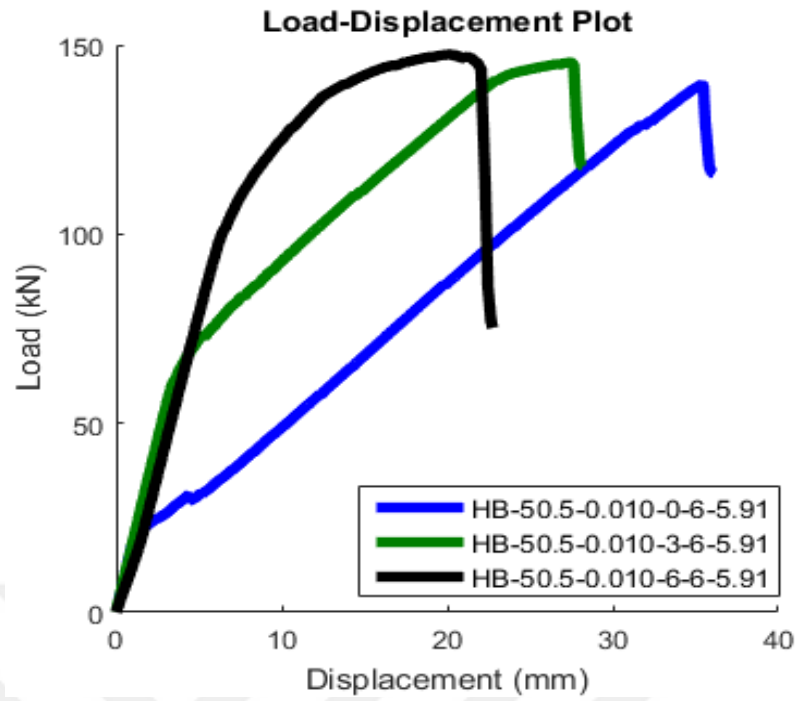


Figure 4.41 Load-Displacement plot of HB-50.5-0.010-(0, 3, 6)-6-5.91.

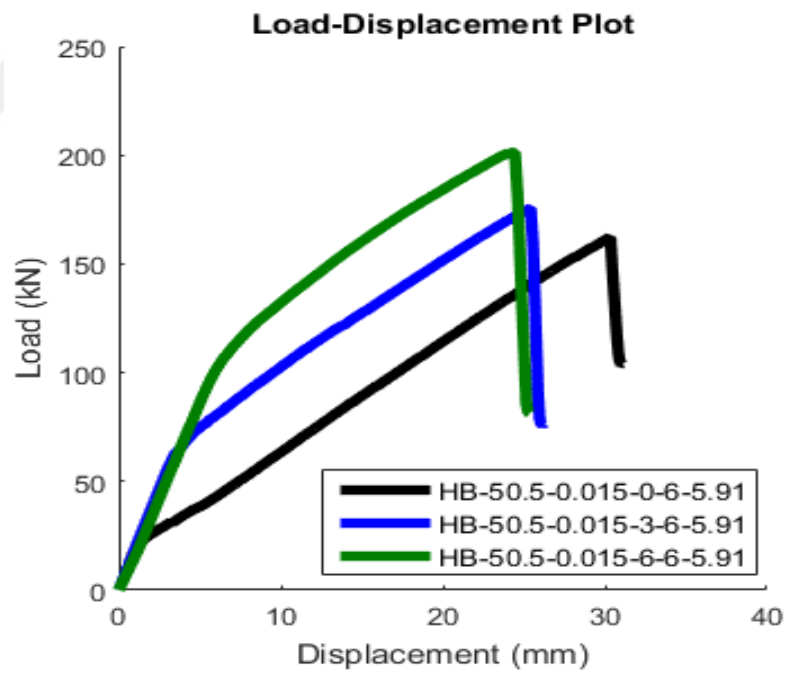


Figure 4.42 Load-Displacement plot of HB-50.5-0.015-(0, 3, 6)-6-5.91.

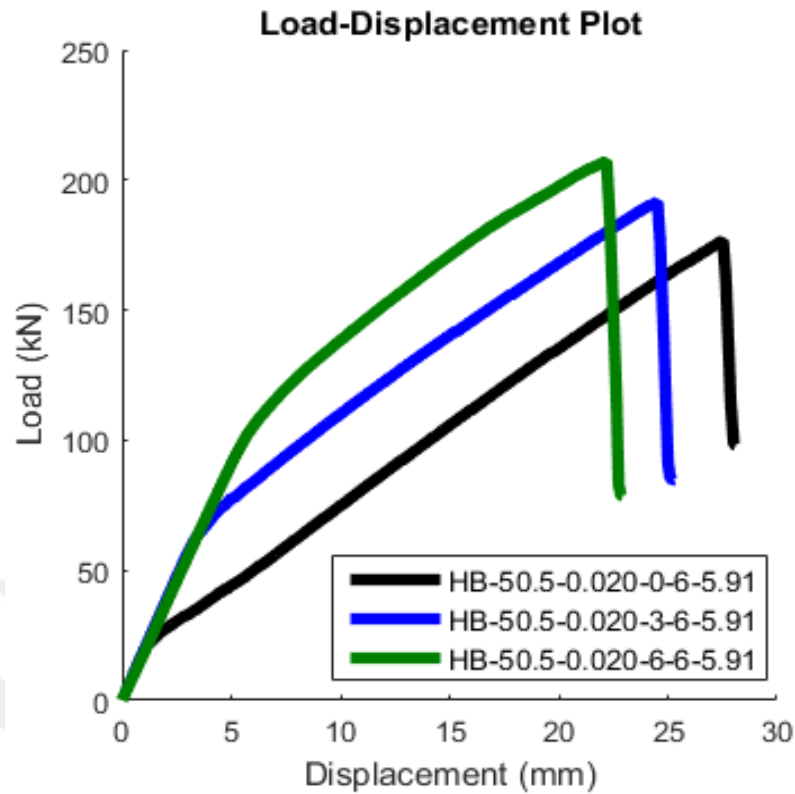


Figure 4.43 Load-Displacement plot of HB-50.5-0.020-(0, 3, 6)-6-5.91.

When the effect of prestressing on HB beams was investigated, the following conclusions were reached:

When the plots above are examined, it is seen that HB beams with concrete strength of 50.5 (N/mm²) and tensile bars ratio of 0.010 are generally not affected by the prestressing force.

In HB beams with concrete strength of 50.5 (N/mm²), it was observed that the prestressing force was effective when the reinforcement ratio was 0.015 and 0.020.

In HB beams with concrete strength of 30 (N/mm²), the reinforcement ratio was observed to be effective in all three reinforcement ratios.

4.2.1 Effect of Prestressing Force on Failure Load

Under this title, the rate of increase in failure load caused by the prestressing force of all beams has been examined. And these increase rates were evaluated.

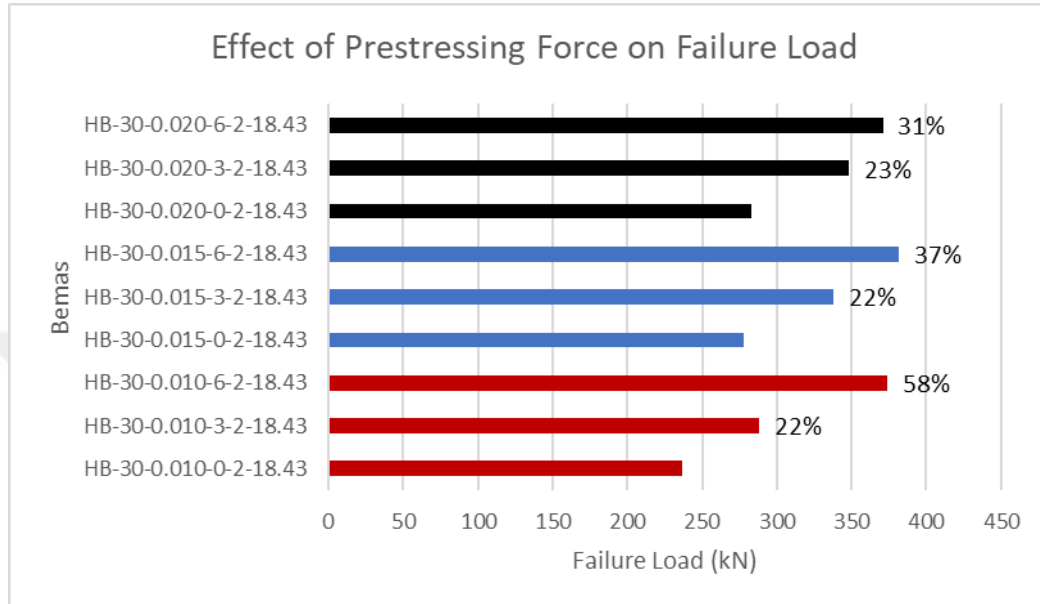


Figure 4.44 FLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=2$

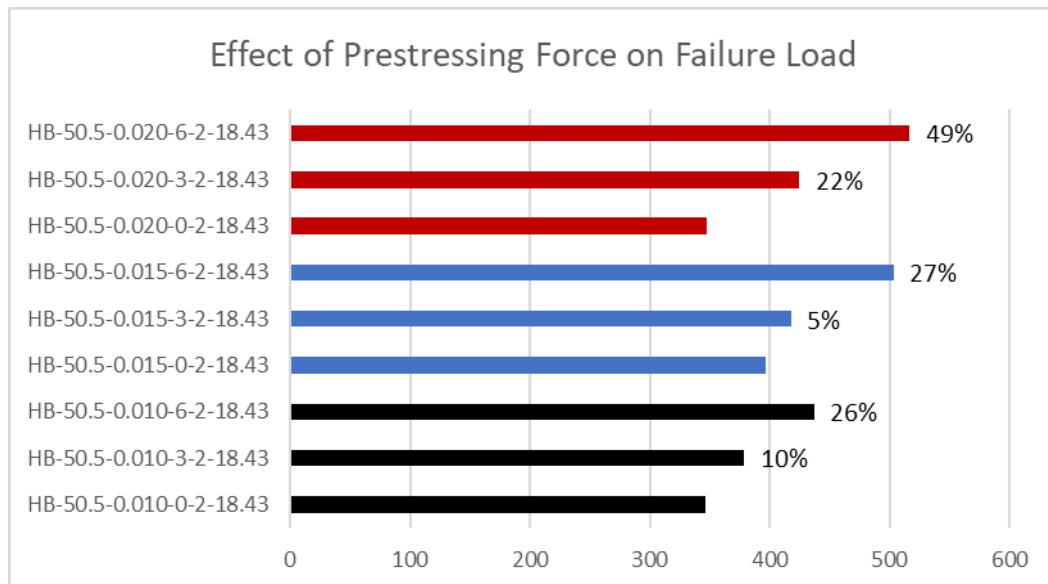


Figure 4.45 FLG of beams with concrete strength of 50.5 (N/mm²) and $\alpha/d_m=2$

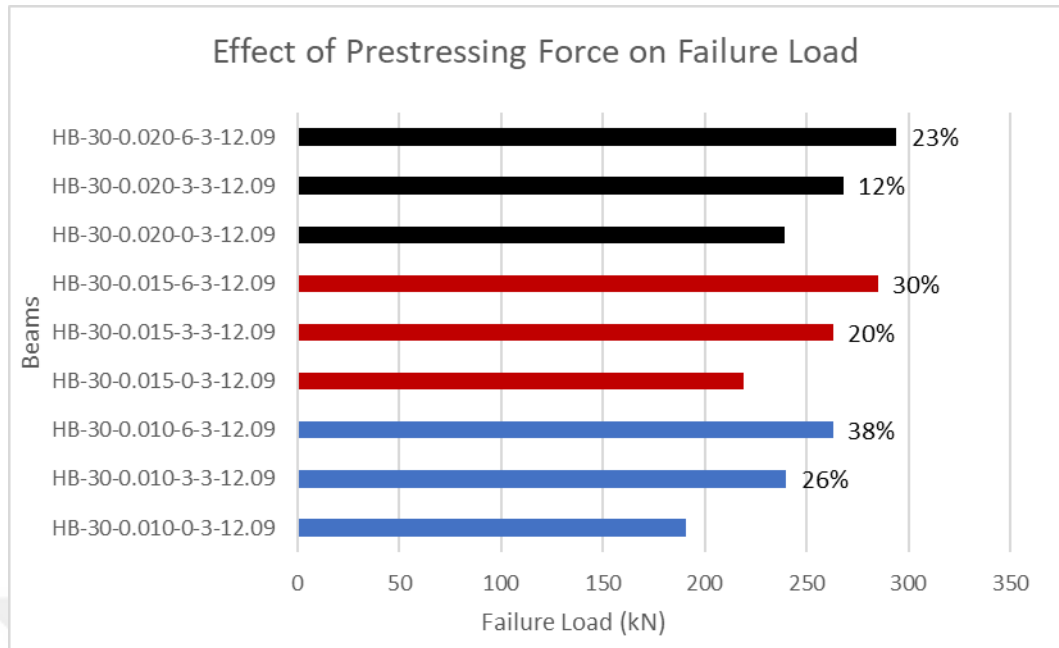


Figure 4.46 FLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=3$

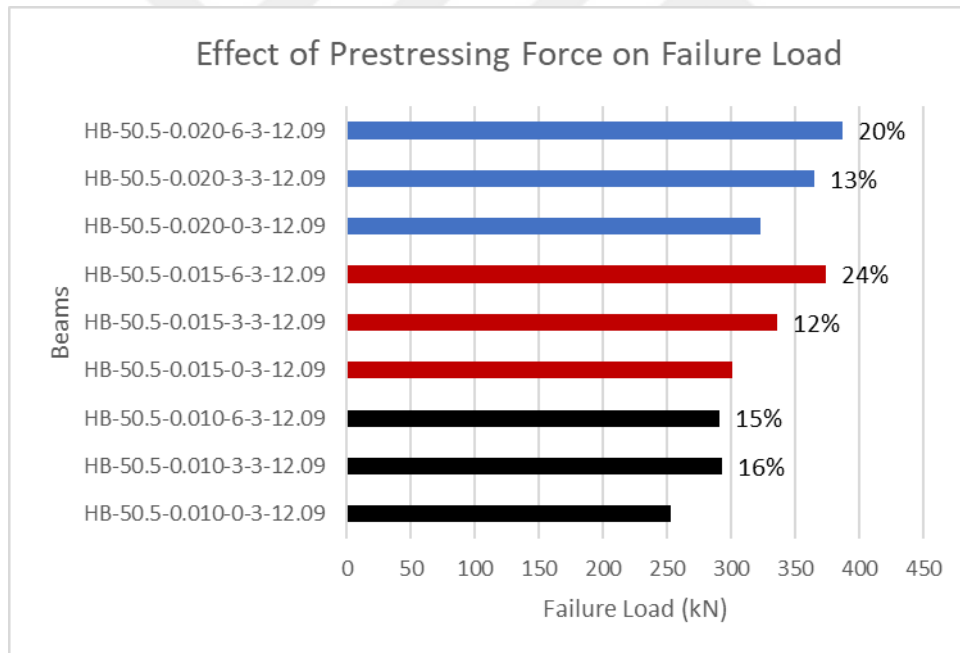


Figure 4.47 FLG of beams with concrete strength of 50.5 (N/mm²) and $\alpha/d_m=3$.

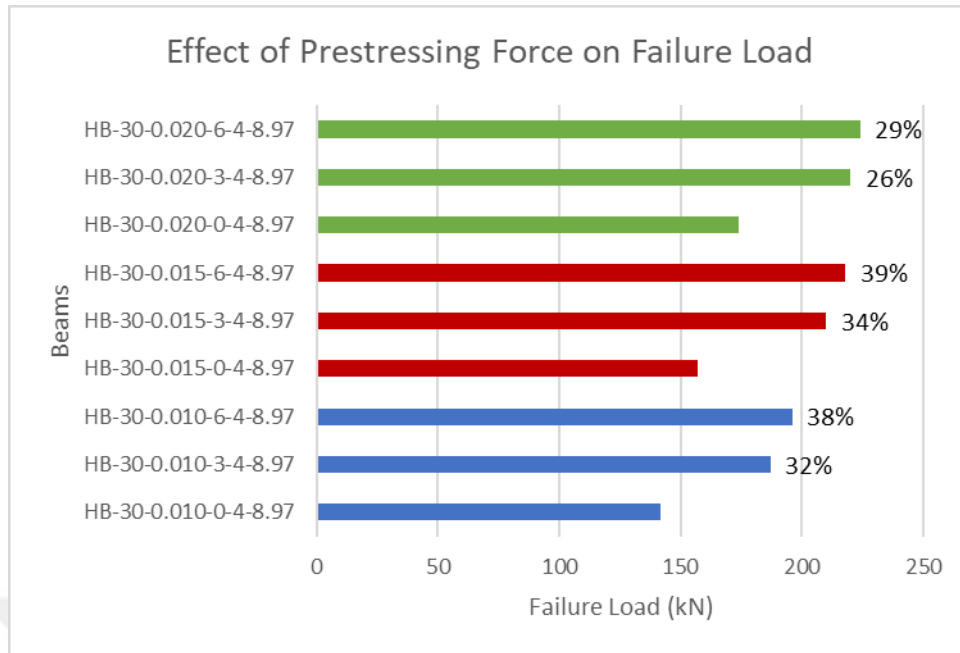


Figure 4.48 FLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=4$.

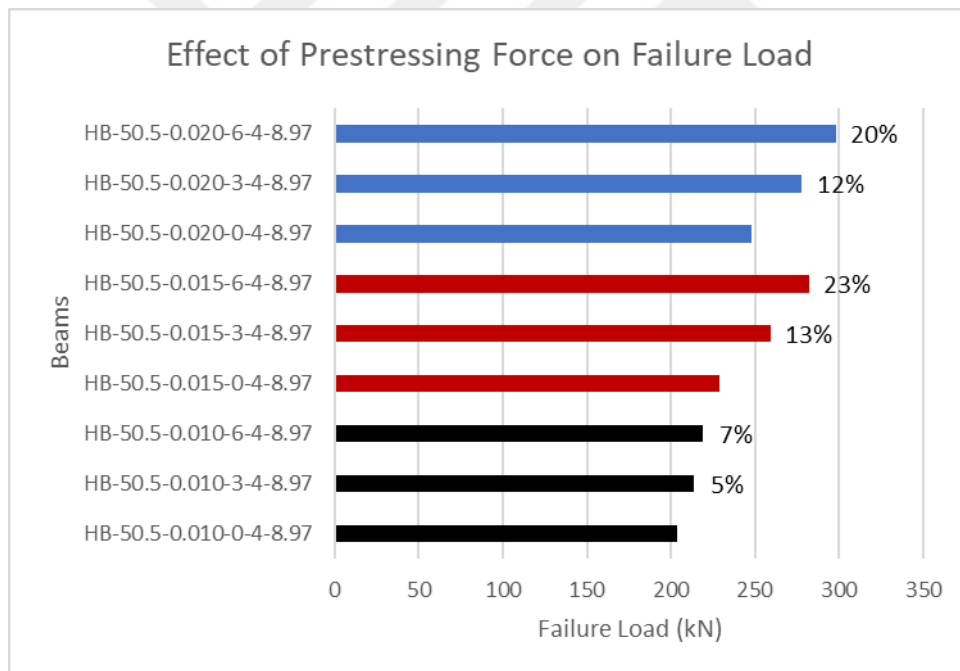


Figure 4.49 FLG of beams with concrete strength of 50.5 (N/mm²) and $\alpha/d_m=4$.

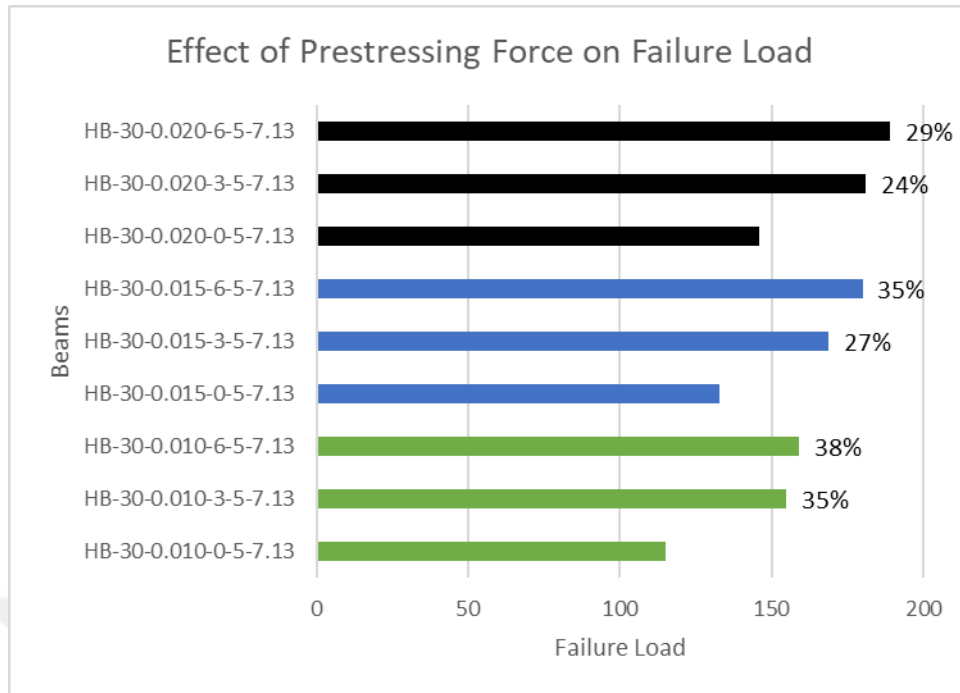


Figure 4.50 FLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=5$.

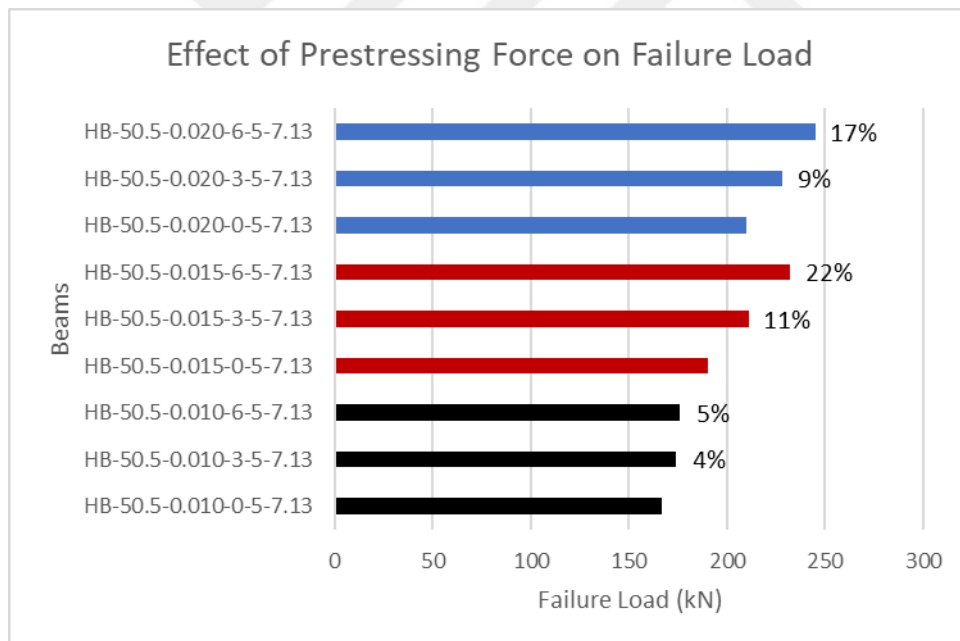


Figure 4.51 FLG of beams with concrete strength of 50.5 (N/mm²) and $\alpha/d_m=5$.

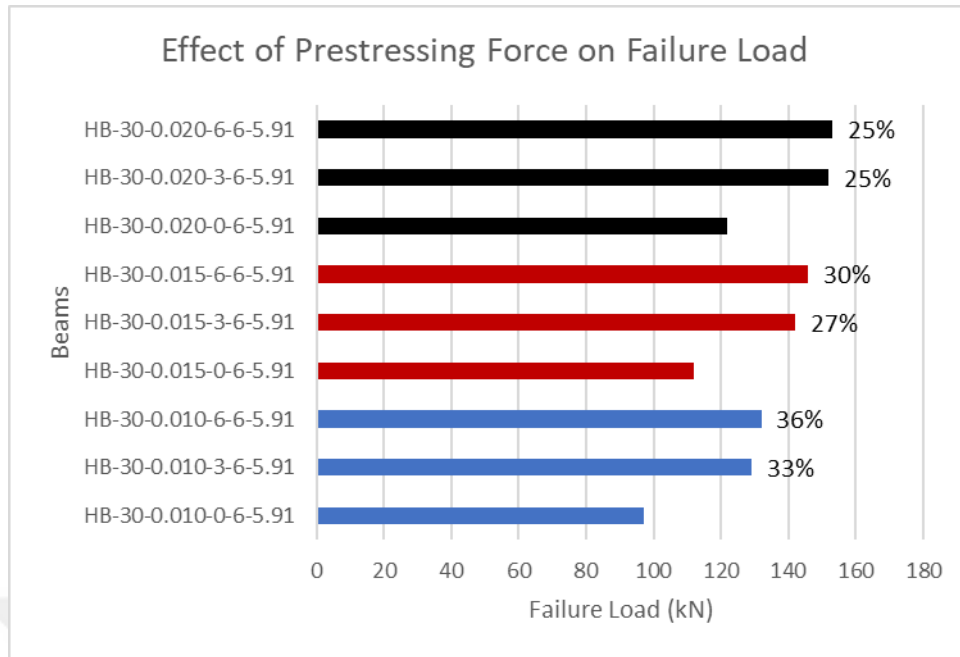


Figure 4.52 FLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=6$.

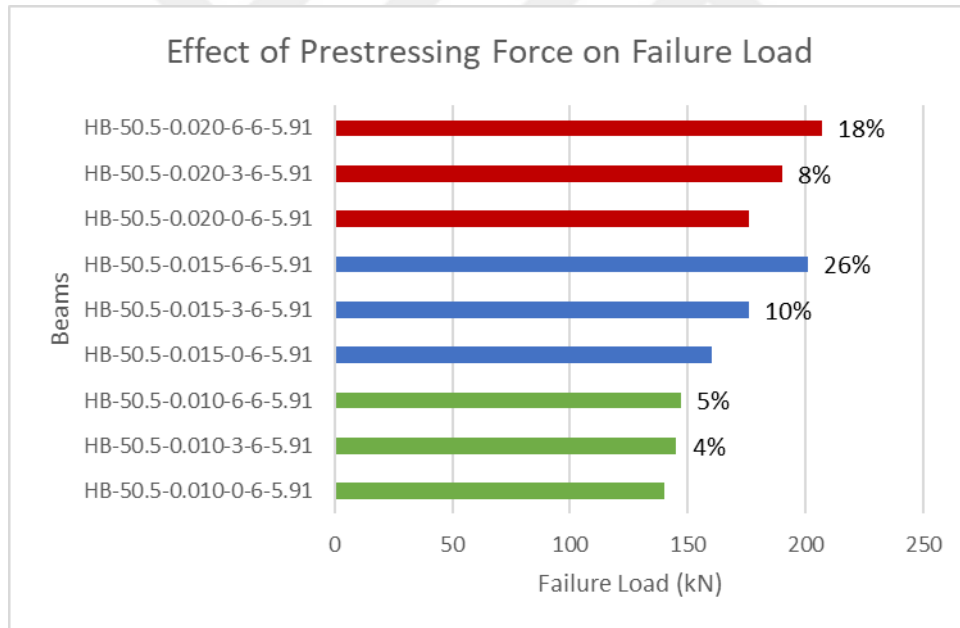


Figure 4.53 FLG of beams with concrete strength of 50.5 (N/mm²) and $\alpha/d_m=6$.

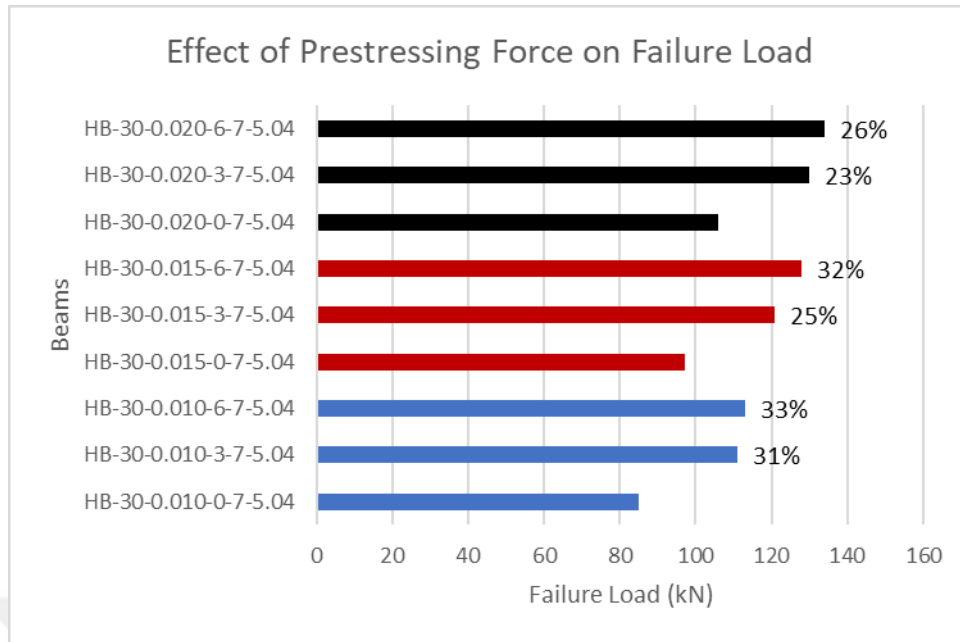


Figure 4.54 FLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=7$.

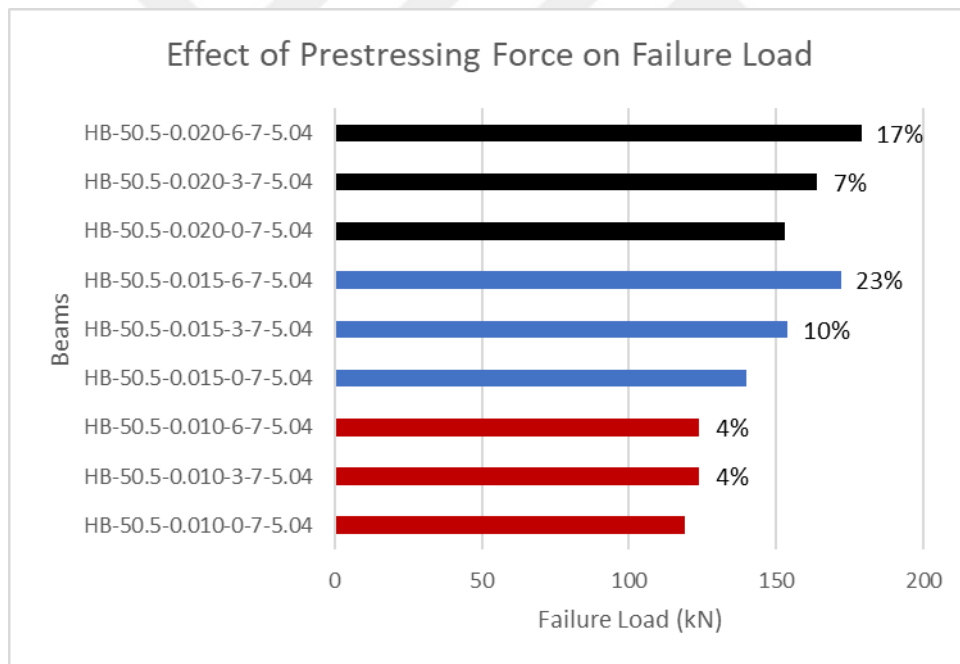


Figure 4.55 FLG of beams with concrete strength of 50.5 (N/mm²) and $\alpha/d_m=7$.

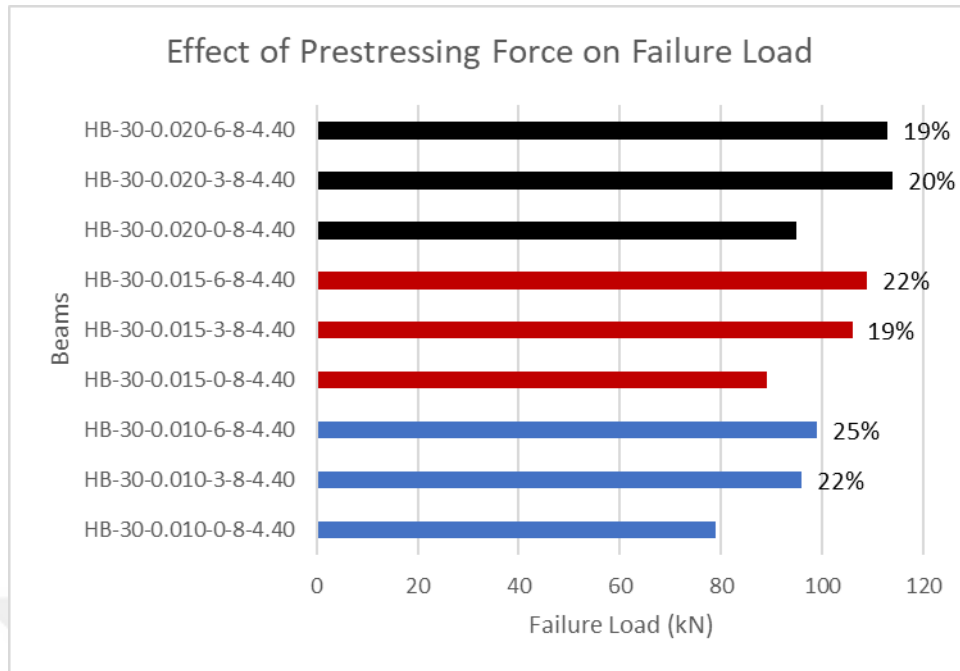


Figure 4.56 FLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=8$.

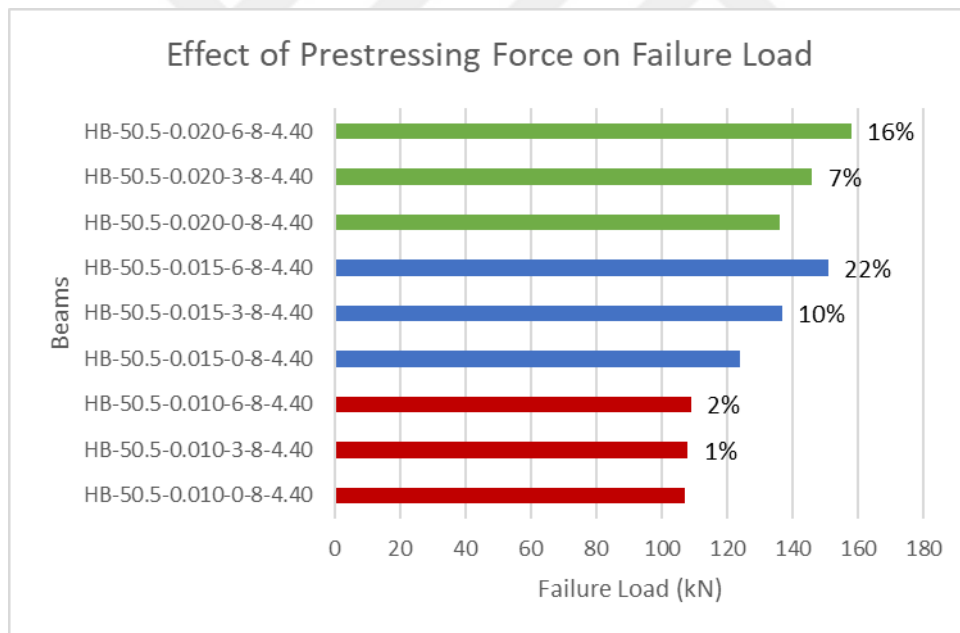


Figure 4.57 FLG of beams with concrete strength of 50.5 (N/mm²) and $\alpha/d_m=8$.

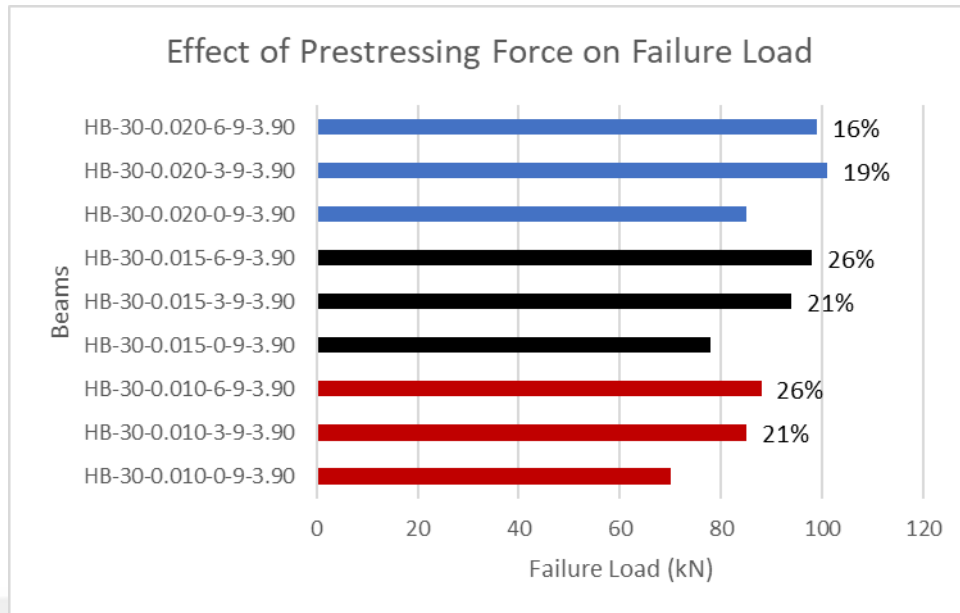


Figure 4.58 FLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=9$.

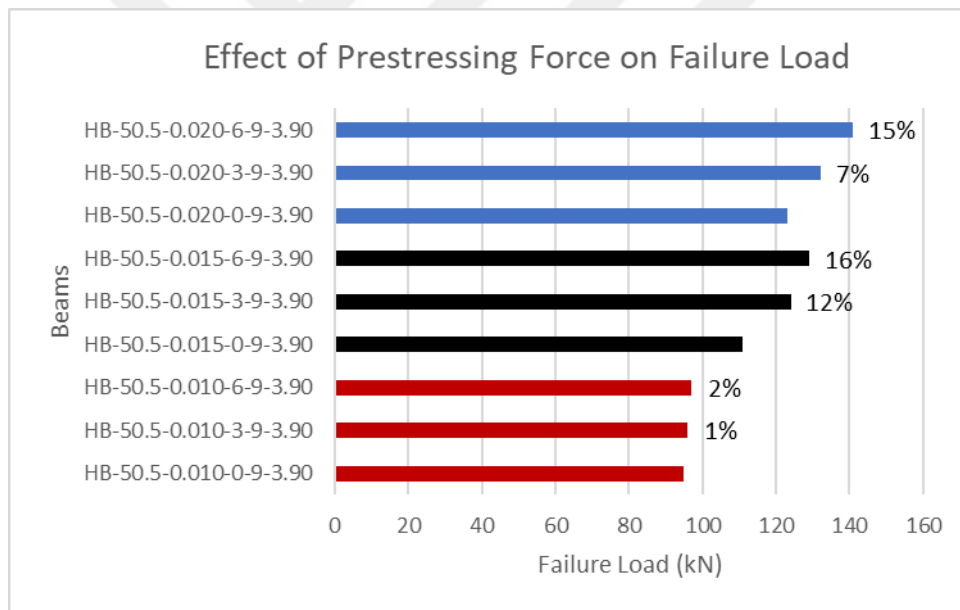


Figure 4.59 FLG of beams with concrete strength of 50.5 (N/mm²) and $\alpha/d_m=9$.

4.2.2 Effect of Prestressing Force on Cracking Load

It is known that the prestressing force has a significant effect on the cracking load of concrete. The cracking load graphs (CLG) showing the cracking load increase ratios due to the prestressing force are given below.

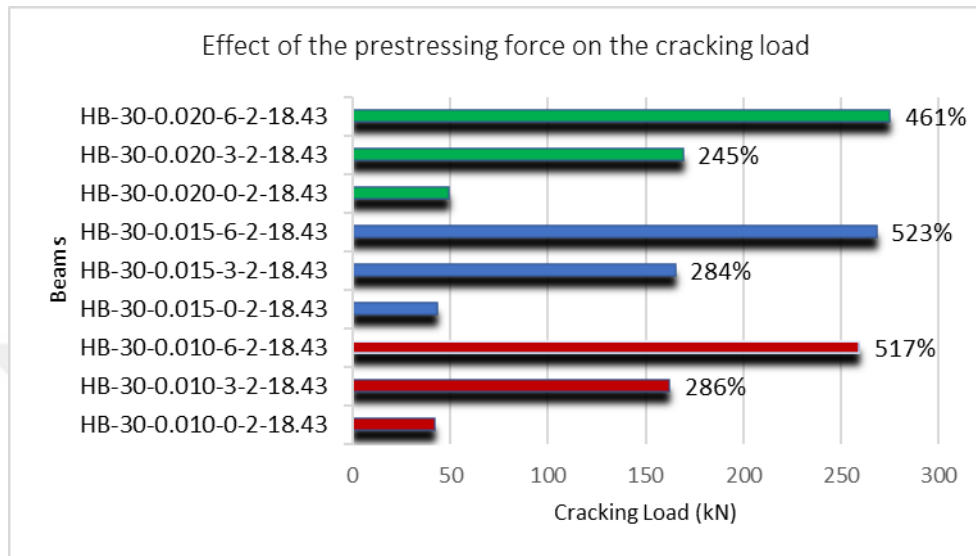


Figure 4.60 CLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=2$.

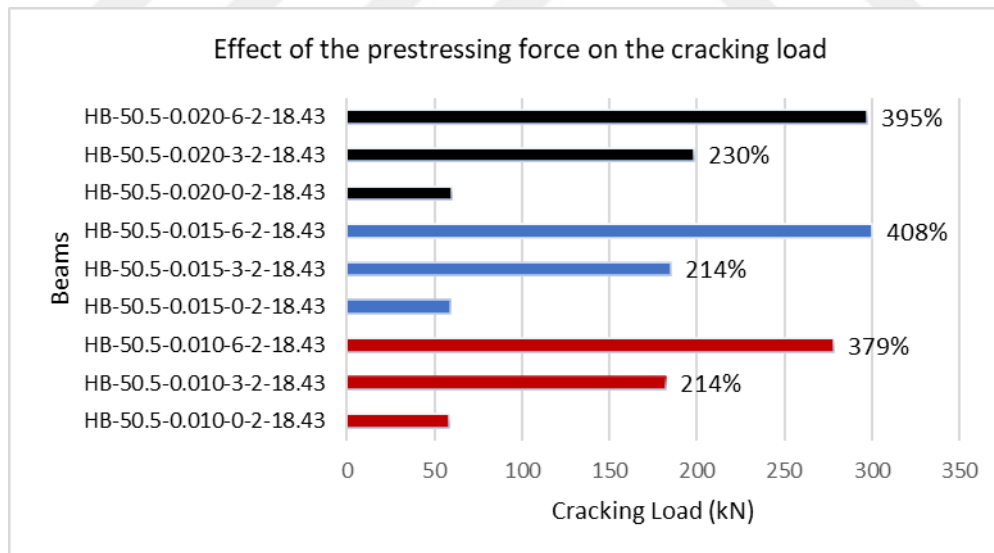


Figure 4.61 CLG of beams with concrete strength of 50.5 (N/mm²) and $\alpha/d_m=2$.

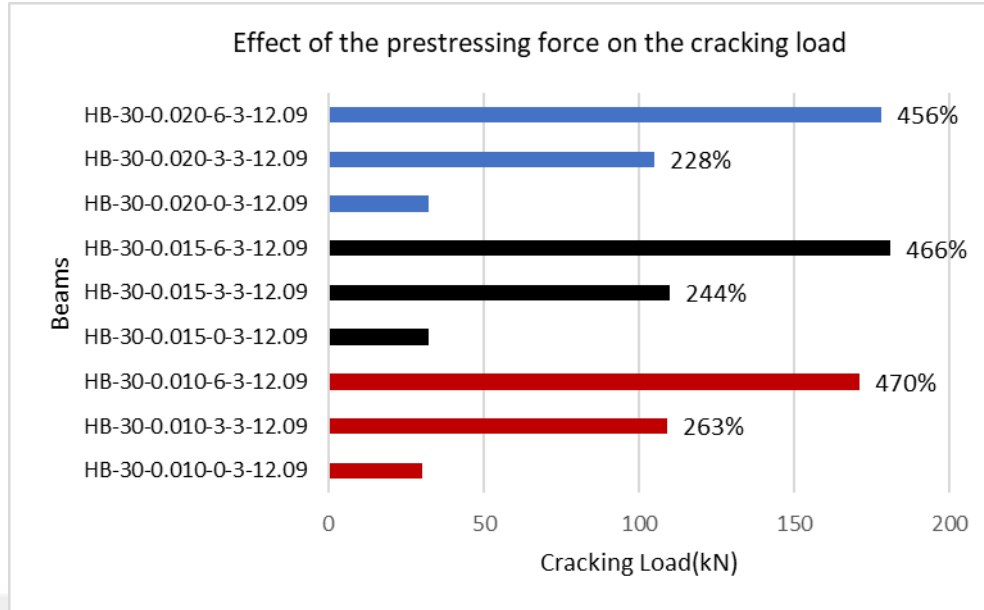


Figure 4.62 CLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=3$.

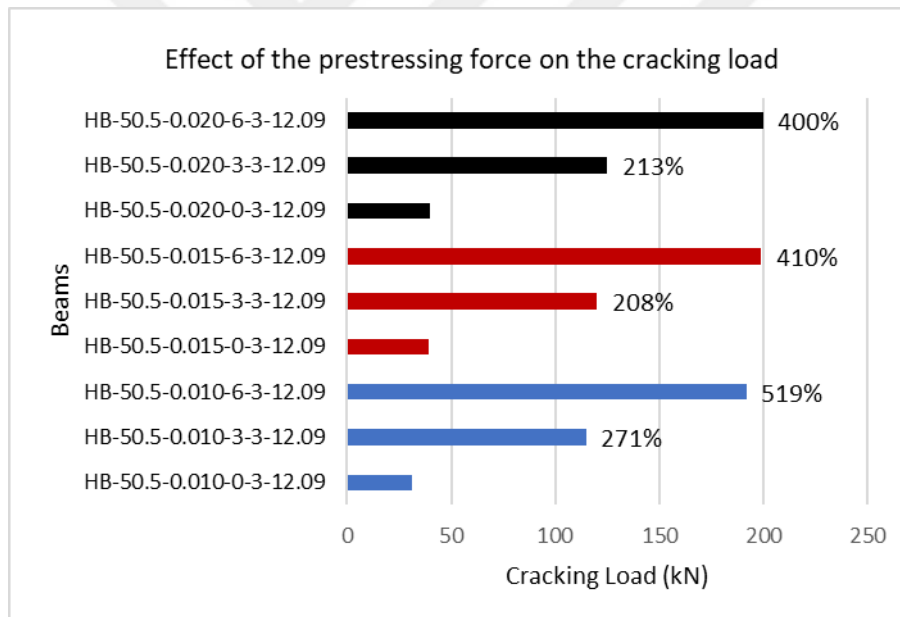


Figure 4.63 CLG of beams with concrete strength of 50.5 (N/mm²) and $\alpha/d_m=3$.

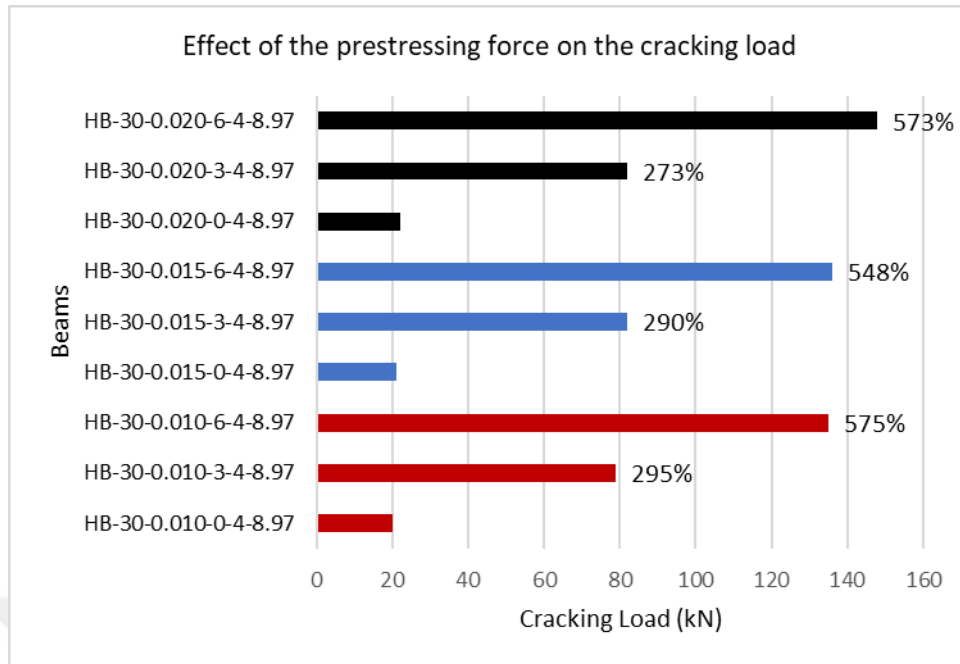


Figure 4.64 CLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=4$.

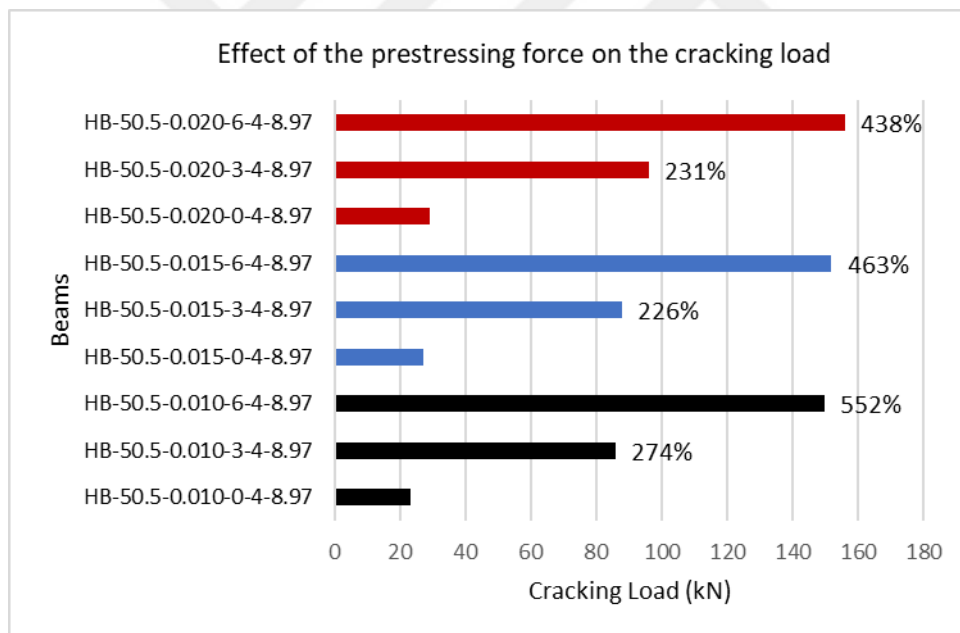


Figure 4.65 CLG of beams with concrete strength of 50.5 (N/mm²) and $\alpha/d_m=4$.

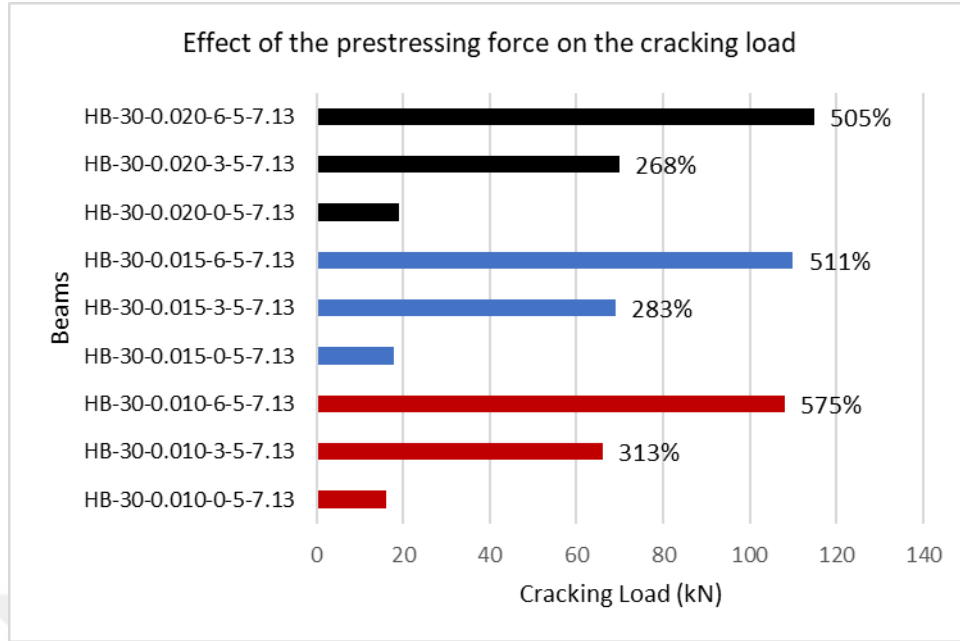


Figure 4.66 CLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=5$.

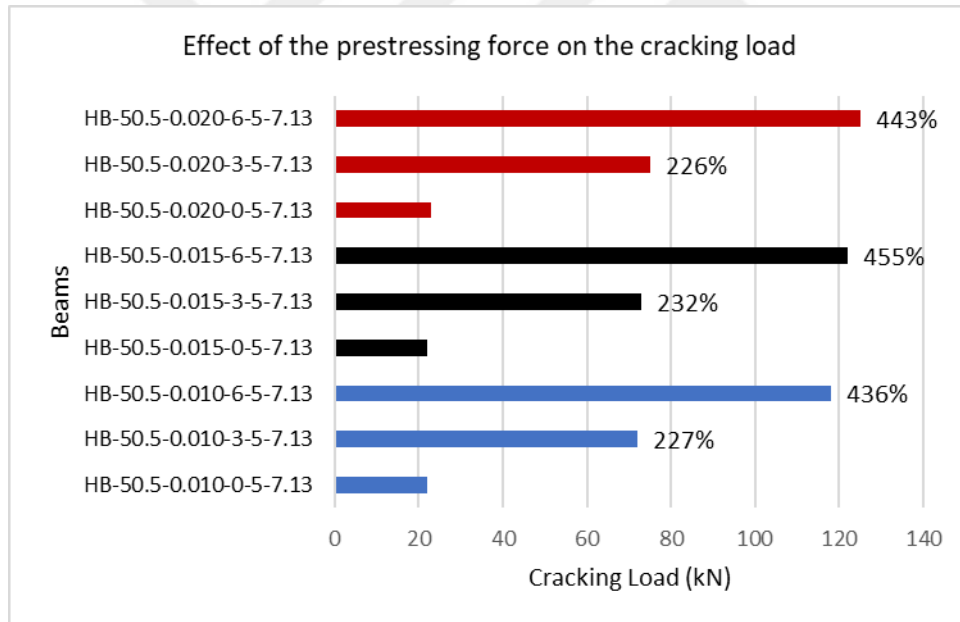


Figure 4.67 CLG of beams with concrete strength of 50.5 (N/mm²) $\alpha/d_m=5$.

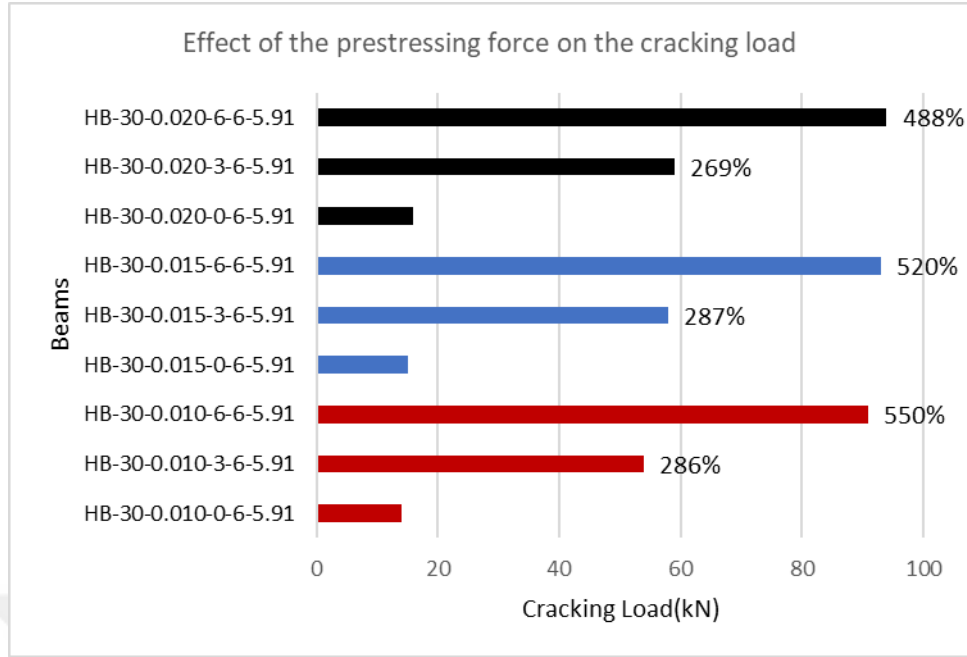


Figure 4.68 CLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=6$.

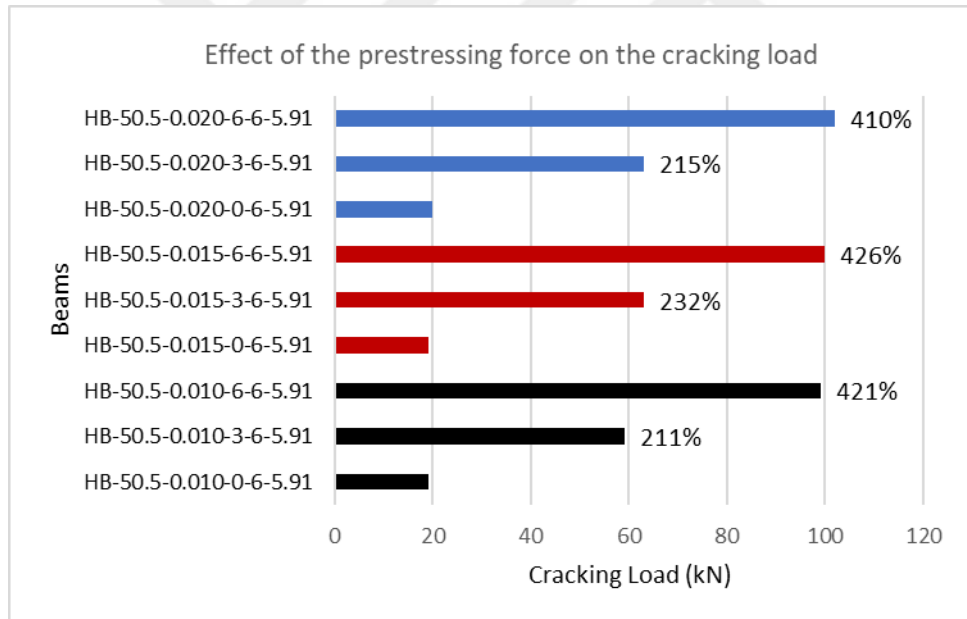


Figure 4.69 CLG of beams with concrete strength of 50.5 (N/mm²) and $\alpha/d_m=6$.

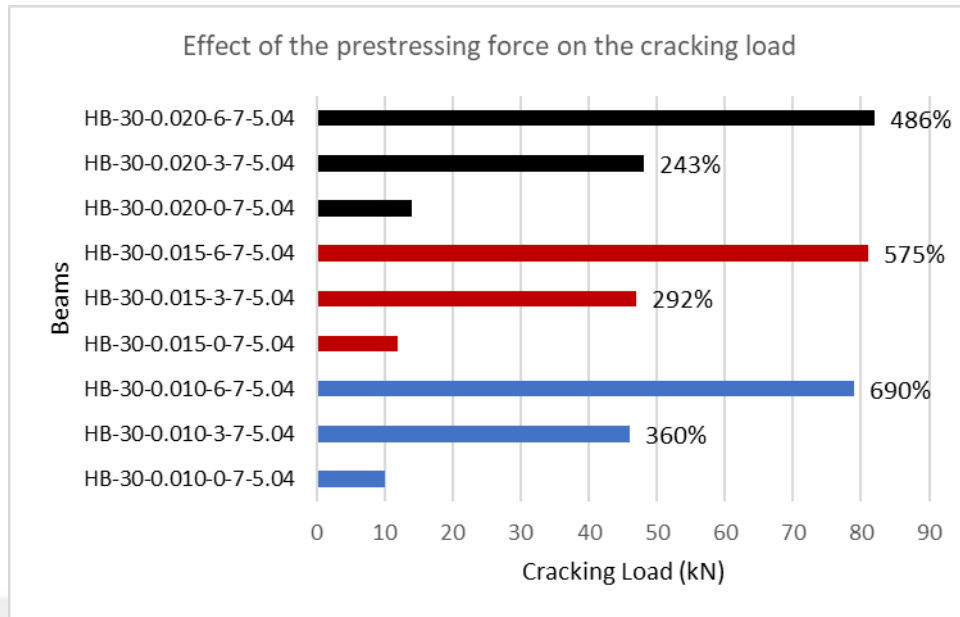


Figure 4.70 CLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=7$.

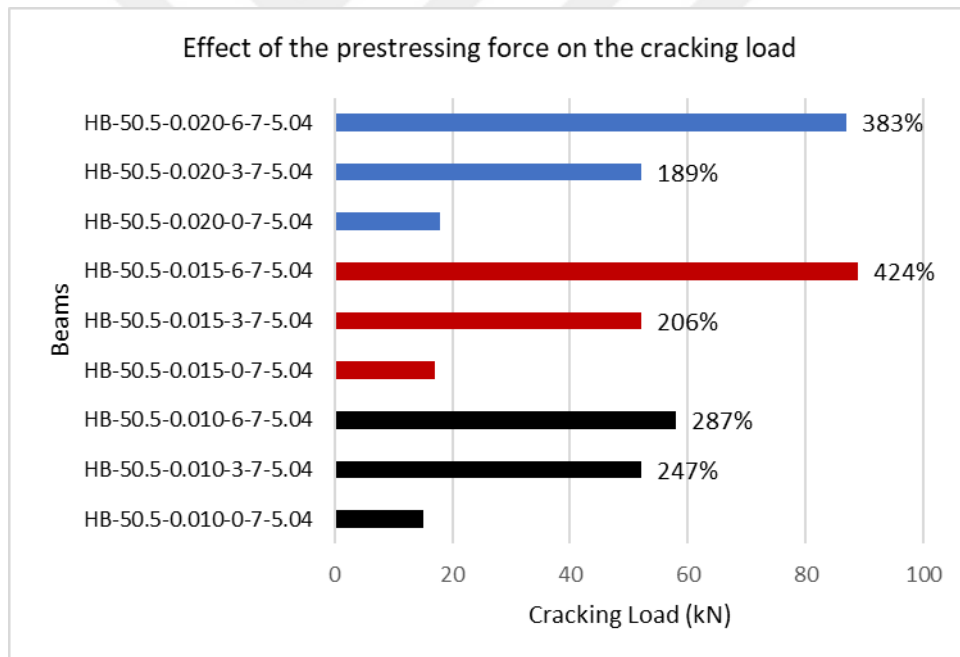


Figure 4.71 CLG of beams with concrete strength of 50.5 (N/mm²) and $\alpha/d_m=7$.

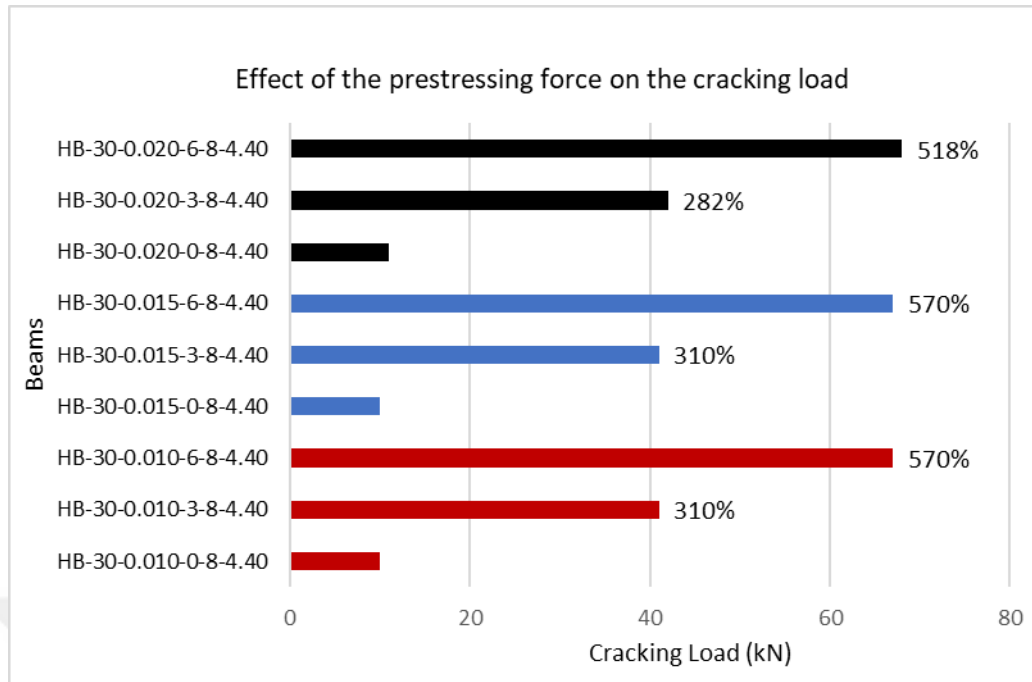


Figure 4.72 CLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=8$.

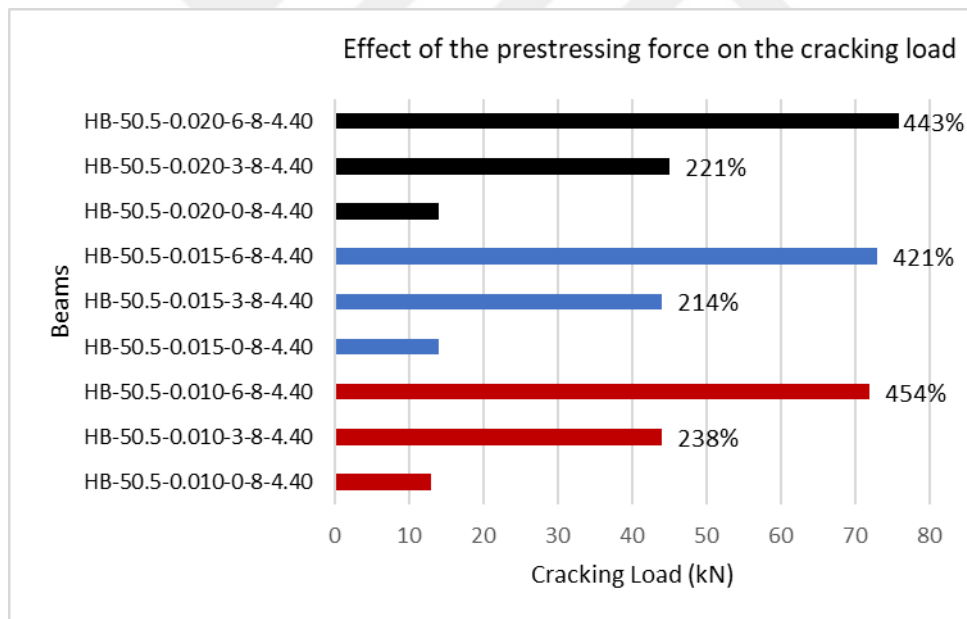


Figure 4.73 CLG of beams with concrete strength of 50.5 (N/mm²) and $\alpha/d_m=8$.

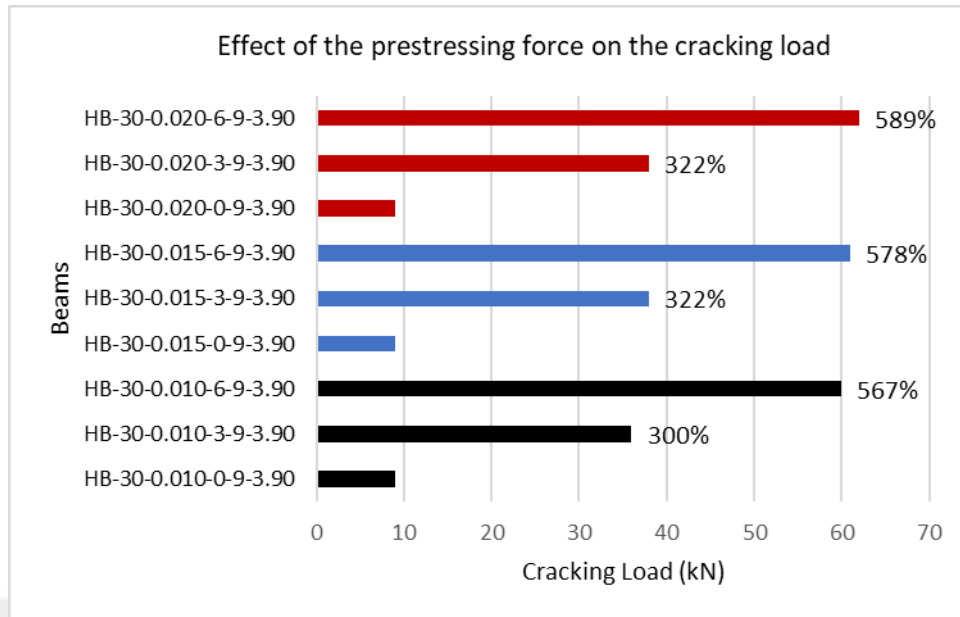


Figure 4.74 CLG of beams with concrete strength of 30 (N/mm²) and $\alpha/d_m=9$.

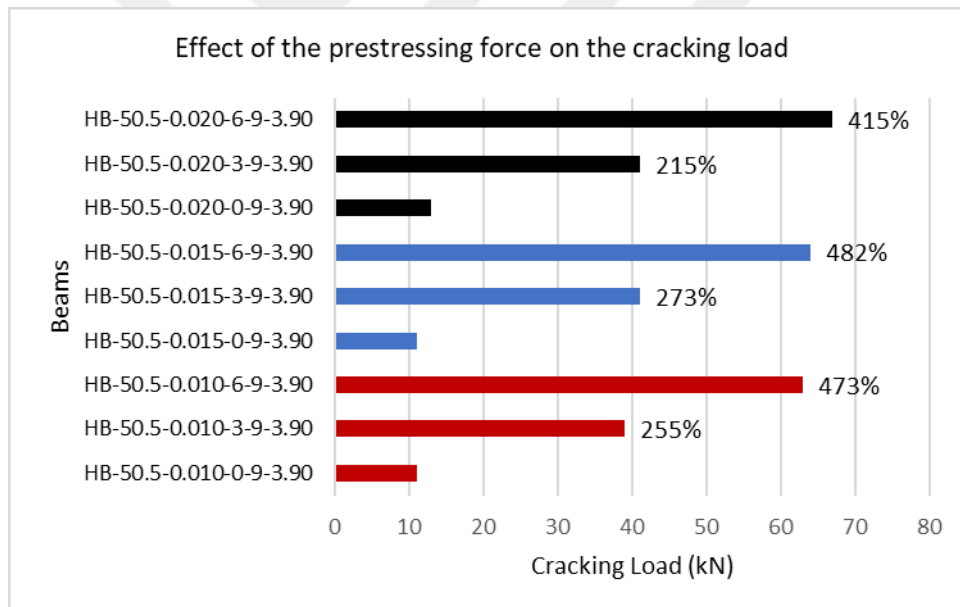


Figure 4.75 CLG of beams with concrete strength of 50.5 (N/mm²) and $\alpha/d_m=9$.

4.3 Area of Tensile Bars Effect

Under this title, the importance of three tensile bar ratios (0.010, 0.015, 0.020) in prestressed HB beams has been investigated and expressed in plots.

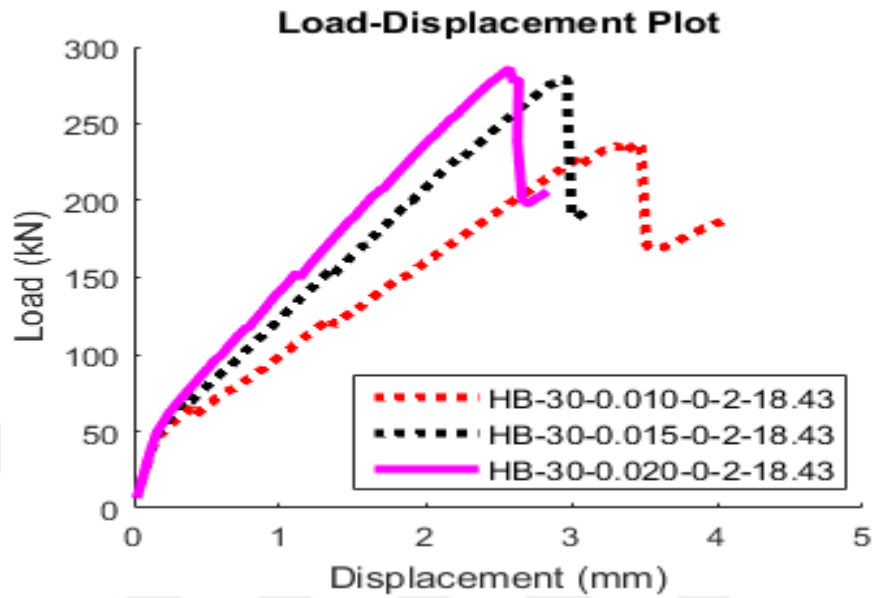


Figure 4.76 Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-0-2-18.43.

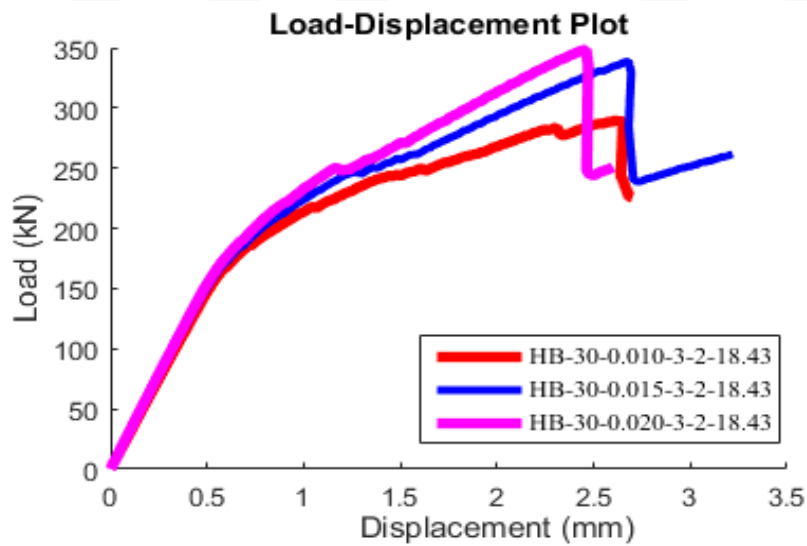


Figure 4.77 Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-3-2-18.43.

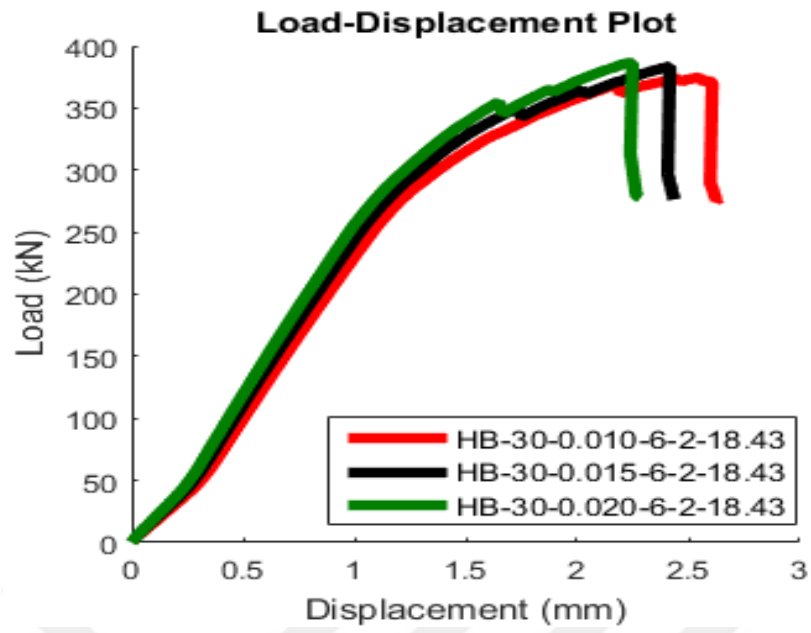


Figure 4.78 Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-6-2-18.43.

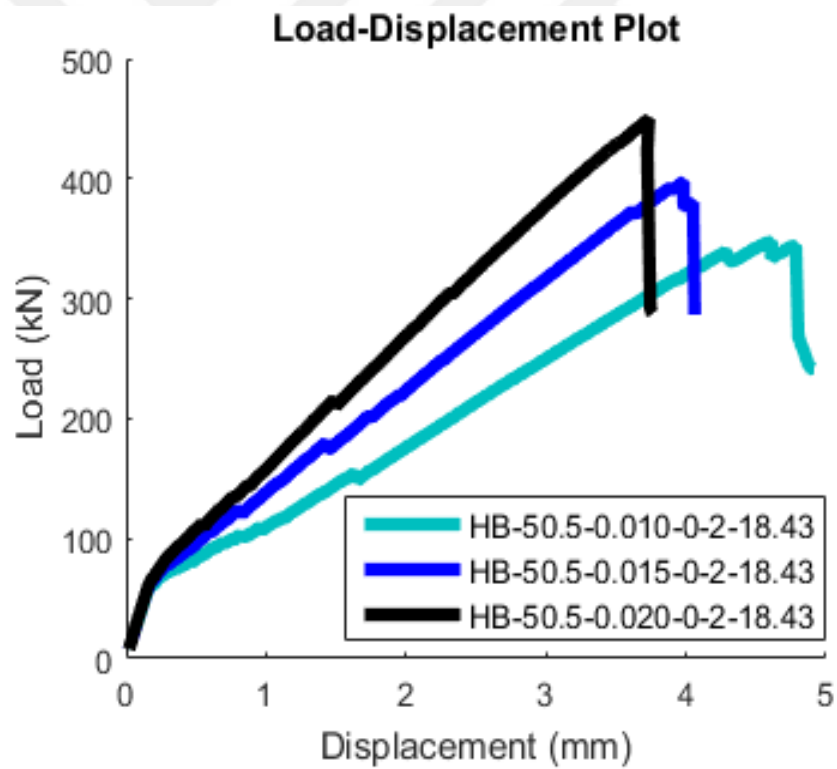


Figure 4.79 Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-0-2-18.43.

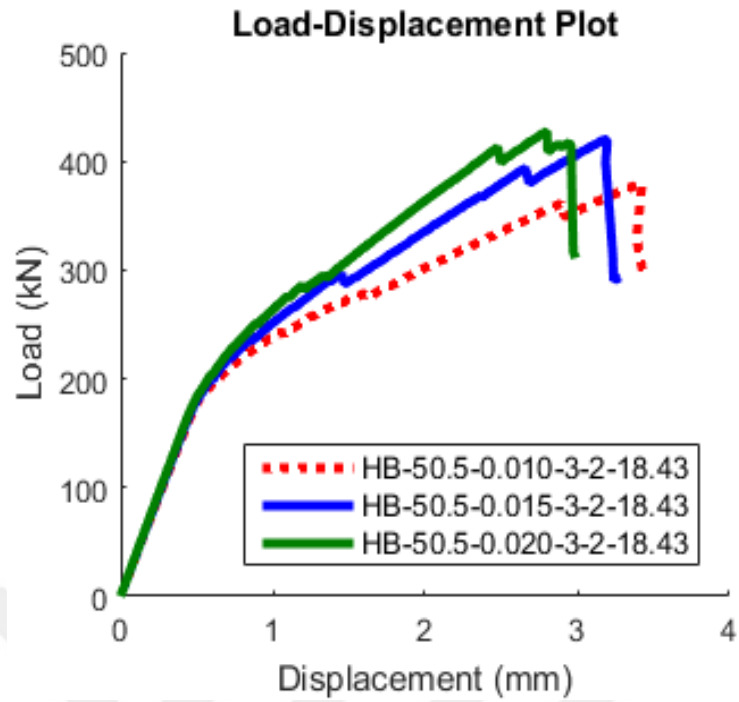


Figure 4.80 Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-3-2-18.43.

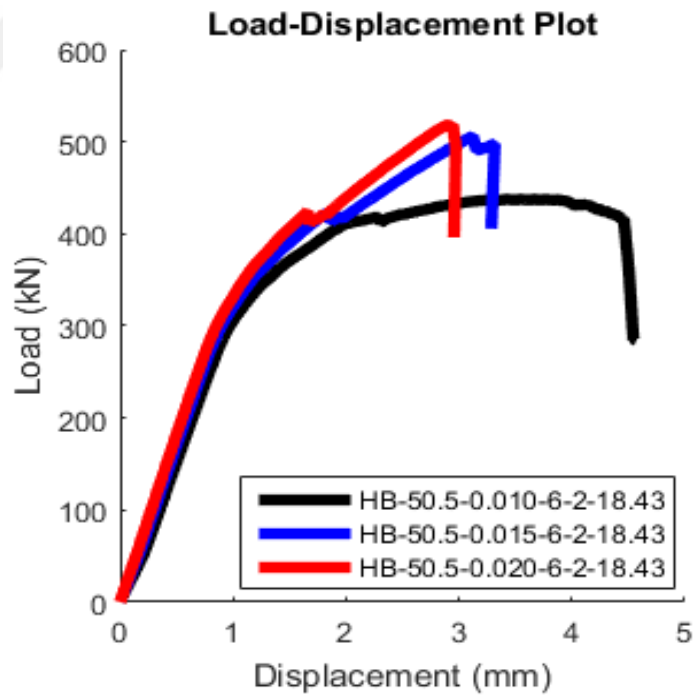


Figure 4.81 Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-6-2-18.43.

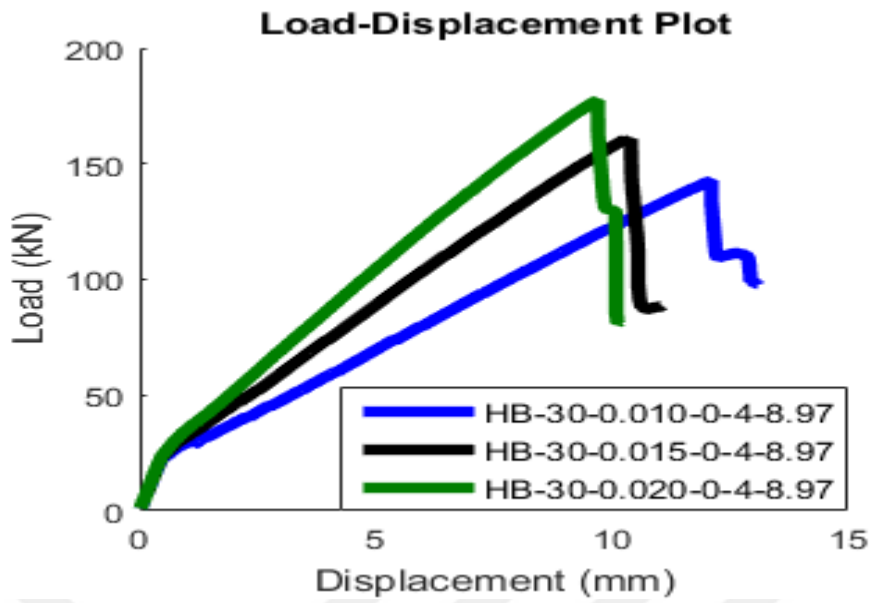


Figure 4.82 Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-0-4-8.97.

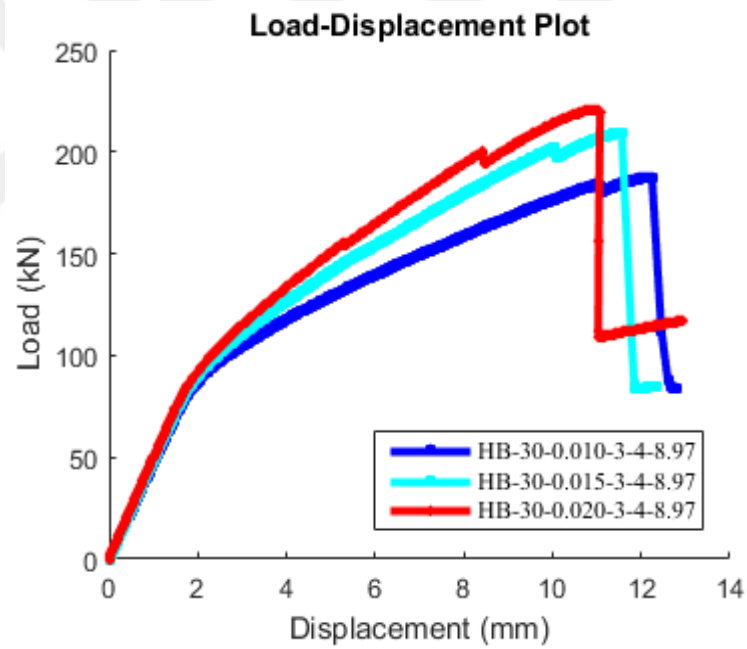


Figure 4.83 Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-3-4-8.97.

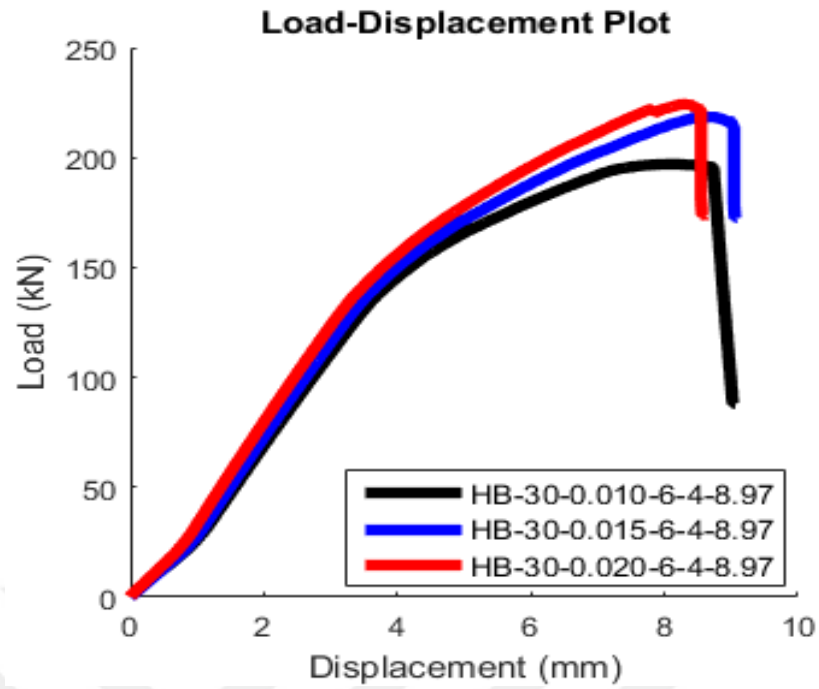


Figure 4.84 Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-6-4-8.97.

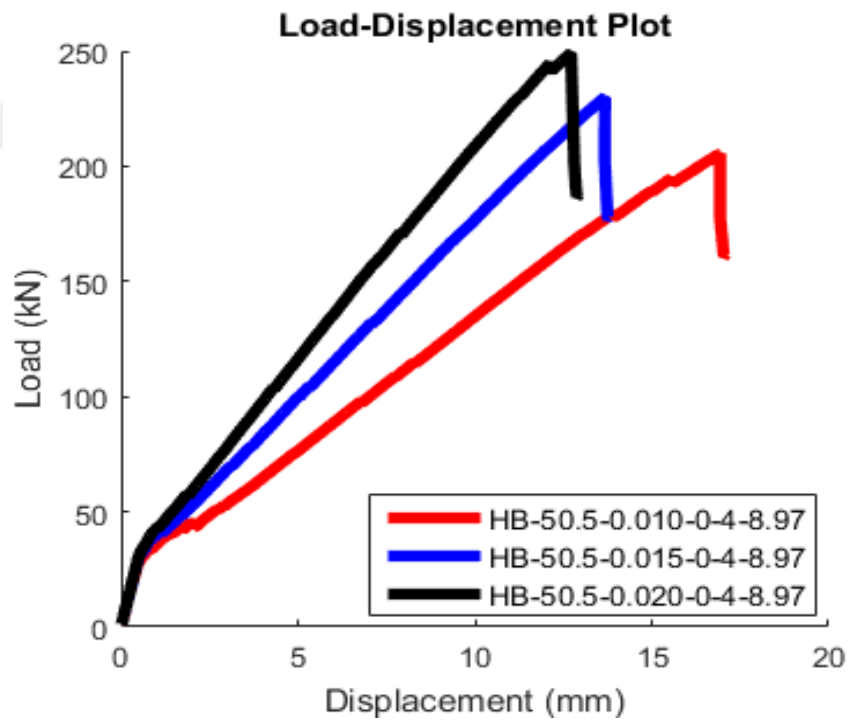


Figure 4.85 Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-0-4-8.97.

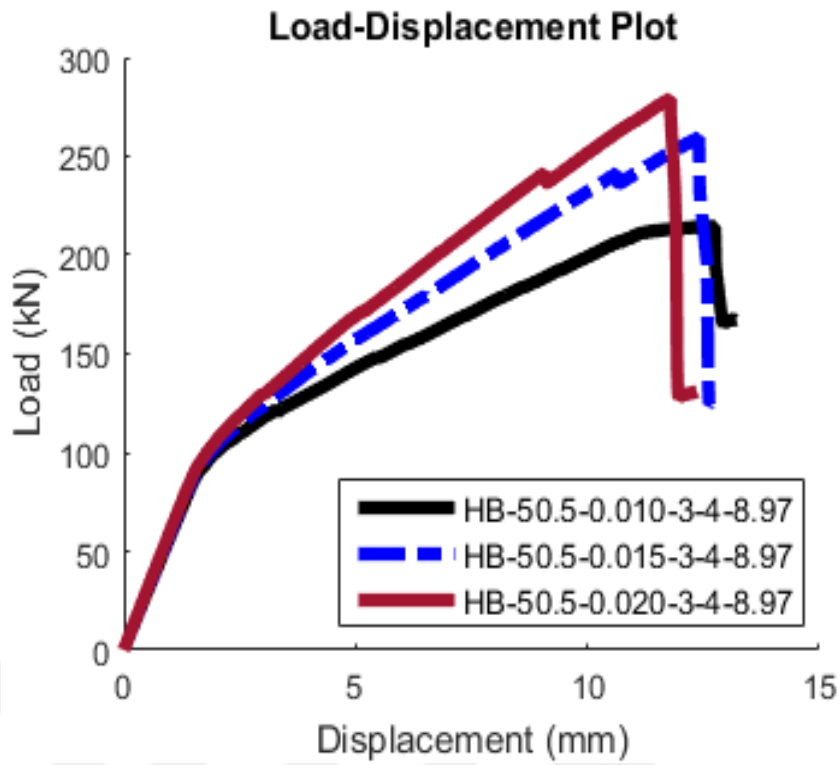


Figure 4.86 Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-3-4-8.97.

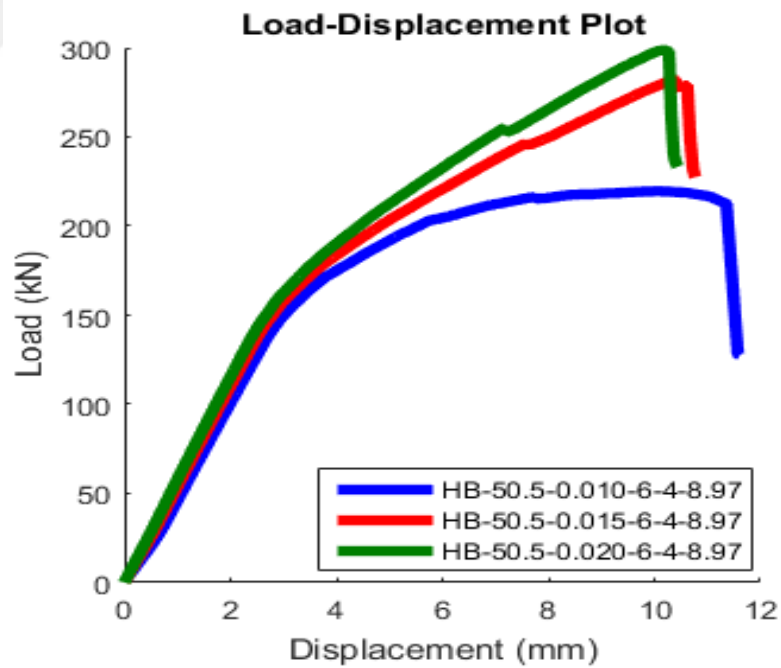


Figure 4.87 Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-6-4-8.97.

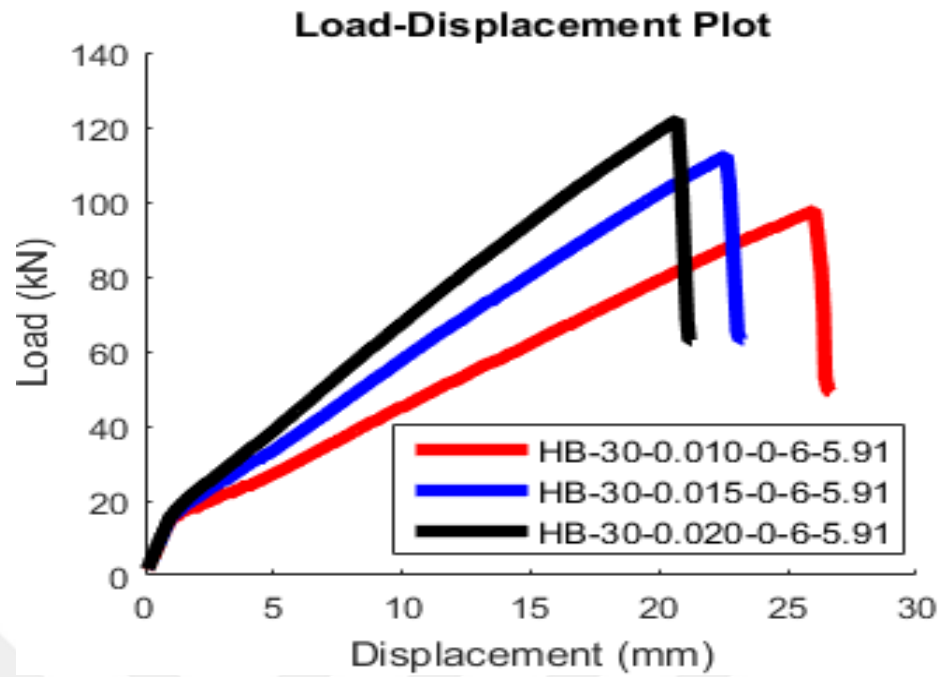


Figure 4.88 Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-0-6-5.91.

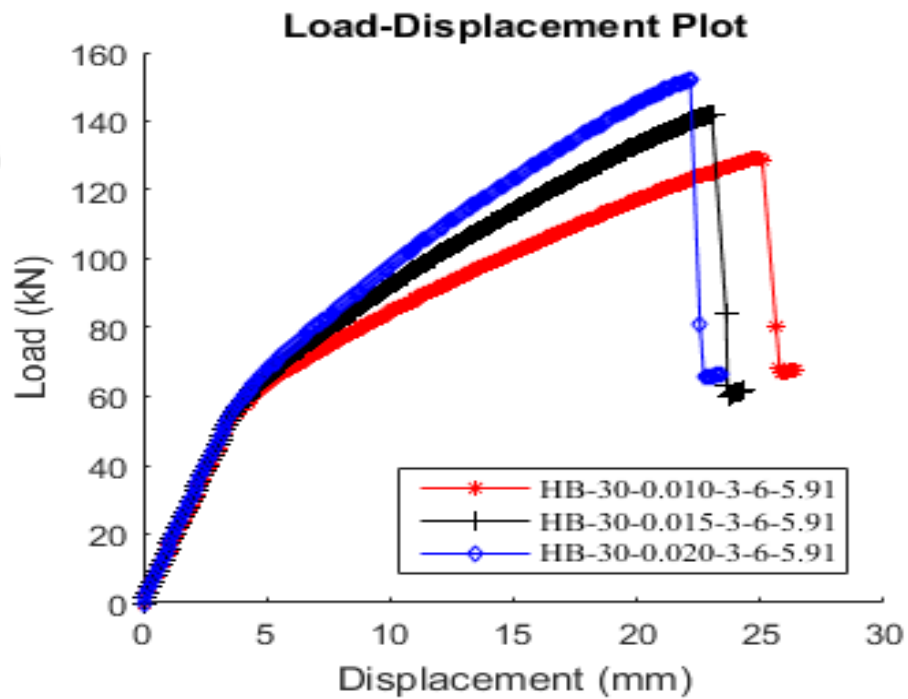


Figure 4.89 Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-3-6-5.91.

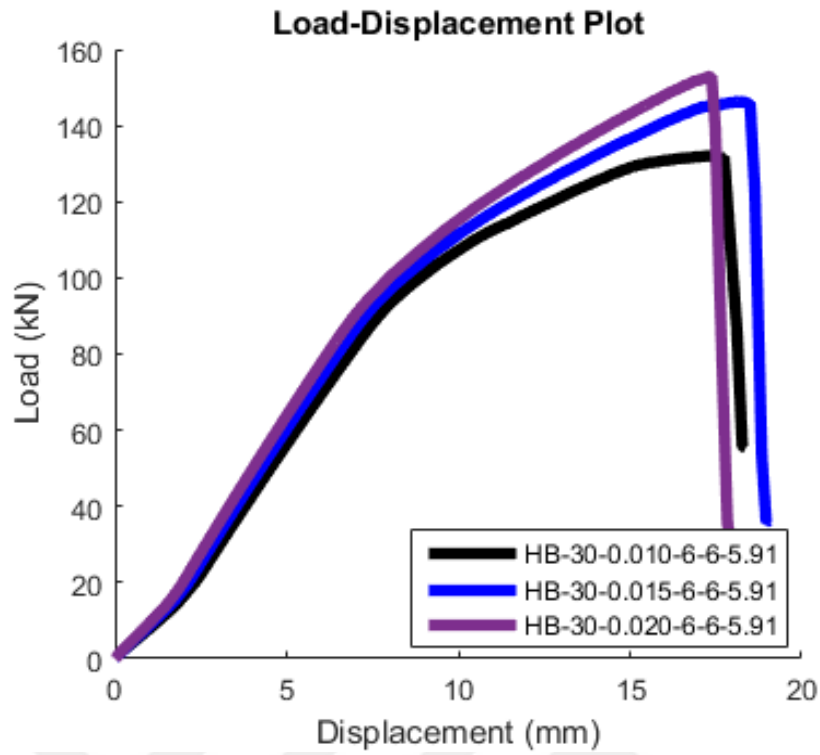


Figure 4.90 Load-Displacement plot of HB-30-(0.010, 0.015, 0.020)-6-6-5.91.

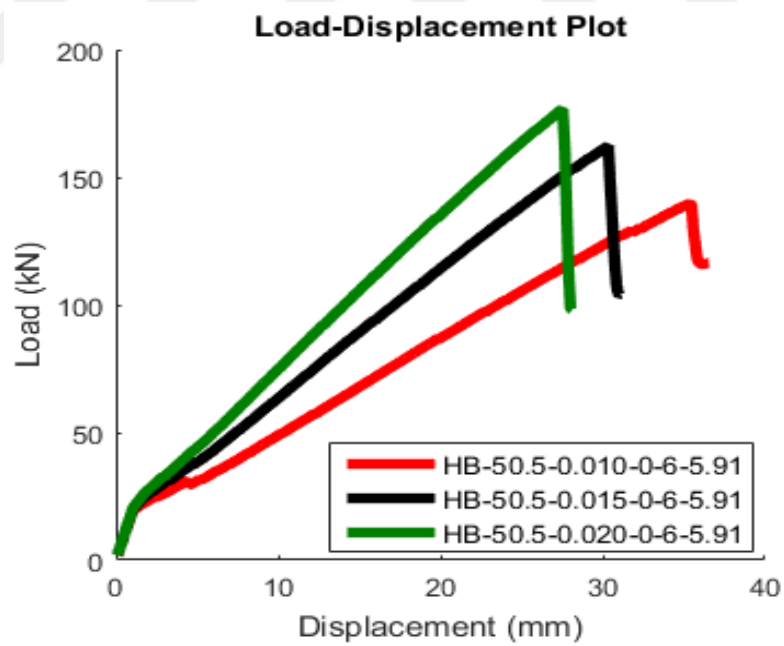


Figure 4.91 Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-0-6-5.91.

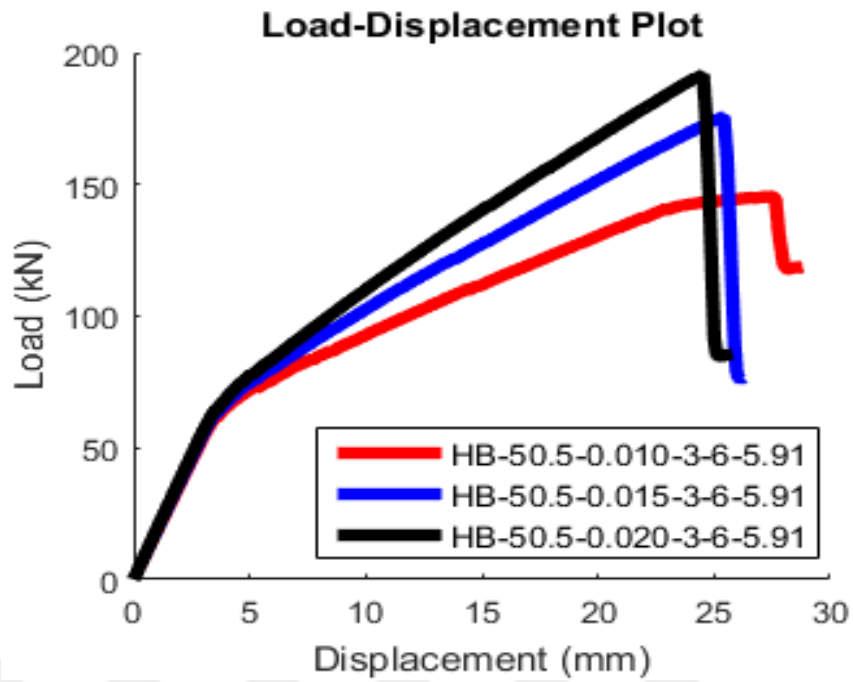


Figure 4.92 Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-3-6-5.91.

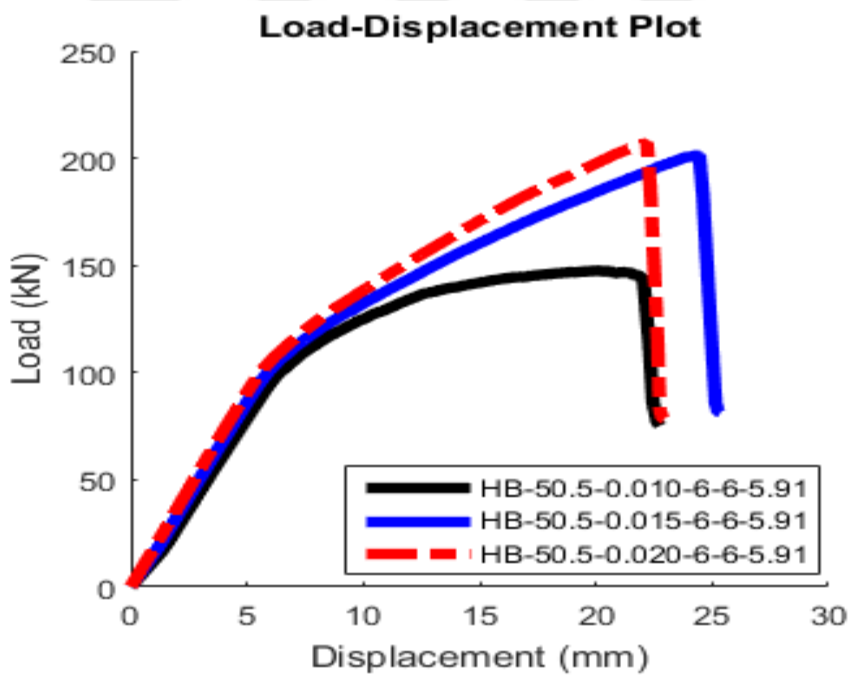


Figure 4.93 Load-Displacement plot of HB-50.5-(0.010, 0.015, 0.020)-6-6-5.91.

4.4 Taper Slope of Beams Effect

The effect of the slope of reinforced concrete HB beams on the prestress was investigated. In order to better understand the importance of the slope in HB beams, the plots of beams with different parameters are examined.

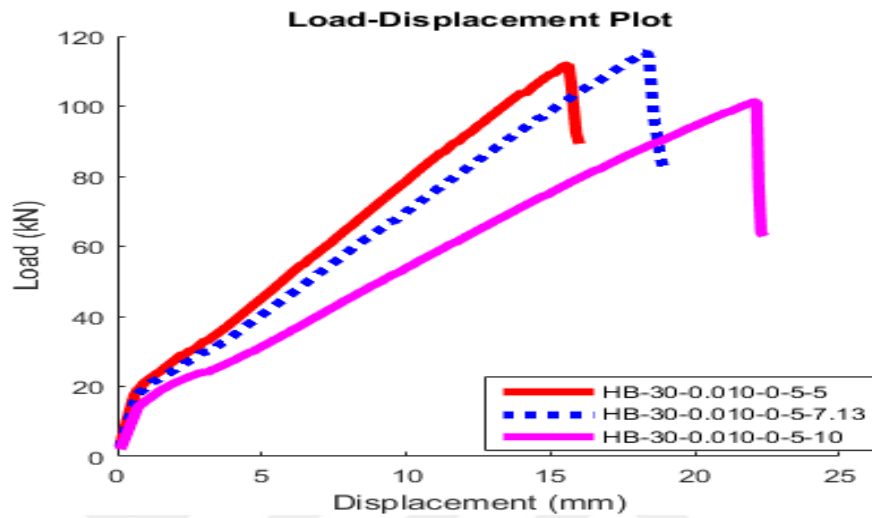


Figure 4.94 Load-Displacement plot of HB-30-0.010-0-5-(5, 7.13, 10).

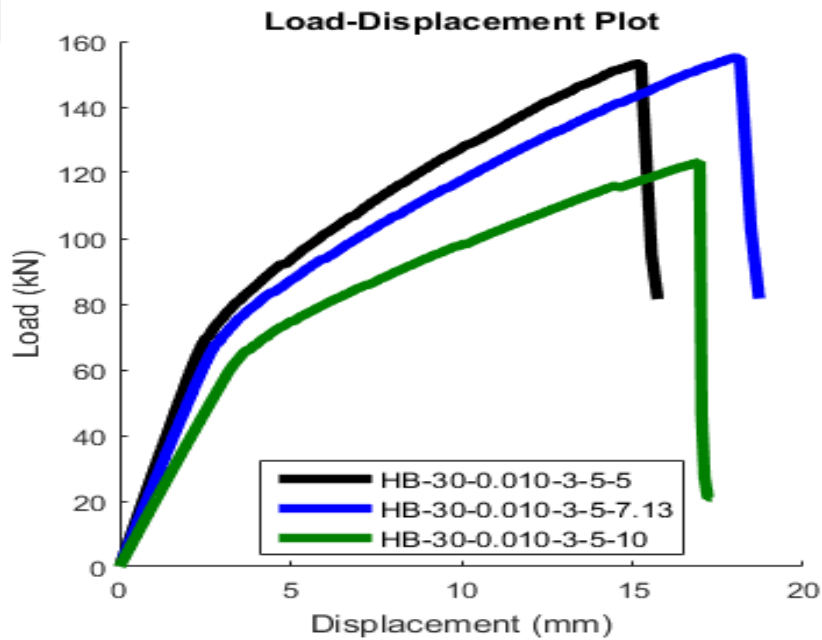


Figure 4.95 Load-Displacement plot of HB-30-0.010-3-5-(5, 7.13, 10).

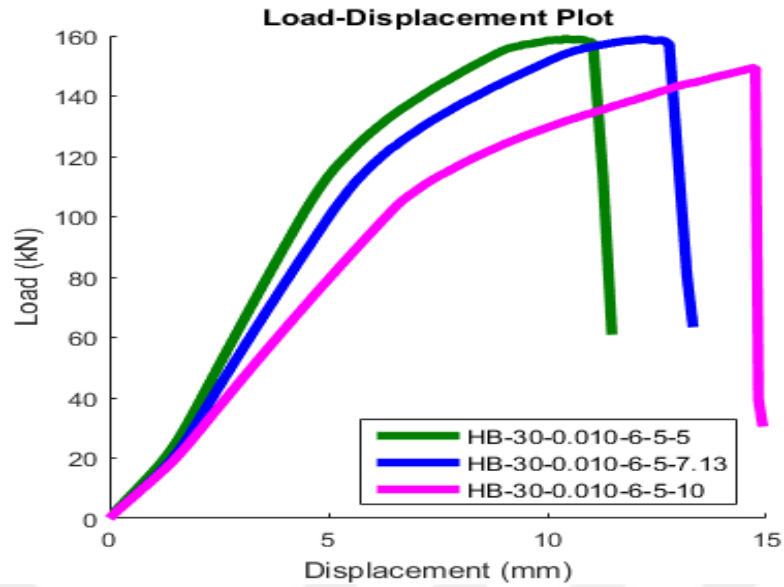


Figure 4.96 Load-Displacement plot of HB-30-0.010-6-5-(5, 7.13, 10).

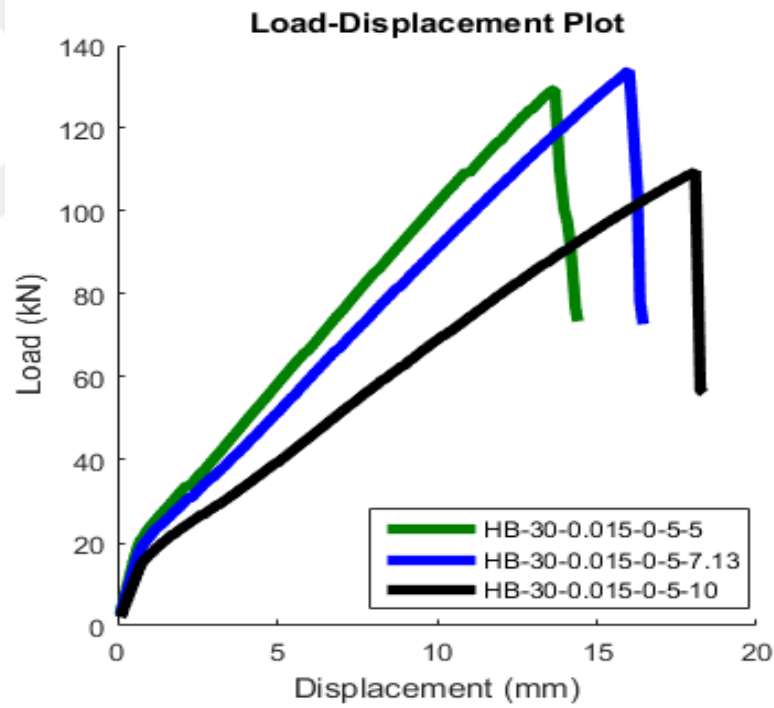


Figure 4.97 Load-Displacement plot of HB-30-0.015-0-5-(5, 7.13, 10).

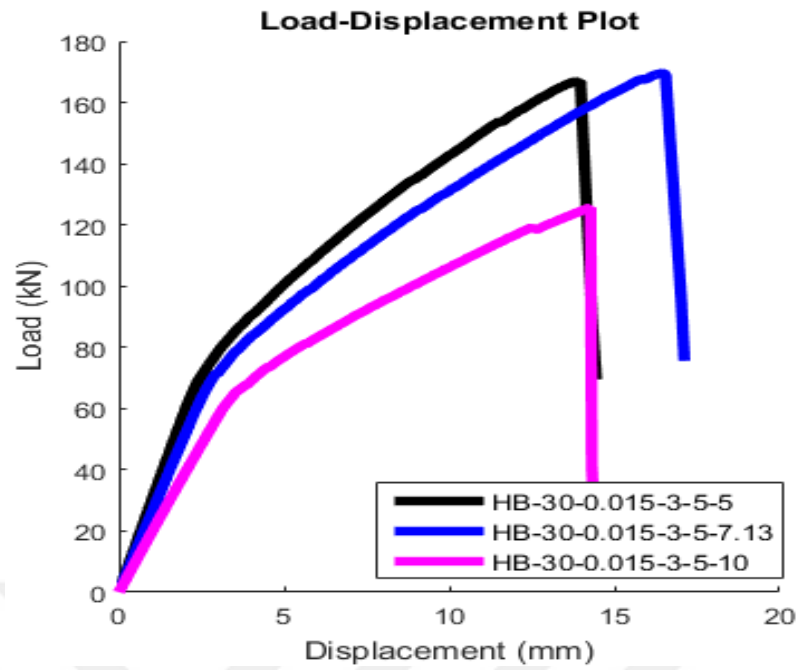


Figure 4.98 Load-Displacement plot of HB-30-0.015-3-5(5, 7.13, 10).

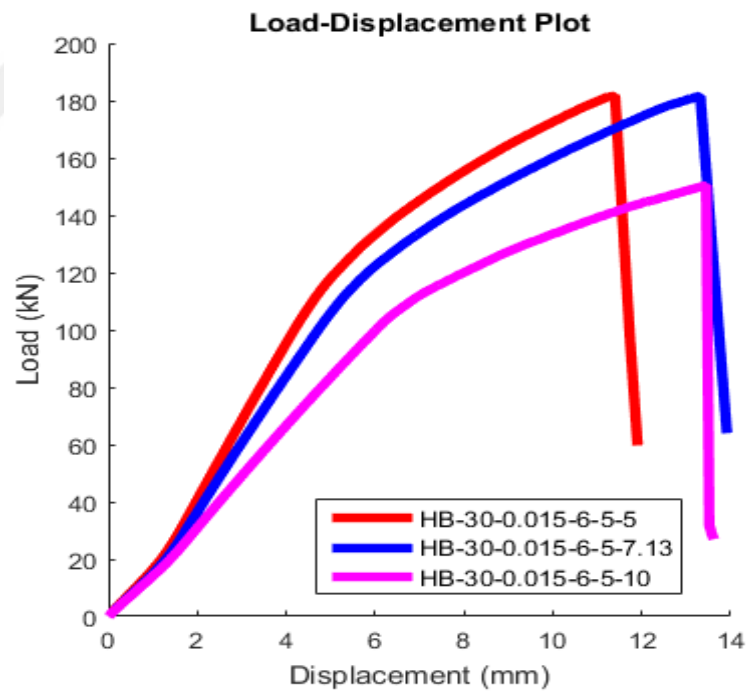


Figure 4.99 Load-Displacement plot of HB-30-0.015-6-5(5, 7.13, 10).

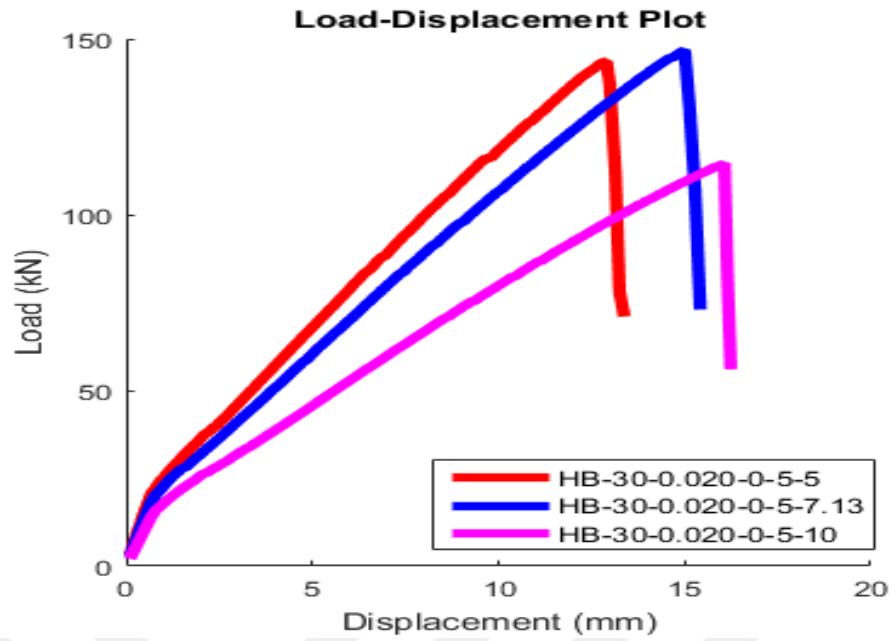


Figure 4.100 Load-Displacement plot of HB-30-0.020-0-5-(5, 7.13, 10).

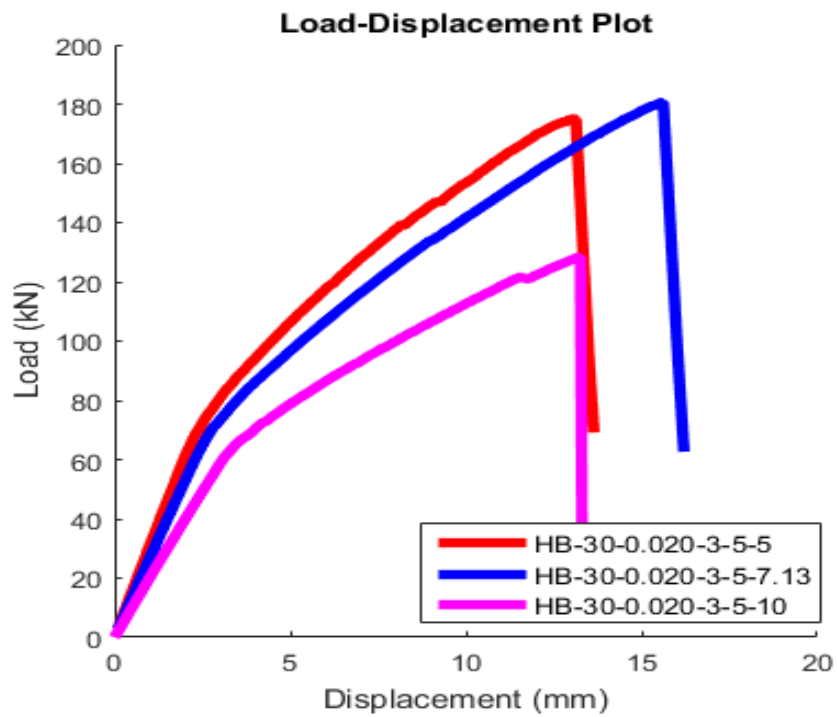


Figure 4.101 Load-Displacement plot of HB-30-0.020-3-5-(5, 7.13, 10).

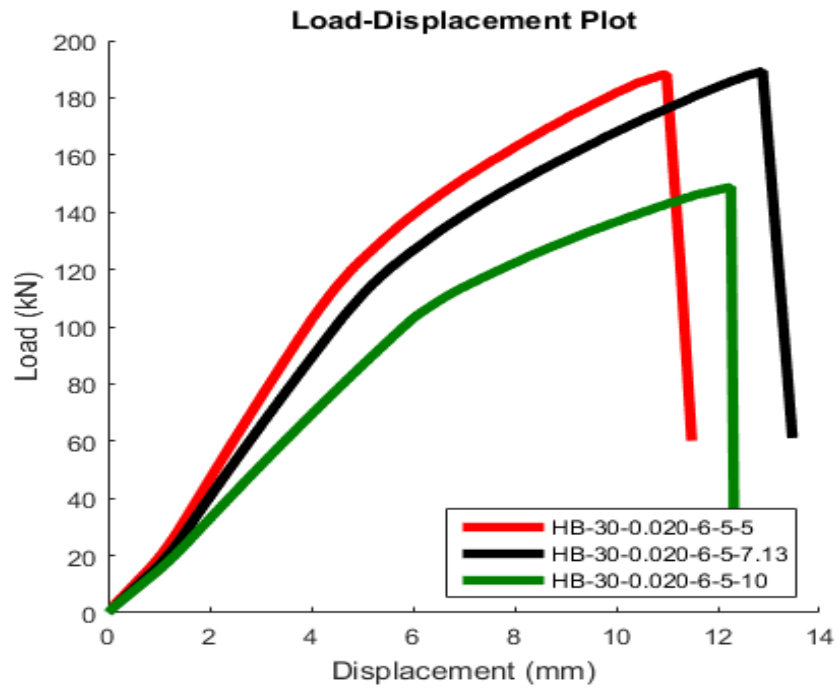


Figure 4.102 Load-Displacement plot of HB-30-0.020-6-5-(5, 7.13, 10).

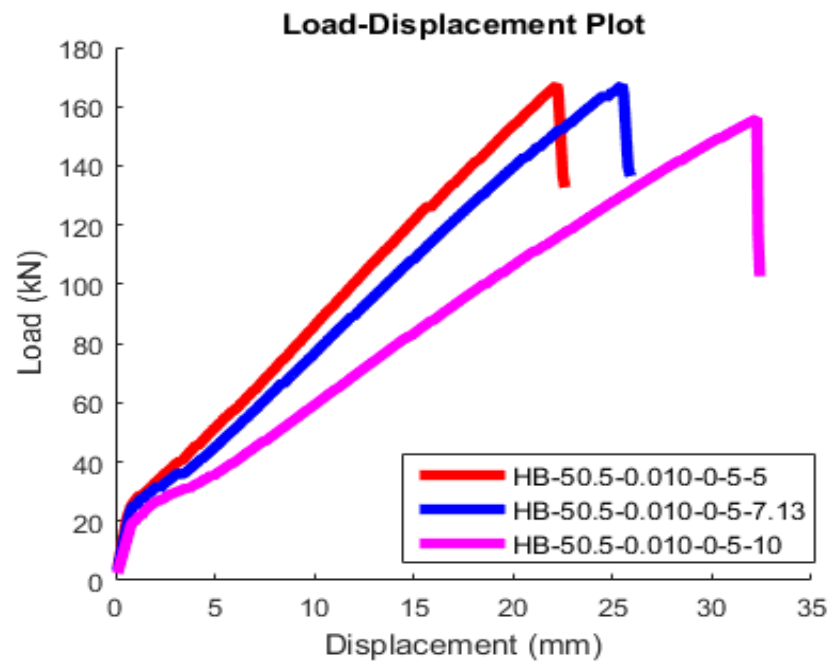


Figure 4.103 Load-Displacement plot of HB-50.5-0.010-0-5-(5, 7.13, 10).

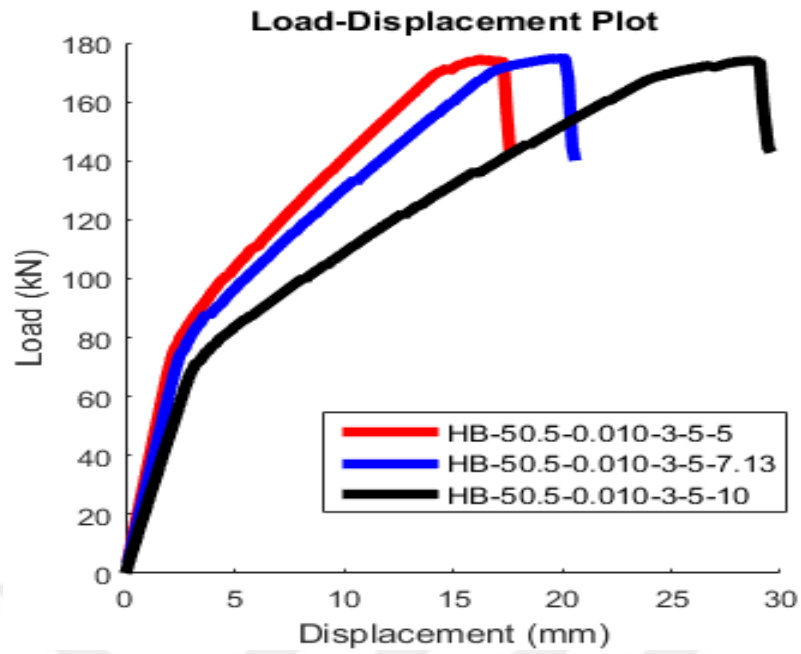


Figure 4.104 Load-Displacement plot of HB-50.5-0.010-3-5-(5, 7.13, 10).

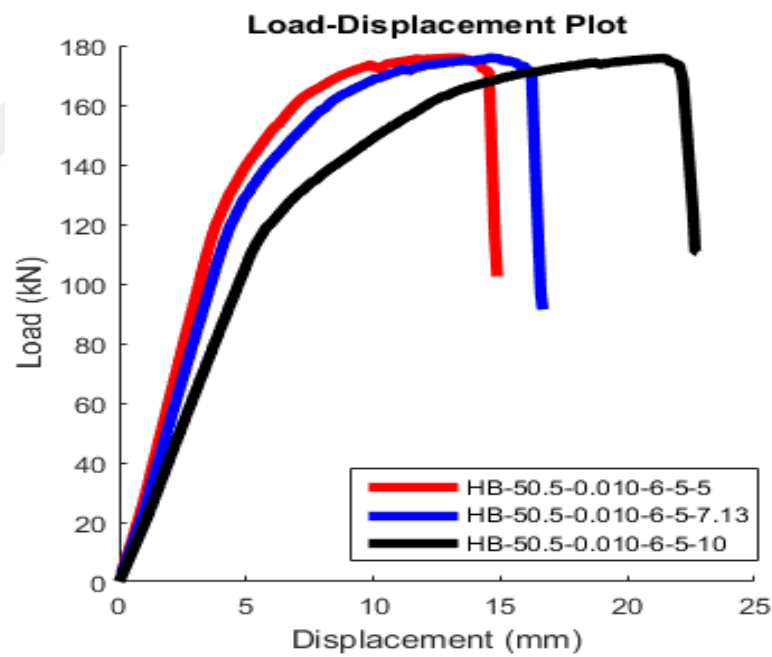


Figure 4.105 Load-Displacement plot of HB-50.5-0.010-6-5-(5, 7.13, 10).

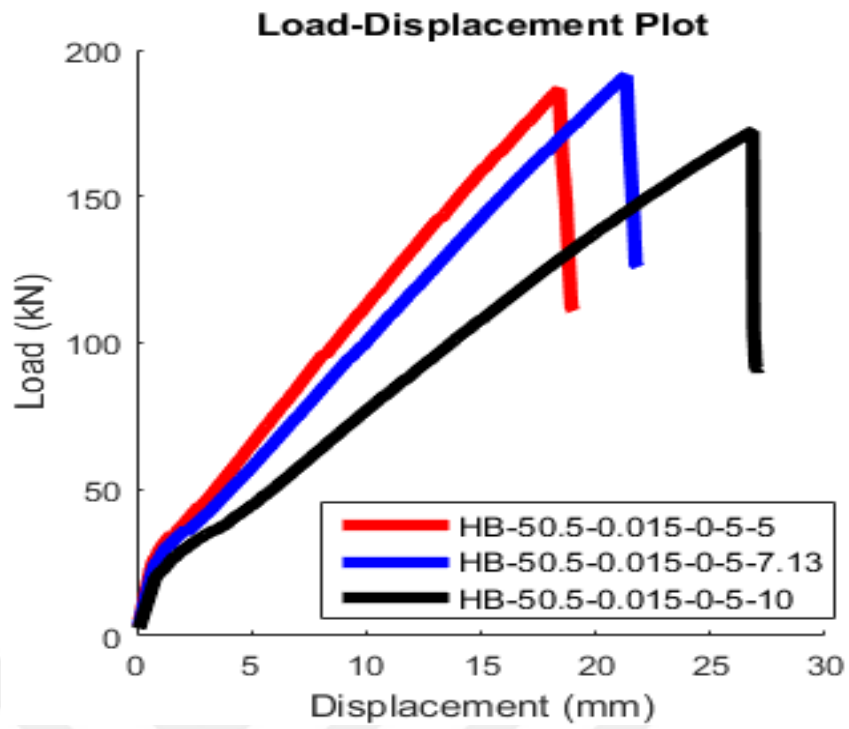


Figure 4.106 Load-Displacement plot of HB-50.5-0.015-0-5-(5, 7.13, 10).

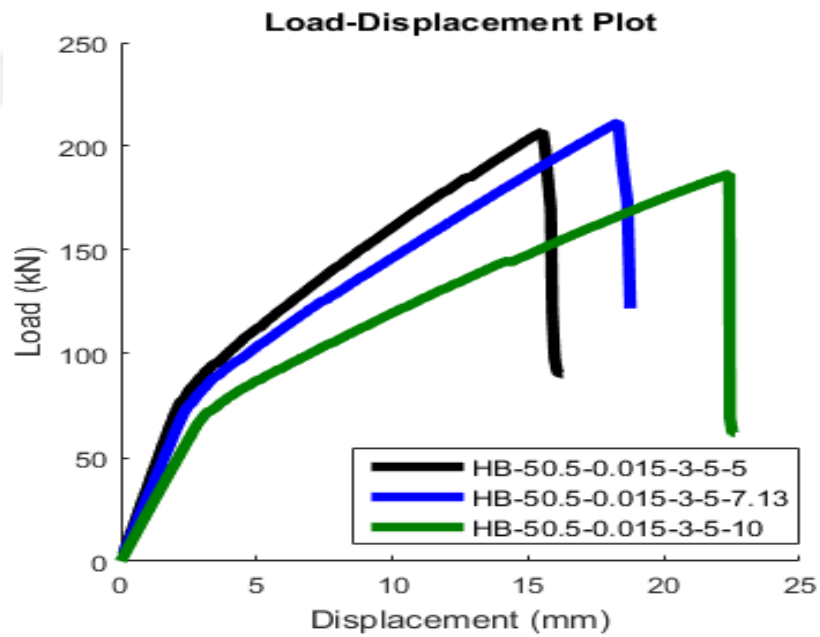


Figure 4.107 Load-Displacement plot of HB-50.5-0.015-3-5-(5, 7.13, 10).

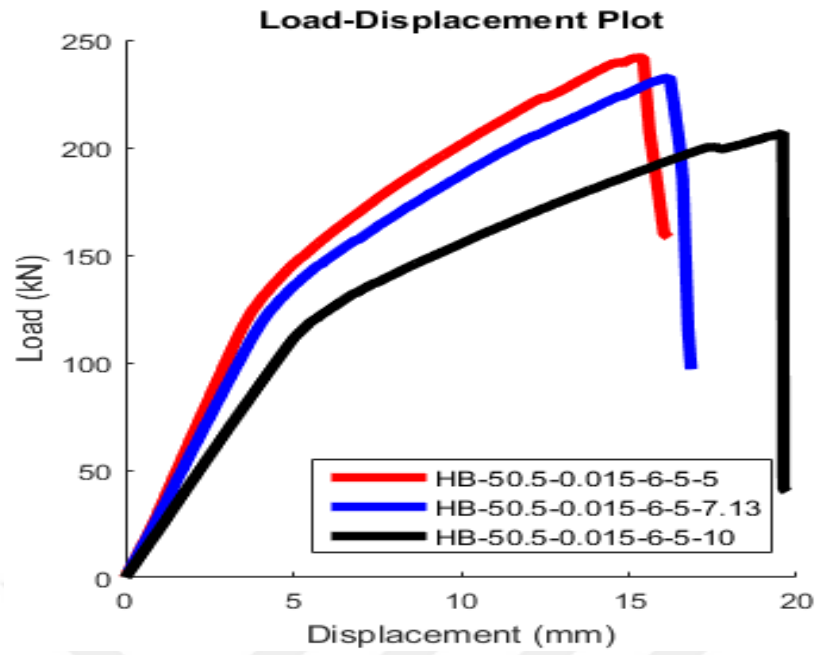


Figure 4.108 Load-Displacement plot of HB-50.5-0.015-6-5-(5, 7.13, 10).

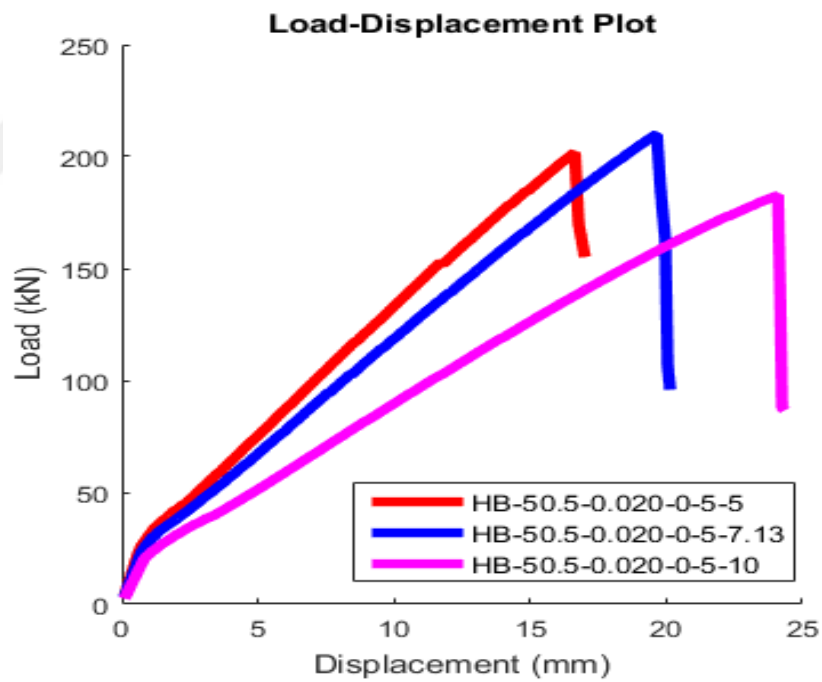


Figure 4.109 Load-Displacement plot of HB-50.5-0.020-0-5-(5, 7.13, 10).

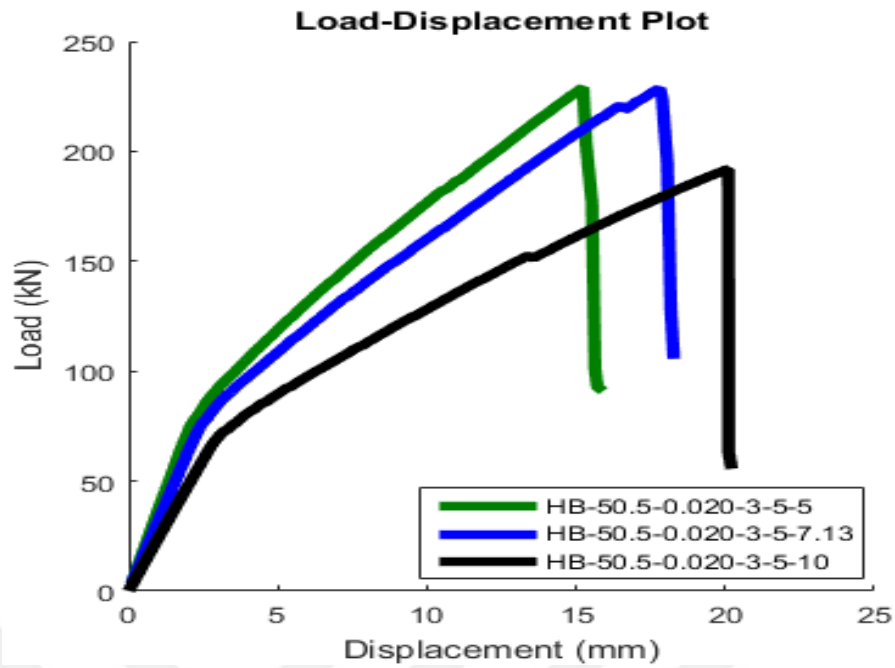


Figure 4.110 Load-Displacement plot of HB-50.5-0.020-3-5-(5, 7.13, 10).

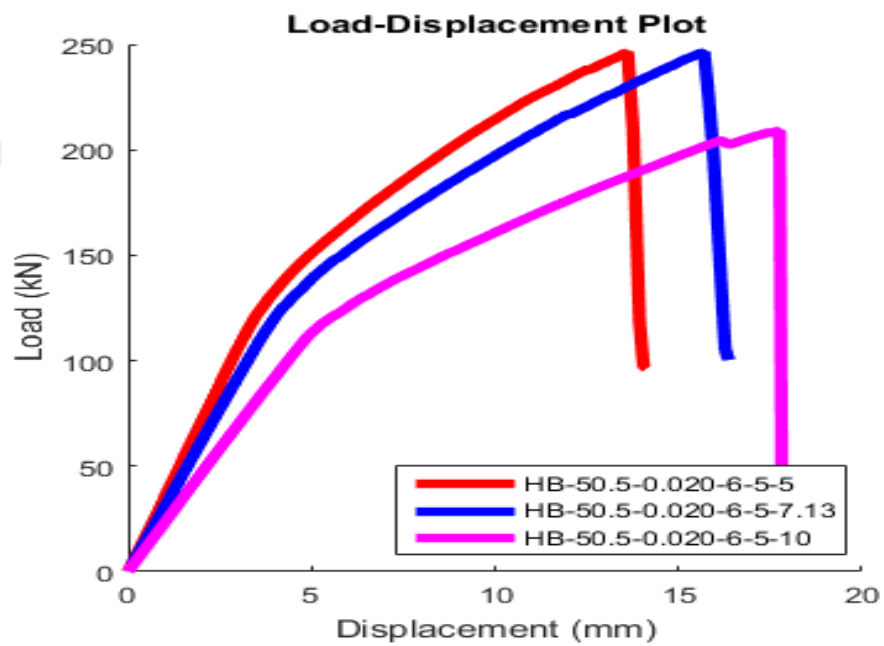


Figure 4.111 Load-Displacement plot of HB-50.5-0.020-6-5-(5, 7.13, 10).

4.5 Effect of α/d_m Ratio

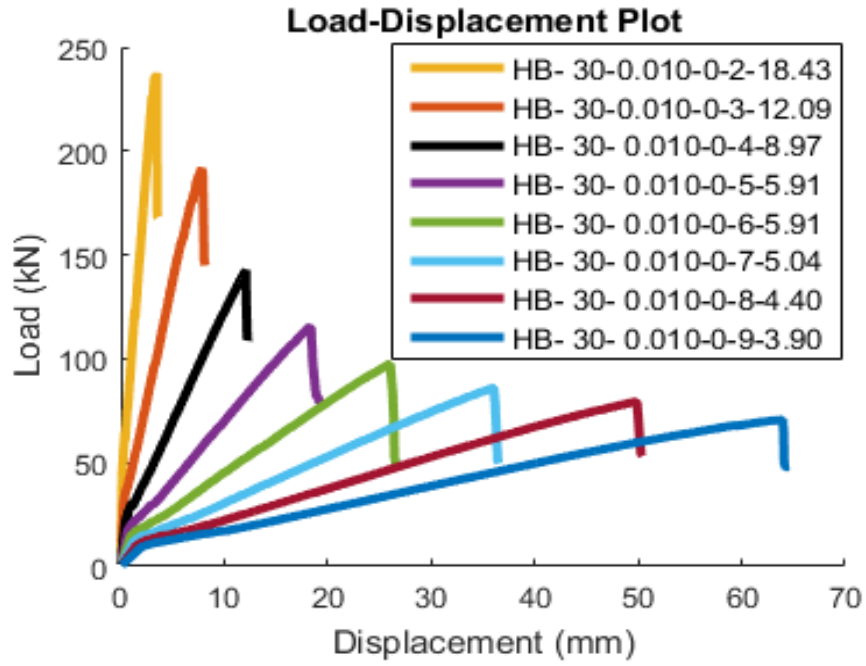


Figure 4.112 L-D plot of HB-30-0.010-0-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).

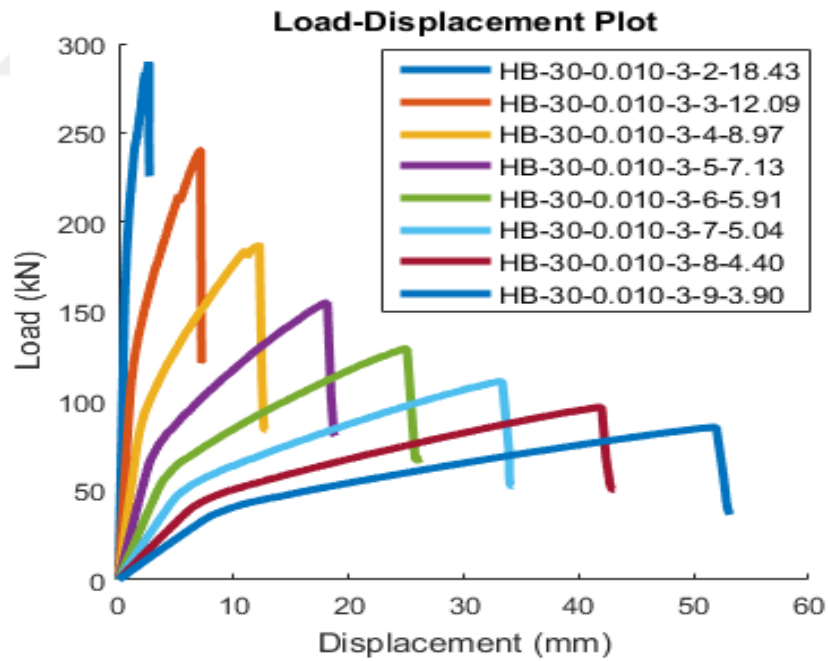


Figure 4.113 L-D plot of HB-30-0.010-3-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).

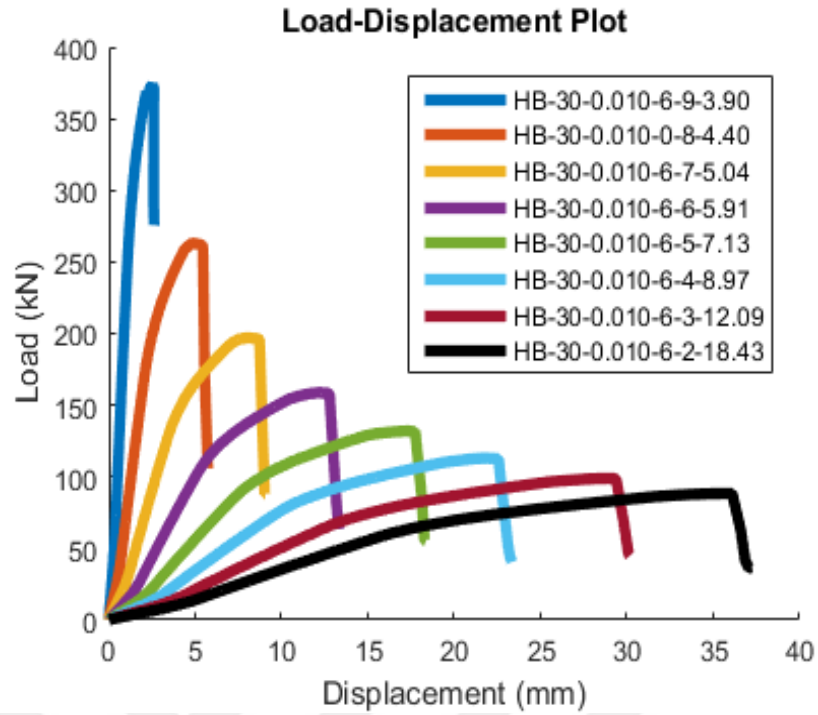


Figure 4.114 L-D plot of HB-30-0.010-6- ($2 \leq \alpha/d_m \leq 9$)- ($3.90 \leq \alpha_c \leq 18.43$).

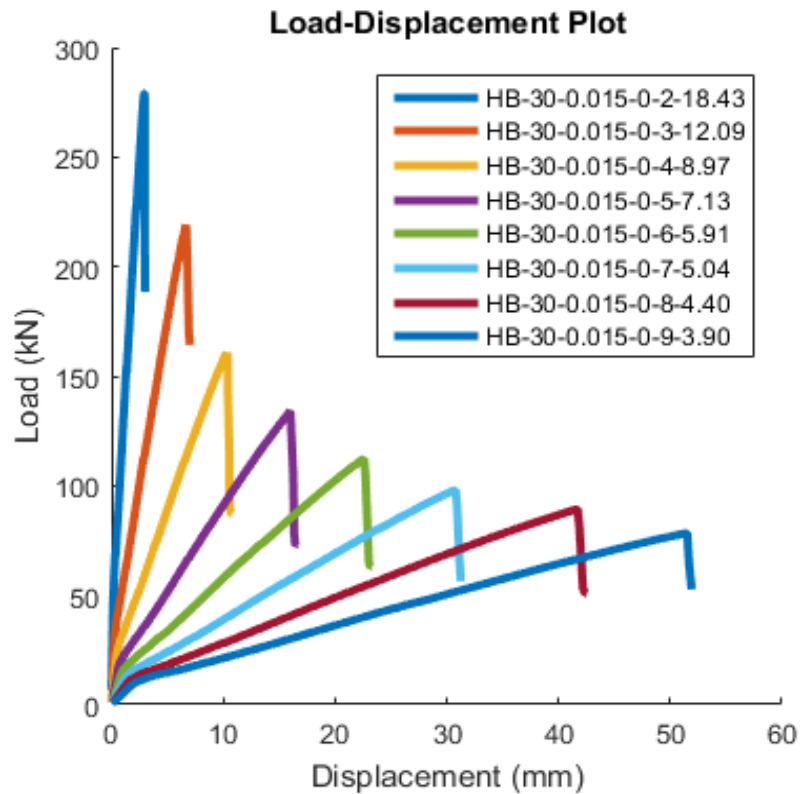


Figure 4.115 L-D plot of HB-30-0.015-0- ($2 \leq \alpha/d_m \leq 9$)- ($3.90 \leq \alpha_c \leq 18.43$).

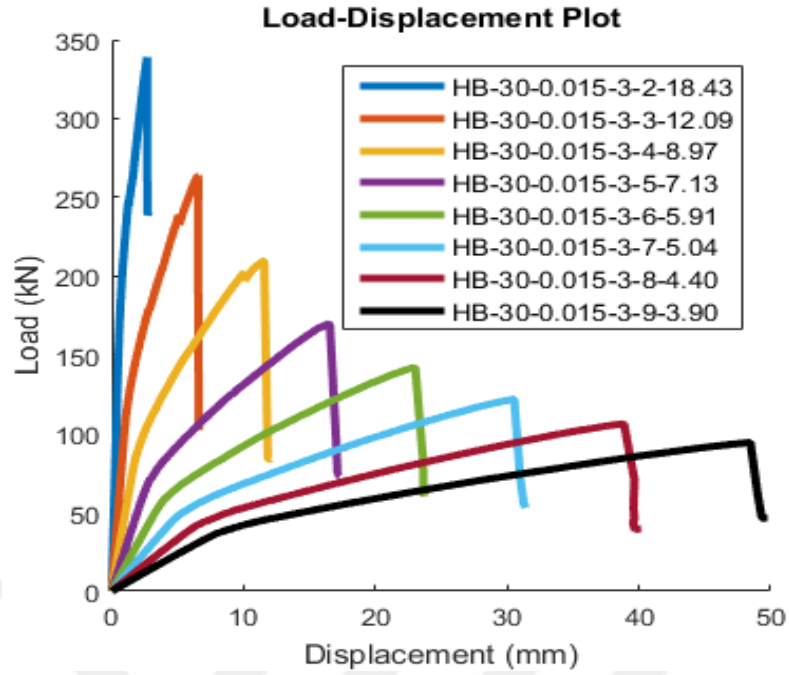


Figure 4.116 L-D plot of HB-30-0.015-3- ($2 \leq \alpha/d_m \leq 9$)- ($3.90 \leq \alpha_c \leq 18.43$)

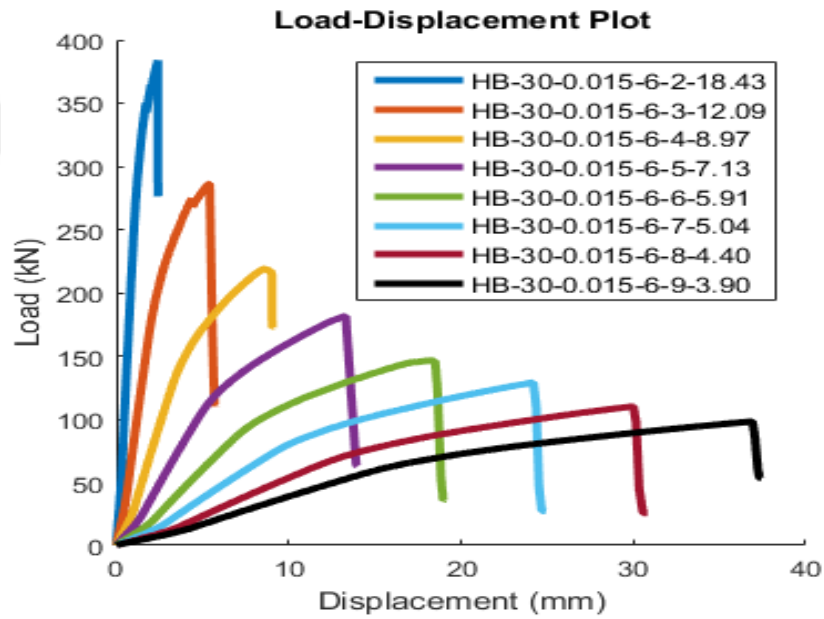


Figure 4.117 L-D plot of HB-30-0.015-6- ($2 \leq \alpha/d_m \leq 9$)- ($3.90 \leq \alpha_c \leq 18.43$).

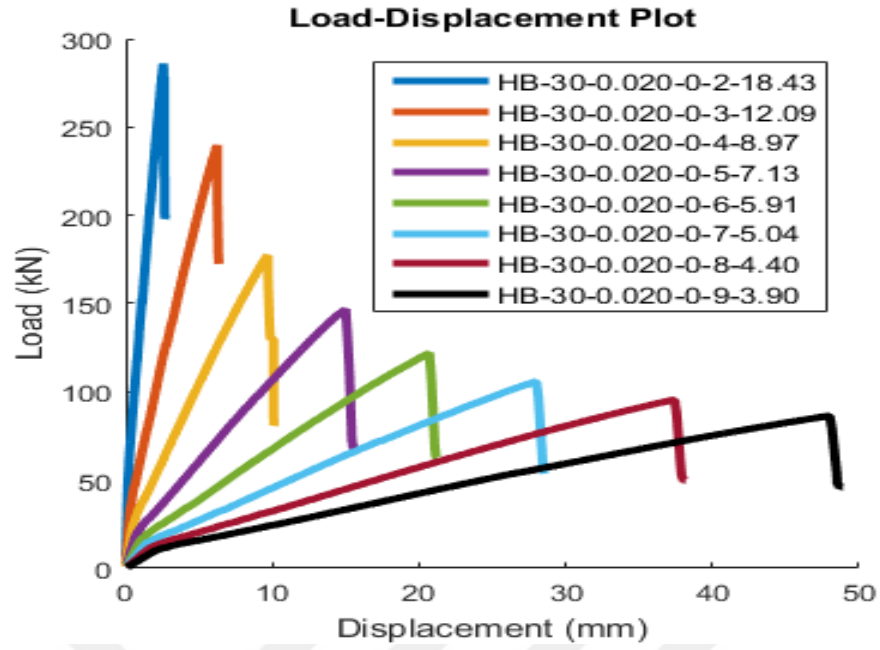


Figure 4.118 L-D plot of HB-30-0.020-0- ($2 \leq \alpha/d_m \leq 9$)- ($3.90 \leq \alpha_c \leq 18.43$)

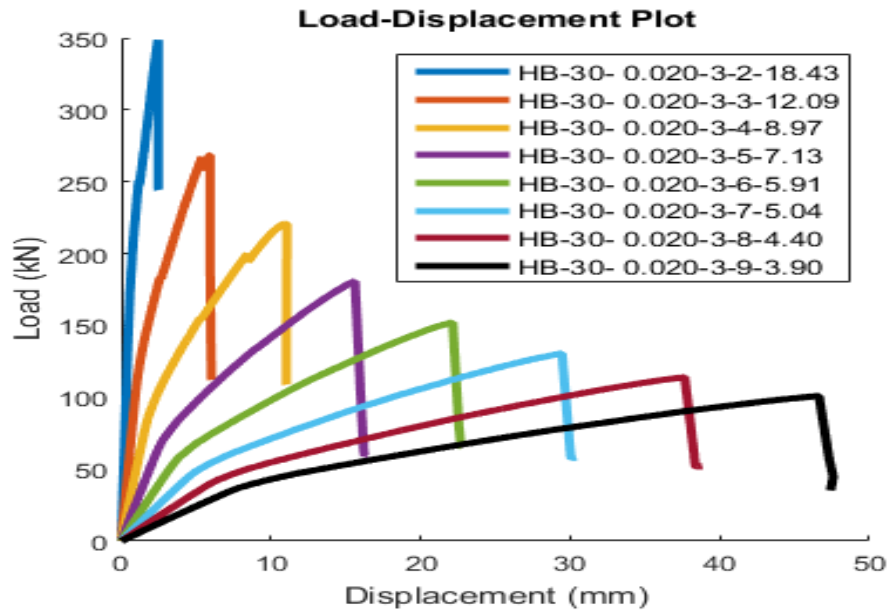


Figure 4.119 L-D plot of HB-30-0.020-3- ($2 \leq \alpha/d_m \leq 9$)- ($3.90 \leq \alpha_c \leq 18.43$)

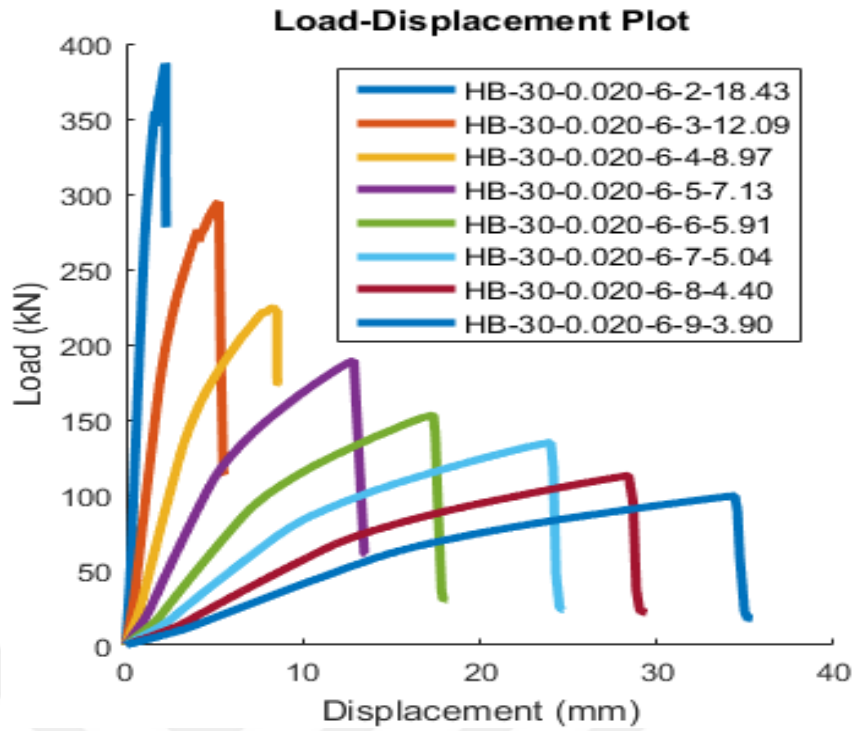


Figure 4.120 L-D plot of HB-30-0.020-6- ($2 \leq \alpha/d_m \leq 9$)- ($3.90 \leq \alpha_c \leq 18.43$)

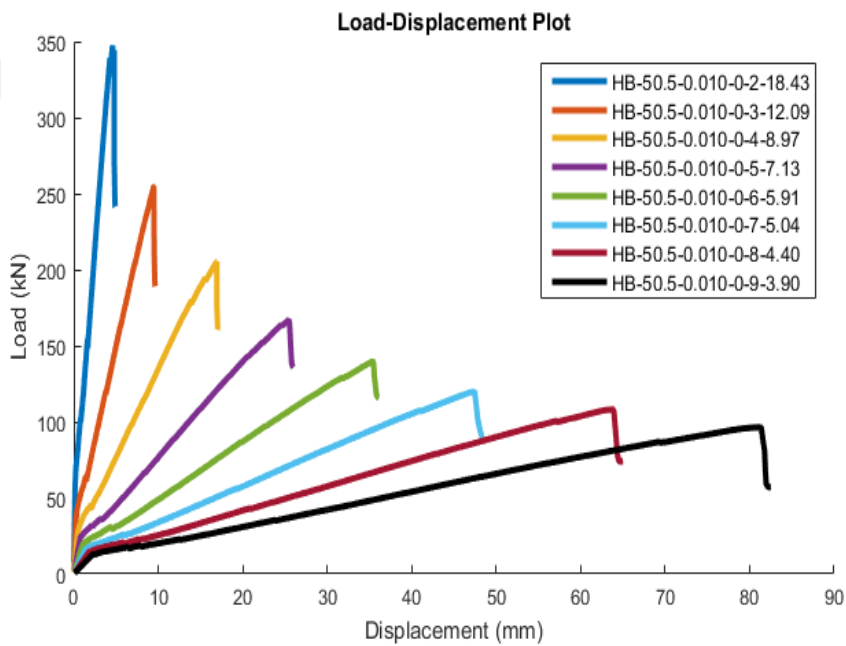


Figure 4.121 L-D plot of HB-50.5-0.010-0- ($2 \leq \alpha/d_m \leq 9$)- ($3.90 \leq \alpha_c \leq 18.43$)

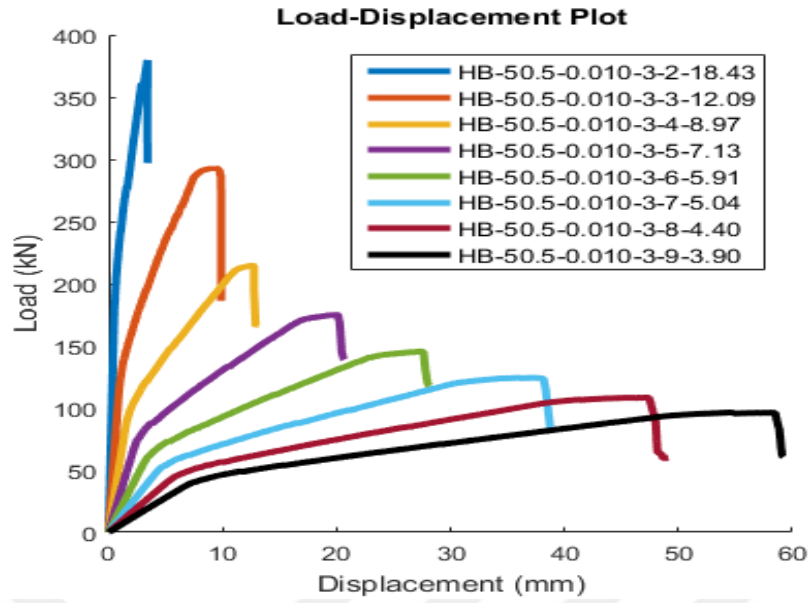


Figure 4.122 L-D plot of HB-50.5-0.010-3-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$)

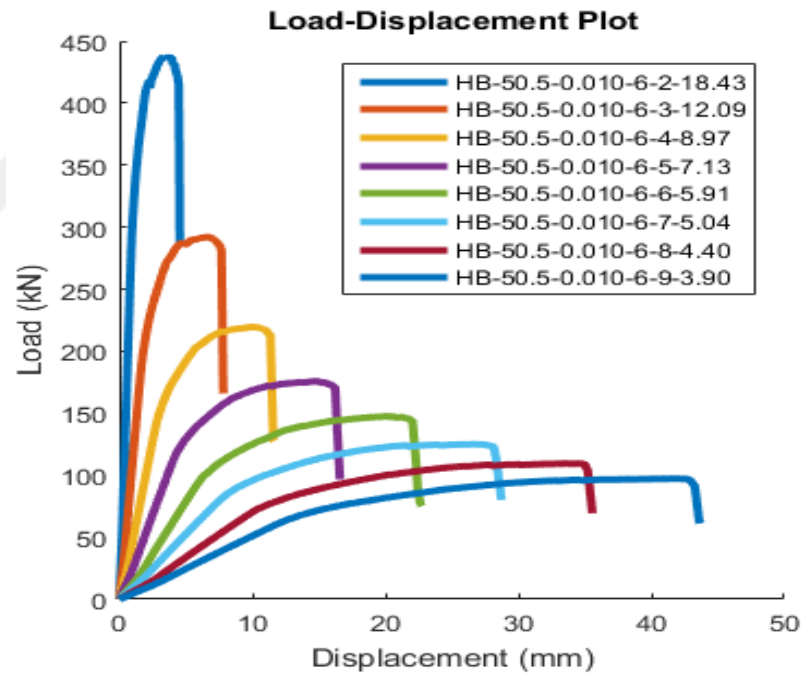


Figure 4.123 L-D plot of HB-50.5-0.010-6-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$)

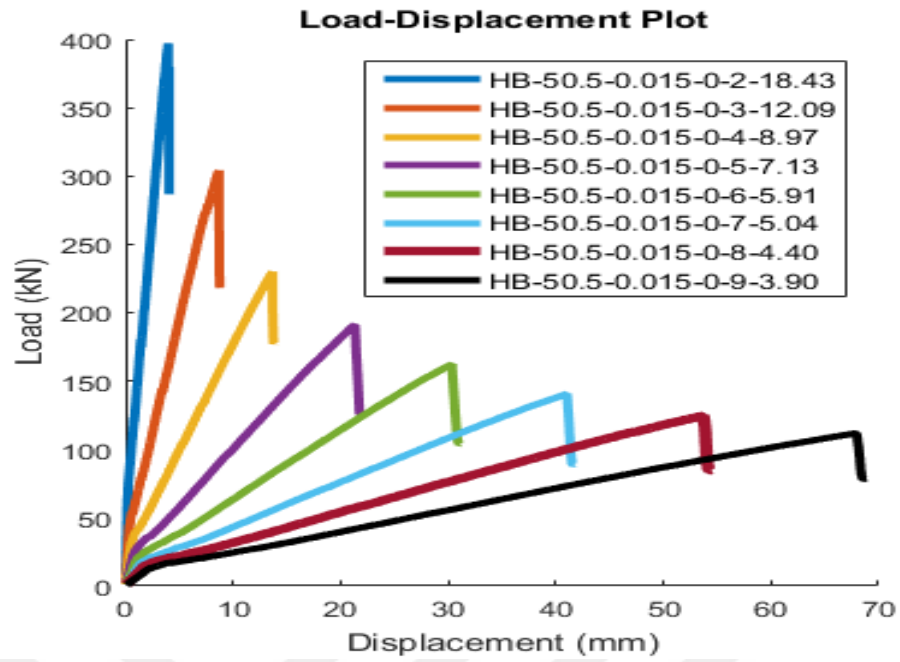


Figure 4.124 L-D plot of HB-50.5-0.015-0- ($2 \leq \alpha/d_m \leq 9$)- ($3.90 \leq \alpha_c \leq 18.43$)

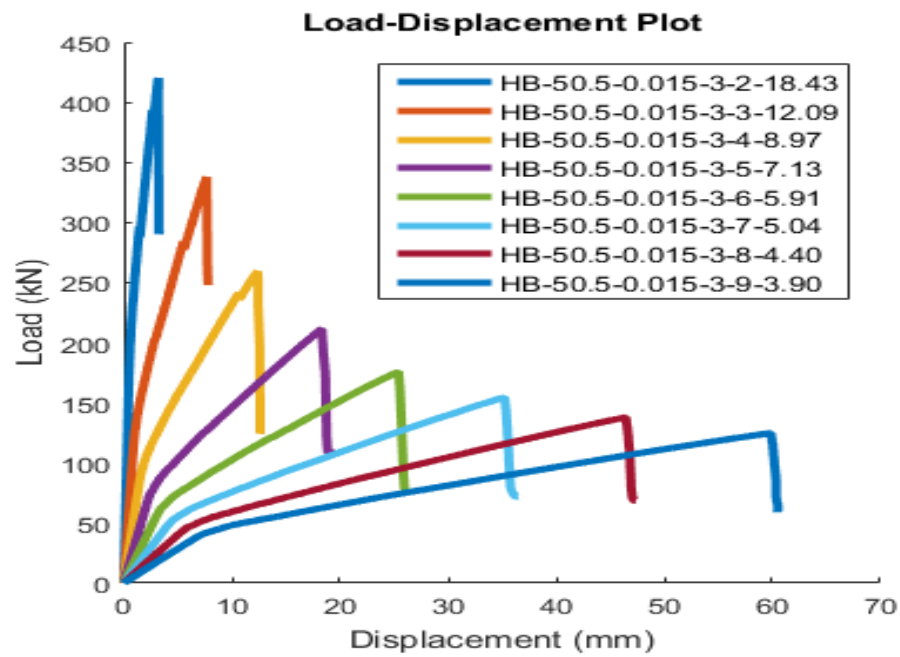


Figure 4.125 L-D plot of HB-50.5-0.015-3- ($2 \leq \alpha/d_m \leq 9$)- ($3.90 \leq \alpha_c \leq 18.43$).

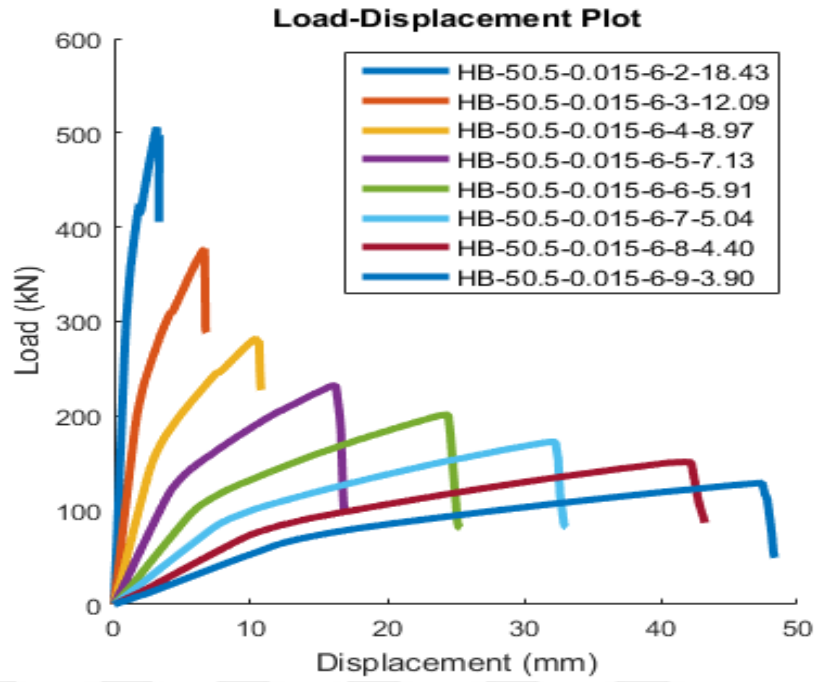


Figure 4.126 L-D plot of HB-50.5-0.015-6- ($2 \leq a/d_m \leq 9$)- ($3.90 \leq \alpha_c \leq 18.43$).

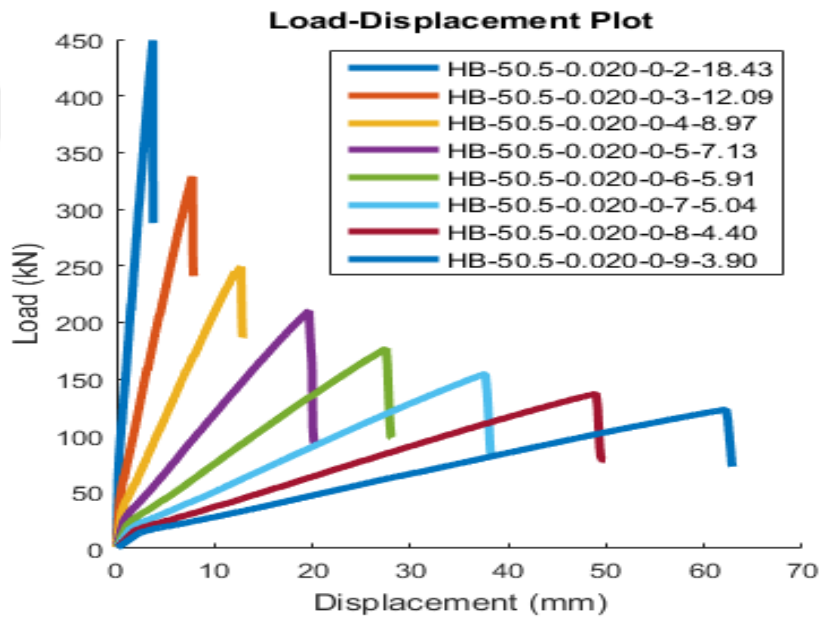


Figure 4.127 L-D plot of HB-50.5-0.020-0- ($2 \leq a/d_m \leq 9$)- ($3.90 \leq \alpha_c \leq 18.43$)

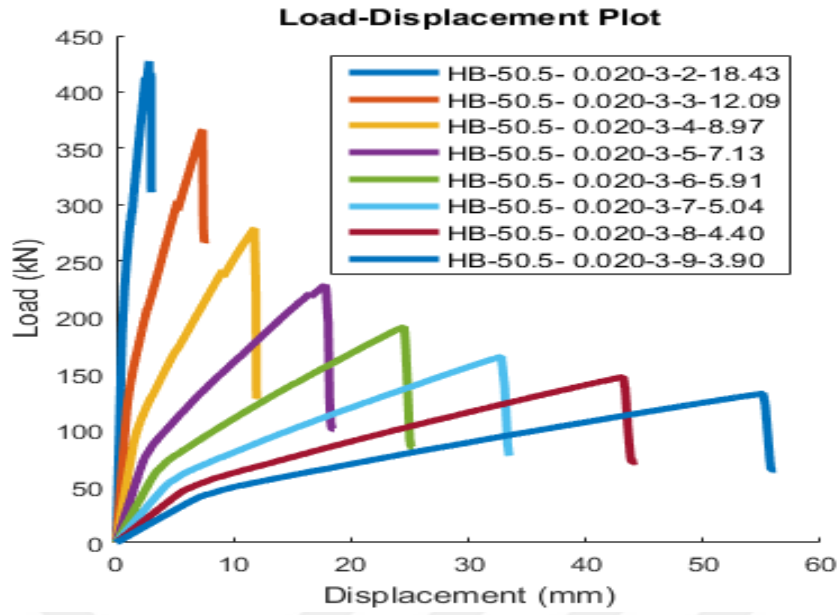


Figure 4.128 L-D plot of HB-50.5-0.020-3-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$).

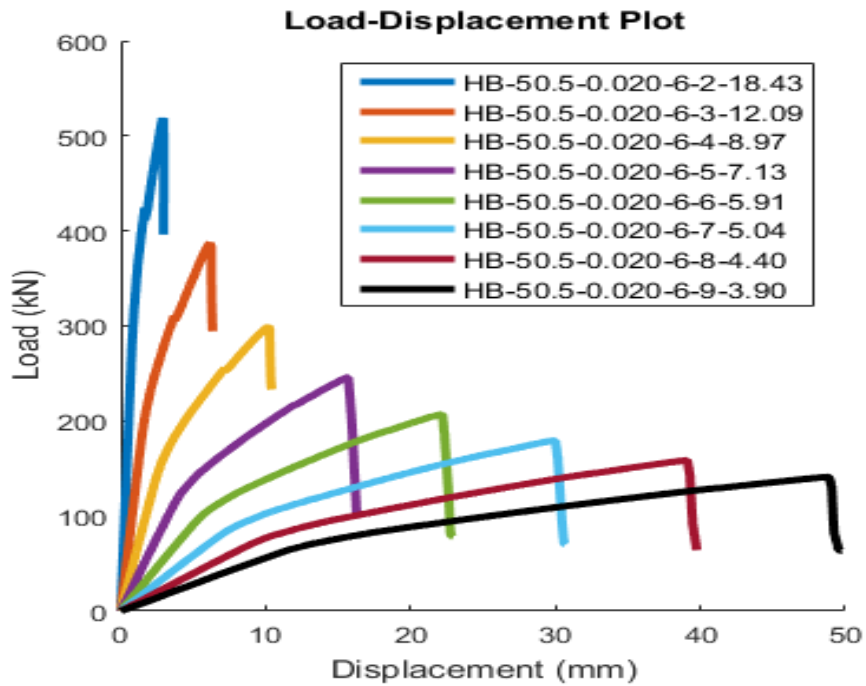


Figure 4.129 L-D plot of HB-50.5-0.020-6-($2 \leq \alpha/d_m \leq 9$)-($3.90 \leq \alpha_c \leq 18.43$)

4.6 PC Haunched Beams & PC Rectangular Beams

Under this title, how PC haunched beams and PC rectangular beams behave under prestress is compared with various parameters.

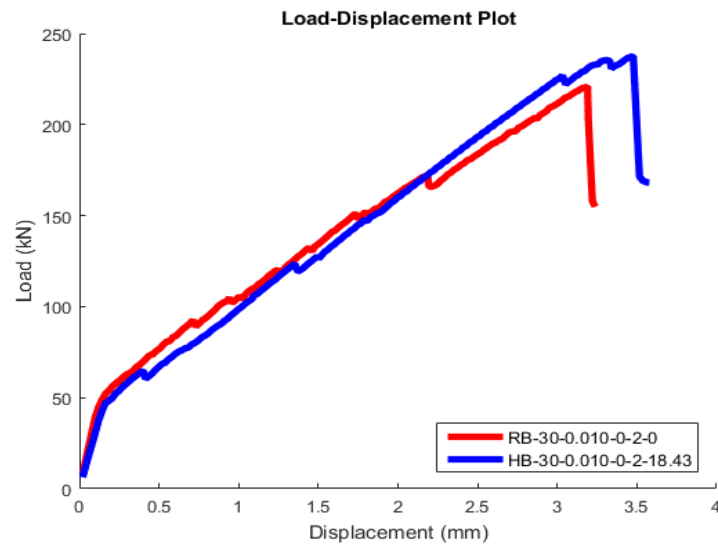


Figure 4.130 L-D plot of RB-30-0.010-0-2-0 and HB-30-0.010-0-2-18.43.

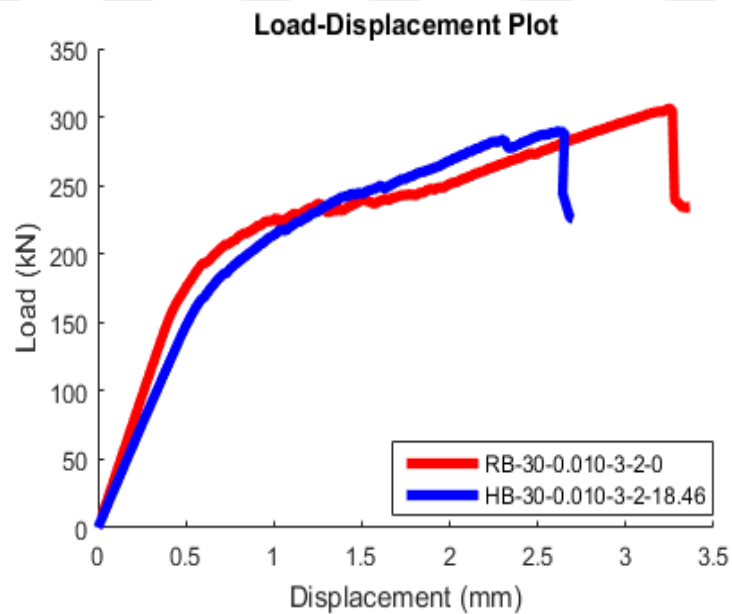


Figure 4.131 L-D plot of RB-30-0.010-3-2-0 and HB-30-0.010-3-2-18.43.

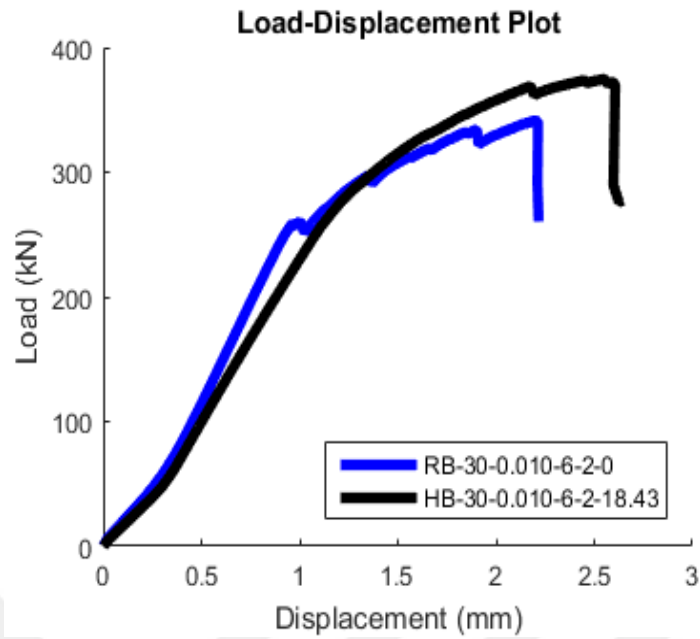


Figure 4.132 L-D plot of RB-30-0.010-6-2-0 and HB-30-0.010-6-2-18.43.

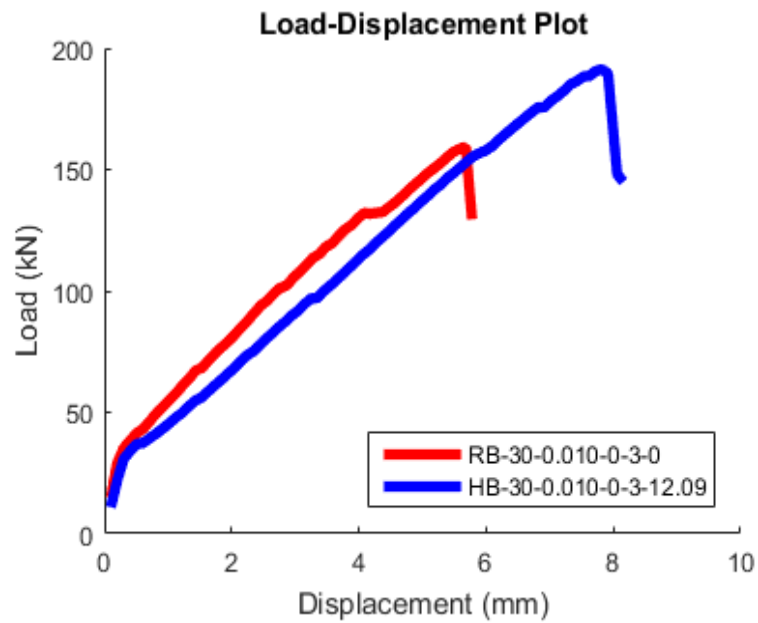


Figure 4.133 L-D plot of RB-30-0.010-0-3-0 and HB-30-0.010-0-3-12.09.

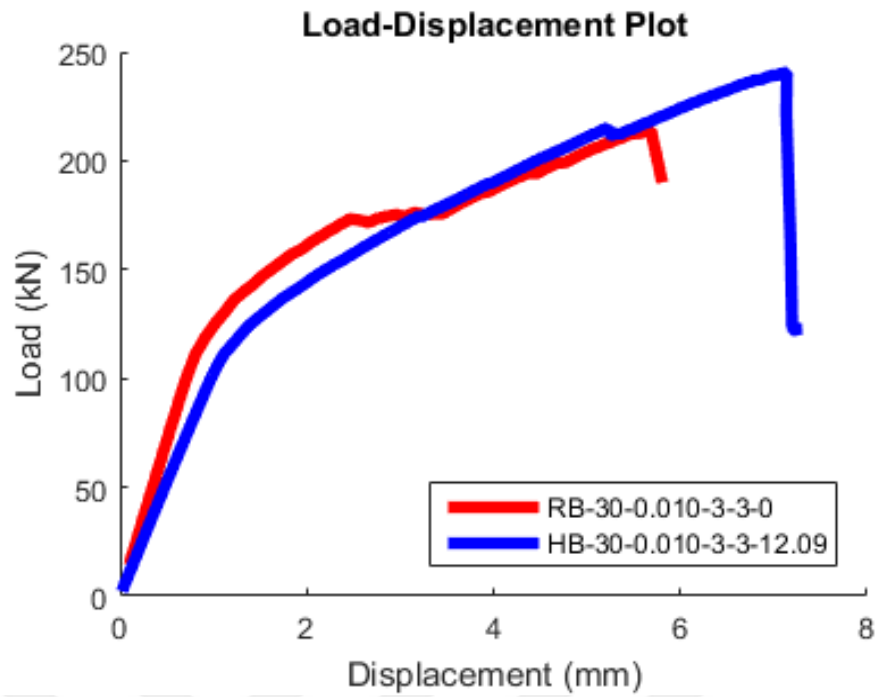


Figure 4.134 L-D plot of RB-30-0.010-3-3-0 and HB-30-0.010-3-3-12.09.

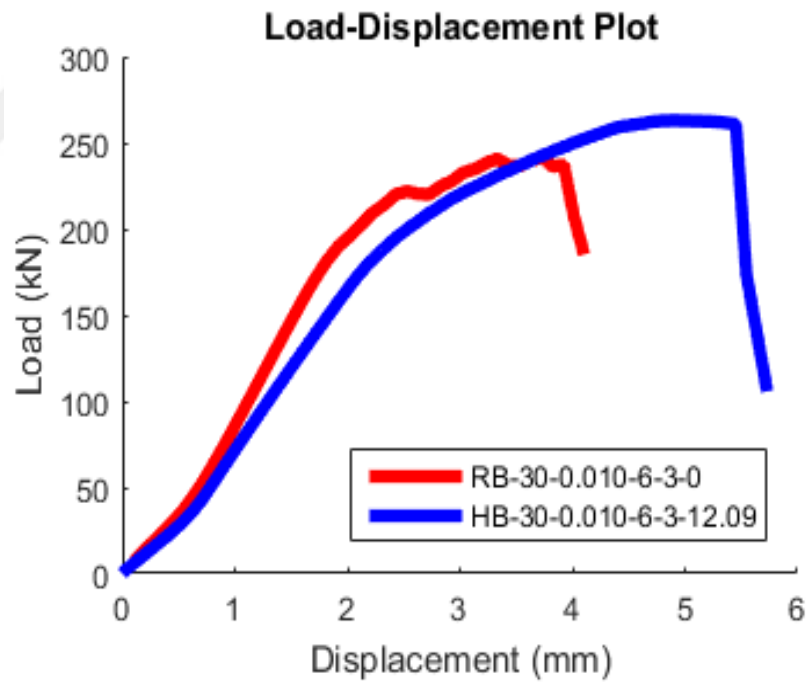


Figure 4.135 L-D plot of RB-30-0.010-6-3-0 and HB-30-0.010-6-3-12.09.

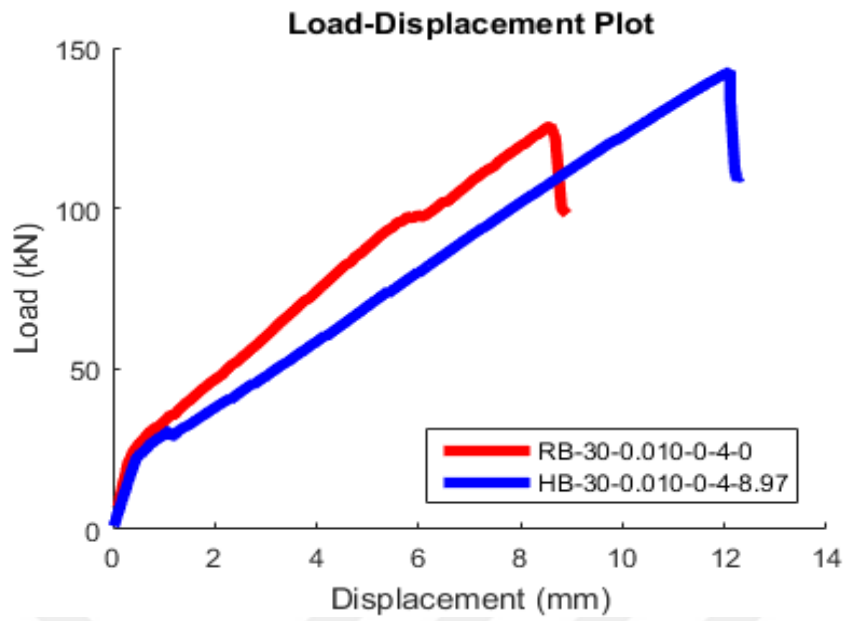


Figure 4.136 L-D plot of RB-30-0.010-0-4-0 and HB-30-0.010-0-4-8.97.

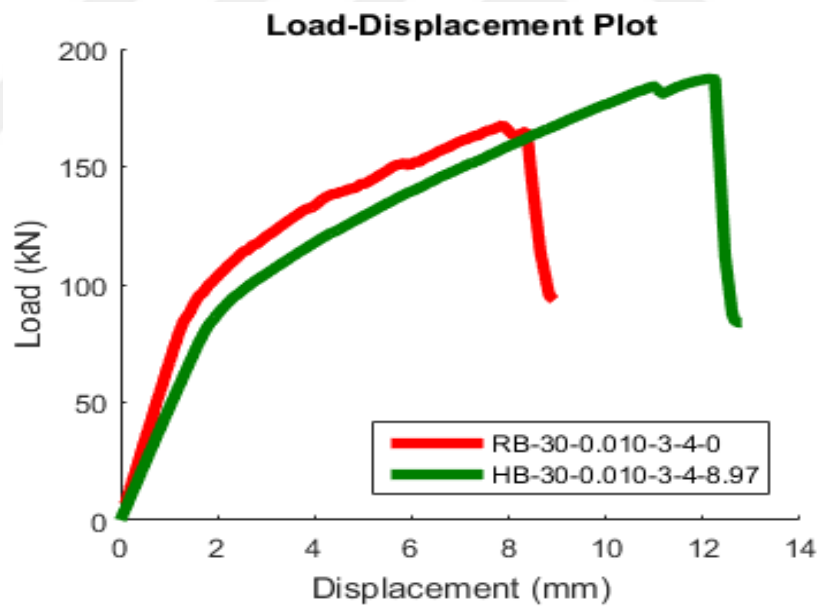


Figure 4.137 L-D plot of RB-30-0.010-3-4-0 and HB-30-0.010-3-4-8.97.

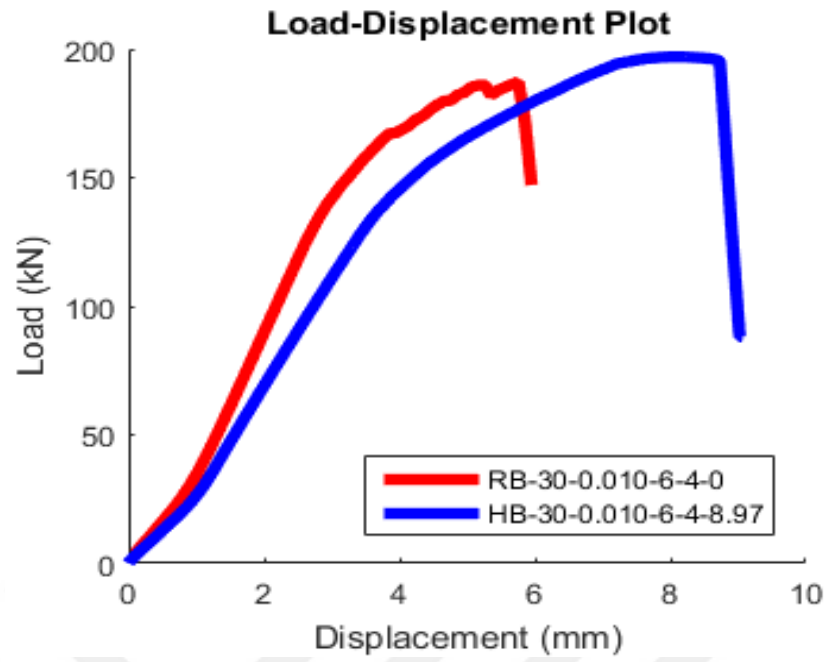


Figure 4.138 L-D plot of RB-30-0.010-6-4-0 and HB-30-0.010-6-4-8.97.

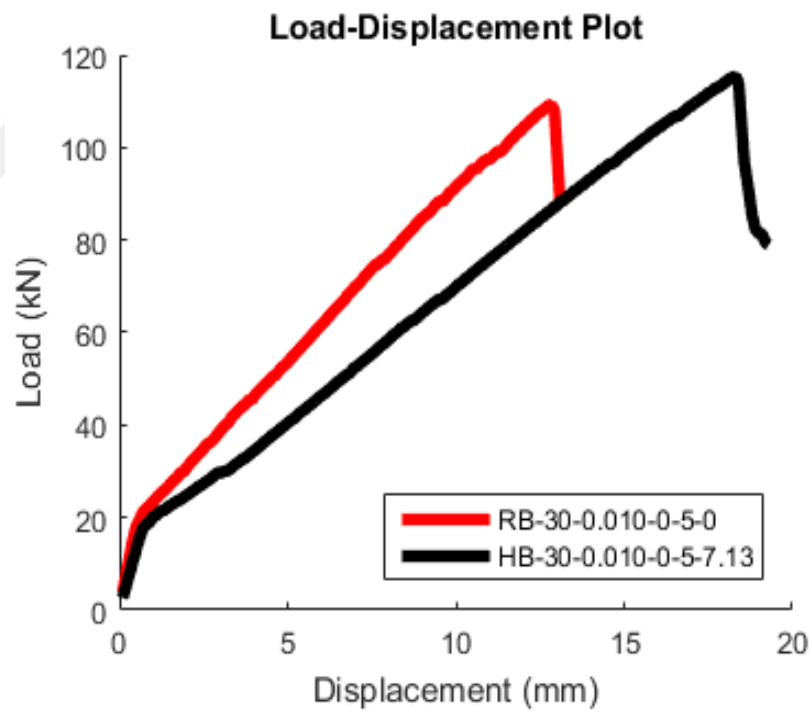


Figure 4.139 L-D plot of RB-30-0.010-0-5-0 and HB-30-0.010-0-5-7.13.

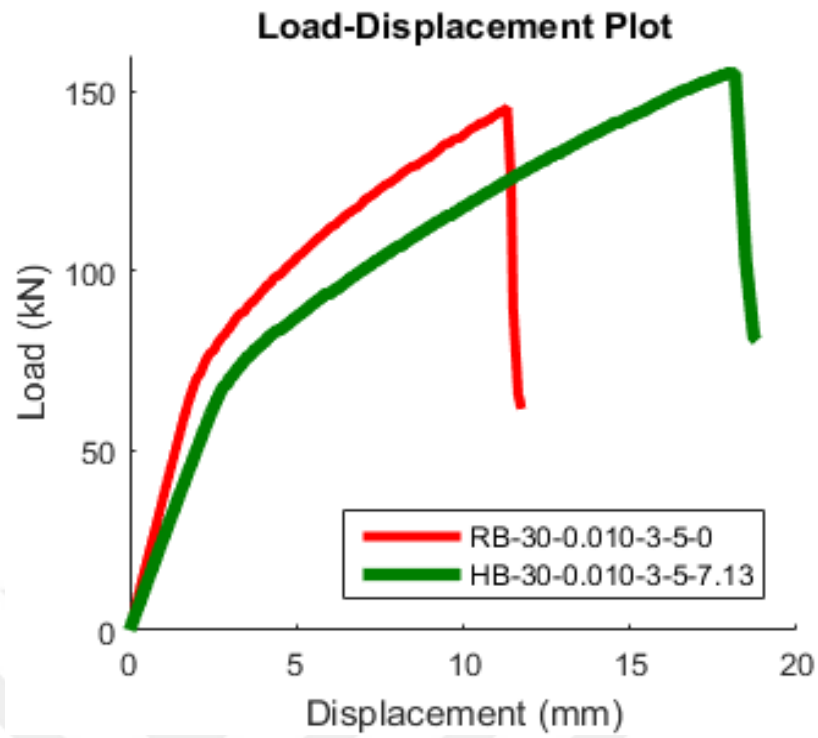


Figure 4.140 L-D plot of RB-30-0.010-3-5-0 and HB-30-0.010-3-5-7.13.

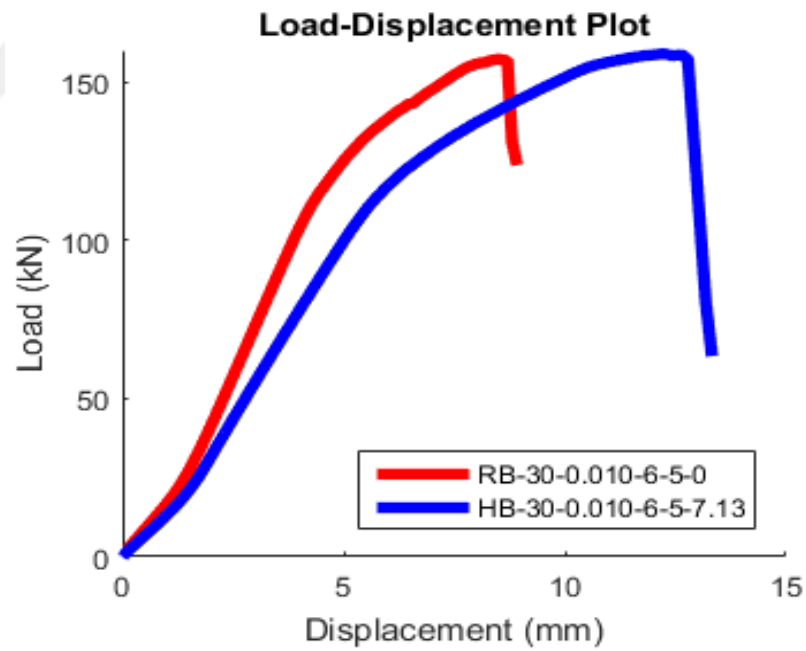


Figure 4.141 L-D plot of RB-30-0.010-6-5-0 and HB-30-0.010-6-5-7.13

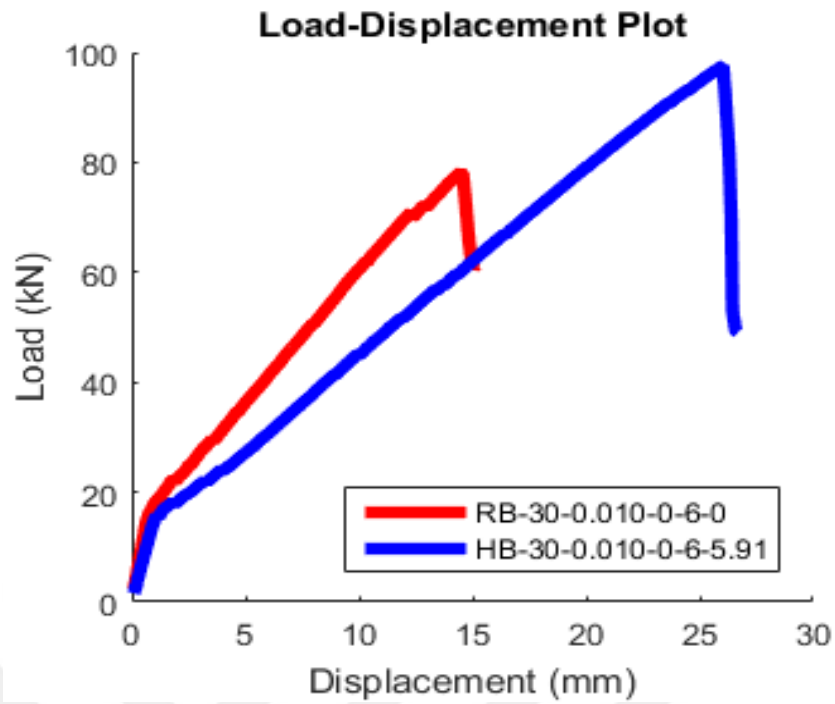


Figure 4.142 L-D plot of RB-30-0.010-0-6-0 and HB-30-0.010-0-6-5.91.

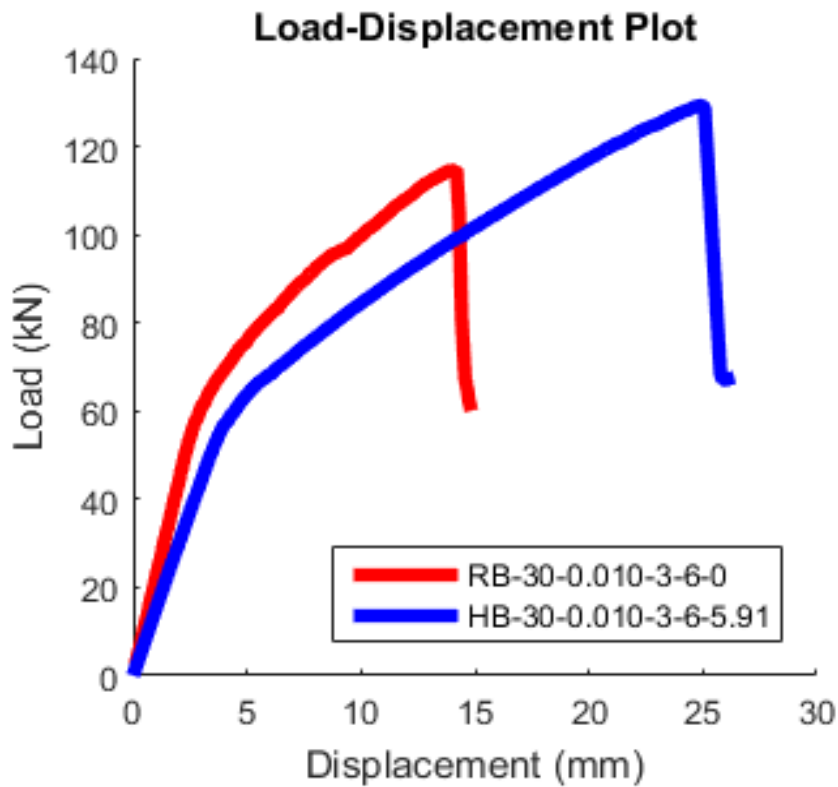


Figure 4.143 L-D plot of RB-30-0.010-3-6-0 and HB-30-0.010-3-6-5.91.

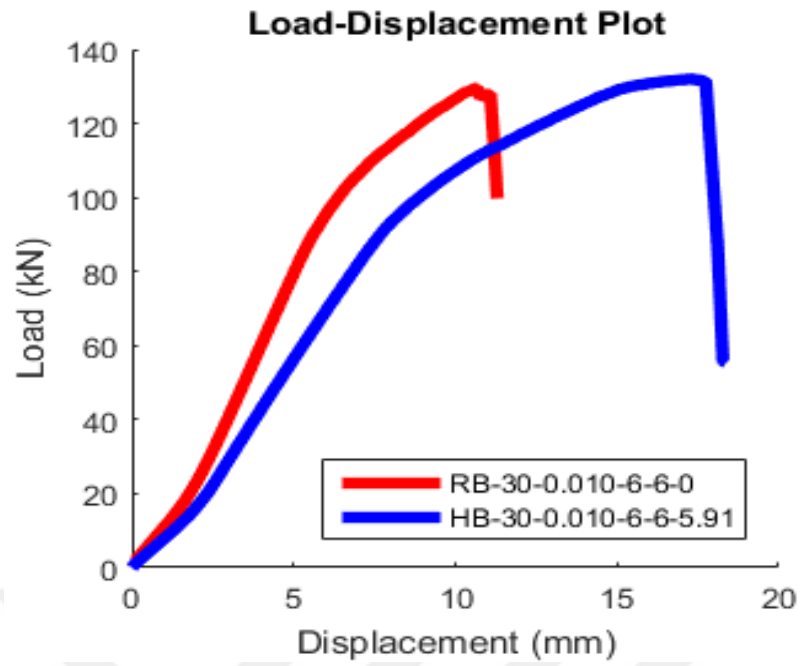


Figure 4.144 L-D plot of RB-30-0.010-6-6-0 and HB-30-0.010-6-6-5.91.

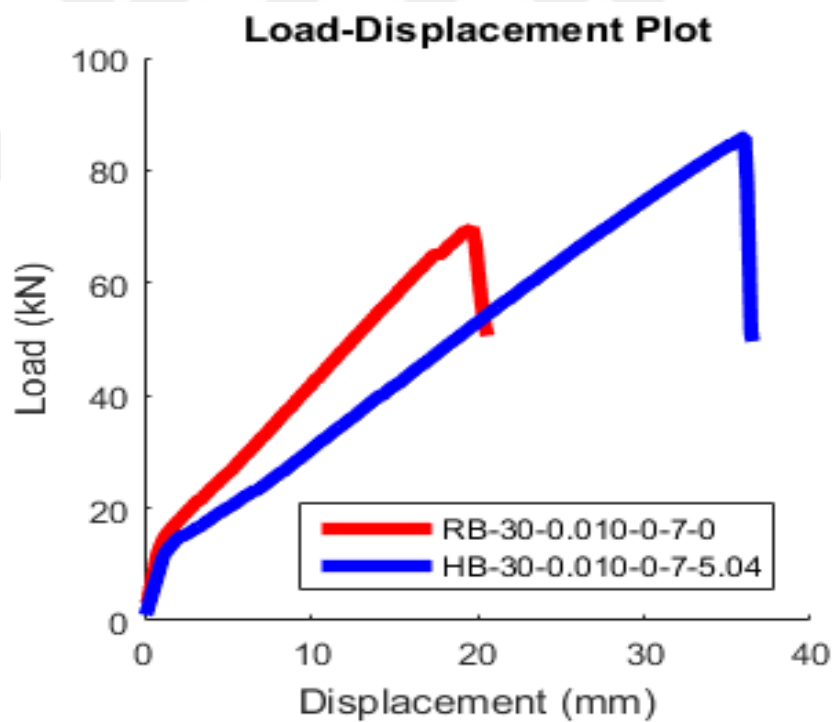


Figure 4.145 L-D plot of RB-30-0.010-0-7-0 and HB-30-0.010-0-7-5.04.

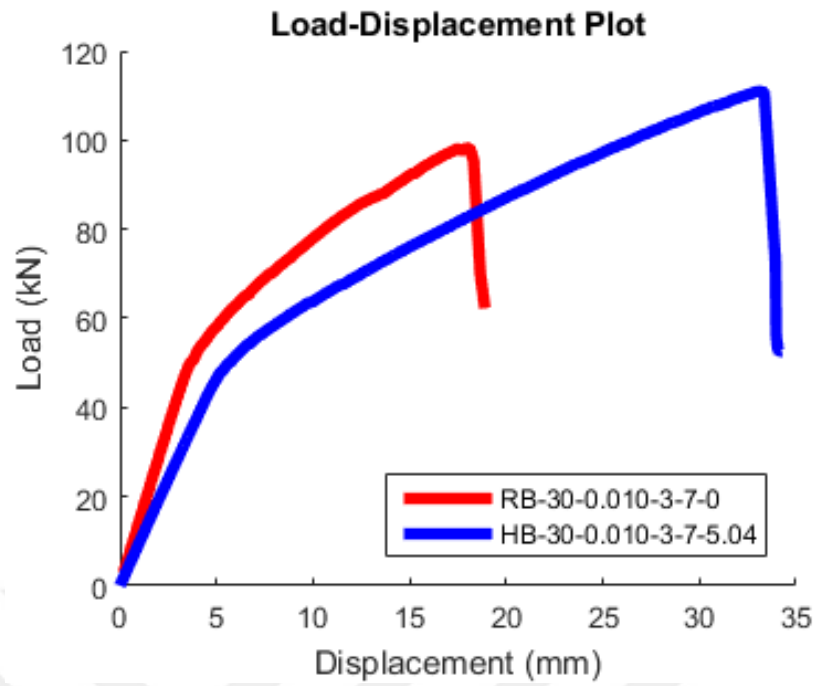


Figure 4.146 L-D plot of RB-30-0.010-3-7-0 and HB-30-0.010-3-7-5.04.

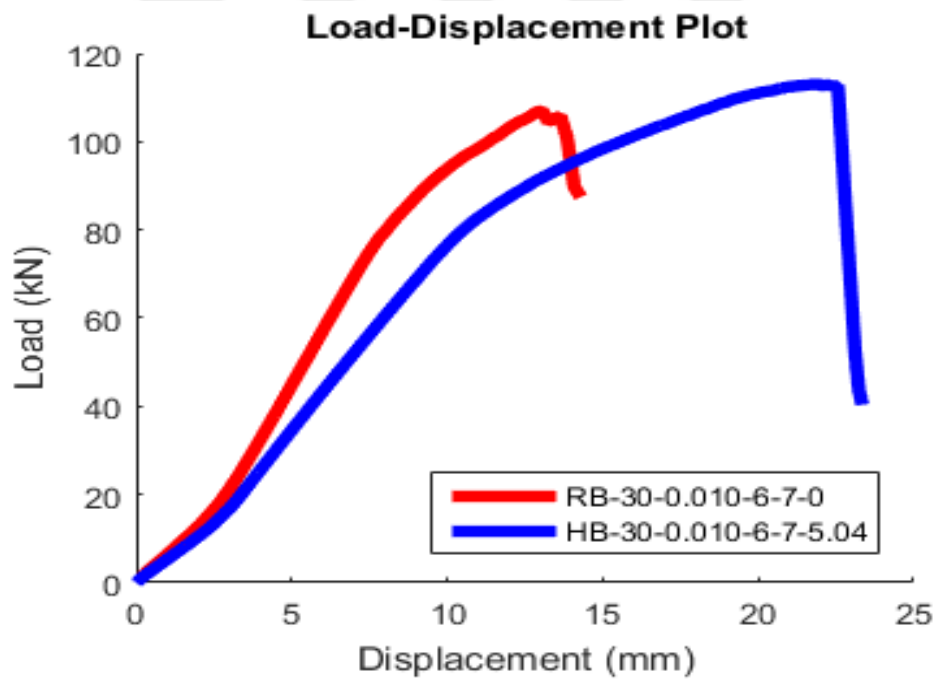


Figure 4.147 L-D plot of RB-30-0.010-6-7-0 and HB-30-0.010-6-7-5.04.

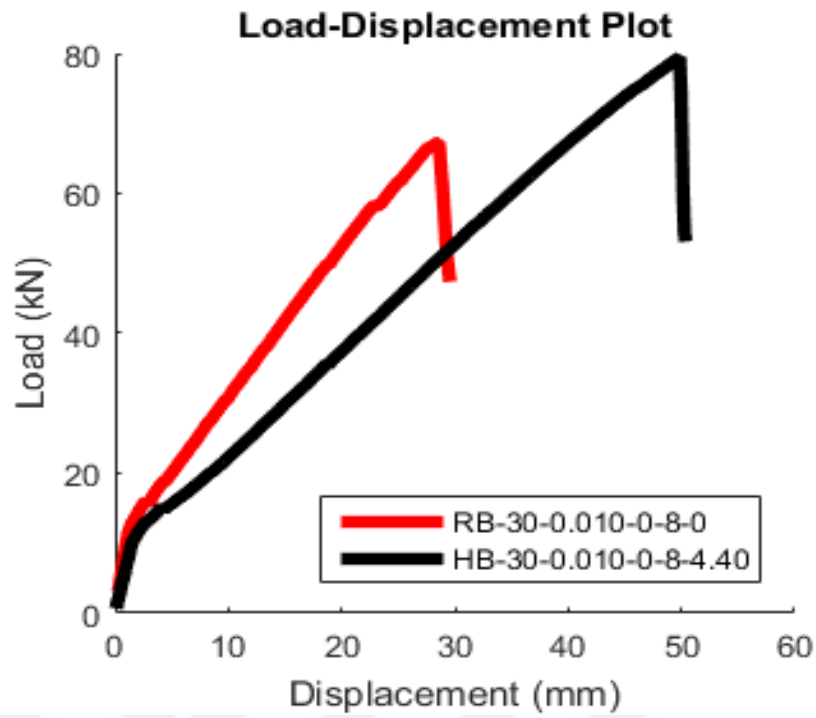


Figure 4.148 L-D plot of RB-30-0.010-0-8-0 and HB-30-0.010-0-8-4.40.

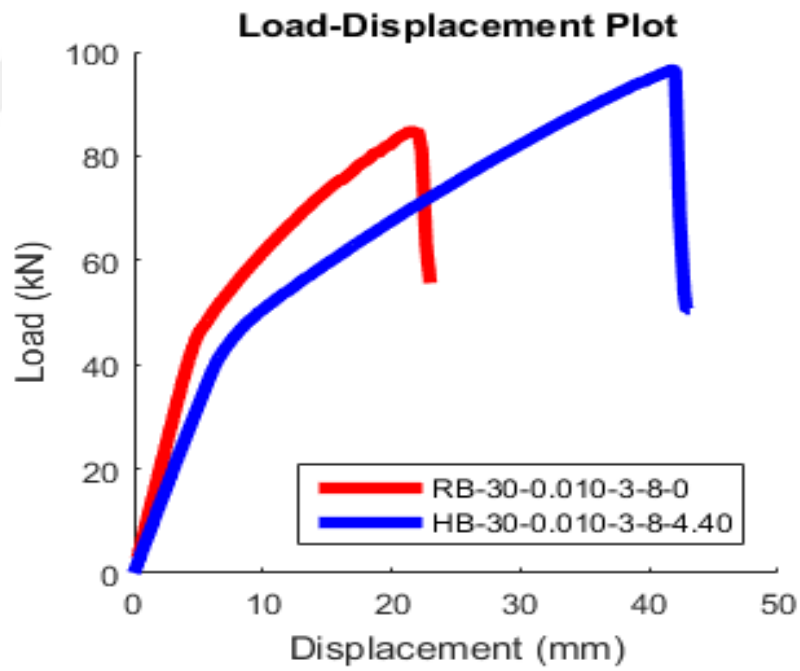


Figure 4.149 L-D plot of RB-30-0.010-3-8-0 and HB-30-0.010-3-8-4.40.

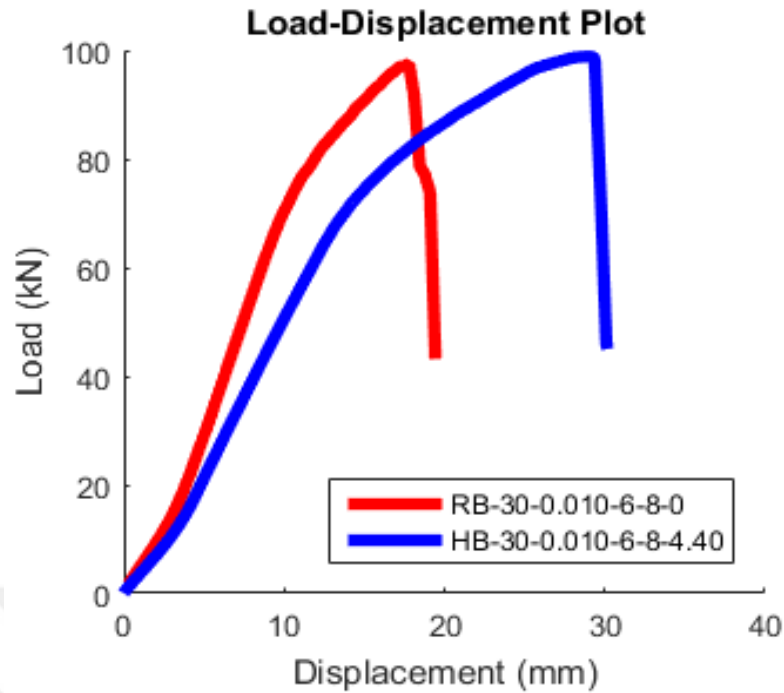


Figure 4.150 L-D plot of RB-30-0.010-6-8-0 and HB-30-0.010-6-8-4.40.

When the Figure (4.131 to 4.151) was examined, the following results were observed.

When the concrete strength is 30 (N / mm²), the ratio of the prestressing bars is 0.010 and no prestressing, the fracture strength of all haunched beams is greater than that of rectangular beams. It was also determined that the maximum displacement of the haunched beams was greater than that of the rectangular beams.

When the concrete strength was 30 (N / mm²), the ratio of prestressing bars was 0.010 and the prestress was 6(N / mm²), the fracture strengths of the haunched beams and rectangular beams were found to be almost similar. Their maximum displacement only was different.

It was determined that when the concrete strength was 30 (N / mm²), the ratio of prestressing bars was 0.010 and the prestress was 6(N / mm²), the cracking of the haunched beams and rectangular beams was the same.

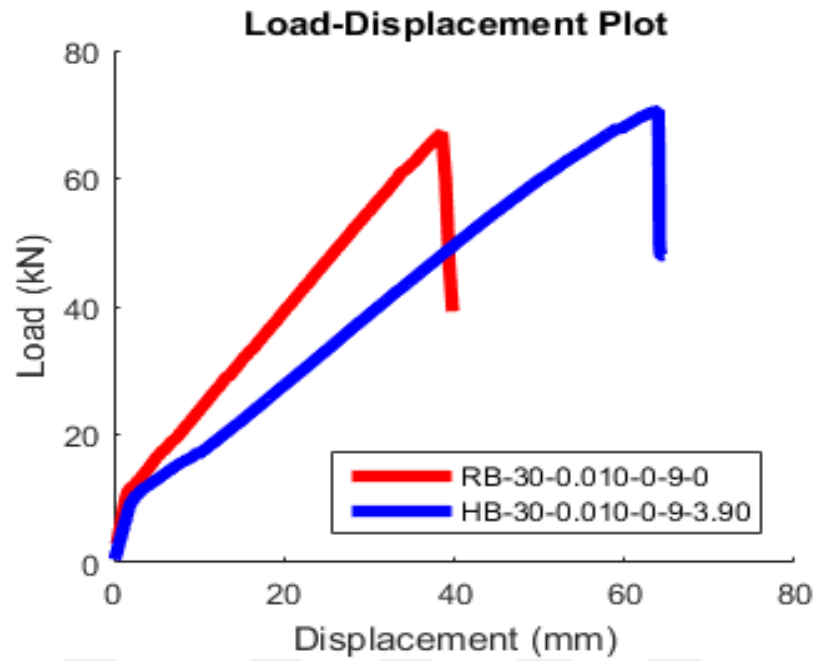


Figure 4.151 L-D plot of RB-30-0.010-0-9-0 and HB-30-0.010-0-9-3.90.

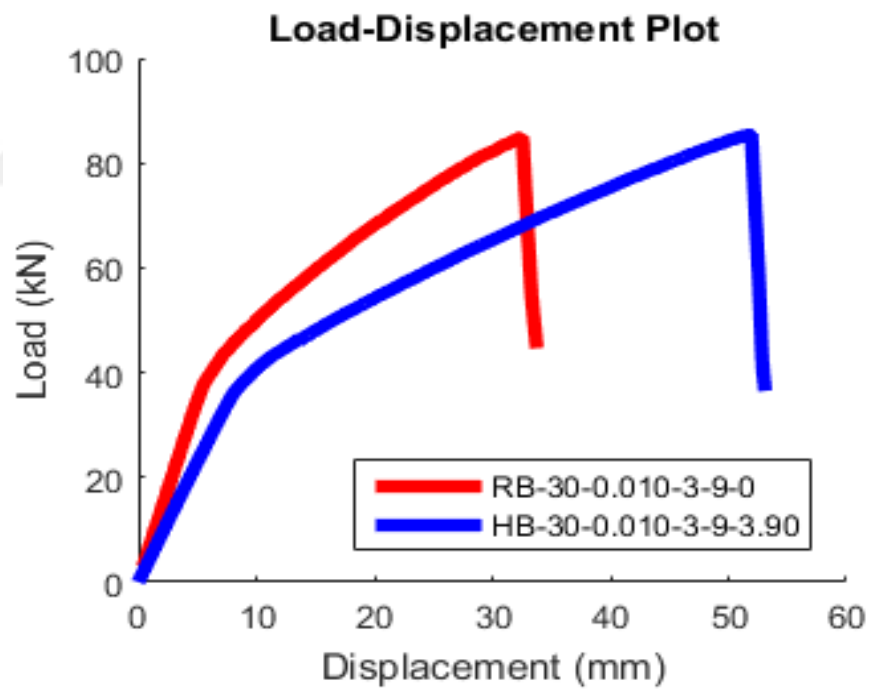


Figure 4.152 L-D plot of RB-30-0.010-3-9-0 and HB-30-0.010-3-9-3.90.

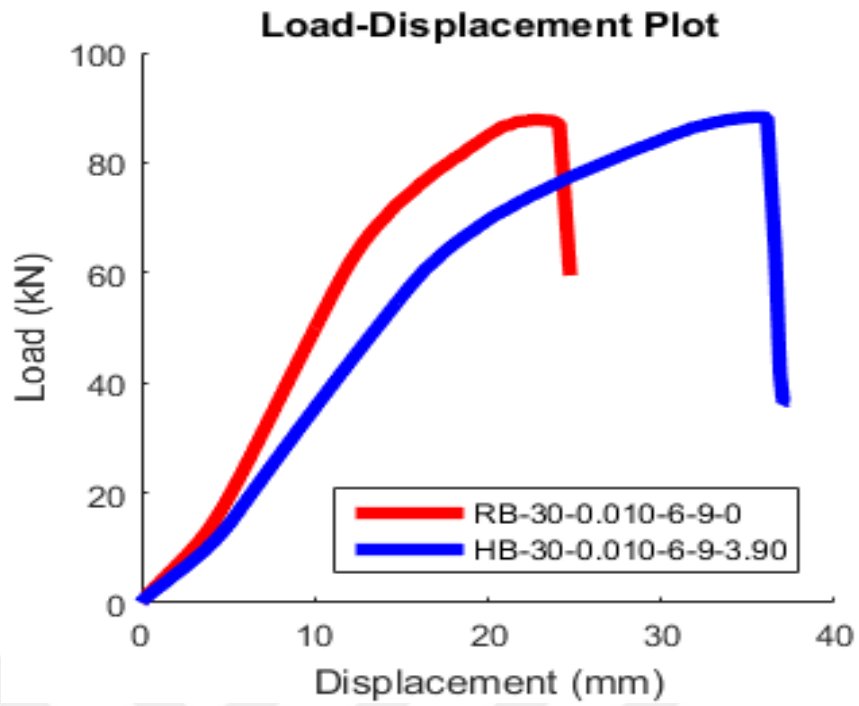


Figure 4.153 L-D plot of RB-30-0.010-6-9-0 and HB-30-0.010-6-9-3.90.

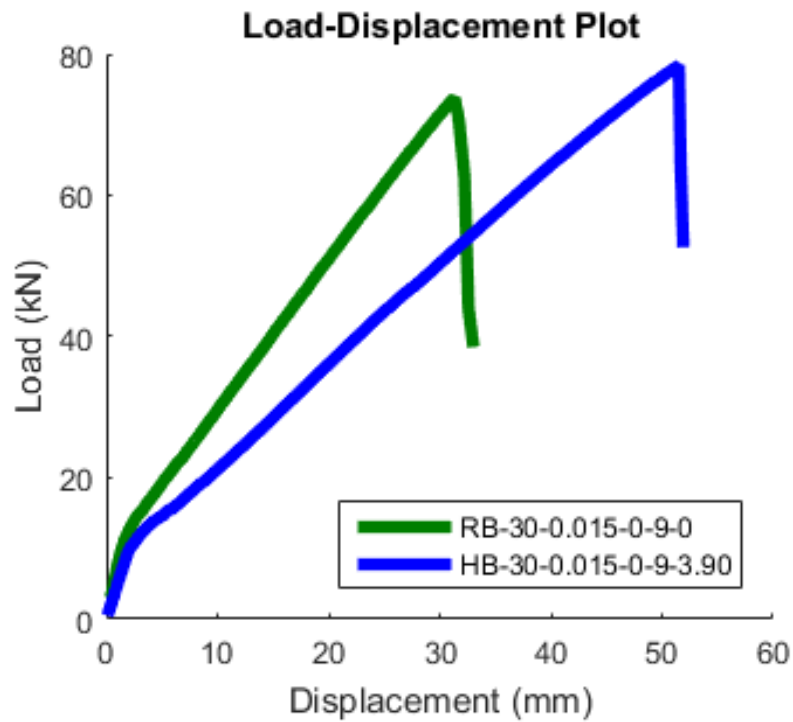


Figure 4.154 L-D plot of RB-30-0.015-0-9-0 and HB-30-0.015-0-9-3.90.

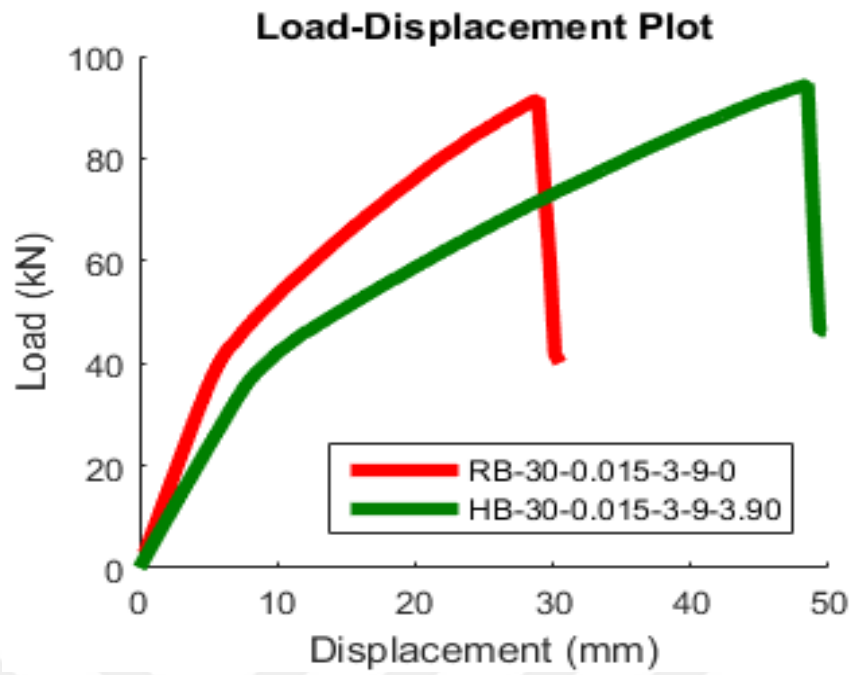


Figure 4.155 L-D plot of RB-30-0.015-3-9-0 and HB-30-0.015-3-9-3.90.

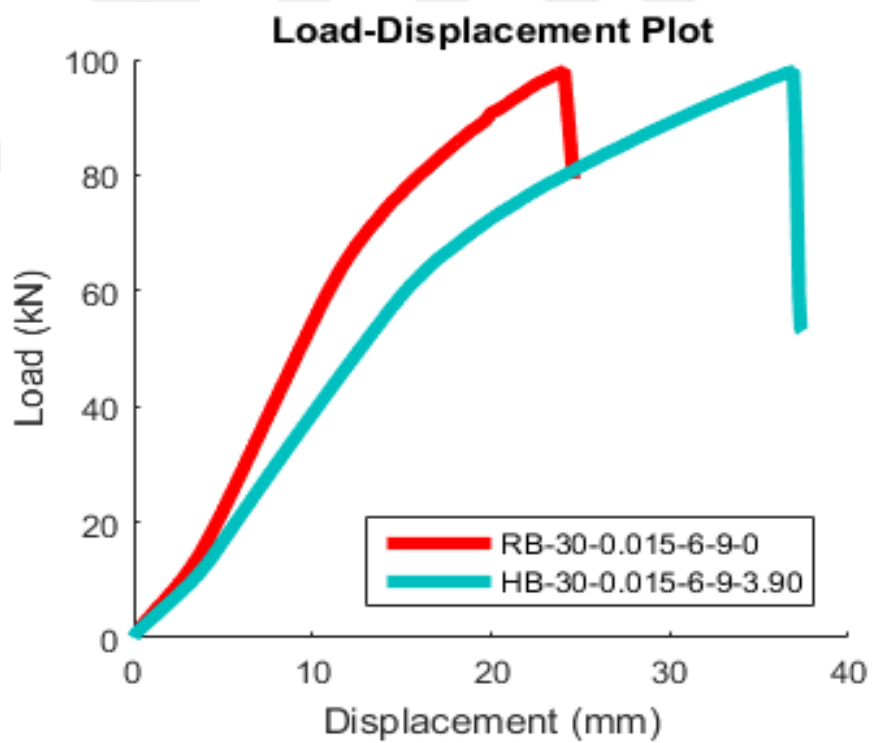


Figure 4.156 L-D plot of RB-30-0.015-6-9-0 and HB-30-0.015-6-9-3.90.

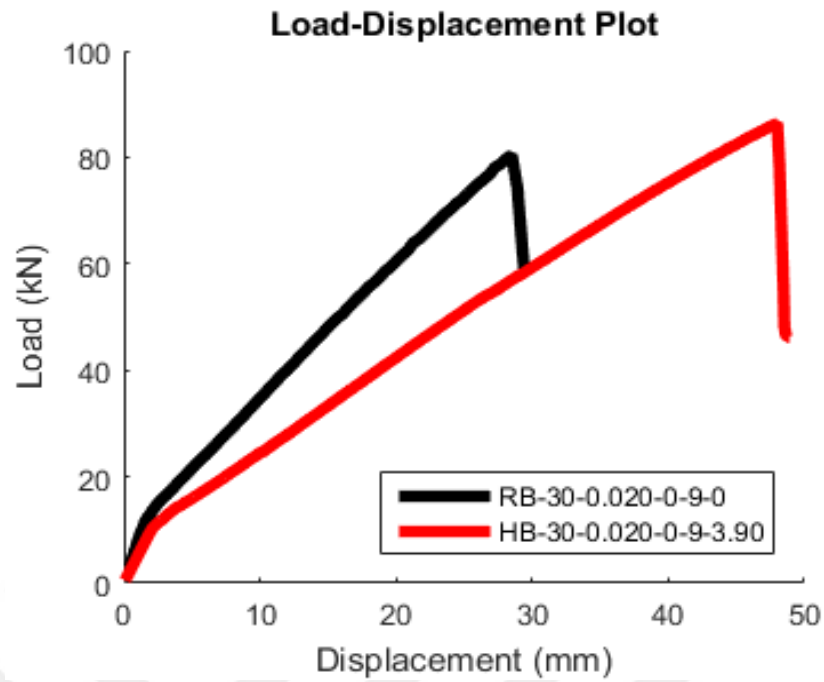


Figure 4.157 L-D plot of RB-30-0.020-0-9-0 and HB-30-0.020-0-9-3.90.

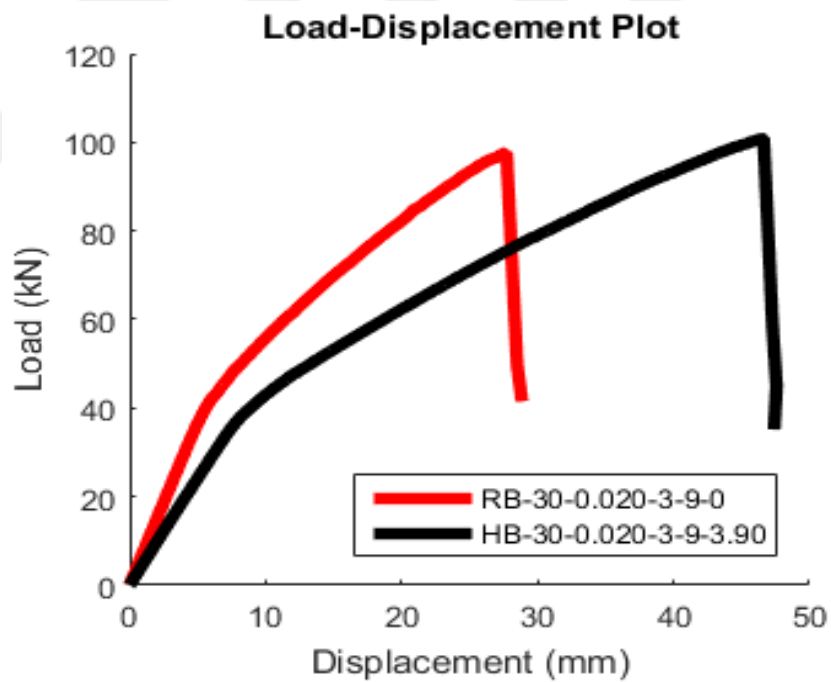


Figure 4.158 L-D plot of RB-30-0.020-3-9-0 and HB-30-0.020-3-9-3.90.

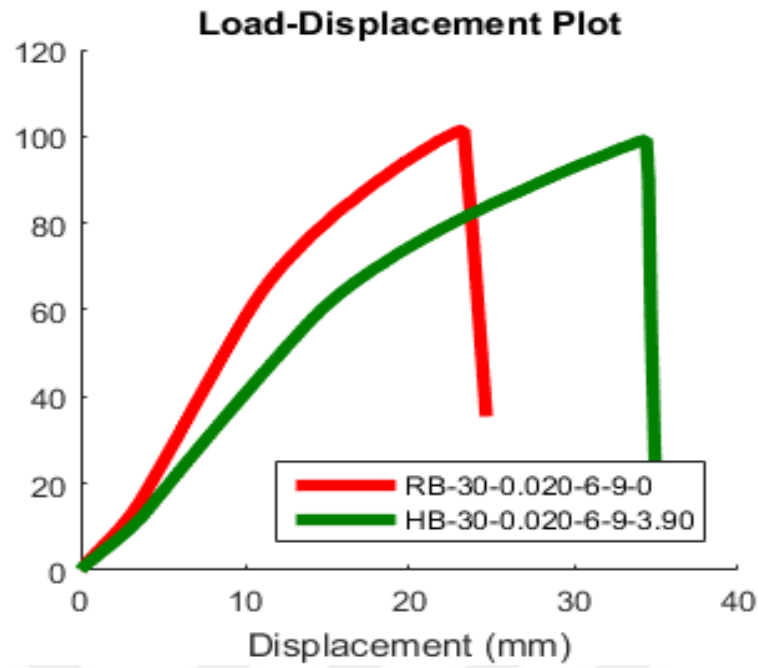


Figure 4.159 L-D plot of RB-30-0.020-6-9-0 and HB-30-0.020-6-9-3.90.

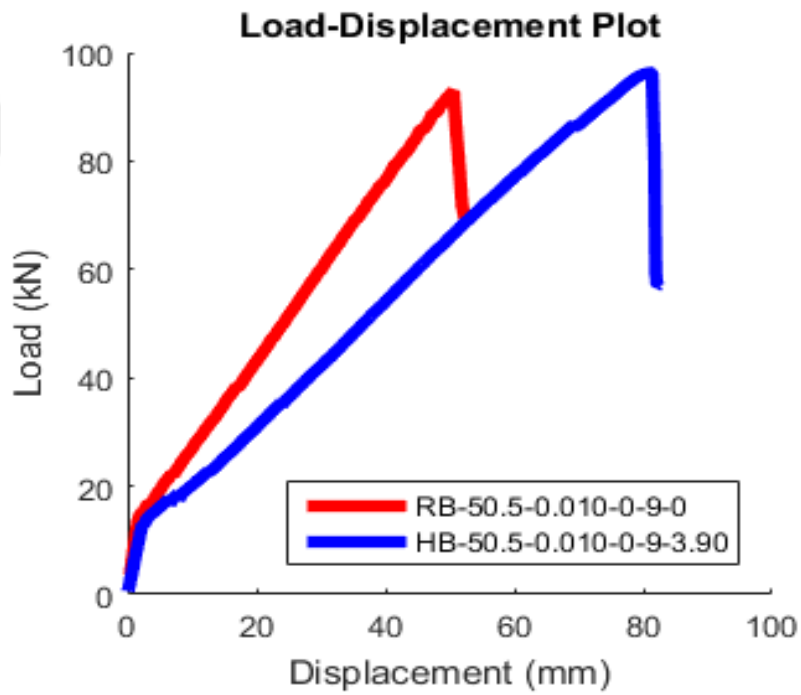


Figure 4.160 L-D plot of RB-50.5-0.010-0-9-0 and HB-50.5-0.010-0-9-3.90.

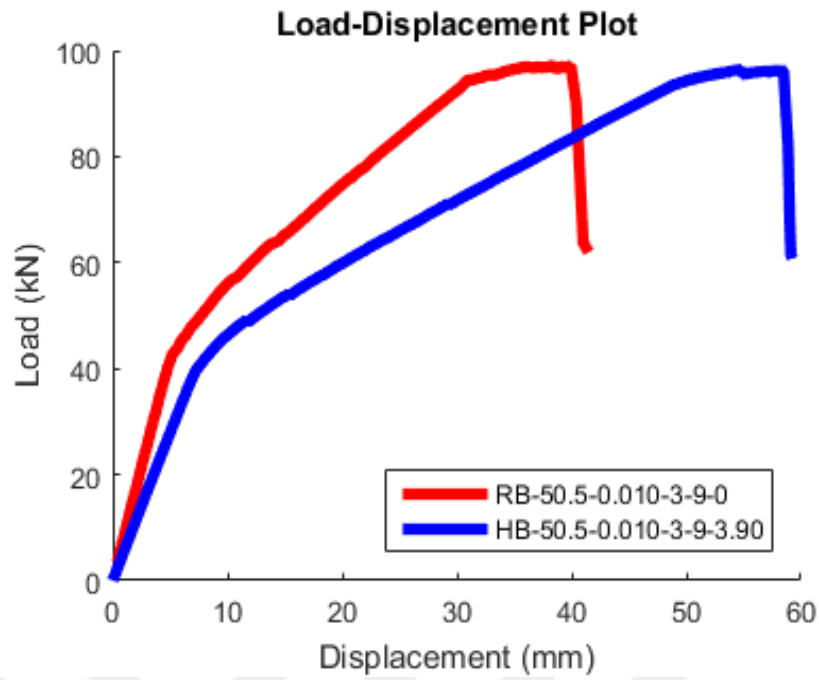


Figure 4.161 L-D plot of RB-50.5-0.010-3-9-0 and HB-50.5-0.010-3-9-3.90.

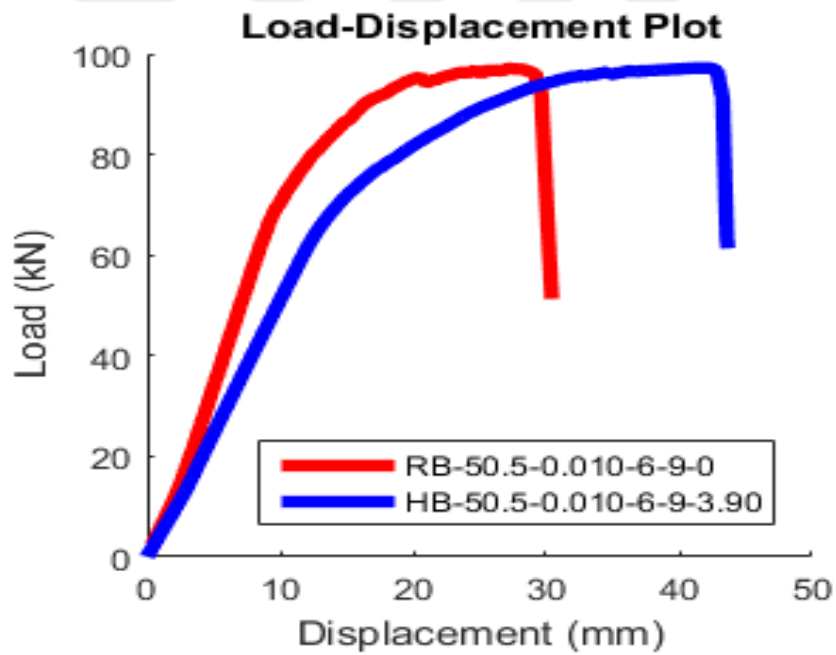


Figure 4.162 L-D plot of RB-50.5-0.010-6-9-0 and HB-50.5-0.010-6-9-3.90.

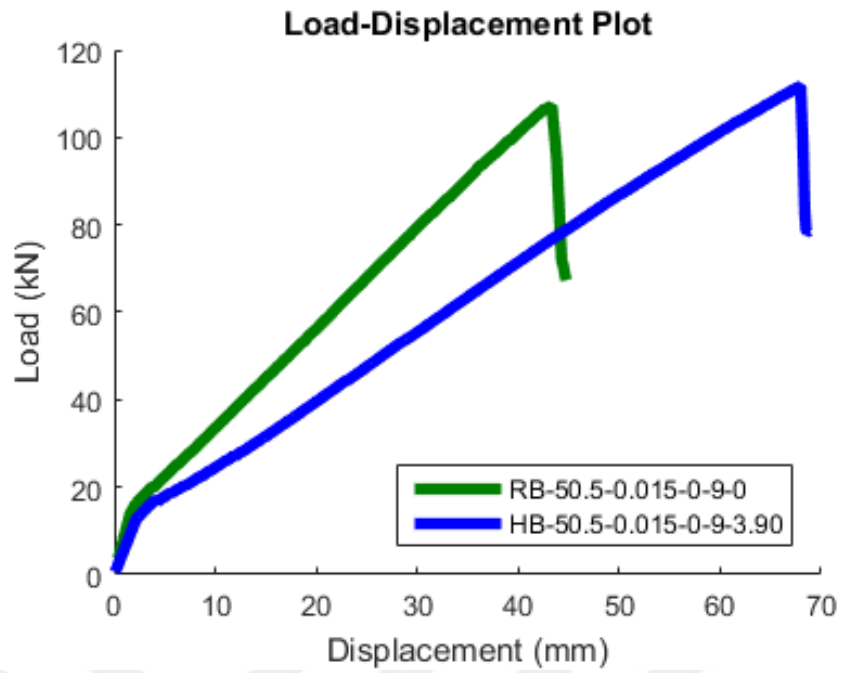


Figure 4.163 L-D plot of RB-50.5-0.015-0-9-0 and HB-50.5-0.015-0-9-3.90.

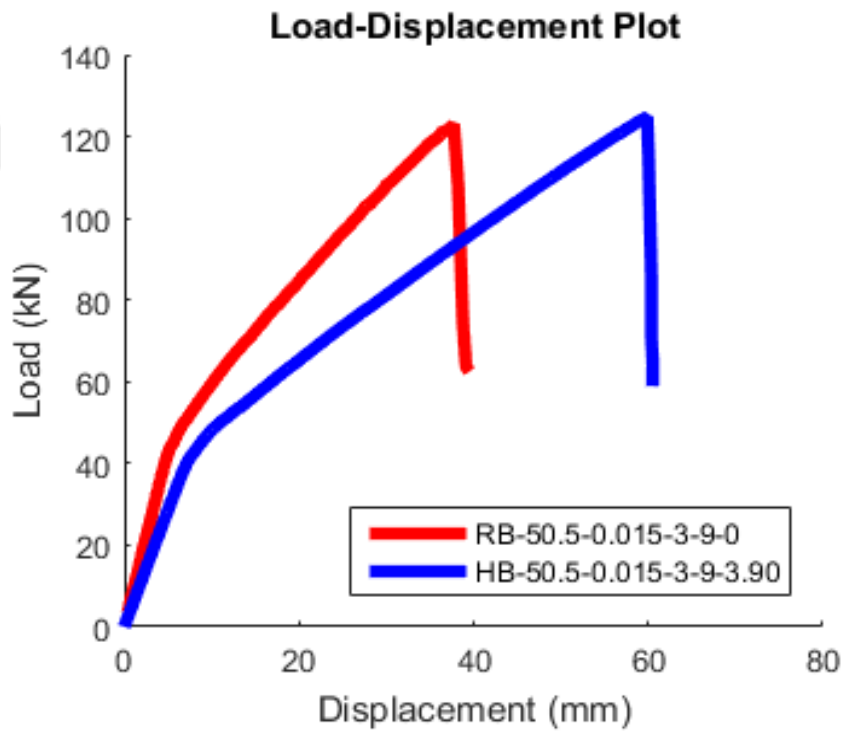


Figure 4.164 L-D plot of RB-50.5-0.015-3-9-0 and HB-50.5-0.015-3-9-3.90.

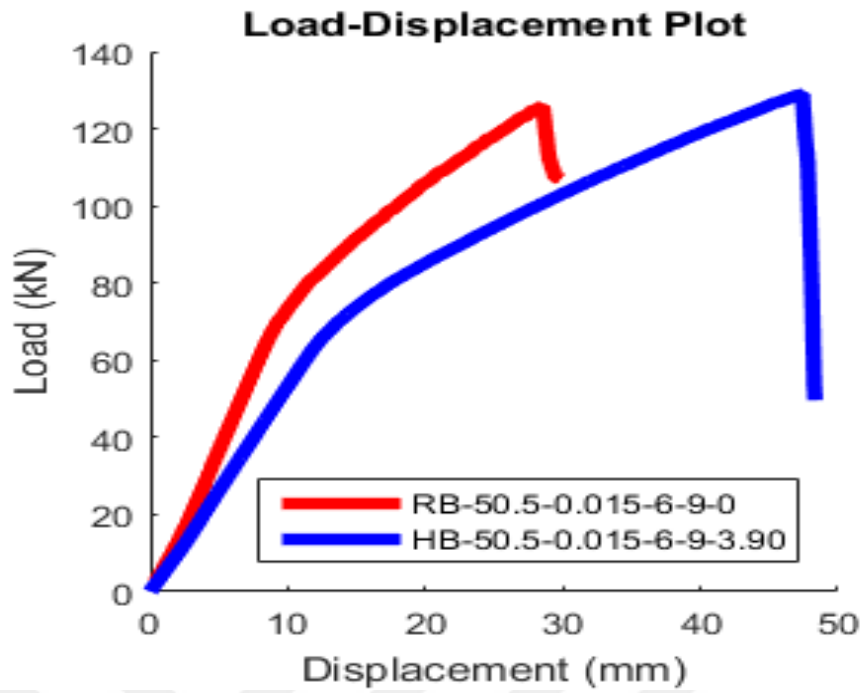


Figure 4.165 L-D plot of RB-50.5-0.015-6-9-0 and HB-50.5-0.015-6-9-3.90.

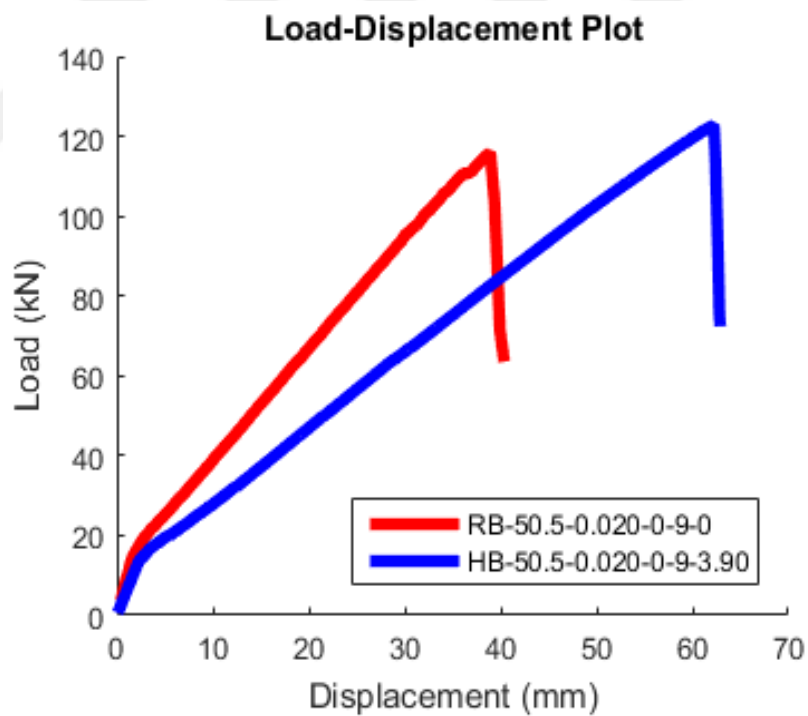


Figure 4.166 L-D plot of RB-50.5-0.020-0-9-0 and HB-50.5-0.020-0-9-3.90.

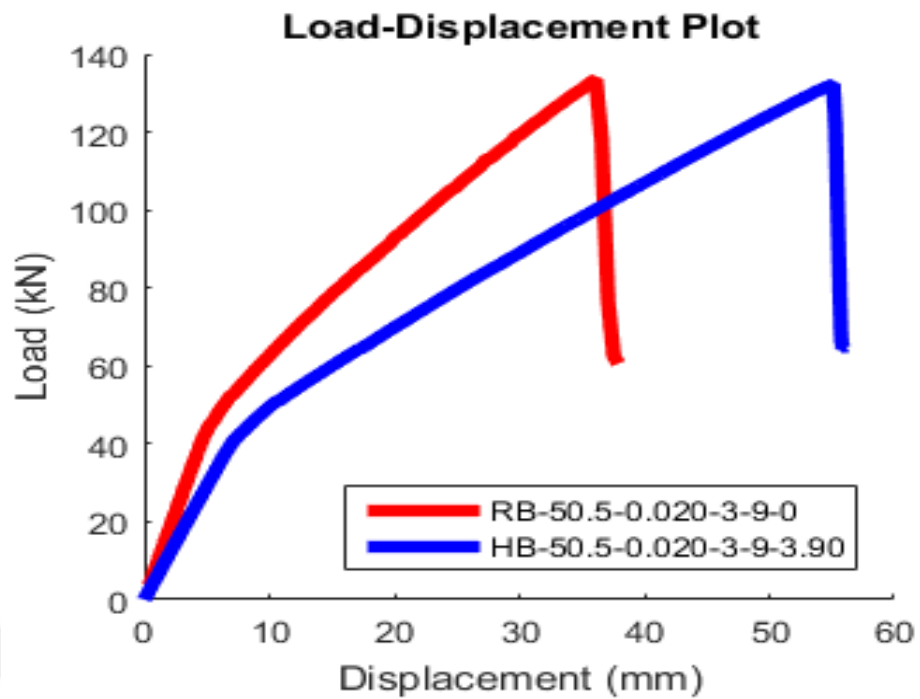


Figure 4.167 L-D plot of RB-50.5-0.020-3-9-0 and HB-50.5-0.020-3-9-3.90.

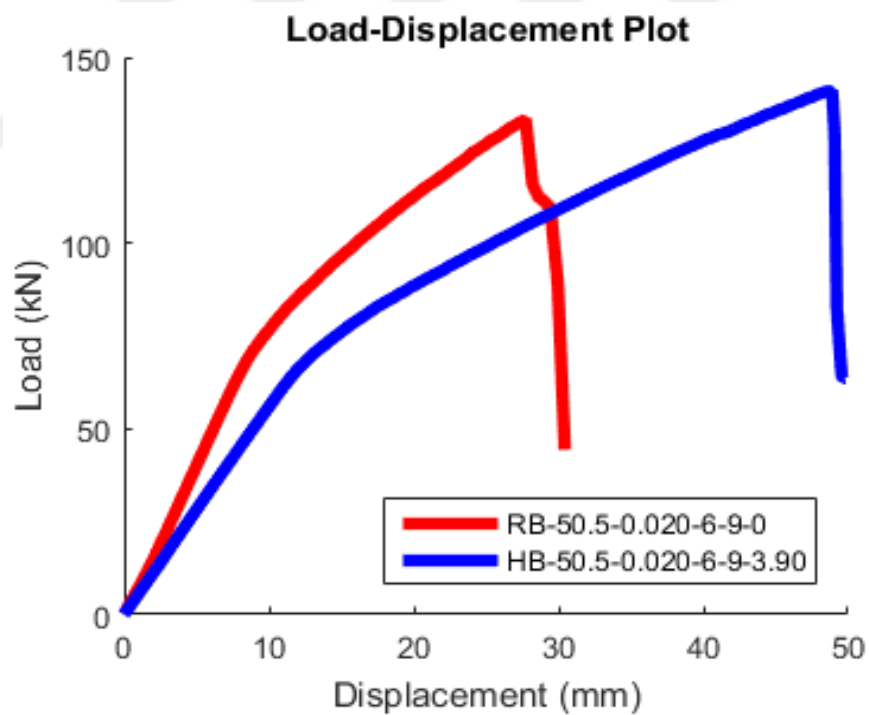


Figure 4.168 L-D plot of RB-50.5-0.020-6-9-0 and HB-50.5-0.020-6-9-3.90.

When the **Figure (4.152 to 4.169)** was examined, the following results were observed:

It was observed that the failure loads of PC haunched beams and PC rectangular beams with $a/d=9$ were the same. But when comparing haunched beams and rectangular beams, the only difference is the maximum displacement.

The results show that the maximum displacement of the haunched beams is greater than that of the rectangular beams.



CHAPTER V

PROBABILISTIC NONLINEAR ANALYSIS OF PC HAUNCHED BEAMS

In this chapter, a probabilistic nonlinear analysis of prestressed concrete (PC) haunched beams have been performed. Probabilistic nonlinear analysis of PC tapered beams was performed by using the SARA (Structural Analysis and Reliability Assessment) Studio version 2.1.1.1 program. Histograms, sensitivity analysis, and reliability results of analyzed beams were evaluated.

5.1 SARA Studio

SARA package program performs probabilistic nonlinear analysis of concrete structures. The FREED and ATENA programs needed the SARA software package to allow a probabilistic nonlinear analysis of concrete structures [12]. In short, it can be said that it provides data exchange between ATENA and FREET programs.

The working principle of SARA can be listed as follows:

1. Introducing and controlling models in ATENA 2D program.
2. Uncertainties and randomness of the input parameters are modeled as random variables described by their probability density function (PDF).
3. Random input parameters are generated according to their PDF using LHS sampling. Statistical correlation among the parameters is imposed using simulated annealing.
4. Generated all beams of random parameters are used as inputs for ATENA 2D computational model.
5. Previous two steps are repeated for all beams.
6. Histograms, Sensitivity Analysis, and Reliability results are evaluated under the Simulation Results Assessment tab.

The relationship between SARA Studio, FReET and ATENA 2D programs can be shown in the Figure 5.1. below.

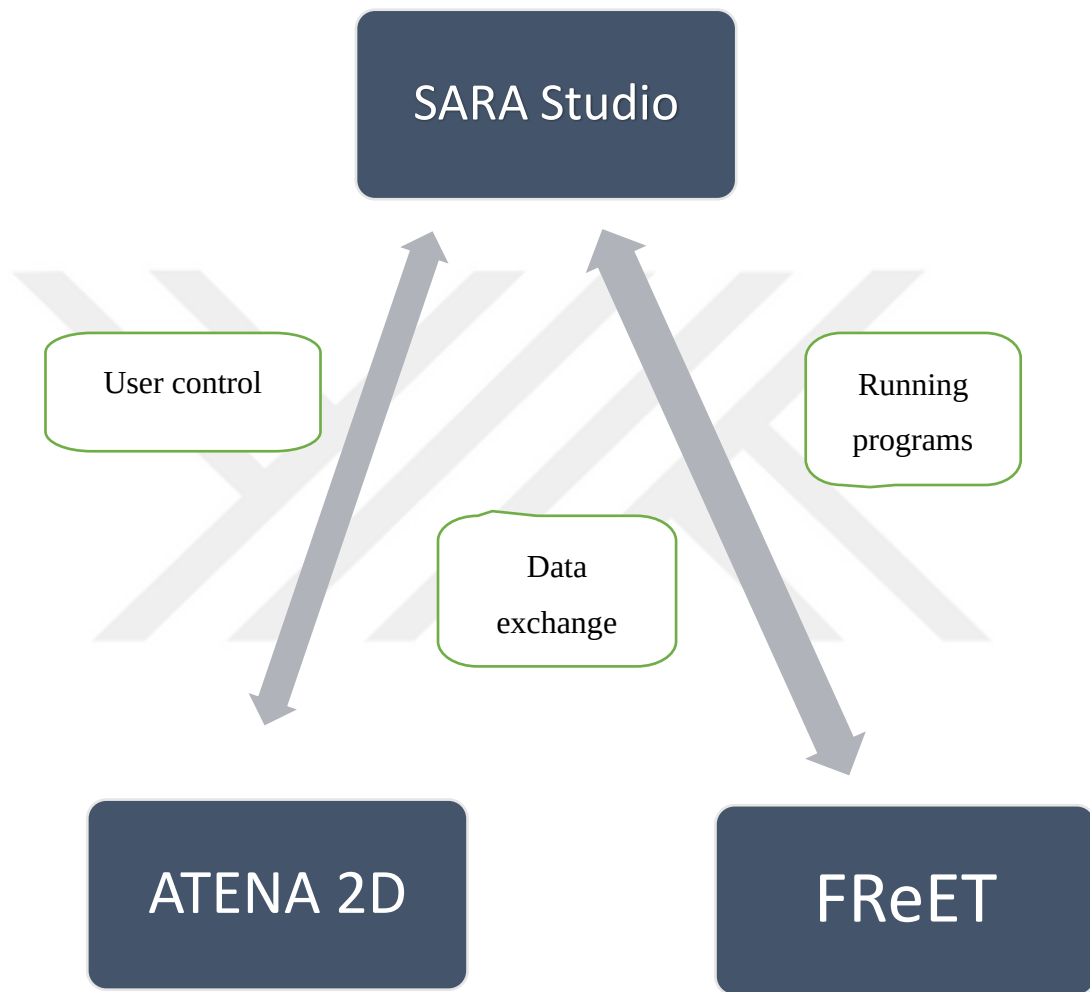


Figure 5.1 The relationship of SARA Studio, FReET and ATENA 2D programs.

5.2 Application of Probabilistic Nonlinear Analysis of Haunched Beams

Probabilistic nonlinear analysis of all PC tapered beams, which were previously analyzed with the ATENA 2D program, is explained step by step below.

First, all beams were modeled with ATENA 2D and introduced to the SARA program. Then the parametrics of the beams are transferred to the FReET program. FReEF (**F**easible **R**eliability **E**ngineering **T**ool) was been improved for probabilistic and stochastic analysis of computationally intensive problems such as nonlinear finite analysis.

The FReET program is examined under three headings:

- Stochastic Model
- Latin Hypercube Sampling
- Simulation Results Assessment

5.2.1 Stochastic Model

Under this heading, Random values and statistical correlation values were determined. Random values and static correlation values were introduced under the Stochastic analysis tab in the FReET Program. Statistical properties of the random variables originated mostly from the database available in the SARA system [13].

5.2.2 Random Variables

A random variable is defined as a function that maps events onto intervals on the axis of real numbers [21]. The distributions of the parameters of concrete and reinforcements are defined in Table 5.1, Table 5.2, and Table 5.3 with the help of the literatures.

Table 5.1 Random variables of compressive strength of concrete.

Variable	Distribution	Reference
E	Lognormal	(Biondini., et al. 2004)
f_t	Weibull	(Lehký., et al 2018)
f_c	Lognormal	(Biondini., et al. 2004)
G_f	Weibull	(Lehký., et al 2018)
b_w	Normal	(Al-Harthy&Frangopol)

Table 5.2 Random variables of tensile bars and compressive bars

Variable	Distribution	Reference
f_{yp}	Lognormal	(Biondini., et al. 2004)
y	Normal	(Mirza and MacGregor)
A_1	Normal	(Naaman and Siriak-sorn.1982)
A_2	Normal	(Naaman and Siriak-sorn.1982)

5.2.3 Statistical Correlation

Table 5.3 Statistical correlation of parameters

	E	f_t	f_c	G_f	f_{yp}	y	A_1	A_2	b_w
E	1	0.7	0.9	0.5	0	0	0	0	0
f_t		1	0.8	0.9	0	0	0	0	0
f_c			1	0.6	0	0	0	0	0
G_f				1	0	0	0	0	0
f_{yp}					1	0	0	0	0
y						1	0	0	0
A_1							1	0	0
A_2								1	0
b_w									1

Not: Static correlation of parameter of concrete is based on Pukl R., Novák D & Bergmeister K [23].

5.2.4 Latin Hypercube Sampling

In the LHS tab, the necessary adjustments were made under three headings.

- General Data
- Check Samples
- Model Analysis

5.2.4.1 General Data

First, the LHS is prepared with the reordered samples using a simulated annealing approach to match the required correlation matrix as closely as possible. The number of simulations and the sampling type are determined in Table 5.5.

Table 5.4 LHS general data adjustment.

Number of Simulations	50
Sampling type	LHS random

5.2.4.2 Check Samples

After the simulation number and sampling type were determined, it was checked.

5.2.4.3 Model Analysis

After the parameters were specified correctly, the analysis was initiated.

5.2.5 Simulation Result Assessment

As a result of the analysis, all prestressed concrete beams' histogram, sensitivity, and reliability analysis results were shown in Table 5.5.

Table 5.5 HB beams' histogram, sensitivity, and reliability analysis

HB-30-0.01-0-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	102	0.011	0.104	130	70	Logistic
	+sensi			-sensi		
b_w	0.73					
E	0.33					
f_t	0.33					
f_{ty}				0.016		

HB-30-0.01-3-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	139	0.008	0.059	156	121	Lognormal(3par)
	+sensi			-sensi		
b_w	0.86					
G_f	0.20					
f_t	0.15					
y				0.14		
HB-30-0.01-6-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	183	0.014	0.077	207	144	Weibull max(3par)
	+sensi			-sensi		
b_w	0.68					
A_1	0.38					
A_2	0.37					
E				0.13		
f_c				0.08		
y				0.04		
HB-30-0.015-0-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	111	0.012	0.105	138	84	Laplace
	+sensi			-sensi		
b_w	0.76					
f_t	0.25					
A_1	0.23					
f_{ty}				0.18		
HB-30-0.015-3-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	144	0.009	0.065	173	126	Weibul min(3par)
	+sensi			-sensi		
b_w	0.90					
y	0.06					
A_1	0.04					
f_c				0.13		
E				0.09		
f_t				0.002		
HB-30-0.015-6-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	189	0.015	0.080	234	157	Weibul min(2par)
	+sensi			-sensi		
b_w	0.88					
f_{ty}	0.02					
y	0.01					
f_c				0.15		
E				0.07		
f_t				0.07		
HB-30-0.020-0-2-18.43						

Name	Mean	Std	COV	Max	Min	Distribution
Load	116	0.012	0.106	148	84	Lognormal(3par)
	+sensi			-sensi		
b_w	0.74					
A_1	0.29					
A_2	0.28					
f_{ty}				0.39		
HB-30-0.020-3-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	150	0.012	0.080	169	117	Beta
	+sensi			-sensi		
b_w	0.79					
y	0.16					
A_1	0.13					
f_c				0.25		
E				0.20		
f_{ty}				0.12		
HB-30-0.020-6-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	189	0.015	0.080	222	152	Lognormal (3par)
	+sensi			-sensi		
b_w	0.90					
f_{ty}	0.07					
G_f	0.05					
f_c				0.18		
E				0.16		
f_t				0.07		
HB-50.5-0.010-0-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	136	0.015	0.109	165	101	Lognormal (3par)
	+sensi			-sensi		
b_w	0.77					
G_f	0.34					
f_t	0.31					
f_{ty}				0.04		
HB-50.5-0.010-3-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	171	0.011	0.063	196	148	Triangular
	+sensi			-sensi		
b_w	0.70					
A_1	0.32					
A_2	0.29					
E				0.18		
f_c				0.17		
HB-50.5-0.010-6-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	206	0.021	104	251	161	Weibull min(2par)

	+sensi			-sensi		
A_1	0.65					
A_2	0.63					
f_{ty}	0.52					
y				0.07		
G_f				0.01		
HB-50.5-0.015-0-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	147	0.015	0.105	187	112	Beta
	+sensi			-sensi		
b_w	0.64					
f_t	0.33					
f_c	0.31					
HB-50.5-0.015-3-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	187	0.015	0.073	233	171	Triangular
	+sensi			-sensi		
b_w	0.75					
A_1	0.41					
A_2	0.40					
f_c				0.23		
E				0.18		
f_t				0.17		
HB-50.5-0.015-6-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	235	0.015	0.064	275	204	Weibull max(3par)
	+sensi			-sensi		
b_w	0.81					
A_1	0.16					
A_2	0.14					
f_{ty}				0.14		
y				0.07		
HB-50.5-0.020-0-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	155	0.016	0.102	199	125	Triangular
	+sensi			-sensi		
b_w	0.70					
A_1	0.23					
y	0.22					
f_c				0.04		
f_{ty}				0.03		
HB-50.5-0.020-3-2-18.43						
Name	Mean	Std	COV	Max	Min	Distribution
Load	200	0.015	0.073	233	171	Triangular
	+sensi			-sensi		
b_w	0.74					

A_1	0.10					
A_2	0.09					
f_c				0.31		
f_t				0.24		
E				0.18		
HB-30-0.015-6-3-12.09						
Name	Mean	Std	COV	Max	Min	Distribution
Load	141	0.011	0.079	163	107	Lognormal (3par)
	+sensi			-sensi		
b_w	0.89					
A_1	0.10					
A_2	0.09					
f_c				0.16		
E				0.14		
y				0.09		
HB-30-0.020-0-3-12.09						
Name	Mean	Std	COV	Max	Min	Distribution
Load	97	0.009	0.099	115	74	Triangular
	+sensi			-sensi		
b_w	0.71					
E	0.51					
f_c	0.5					
y				0.05		
HB-30-0.020-3-3-12.09						
Name	Mean	Std	COV	Max	Min	Distribution
Load	121	0.011	0.094	142	98	Triangular
	+sensi			-sensi		
b_w	0.78					
E	0.28					
G_f	0.23					
f_c				0.04		
HB-30-0.020-6-3-12.09						
Name	Mean	Std	COV	Max	Min	Distribution
Load	144	0.011	0.076	171	120	Triangular
	+sensi			-sensi		
b_w	0.90					
G_f	0.10					
f_t	0.09					
f_{ty}				0.03		
f_c				0.02		
y				0.02		
HB-50.5-0.010-0-3-12.09						
Name	Mean	Std	COV	Max	Min	Distribution
Load	107	0.011	0.103	132	86	Triangular
	+sensi			-sensi		
b_w	0.72					

f_t	0.40					
f_c	0.33					
y				0.05		
HB-50.5-0.010-3-3-12.09						
Name	Mean	Std	COV	Max	Min	Distribution
Load	130	0.011	0.088	158	110	Weibull min(3par)
	+sensi			-sensi		
b_w	0.46					
A_1	0.43					
A_2	0.42					
y				0.15		

HB-50.5-0.020-6-3-12.09						
Name	Mean	Std	COV	Max	Min	Distribution
Load	183	0.013	0.072	207	150	Triangular
	+sensi			-sensi		
b_w	0.80					
f_t	0.42					
E	0.39					
f_{ty}				0.06		
HB-30-0.010-0-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	73	0.008	0.114	89	53	Gamma negative(3par)
	+sensi			-sensi		
b_w	0.70					
A_l	0.42					
A_2	0.40					
f_c				0.22		
E				0.20		
y				0.13		
HB-30-0.010-3-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	86	0.0072	0.084	98	70	Rayleigh
	+sensi			-sensi		
b_w	0.48					
A_l	0.30					
A_2	0.29					
E				0.28		
f_c				0.22		
f_t				0.14		
HB-30-0.010-6-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	96	0.010	0.106	116	74	Rectangular
	+sensi			-sensi		

f_{ty}	0.63					
A_1	0.56					
A_2	0.54					
f_c				0.14		
y				0.09		
E				0.09		
HB-30-0.015-0-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	79	0.008	0.110	103	60	Lognormal(2par)
	+sensi			-sensi		
b_w	0.48					
f_{ty}	0.48					
A_1	0.24					
y				0.06		
HB-30-0.015-3-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	98	0.007	0.079	114	78	Beta
	+sensi			-sensi		
b_w	0.77					
f_t	0.24					
G_f	0.23					
y				0.17		
f_{ty}				0.07		
HB-30-0.015-6-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	108	0.014	0.130	142	78	Lognormal (2par)
	+sensi			-sensi		
b_w	0.47					
A_2	0.31					
A_1	0.30					
f_{ty}				0.47		
f_c				0.25		
E				0.21		
HB-30-0.020-0-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	87	0.012	0.143	115	65	Triangular
	+sensi			-sensi		
b_w	0.63					
A_1	0.18					
A_2	0.18					
f_c				0.31		
E				0.23		
y				0.14		
HB-30-0.020-3-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	100	0.007	0.067	114	83	Normal
	+sensi			-sensi		
b_w	0.85					
G_f	0.32					

F_t	0.29					
y				0.09		
A_I				0.09		
A_2				0.08		
HB-30-0.020-6-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	110	0.008	0.079	128	88	Weibull max(3par)
	+sensi			-sensi		
b_w	0.73					
A_I	0.14					
A_2	0.12					
f_c				0.27		
E				0.25		
f_{ty}				0.24		
HB-50.5-0.010-0-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	92	0.009	0.104	112	72	Lognormal(2par)
	+sensi			-sensi		
b_w	0.59					
A_2	0.26					
A_I	0.25					
y				0.18		
f_t				0.02		
f_c				0.01		
HB-50-0.010-3-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	104	0.011	0.107	134	82	Logistic
	+sensi			-sensi		
A_I	0.52					
f_{ty}	0.51					
A_2	0.51					
y				0.15		
E				0.13		
f_c				0.04		
HB-50.5-0.010-6-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	107	0.014	0.129	140	76	Beta
	+sensi			-sensi		
f_{ty}	0.67					
A_I	0.59					
A_2	0.57					
f_c				0.30		
E				0.28		
f_t				0.26		
HB-50.5-0.015-0-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	110	0.017	0.154	141	72	Beta
	+sensi			-sensi		
E	0.54					
f_c	0.48					

b_w	0.36					
y				0.21		
HB-50.5-0.015-3-4-8.97						
Name	mean	Std	COV	Max	Min	Distribution
Load	123	0.009	0.074	140	104	Beta
	+sensi			-sensi		
b_w	0.79					
f_t	0.29					
E	0.26					
f_c				0.08		
HB-50.5-0.015-6-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	107	0.014	0.130	132	76	Gamma (2par)
	+sensi			-sensi		
b_w	0.34					
f_{ty}	0.24					
A_1	0.16					
y				0.26		
f_c				0.09		
E				0.07		
HB-50.5-0.020-0-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	114	0.012	0.108	138	89	Normal
	+sensi			-sensi		
b_w	0.60					
A_1	0.26					
A_2	0.26					
y				0.31		
HB-50.5-0.020-3-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	125	0.011	0.091	161	91	Laplace
	+sensi			-sensi		
b_w	0.84					
f_t	0.37					
G_f	0.34					
HB-50.5-0.020-6-4-8.97						
Name	Mean	Std	COV	Max	Min	Distribution
Load	141	0.014	0.102	174	110	Lognormal (2par)
	+sensi			-sensi		
b_w	0.65					
E	0.29					
A_1	0.25					
HB-30-0.010-0-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	58	0.007	0.129	72	42	Half-Normal negative
	+sensi			-sensi		
b_w	0.56					

A_1	0.35					
A_2	0.34					
y				0.18		
f_t				0.12		
G_f				0.12		
HB-30-0.010-3-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	71	0.010	0.147	95	48	Beta
	+sensi			-sensi		
b_w	0.23					
f_{ty}	0.22					
A_1	0.21					
E				0.78		
f_c				0.77		
f_t				0.65		
HB-30-0.010-6-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	78	0.009	0.121	98	59	Beta
	+sensi			-sensi		
A_2	0.51					
A_1	0.51					
b_w	0.44					
f_c				0.33		
f_t				0.28		
E				0.26		
HB-30-0.015-0-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	68	0.007	0.106	86	53	Logistic
	+sensi			-sensi		
b_w	0.73					
A_2	0.30					
A_1	0.30					
f_c				0.16		
y				0.15		
E				0.14		
HB-30-0.015-3-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	83	0.008	0.097	97	63	Beta
	+sensi			-sensi		
b_w	0.65					
A_1	0.33					
A_2	0.31					
f_c				0.44		
E				0.42		
F_t				0.34		
HB-30-0.015-6-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	90	0.008	0.096	106	68	Weibull min(3par)
	+sensi			-sensi		
b_w	0.57					
A_2	0.21					

A_1	0.21					
f_c				0.52		
E				0.44		
f_t				0.35		
HB-30-0.020-0-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	75	0.007	0.090	91	65	Rayleigh
	+sensi			-sensi		
b_w	0.64					
A_1	0.23					
A_2	0.22					
y				0.25		
f_{ty}				0.04		
f_c				0.04		
HB-30-0.020-3-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	85	0.008	0.100	106	69	Logistic
	+sensi			-sensi		
b_w	0.72					
E	0.25					
f_c	0.15					
y				0.18		
f_{ty}				0.17		
HB-30-0.020-6-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	93	0.007	0.077	103	73	Gumbel Min. EV 1
	+sensi			-sensi		
b_w	0.75					
f_{ty}	0.03					
A_1	0.01					
f_c				0.32		
E				0.31		
f_t				0.19		
HB-50.5-0.010-0-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	79	0.010	0.132	111	58	Lognormal(3par)
	+sensi			-sensi		
A_1	0.47					
A_2	0.45					
b_w	0.31					
E				0.44		
f_c				0.41		
f_t				0.26		
HB-50.5-0.010-3-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	86	0.011	0.122	114	66	Logistic
	+sensi			-sensi		
A_1	0.70					
A_2	0.69					
f_{tv}	0.57					

E					0.14	
f_c					0.11	
y					0.10	
HB-50.5-0.010-6-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	86	0.011	0.125	105	61	Beta
	+sensi			-sensi		
A_1	0.68					
A_2	0.67					
f_{ty}	0.61					
y				0.04		
HB-50.5-0.015-0-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	90	0.014	0.160	120	61	Beta
	+sensi			-sensi		
b_w	0.58					
A_1	0.29					
A_2	0.28					
E				0.39		
f_c				0.34		
f_t				0.15		
HB-50.5-0.015-3-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	104	0.009	0.089	124	81	Weibull max(3par)
	+sensi			-sensi		
b_w	0.49					
A_1	0.41					
A_2	0.40					
y				0.13		
HB-50.5-0.015-6-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	115	0.012	0.101	136	80	Weibull max(3par)
	+sensi			-sensi		
A_1	0.64					
A_2	0.62					
f_{ty}	0.41					
y				0.09		
HB-50.5-0.020-0-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	97	0.012	0.129	124	75	Triangular
	+sensi			-sensi		
b_w	0.47					
A_1	0.29					
E	0.28					
y				0.21		
HB-50.5-0.020-3-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution

Load	109	0.008	0.078	129	91	logistic
	+sensi			-sensi		
b_w	0.85					
A_1	0.25					
A_2	0.25					
y				0.16		
HB-50.5-0.020-6-5-7.13						
Name	Mean	Std	COV	Max	Min	Distribution
Load	127	0.012	0.091	152	106	Normal
	+sensi			-sensi		
b_w	0.72					
A_2	0.19					
A_1	0.18					
f_c				0.30		
E				0.29		
f_t				0.24		
HB-30-0.010-0-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	51	0.005	0.095	60	43	Beta
	+sensi			-sensi		
b_w	0.64					
A_1	0.32					
A_2	0.31					
f_c				0.30		
E				0.25		
y				0.13		
HB-30-0.010-3-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	61	0.006	0.093	75	48	Gumbel Max. EV 1
	+sensi			-sensi		
b_w	0.62					
A_2	0.25					
A_1	0.24					
f_c				0.01		
y				0.01		
HB-30-0.010-6-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	62	0.006	0.102	78	45	Logistic
	+sensi			-sensi		
f_{ly}	0.54					
b_w	0.47					
A_1	0.39					
y				0.10		
f_c				0.07		
E				0.03		
HB-30-0.015-0-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	58	0.005	0.096	73	47	Student t
	+sensi			-sensi		

b_w	0.54					
A_1	0.44					
A_2	0.44					
f_c				0.33		
E				0.29		
f_t				0.27		
HB-30-0.015-3-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	70	0.0075	0.107	88	55	Laplace
	+sensi			-sensi		
b_w	0.67					
A_1	0.05					
A_2	0.04					
F_c				0.39		
E				0.35		
f_t				0.23		
HB-30-0.015-6-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	71	0.005	0.074	83	61	Beta
	+sensi			-sensi		
b_w	0.51					
A_1	0.21					
A_2	0.18					
f_c				0.39		
f_t				0.30		
E				0.29		
HB-30-0.020-0-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	63	0.005	0.084	74	51	Weibull max(3par)
	+sensi			-sensi		
b_w	0.70					
A_1	0.36					
A_2	0.35					
f_c				0.28		
f_t				0.19		
E				0.19		
HB-30-0.020-3-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	74	0.007	0.099	89	52	Student t
	+sensi			-sensi		
b_w	0.47					
f_{ty}	0.28					
A_1	0.23					
f_t				0.46		
f_c				0.45		
G_f				0.37		
HB-30-0.020-6-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	72	0.007	0.103	85	56	Weibull min(3par)
	+sensi			-sensi		

b_w	0.59					
f_{ty}	0.21					
A_1	0.14					
f_c				0.19		
E				0.17		
y				0.02		
HB-50.5-0.010-0-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	66	0.007	0.109	80	51	Beta
	+sensi			-sensi		
A_1	0.56					
A_2	0.56					
f_{ty}	0.43					
E				0.23		
y				0.23		
f_c				0.23		
HB-50.5-0.010-3-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	72	0.008	0.115	92	54	Weibull min(3par)
	+sensi			-sensi		
A_2	0.65					
A_1	0.65					
b_w	0.08					
f_c				0.11		
y				0.08		
E				0.07		
HB-50.5-0.010-6-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	71	0.008	0.113	87	50	Logistic
	+sensi			-sensi		
A_1	0.67					
A_2	0.66					
f_{ty}	0.44					
E				0.16		
f_t				0.13		
G_f				0.12		
HB-50.5-0.015-0-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	82	0.008	0.099	100	65	Triangular
	+sensi			-sensi		
b_w	0.57					
f_{ty}	0.44					
A_1	0.33					
y				0.15		
f_c				0.09		
E				0.05		
HB-50.5-0.015-3-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	92	0.012	0.129	120	73	Gamma (2par)
	+sensi			-sensi		

f_{ty}	0.70					
b_w	0.46					
A_1	0.09					
y				0.17		
f_t				0.17		
G_f				0.16		
HB-50.5-0.015-6-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	92	0.010	0.110	114	74	Weibull max(3 par)
	+sensi			-sensi		
b_w	0.62					
A_1	0.36					
A_2	0.35					
HB-50.5-0.020-0-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	87	0.008	0.098	108	69	Lognormal (2par)
	+sensi			-sensi		
b_w	0.70					
f_{ty}	0.34					
A_1	0.16					
f_c				0.34		
E				0.26		
f_t				0.25		
HB-50.5-0.020-3-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	97	0.010	0.104	125	74	Logistic
	+sensi			-sensi		
f_{ty}	0.63					
b_w	0.38					
A_1	0.21					
f_t				0.15		
G_f				0.14		
f_c				0.14		
HB-50.5-0.020-6-6-5.91						
Name	Mean	Std	COV	Max	Min	Distribution
Load	102	0.010	0.105	124	84	Beta
	+sensi			-sensi		
b_w	0.67					
A_1	0.31					
A_2	0.30					
f_c				0.14		
f_t				0.13		
G_f				0.09		
HB-30-0.010-0-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	43	0.005	0.119	53	33	Beta
	+sensi			-sensi		

f_{ty}	0.48					
b_w	0.41					
A_I	0.29					
y				0.18		
f_c				0.12		
E				0.11		
HB-30-0.010-3-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	54	0.004	0.084	65	42	Lognormal (2par)
	+sensi			-sensi		
A_I	0.59					
A_2	0.58					
b_w	0.52					
f_c				0.20		
E				0.18		
y				0.15		
HB-30-0.010-6-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	56	0.006	0.115	66	40	Beta
	+sensi			-sensi		
F_y	0.68					
A_I	0.48					
A_2	0.48					
y				0.15		
E				0.11		
f_c				0.10		
HB-30-0.015-0-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	50	0.005	0.097	62	39	Student t
	+sensi			-sensi		
b_w	0.57					
A_I	0.41					
A_2	0.40					
E				0.25		
f_c				0.24		
y				0.20		
HB-30-0.015-3-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	60	0.006	0.095	71	46	Weibull max(3par)
	+sensi			-sensi		
b_w	0.69					
A_I	0.22					
A_2	0.20					
f_c				0.43		
E				0.39		
f_t				0.24		
HB-30-0.015-6-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	63	0.006	0.098	78	47	Laplace
	+sensi			-sensi		
b_w	0.75					

A_1	0.24					
A_2	0.23					
f_c				0.37		
E				0.31		
f_t				0.21		
HB-30-0.020-0-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	56	0.006	0.102	73	43	Student t
	+sensi			-sensi		
b_w	0.69					
A_2	0.33					
A_1	0.30					
f_c				0.25		
E				0.20		
f_t				0.14		
HB-30-0.020-3-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	65	0.006	0.096	84	52	Student t
	+sensi			-sensi		
b_w	0.66					
A_1	0.23					
A_2	0.22					
f_c				0.52		
E				0.47		
f_t				0.36		
HB-30-0.020-6-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	68	0.007	0.100	84	55	Triangular
	+sensi			-sensi		
b_w	0.73					
A_1	0.22					
A_2	0.22					
f_c				0.39		
E				0.33		
f_t				0.20		
HB-50.5-0.010-0-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	57	0.008	0.136	72	40	Gamma (2par)
	+sensi			-sensi		
A_1	0.41					
A_2	0.39					
b_w	0.24					
E				0.59		
f_c				0.54		
f_t				0.27		
HB-50.5-0.010-3-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	63	0.007	0.117	79	49	Beta
	+sensi			-sensi		
f_{ty}	0.64					
A_1	0.63					

A_2	0.63					
f_c				0.26		
f_t				0.25		
E				0.22		
HB-50.5-0.010-6-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	61	0.008	0.118	84	51	Rayleigh
	+sensi			-sensi		
A_1	0.33					
A_2	0.33					
f_{ty}	0.24					
y				0.06		
HB-50.5-0.015-0-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	67	0.067	0.018	84	51	Rayleigh
	+sensi			-sensi		
b_w	0.48					
A_2	0.33					
A_1	0.32					
f_c				0.51		
E				0.50		
f_t				0.40		
HB-50.5-0.015-3-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	81	0.007	0.090	103	67	Rayleigh
	+sensi			-sensi		
b_w	0.49					
A_1	0.42					
A_2	0.42					
y				0.11		
f_c				0.05		
E				0.03		
HB-50.5-0.015-6-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	84	0.008	0.102	112	68	Logistic
	+sensi			-sensi		
A_1	0.66					
A_2	0.63					
f_{ty}	0.47					
f_c				0.09		
E				0.06		
y				0.05		
HB-50.5-0.020-0-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	76	0.007	0.095	90	58	Weibull min (2 par)
	+sensi			-sensi		
b_w	0.65					
A_1	0.25					
A_2	0.24					

f_c						0.49
E						0.45
f_t						0.34
HB-50.5-0.020-3-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	85	0.009	0.106	102	65	Logistic
	+sensi			-sensi		
b_w		0.36				
A_1		0.28				
A_2		0.28				
f_c						0.33
E						0.29
y						0.22
HB-50.5-0.020-6-7-5.04						
Name	Mean	Std	COV	Max	Min	Distribution
Load	94	0.009	0.093	115	79	Triangular
	+sensi			-sensi		
b_w		0.71				
A_2		0.33				
A_1		0.32				
f_c						0.33
E						0.24
f_t						0.17
HB-30-0.010-0-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	37	0.004	0.099	45	30	Beta
	+sensi			-sensi		
b_w		0.49				
A_1		0.47				
A_2		0.44				
f_{ty}						0.30
f_c						0.19
E						0.14
HB-30-0.010-3-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	46	0.005	0.101	61	36	Weibull min(3par)
	+sensi			-sensi		
A_1		0.55				
A_2		0.54				
b_w		0.43				
f_c						0.16
y						0.15
E						0.12
HB-30-0.010-6-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	47	0.005	0.105	56	35	Beta
	+sensi			-sensi		
A_1		0.57				
A_2		0.57				

b_w	0.49					
f_c				0.05		
y				0.03		
HB-30-0.015-0-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	45	0.004	0.087	55	36	Student t
	+sensi			-sensi		
b_w	74					
A_1	0.27					
A_2	0.27					
f_c				0.37		
f_t				0.33		
E				0.26		
HB-30-0.015-3-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	52	0.005	0.091	65	44	Weibull min(3par)
	+sensi			-sensi		
b_w	0.59					
A_1	0.29					
A_2	0.27					
E				0.54		
f_c				0.52		
f_t				0.34		
HB-30-0.015-6-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	54	0.005	0.102	65	44	Beta
	+sensi			-sensi		
b_w	0.68					
A_1	0.22					
A_2	0.21					
f_c				0.32		
E				0.23		
f_t				0.16		
HB-30-0.020-0-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	51	0.005	0.109	62	38	Logistic
	+sensi			-sensi		
b_w	0.59					
A_1	0.31					
A_2	0.30					
f_{ty}				0.42		
f_c				0.28		
E				0.22		
HB-30-0.020-3-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	57	0.006	0.106	71	41	Normal
	+sensi			-sensi		
b_w	0.36					

f_{ty}	0.21					
A_1	0.08					
G_f				0.33		
f_t				0.30		
f_c				0.20		
HB-30-0.020-6-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	55	0.006	0.104	66	41	Triangular
	+sensi			-sensi		
b_w	0.81					
A_2	0.19					
A_1	0.19					
f_c				0.17		
E				0.13		
HB-50.5-0.010-0-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	50	0.007	0.133	69	35	Logistic
	+sensi			-sensi		
A_2	0.60					
A_1	0.59					
f_{ty}	30					
y				0.13		
f_c				0.010		
E				0.08		
HB-50.5-0.010-3-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	53	0.006	0.121	70	35	Logistic
	+sensi			-sensi		
f_{ty}	0.66					
A_1	0.60					
A_2	0.60					
f_c				0.24		
E				0.21		
f_t				0.16		
HB-50.5-0.010-6-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	53	0.006	0.115	67	40	Lognormal(2 par)
	+sensi			-sensi		
Fy	0.68					
A_1	0.57					
A_2	0.55					
f_c				0.09		
y				0.05		
E				0.04		
HB-50.5-0.015-0-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	64	0.006	0.093	76	44	Normal
	+sensi			-sensi		

b_w	0.80					
A_2	0.31					
A_1	0.30					
f_c				0.23		
y				0.18		
f_t				0.17		
HB-50.5-0.015-3-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	68	0.007	0.098	88	53	Beta
	+sensi			-sensi		
b_w	0.54					
A_2	0.45					
A_1	0.43					
y				0.05		

HB-50.5-0.015-6-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	69	0.008	0.116	93	56	Beta
	+sensi			-sensi		
b_w	0.53					
A_l	0.31					
A_2	0.31					
f_c				0.12		
E				0.09		
y				0.06		

HB-50.5-0.020-0-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	68	0.006	0.092	84	55	Triangular
	+sensi			-sensi		
b_w	0.70					
A_1	0.32					
A_2	0.31					
f_c				0.47		
E				0.45		
f_t				0.34		

HB-50.5-0.020-3-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	76	0.008	0.102	92	62	Half-Normal
	+sensi			-sensi		
b_w	0.48					
A_2	0.21					
A_1	0.21					
f_c				0.54		
f_t				0.47		
E				0.44		

HB-50.5-0.020-6-8-4.40						
Name	Mean	Std	COV	Max	Min	Distribution
Load	77	0.009	0.123	95	59	Gamma (2 par)
	+sensi			-sensi		
b_w	0.66					
A_l	0.31					

A_2	0.31					
f_{ty}				0.15		
HB-30-0.010-0-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	36	0.004	0.111	47	27	Lognormal (2 par)
	+sensi			-sensi		
b_w	0.50					
A_1	0.43					
A_2	0.43					
E				0.26		
f_c				0.24		
f_t				0.14		
HB-30-0.010-3-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	42	0.005	0.113	53	31	Weibull min(2 par)
	+sensi			-sensi		
A_1	0.55					
A_2	0.55					
b_w	0.49					
E				0.30		
f_c				0.29		
f_t				0.25		
HB-30-0.010-6-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	42	0.005	0.122	53	29	Gumbel Min. EV 1
	+sensi			-sensi		
A_1	0.63					
A_2	0.62					
f_{ty}	0.53					
f_c				0.18		
E				0.16		
f_t				0.14		
HB-30-0.015-0-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	41	0.005	0.115	54	32	Gamma (2 par)
	+sensi			-sensi		
b_w	0.64					
A_1	0.37					
A_2	0.34					
f_c				0.19		
E				0.15		
HB-30-0.015-3-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	48	0.004	0.093	57	38	Weibull max (3 par)
	+sensi			-sensi		
b_w	0.78					
A_2	0.23					

A_l	0.23					
f_c				0.36		
E				0.28		
f_t				0.28		
HB-30-0.015-6-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	50	0.004	0.080	63	42	Logistic
	+sensi			-sensi		
b_w	0.70					
A_l	0.33					
A_2	0.32					
f_c				0.32		
E				0.29		
f_t				0.23		
HB-30-0.020-0-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	44	0.005	0.112	79	31	Normal
	+sensi			-sensi		
b_w	0.61					
E	0.37					
f_c	0.33					
y				0.14		
HB-30-0.020-3-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	51	0.005	0.104	67	40	Weibull min (3 par)
	+sensi			-sensi		
b_w	0.52					
A_l	0.21					
A_2	0.21					
E				0.45		
f_t				0.32		
y				0.13		
HB-30-0.020-6-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	51	0.005	0.099	60	39	Gumbel Min. EV 1
	+sensi			-sensi		
b_w	0.61					
A_2	0.28					
A_l	0.28					
f_c				0.66		
E				0.62		
f_t				0.47		
HB-50.5-0.010-0-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	44	0.005	0.116	53	33	Beta
	+sensi			-sensi		
A_2	0.60					
A_l	0.60					

f_{ly}	0.29					
y				0.13		
HB-50.5-0.010-3-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	48	0.005	0.116	58	34	Gumbel Min. EV 1
	+sensi			-sensi		
A_1	0.62					
A_2	0.61					
f_{ly}	0.61					
y				0.01		
HB-50.5-0.010-6-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	49	0.007	0.146	63	27	Lognormal (3 par)
	+sensi			-sensi		
A_1	0.63					
A_2	0.62					
f_{ly}	0.61					
E				0.12		
y				0.10		
f_c				0.08		
HB-50.5-0.015-0-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	56	0.005	0.096	67	43	logistic
	+sensi			-sensi		
A_1	0.55					
A_2	0.54					
b_w	0.53					
f_c				0.30		
E				0.22		
f_t				0.21		
HB-50.5-0.015-3-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	62	0.007	0.108	76	50	Rayleigh negative
	+sensi			-sensi		
b_w	0.56					
A_2	0.51					
A_1	0.51					
y				0.17		
HB-50.5-0.015-6-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	65	0.007	0.106	84	52	Normal
	+sensi			-sensi		
A_1	0.60					
A_2	0.59					

f_{ly}	0.52					
f_c				0.13		
f_t				0.09		
G_f				0.08		
HB-50.5-0.020-0-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	63	0.006	0.100	76	46	Weibull min (3 par)
	+sensi			-sensi		
b_w	0.67					
A_1	0.22					
A_2	0.21					
y				0.19		
G_f				0.15		
f_t				0.10		
HB-50.5-0.020-3-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	68	0.005	0.075	78	57	Lognormal (3par)
	+sensi			-sensi		
b_w	0.76					
A_2	0.34					
A_1	0.34					
y				0.25		
G_f				0.14		
Ft				0.11		
HB-50.5-0.020-6-9-3.90						
Name	Mean	Std	COV	Max	Min	Distribution
Load	73	0.006	0.092	91	61	Beta
	+sensi			-sensi		
b_w	0.78					
A_1	0.33					
A_2	0.32					
E				0.07		
y				0.06		
f_c				0.04		
HB-30-0.010-0-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	57	0.005	0.092	66	47	Triangular
	+sensi			-sensi		
b_w	0.54					
f_{ly}	0.32					
A_1	0.30					
f_t				0.23		
f_c				0.23		
G_f				0.21		
HB-30-0.010-3-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	71	0.006	0.090	86	61	Beta
	+sensi			-sensi		
A_1	0.57					
b_w	0.43					

A_2	0.02	
f_c		0.29
E		0.26
F_t		0.23

HB-30-0.010-6-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	76	0.008	0.110	99	58	Triangular
	+sensi			-sensi		
f_{ty}	0.65					
A_1	0.53					
b_w	0.22					
f_c				0.17		
G_f				0.17		
E				0.16		
HB-30-0.015-0-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	66	0.007	0.106	87	53	Lognormal(2par)
	+sensi			-sensi		
b_w	0.64					
A_1	0.43					
A_2	0.13					
y				0.17		
f_c				0.15		
E				0.14		
HB-30-0.015-3-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	82	0.007	0.086	98	61	Lognormal(3par)
	+sensi			-sensi		
b_w	0.75					
A_1	0.11					
A_2	0.05					
F_y				0.27		
f_{ty}				0.25		
f_t				0.16		
HB-30-0.015-6-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	90	0.007	0.073	100	72	Weibull min (3 par)
	+sensi			-sensi		
b_w	0.69					
A_1	0.20					
A_2	0.13					
f_c				0.40		
E				0.34		
f_t				0.33		
HB-30-0.020-0-5-5						
Name	Mean	Std	COV	Max	Min	Distribution

Load	73	0.007	0.097	88	61	Beta
	+sensi			-sensi		
b_w	0.76					
A_I	0.25					
f_{ty}	0.23					
y				0.12		
HB-30-0.020-3-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	87	0.007	0.079	97	68	Weeibull max(3par)
	+sensi			-sensi		
b_w	0.81					
A_I	0.09					
E	0.01					
y				0.22		
f_c				0.06		
f_t				0.04		
HB-30-0.020-6-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	95	0.008	0.083	116	82	Lognormal(3par)
	+sensi			-sensi		
b_w	0.81					
A_I	0.17					
f_c				0.34		
E				0.31		
f_t				0.27		
HB-50.5-0.010-0-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	82	0.008	0.102	104	68	Lognormal (3par)
	+sensi			-sensi		
f_{ty}	0.49					
A_I	0.48					
b_w	0.42					
f_c				0.19		
E				0.18		
y				0.18		
HB-50.5-0.010-3-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	87	0.011	0.127	107	67	Beta
	+sensi				-sensi	
A_I	0.67					
b_w	0.21					
A_2	0.14					
f_c				0.22		
f_t				0.19		
E				0.17		
HB-50.5-0.010-6-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	87	0.011	0.130	110	65	Beta

	+sensi			-sensi		
f_{ty}	0.72					
A_1	0.59					
b_w	0.15					
y				0.10		
G_f				0.06		
f_t				0.06		
HB-50.5-0.015-0-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	89	0.009	0.097	107	65	Weibull max(3par)
	+sensi			-sensi		
b_w	0.66					
f_{ty}	0.38					
A_1	0.27					
A_2				0.13		
y				0.11		
f_c				0.09		
HB-50.5-0.015-3-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	106	0.007	0.064	112	87	laplace
	+sensi			-sensi		
b_w	0.61					
f_{ty}	0.31					
A_2	0.15					
E				0.12		
f_c				0.12		
y				0.11		
HB-50.5-0.015-6-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	116	0.009	0.079	143	93	Gumbel Max. EV 1
	+sensi			-sensi		
f_{ty}	0.55					
A_1	0.48					
b_w	0.40					
f_c				0.09		
E				0.09		
y				0.07		
HB-50.5-0.020-0-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	97	0.011	0.110	123	75	Logistic
	+sensi			-sensi		
b_w	0.78					
f_{ty}	0.29					
G_f	0.24					
y				0.02		
HB-50.5-0.020-3-5-5						
Name	Mean	Std	COV	Max	Min	Distribution

Load	115	0.009	0.079	129	93	Triangular
	+sensi			-sensi		
b_w	0.76					
G_f	0.23					
A_1	0.22					
y				0.24		
HB-50.5-0.020-6-5-5						
Name	Mean	Std	COV	Max	Min	Distribution
Load	126	0.010	0.083	153	103	Rayleigh
	+sensi			-sensi		
b_w	0.70					
A_1	0.27					
G_f	0.14					
y				0.18		
f_c				0.02		
HB-30-0.010-0-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	47	0.009	0.190	66	25	Lognormal (3par)
	+sensi			-sensi		
b_w	0.32					
A_1	0.14					
f_{ty}				0.45		
y				0.20		
G_f				0.14		
HB-30-0.010-3-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	59	0.008	0.138	77	41	Lognormal (2 par)
	+sensi			-sensi		
b_w	0.38					
A_1	0.14					
f_{ty}	0.13					
y				0.26		
A_2				0.16		
f_c				0.02		
HB-30-0.010-6-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	70	0.013	0.185	96	33	Weibull max(3par)
	+sensi			-sensi		
b_w	0.53					
f_{ty}	0.47					
A_1	0.09					
f_c				0.22		
E				0.18		
f_t				0.06		
HB-30-0.015-0-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	54	0.008	0.147	72	37	Logistic
	+sensi			-sensi		

b_w	0.56					
f_{ty}	0.39					
A_1	0.09					
y				0.20		
f_t				0.14		
f_c				0.09		
HB-30-0.015-3-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	64	0.011	0.178	95	42	Exponential
	+sensi			-sensi		
b_w	0.42					
f_{ty}	0.09					
A_1	0.08					
y				0.31		
f_t				0.15		
f_c				0.15		
HB-30-0.015-6-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	75	0.010	0.136	92	47	Lognormal(3par)
	+sensi			-sensi		
b_w	0.67					
f_c				0.27		
E				0.21		
f_t				0.16		
HB-30-0.020-0-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	52	0.008	0.149	67	33	Weibull min(3 par)
	+sensi			-sensi		
b_w	0.69					
A_2	0.09					
E	0.08					
y				0.23		
f_{ty}				0.09		
f_c				0.04		
HB-30-0.020-3-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	66	0.013	0.198	94	42	Weibull min(2par)
	+sensi			-sensi		
b_w	0.42					
A_1	0.18					
G_f	0.02					
f_{ty}				0.70		
y				0.16		
f_c				0.11		
HB-30-0.020-6-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	71	0.013	0.189	96	43	Triangular
	+sensi			-sensi		
f_{ty}	0.63					

b_w	0.37					
A_2	0.09					
y				0.24		
E				0.23		
f_c				0.15		
HB-50.5-0.010-0-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	59	0.008	0.14	80	37	Weibull max(2 par)
	+sensi			-sensi		
E	0.53					
f_t	0.49					
G_f	0.46					
y				0.35		
f_{ty}				0.17		
HB-50.5-0.010-3-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	68	0.0007	0.110	85	48	Logistic
	+sensi			-sensi		
b_w	0.38					
G_f	0.05					
f_t	0.04					
y				0.36		
E				0.14		
f_c				0.08		
HB-50.5-0.010-6-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	86	0.015	0.179	111	53	Beta
	+sensi			-sensi		
f_{ty}	0.78					
A_1	0.44					
b_w	0.19					
y				0.07		
E				0.02		
f_c				0.01		
HB-50.5-0.015-0-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	60	0.014	0.238	95	24	Laplace
	+sensi			-sensi		
f_{ty}	0.60					
b_w	0.34					
f_t	0.32					
y				0.23		
A_2				0.05		
HB-50.5-0.015-3-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	73	0.015	0.200	104	47	Weibull min(2 par)
	+sensi			-sensi		
b_w	0.11					
G_f	0.08					
A_1	0.08					

f_{ty}						0.58
y						0.21
A_2						0.09
HB-50.5-0.015-6-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	98	0.013	0.140	133	61	Weibull min (2par)
	+sensi			-sensi		
f_{ty}		0.52				
b_w		0.37				
A_1		0.15				
f_c					0.34	
y					0.30	
E					0.26	
HB-50.5-0.020-0-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	72	0.008	0.114	87	52	Rayleigh
	+sensi			-sensi		
b_w		0.70				
E		0.38				
f_c		0.34				
y					0.06	
A_2					0.05	
HB-50.5-0.020-3-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	76	0.010	0.136	100	54	Weibull max(3 par)
	+sensi			-sensi		
f_{ty}		0.47				
f_t		0.25				
b_w		0.20				
y					0.38	
A_1					0.004	
HB-50.5-0.020-6-5-10						
Name	Mean	Std	COV	Max	Min	Distribution
Load	107	0.015	0.139	137	80	Rayleigh negative
	+sensi			-sensi		
b_w		0.38				
E		0.15				
A_1		0.11				
y					0.25	
f_{ty}					0.24	
A_2					0.09	

Table 5.6 Distribution of HB beams

Distribution type	Number of HB beams
Logistic	20
Lognormal (3par)	14
Weibull max(3par)	17
Weibull min(3par)	11
Weibull min(2par)	5
Weibull max(2par)	1
Laplace	7
Beta	36
Triangular	20
Rayleigh negative	4
Gamma(3par)	1
Gamma negative	1
Gamma(2par)	5
Student t	6
Gumbel min EV 1	4
Gumbel max EV 1	1
Normal	7
Half-Normal negative	1
Rayleigh	7
Half-normal	1
Exponential	1
Lognormal (2par)	10
	Total HB beams 180

The distribution type table gives the following results:

- The five most effective distribution types are Beta, Triangular, Logistic, Weibull max(3par), and Lognormal (3par), respectively.
- It was observed that the Triangular and Logistic distribution types were in the same number, but it was observed that there was a change depending on some parameters.
- Beta distribution type was seen in all α/d_m ratios in general.

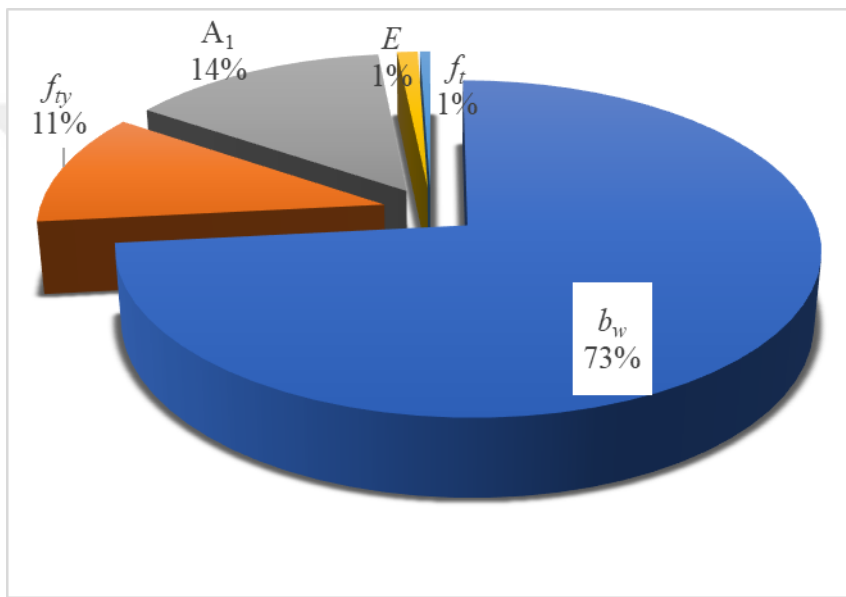


Figure 5.1 Distribution plot of sensitivity factors.

When Figure 5.2 is examined, the three most dominant parameters are as follows:

The most dominant parameters were the beamwidth (b_w). Other dominant parameters are the yield strength (f_{ty}) of the tensile bar and the tensile bar area (A_1).

CHAPTER VI

CONCLUSIONS

Based on the results of the experimental, analytical and probabilistic nonlinear analysis, the following conclusions can be drawn.

It was observed that there was a displacement of about 0.8% in the failure load value obtained in the analytical result and around 0% in the maximum displacement values. And these results were determined within acceptable limits in terms of the finite element method.

When the average prestress level was 6 (N / mm²) in the cross-section of the loading point, it was observed that cracking occurred in low compressive strength concrete but no cracking occurred in high strength concrete. This result shows why high-strength concrete should be used in prestressed concrete.

When the average prestress level is 3 (N / mm²) in the section of the loading point, it has been observed that there is no cracking in low compressive strength concrete and high strength concrete. This result shows that a small prestressing force can be applied to low-strength concrete.

In the experimental study and the prestressed concrete HB models created in the ATENA 2D program, it is observed that the failure load of the beam is higher and the maximum displacement amount decreases with the increase of the prestressing bar ratio.

While the concrete strength was 50.5 (N/mm²) and the tensile bar ratio was 0.010, it was observed that the prestressing force hadn't effect on the failure load in all beams with $\alpha/d_m > 3$ but a decrease was observed in the maximum displacement.

While the concrete strength was 50.5 (N/mm²) and the prestressing bar ratio was 0.020, the failure load increased with the increase in the prestressing force in all beams and it was observed that there was a decrease in the maximum displacement.

Beta distribution decreased with the increase of mean load.

When $\alpha/d_m > 4$, it was observed that the average load didn't increase when the average prestress level increased from 3 (N/mm²) to 6 (N/mm²).

While the concrete strength was 30 (N/mm²) and the prestressing bar ratio was 0.010, the failure load increased with the increase in the prestressing force in all beams and it was observed that there was a decrease in the maximum displacement.

In general, it was observed that there wasn't a change in the failure load of all beams with $\alpha/d_m > 3$ when the concrete strength was 30 (N / mm²), the prestressing bar ratio was 0.020, the prestressing was 3 (N/mm²) and 6 (N/mm²) .

It was observed that there was an increase in maximum displacement of all beams with $\alpha/d_m > 3$ when the concrete strength was 30 (N / mm²), the prestressing bar ratio was 0.020, and the prestressing was 3 (N/mm²).

It was observed that there was decreasing in maximum displacement of all beams with $\alpha/d_m > 3$ when the concrete strength was 30 (N / mm²), the prestressing bar ratio was 0.020, and the prestressing was 6 (N/mm²).

When the concrete strength is 30 (N / mm²), the ratio of the prestressing bars is 0.010 and no prestressing, the fracture strength of all haunched beams is greater than that of rectangular beams. It was also determined that the maximum displacement of the haunched beams was greater than that of the rectangular beams.

When the concrete strength was 30 (N / mm²), the ratio of prestressing bars was 0.010 and the prestress was 6 (N / mm²), the fracture strengths of the haunched beams and rectangular beams were found to be almost similar. Their maximum displacement only was different.

When the concrete strength was 30 (N / mm²), the ratio of prestressing bars was 0.010 and the prestress was 6 (N / mm²), the cracking of the haunched beams and rectangular beams was the same.

The five most effective distribution types are Beta, Triangular, Logistic, Weibull max(3par), and Lognormal (3par), respectively.

Beta distribution type was seen in all α/d_m ratios in general.

The most dominant parameters were the beamwidth(b_w). Other dominant parameters are the yield strength(f_{ty}) of the tensile bar and the tensile bar area(A_1).

When beta distribution type beams are examined, one of the general common features is beams with a tensile bar ratio of 0.010 and 0.015.

HB beams with logistic distribution type were generally seen in beams with $\alpha/d_m > 4$.

Unlike betas, beams with Triangular type distribution are available in all three reinforcement ratios. It was also observed that it was not found in HB beams with $\alpha/d_m = 9$.

Future Research

All concrete groups should be analyzed in order to better understand the effect of concrete strength on prestressing.

In this study, an experimental study of one PC haunched beam was carried out. Experimental study of PC haunched beam with different size and different parameters can be done to better understand the PC haunched beams.

Different prestressing forces can be used to understand the effect of prestressing force on concrete strength.

Analyzes can be further elaborated using different mesh densities and different nonlinear step ranges.

In this study, only probabilistic nonlinear analysis of PC haunched beams was performed. Probabilistic nonlinear analysis of both haunched and rectangular beams can be done to better understand the distribution of beams.

A regression study of all analyzed beams can be done.



REFERENCES

- [1] Hou, C., Nakamura T., Iwanaga, T., Niwa, J., (2016). Shear Behavior of Reinforced Concrete and Prestressed Concrete Tapered Beams without Stirrups. *Journal of JSCE*, **(5)** 170-189.
- [2] Barr, P. J., Eberhard, M. O. and Stanton, J. F. (2001). Live-Load Distribution Factors in Prestressed Concrete Bridges, *Journal of Bridge Engineering*, **6 (5)** 298-306.
- [3] Al-abdul Adheim, M. (2006) Nonlinear Finite Element Analysis of Prestressed Concrete Beams Under Combined Torsion and Bending up to Failure, Ph.D. Thesis, University of Baghdad, 1-312.
- [4] Akgül, F. and Frangopol, D. M. (2004) Lifetime Performance Analysis of Existing Prestressed Concrete Bridge Superstructures, *Journal of Structural Engineering*, **130(2)** 1889-1903.
- [5] Fanning, P. (2001) Nonlinear Models of Reinforced and Post-tensioned Concrete Beams, *EJSE International Electronic Journal of Structural Engineering*, **(2)** 111-119.
- [6] JSCE, Standard specifications for concrete structures-2012 Design, JSCE Guidelines for Concrete, 2013. (in Japanese).
- [7] ANSYS, ANSYS User's Manuel Revision 10.0, ANSYS, Inc, Cannonsburg, Pennsylvania, 1-118(2005).
- [8] ATENA Program Documentation Part 4-1 Tutorial for Program ATENA 2D.
- [9] ATENA Program Documentation Part 4-2 Tutorial for Program ATENA 3D.
- [10] Şener, S. (2006). *Öngerilmeli beton*. Alp Yayınevi.

- [11] Karaesmen E., (2015). *Ardgermeli beton ve yeni çözümler*. Freysaş.
- [12] Cervenka V. and Pukl, R. (2004). SARA Program Documentation- User Manual Czech Republic, Cervenka Consulting, Prague.
- [13] Novák D., Vořechovský M., Rusina R., Lehky D. (2004). FreET Program Documentation– Part 2: User Manuel, Czech Republic, Cervenka Consulting.
- [14] Novák D., Vořechovský M., Rusina R., Small-sample Probabilistic Assessment – software FREET, *Proc 9th Int. Conf. on Applications of Statistics and Probability in Civil Engineering – ICASP 9*, Rotterdam: Millpress, 91-96.
- [15] Biondini F., Bontempi F., Frangopol D. M., Malerba P. G., (2004). Reliability of Material and Geometrically Non-linear Reinforced and Prestressed Concrete Structures, *Computers & Structures*, **82(13–14)**, 1021-1031, ISSN 0045-7949, <https://doi.org/10.1016/j.compstruc.2004.03.010>.
- [16] Naaman, A. E., and Siriakson, A. (1982). Reliability of Partially Prestressed Concrete Beams at Serviceability Limit States. *PCI J.*, **27(6)**, 66-85
- [17] Al-Harthy A. S., Frangopol D. M., (1994). Reliability Assessment of Prestressed Concrete Beams. Vol. 120, Issue 1 (January 1994) . [https://doi.org/10.1061/\(ASCE\)0733-9445\(1994\)120:1\(180](https://doi.org/10.1061/(ASCE)0733-9445(1994)120:1(180)
- [18] Lixia Pan, Lukáš Novák, David Lehký, Drahomír Novák, Maosen Cao, Neural network ensemble-based sensitivity analysis in structural engineering: Comparison of selected methods and the influence of statistical correlation, *Computers&Structures*, 10.1016/j.compstruc.2020.106376, 242, (1 06376), (2021).
- [19] Cervenka, V. Jendele L, Cervenka J. ATENA program documentation – Part 1: Theory. Prague, Czech Republic: Cervenka Consulting, 2016.

- [20] Leandro S. Moreira, João Batista M. Sousa, Evandro Parente, Nonlinear finite element simulation of unbonded prestressed concrete beams, *Engineering Structures*, Volume 170, 2018, Pages 167-177, ISSN 0141-
<https://doi.org/10.1016/j.engstruct.2018.05.077>.
- [21] Nowak, S. A., Collins R. K., “*Reliability of Structures*” (2nd ed). CRC Press.
- [22] Mirza SA, MacGregor JG. ‘Variations in dimensions of reinforced concrete members’. *J Struct Div*, ASCE 1979;105(ST4):751–66.
- [23] Pukl R., Novák D., & Bergmeister K, (2003). “Reliability assessment of concrete structures”. In: *Computational modelling of concrete structures (Euro-C 2003)*, St. Johann in Pongau, Austria.

CIRRICULUM VITAE

Family name: ÖZOĞUL

First name: İSMAİL

Education: Bachelor-Degree

Institution (Date from - Date to)	Degree(s) or Diploma(s) obtained:
Gaziantep University 16/07/2019-Current	Civil Engineering (Master Degree)
Hasan Kalyoncu University 01/09/2014-18/06/2019	Civil Engineering (Bachelor)

Language

English

Other skills: Matlab / Autocad / Revit / Sta4cad / SAP2000 / ATENA 2D / ATENA 3D / SARA Studio

Conferences

5th International Conference on Computational Mathematics and Engineering Sciences, (CMES-2021), 08-10 2021, VAN- TURKEY

Certifications

5th International Conference on Computational Mathematics and Engineering Sciences, (CMES-2021), 08-10 2021, VAN- TURKEY.