ColumnBase Verification Report, Version 4.0

Integrated Software for Analysis and Design of Column-Base Connections using Three Dimensional Finite Element Modeling

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PCEESoft Inc.
Professional Civil & Earthquake Engineering Software Incorporation

Imam Ali; who his greatness not yet known, said:
Knowledge is a great treasure which does not come to an end.

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Table of Content

Introduction

Outputs of ColumnBase program have been verified by several reliable laboratory experiments, and its accuracy has been proved. Compared tests include a wide range of laboratory tests that are distinguished as benchmark experimental tests in the column-base connection researches. Now, experimental researches from university of California Davis, university of Athens and university of Liege are investigated and results of comparisons are explained in the next chapters.

Experimental Tests

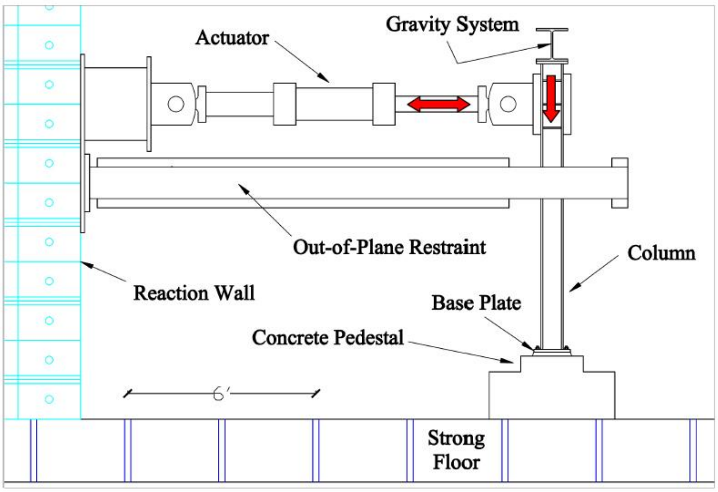
1. Ivan Gomez; Amit Kanvinde and Gregory Deierlein (2010)

Gomez et al [1] presented results of an experimental study, investigating the response of exposed column base connections subjected to axial compression force and strong-axis bending. The main scientific basis of this study consists of a series of seven large scale experiments on exposed column base connections subjected to a combination of axial compressive load and cyclic lateral deformations. In this research [1], Only Test#1 was loaded monotonically, thus this test is chosen for evaluation of ColumnBase results.

1.1 Test Setup

Base connection tests were conducted at the UC Berkeley Network for Earthquake Engineering Simulation (NEES) Structures Laboratory in Richmond, California. Test setup is shown in Figure 1-1.

a) photograph



b) schematic

Figure 1-1, Typical test setup

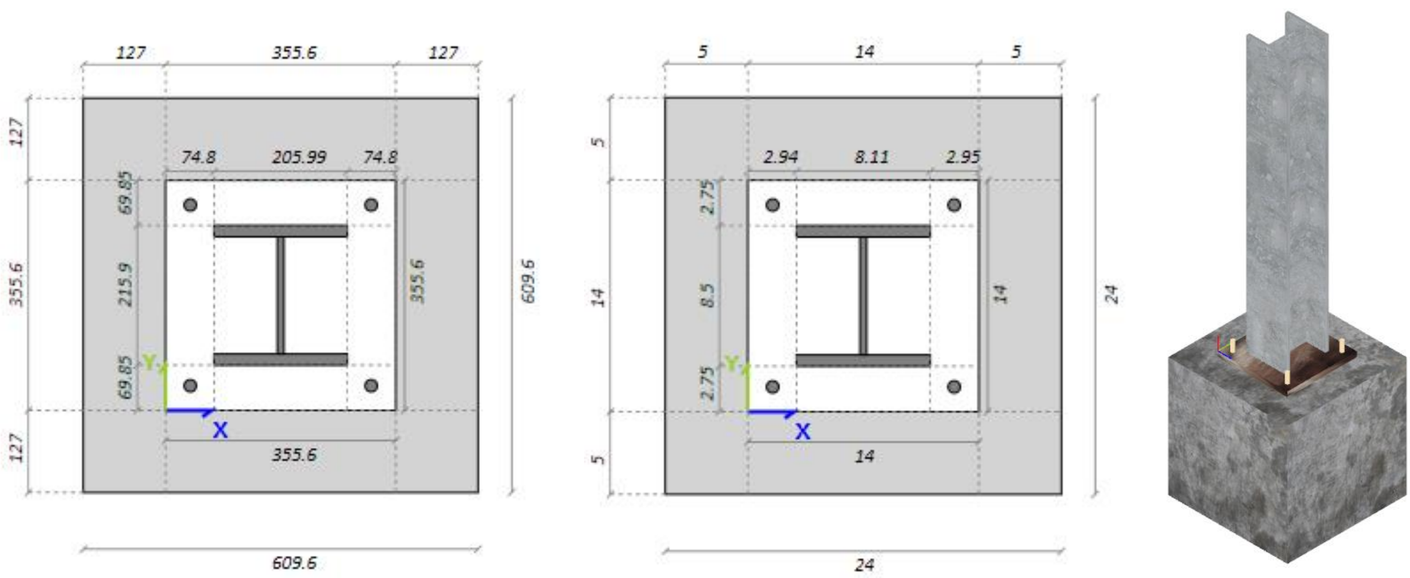
1.2 Material Properties

Material properties of all parts in the test model are shown in the table below.

Part	Material Properties		
Base Plate	Modulus of Elasticity	216495.38 MPa	(31400 ksi)
	Yielding Stress	278.55 MPa	(40.4 ksi)
	Ultimate Stress	473.67 MPa	(68.7 ksi)
Column	Grade	A992, Grade 50	
	Modulus of Elasticity	199947.96 MPa	(29000 ksi)
	Yielding Stress	344.74 MPa	(50 ksi)
	Ultimate Stress	448.16 MPa	(65 ksi)
Anchor Rods	Grade	Grade 105	
	Modulus of Elasticity	202981.65 MPa	(29440 ksi)
	Yielding Stress	786 MPa	(114 ksi)
	Ultimate Stress	1010.08 MPa	(146.5 ksi)
Footing	Modulus of Elasticity	24575 MPa	(3564.3 ksi)
	Specified Strength	27.34 MPa	(3.97 ksi)
Grout	Modulus of Elasticity	33601 MPa	(4873.4 ksi)
	Specified Strength	51.11 MPa	(7.41 ksi)

1.3 Geometry Properties

Base plate dimensions are 35.56 mm by 35.56 mm (14" by 14") in area and 25.4 mm (1 inch) in thickness. The W8×48 cantilever column has been welded to the center of the base plate. The Height of the column is 2350 mm (92.5 in) from the point of application of the load to the top of the base plate. A grout pad with an average thickness of 38 mm (1.5") has been installed underneath the base plate. In the test, a concrete pedestal exists above footing and footing dimensions are 1219.2 mm by 1219.2 mm (48" by 48") in area and 457.2 mm (18") in depth. In the ColumnBase model, the pedestal is ignored and the footing is modeled by 609x609x609 mm (24"x24"x24") concrete block. Four headed anchor rods with 19.05 mm (3/4") in diameter and 558.8 mm (22") in length (From the bottom surface of the plate to the top of the anchor rod head) were modeled. The Model geometry in ColumnBase is shown in Figure 1-2.



a) SI units (mm) b) US units (inch) c) 3D Model

Figure 1-2, Model geometry in ColumnBase

1.4 Loading

The model is loaded without any axial (gravity) load. A shear force which generates major moment on the column is applied monotonically at the top of the column and results will be investigated. Details of loading are shown in the table below.

Load Combination	Shear Force		Base Moment	
LoadCombo4	30 KN	(6.744 kips)	70.5 KN.m	(622.207 kip.in)
LoadCombo3	20 KN	(4.496 kips)	47.0 KN.m	(415.985 kip.in)
LoadCombo2	15 KN	(3.372 kips)	35.25KN.m	(311.989 kip.in)
LoadCombo1	10 KN	(2.248 Kips)	23.5 KN.m	(207.993 kip.in)

1.5 Setting Program Parameters

1) Set column section to W8X48 and it's height to 2350 mm (92.5").

2) In 'Analysis Options' set 'Total Defined Height' for 'Set Height of Column to be modeled' option.

3) In input interface > Loading tab, click 'Specified by User' in 'Loading Preferences' and set 'Apply Shear Forces at Level' to 'Top of Column'.

ColumnBase model file for Gomez test is available in "…\Documentation\Verification Models\Gomez2010.cb"

1.6 Results

From Ref [1], test data were described below.

Base Moment: Lateral force multiplied by the distance of the point of load application to the top of the base plate (2350 mm or 92.5 inches).

Base Rotation: The difference of the lateral displacement and the base plate slip, divided by the column cantilever length (92.5 inches), minus the lateral force divided by the elastic rotational stiffness of column.

Column Drift (Drift): Lateral displacement divided by the distance of the point of load application to the top of the base plate (92.5 inches).

Lateral Displacement: Lateral displacement of the horizontal actuator; equal to the lateral displacement of the column 92.5 inches from the top of the base plate.

Connection Stiffness: Rotational stiffness constant (β) of the column-base connection is obtained from the slope of the lateral force versus lateral displacement plots at small (i.e. elastic) displacements (specifically ±6.35mm or ±0.25" lateral displacement).

$$\Delta = V.\left(\frac{1}{k_{col}} + \frac{L^2}{\beta}\right)$$

Columnbase outputs for defined loadings are shown in the table below.

Load Combination	Lateral Displacement	Rotational stiffness constant (β)	
LoadCombo3	17.15 mm	9601.78 KN.m/Rad	(84983 kip.in/Rad)
LoadCombo2	12.86 mm	9601.72 KN.m/Rad	(84982 kip.in/Rad)
LoadCombo1	8.58 mm	9601.78 KN.m/Rad	(84983 kip.in/Rad)

From Ref [1], the rotational stiffness constant for Test#1 is 9727.99 KN.m/Rad (86100 kip.in/Rad). According to above table, ColumnBase's output for the rotational stiffness constant has only 1.3% difference with Ref [1] ones. It proves good accuracy of the program in calculating of the realistic rotational stiffness of column-base connections.

Figure 1-3 to 1-6 are shown ColumnBase's results compared with Ref [1] ones. Comparison of the results shows that ColumnBase's results have acceptable accuracy for simulation of realistic behavior of column-base connections in the elastic zone.

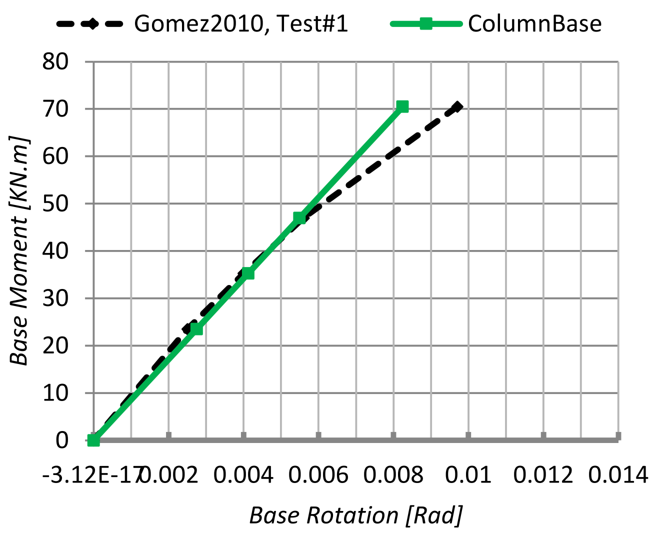


Figure 1-3, Base rotation vs. base moment

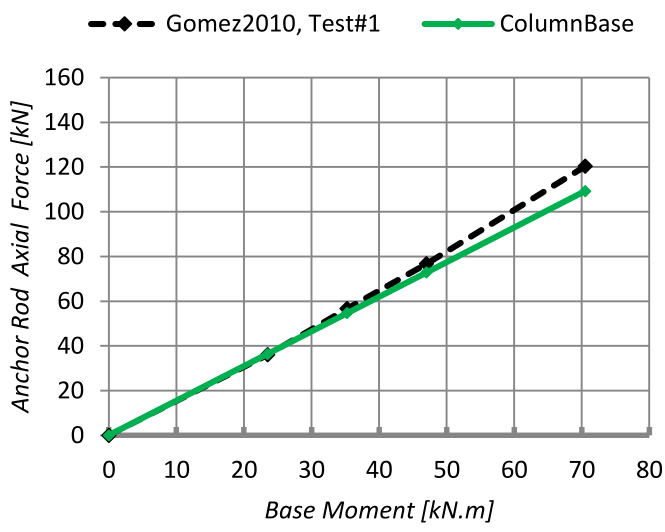


Figure 1-4, Base moment vs. anchor rod axial force

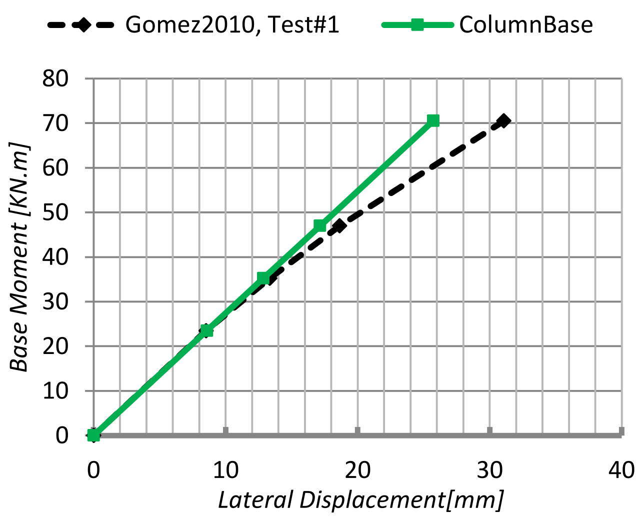


Figure 1-5, Lateral displacement vs. base moment

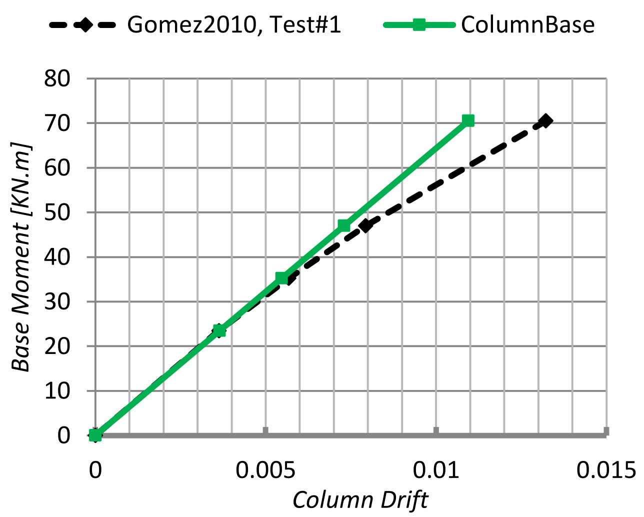


Figure 1-6, Column drift vs. base moment

1.7 References

[1] Gomez, I., Kanvinde, A.M., Deierlein, G.G. "Exposed column base connections subjected to axial compression and flexure." Report Submitted to the American Institute of Steel Construction (AISC), Chicago, IL. ; 2010. [CrossRef]

[2] Gomez, I. R. 2010. Behavior and Design of Column Base Connections. Doctor of Philosophy, University of California Davis.

2. G.N. Stamatopoulos , J. Ch. Ermopoulos (2011)

Stamatopoulos's research [1] devoted to experimental and analytical investigation of the steel column bases. In this study, for eight sets of tests, the M–ϕ curves for the behavior of steel column base were investigated. For evaluating of ColumnBase's outputs via Ref [1], SP1, SP5 and SP6 specimens have been chosen.

2.1 Test Setup

Test setup is shown in Figures 2-1 and 2-2.

Figure 2-1, Test Setup

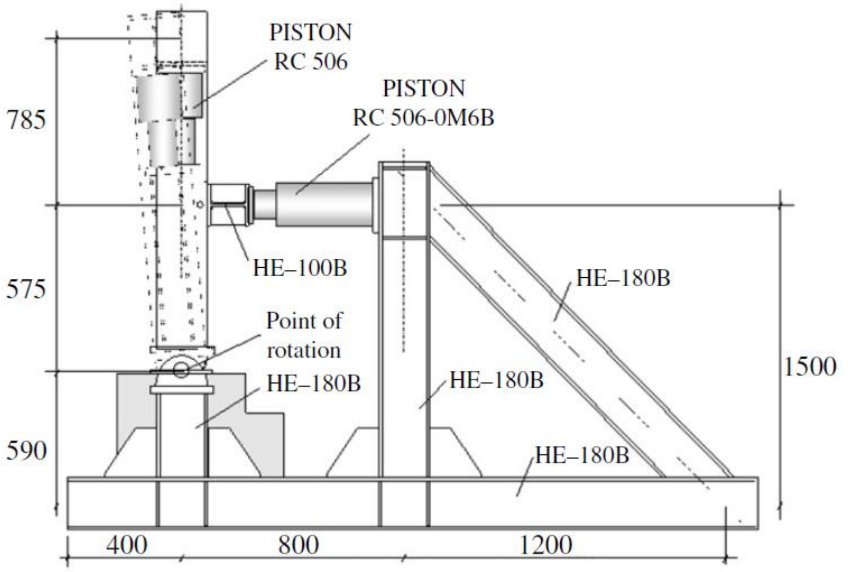


Figure 2-2, Geometry configuration of the frame

2.2 Material Properties

Material properties for plate, anchor rods and footing are shown in the table below.

No.	Plate Material		Anchor Rods Material		Footing Material
	Modulus of Elasticity	Yielding Stress	Modulus of Elasticity	Yielding Stress	fck,cube
SP1	210101.01 MPa	416 MPa	210045.66 MPa	460 MPa	29.2 MPa
SP5	210098.71 MPa	276.7 MPa	207864.41 MPa	613.2 MPa	32.0 MPa
SP6	210101.01 MPa	416 MPa	207864.41 MPa	613.2 MPa	31.0 MPa

Modulus of elasticity for footing material was obtained from EN1992-1-1 using SCHMIDT test results. Also the cube specimen strength of concrete was converted to the standard cylindrical specimen using the mentioned code.

2.3 Geometry Properties

The geometry of connection parts for SP1, SP5 and SP6 specimens are shown in the table below. The embedded length of anchor rods is 17 times of the anchor diameter and the type of anchors is headed.

No.	Column	Base Plate Dimensions	Anchor Rods	Footing Dimensions
SP1	HEB-120	240 x 140 x 16 mm	M12	500 x 500 x 400 mm
SP5	HEB-120	240 x 140 x 16 mm	M16	500 x 500 x 400 mm
SP6	HEB-120	240 x 140 x 16 mm	M16	500 x 500 x 400 mm

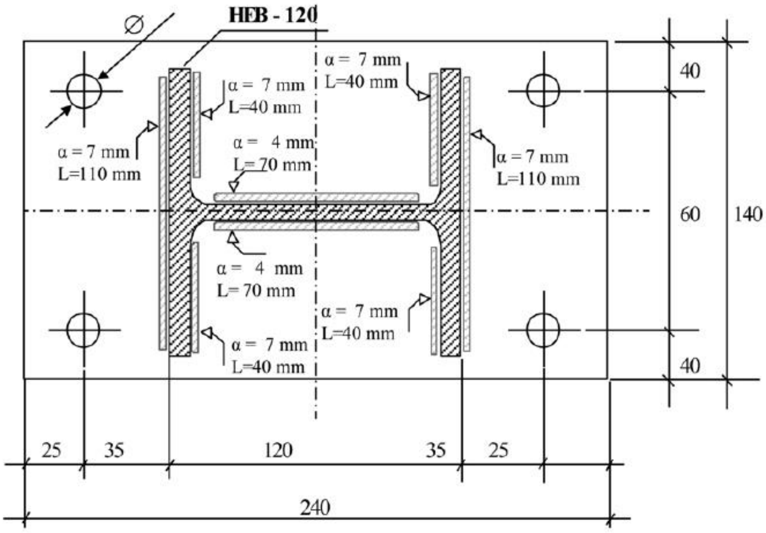


Figure 2-3, Base plate geometry configuration

2.4 Loading

According to Figure 2-2, the level of applying shear force is 575 mm from top of the base plate. Loading details for four load combinations are shown in the table below.

No	Load Combination	Axial Force	Shear Force	Base Moment
SP1	LoadCombo1	-99.26 KN	7.113 KN	4.09 KN.m
	LoadCombo2	-99.26 KN	14.243 KN	8.19 KN.m
	LoadCombo3	-99.26 KN	21.357 KN	12.28 KN.m
	LoadCombo4	-99.26 KN	28.487 KN	16.38 KN.m
SP5	LoadCombo1	-99.26 KN	14.243 KN	8.19 KN.m
	LoadCombo2	-99.26 KN	28.487 KN	16.38 KN.m
	LoadCombo3	-99.26 KN	42.713 KN	24.56 KN.m
SP6	LoadCombo1	-99.26 KN	14.243 KN	8.19 KN.m
	LoadCombo2	-99.26 KN	28.487 KN	16.38 KN.m
	LoadCombo3	-99.26 KN	42.713 KN	24.56 KN.m

2.5 Setting Program Parameters

1) Set column section to HE120B and its height to 575 mm.

2) In 'Analysis Options' set 'Total Defined Height' for 'Set Height of Column to be modeled' option.

3) In input interface > Loading tab, click 'Specified by User' in 'Loading Preferences' and set axial force and shear forces at Level of top of the column.

2.6 Results

According to Ref [1] for calculating the base plate rotation (ϕ) regarding to the concrete foundation, the vertical deformation at the points very close to the column flanges are measured. In the test model, for measuring these values, two deformation gauges were installed very close to the column flanges (Figure 2-4). The first gauge was located close to the tension flange of the column and the second one on the compression flange.

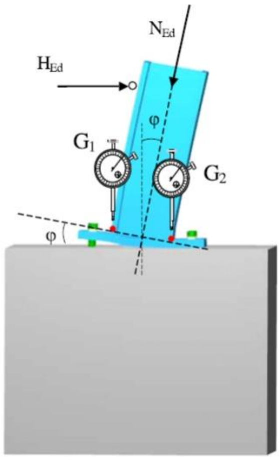


Figure 2-4, Determination of the angle of rotation ϕ from Ref [1]

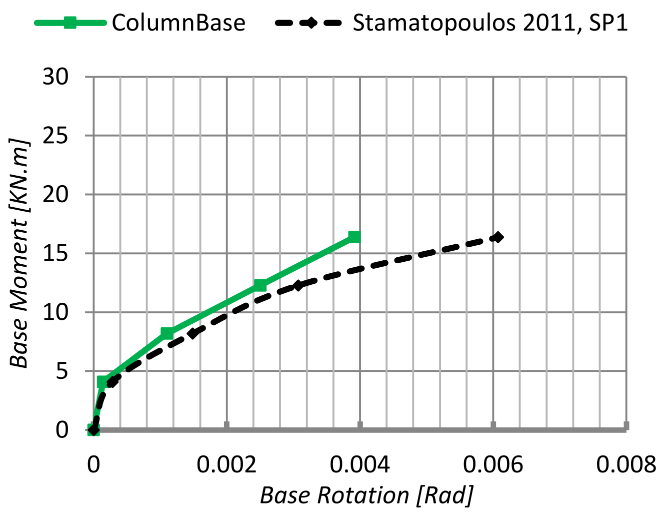


Figure 2-5, M–ϕ curve of SP1 specimen

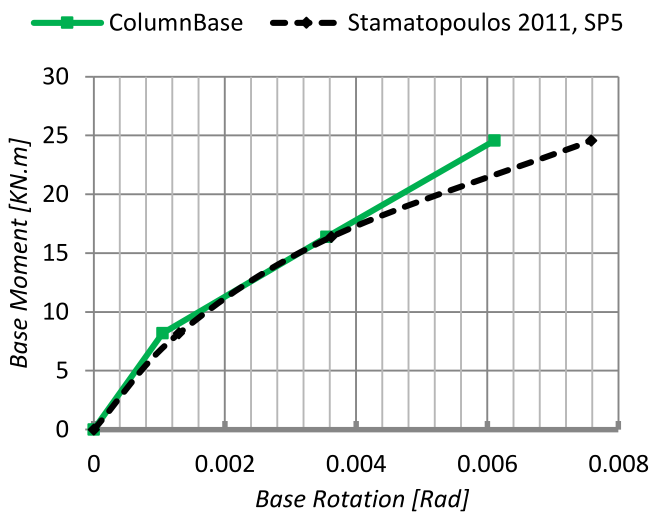


Figure 2-6, M–ϕ curve of SP5 specimen

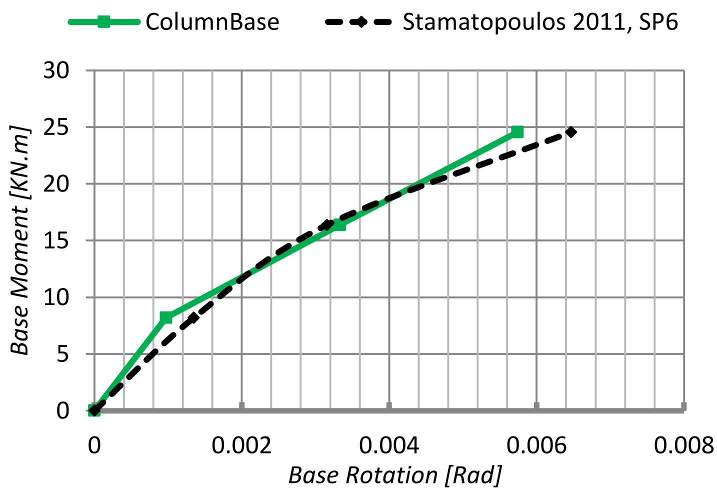


Figure 2-7, M–ϕ curve of SP6 specimen

Comparison of results (Figures 2-5 to 2-7) shows that ColumnBase's results are reliable in calculating of M-ϕ behavior of column-base connections.

2.7 References

[1] Stamatopoulos G.N., Ermopoulos J.Ch., Experimental and analytical investigation of steel column bases, Journal of Constr. Steel Research, 67, 9, 1341-1357 (2011). [CrossRef]

3. J.P. Jaspart, D. Vandegans (1998)

Jaspart et al [1] carried out twelve experimental tests on column bases to investigate the rotational behavior of these connections. In Jaspart's research [1], the component method described in Annex J of Eurocode 3 [3] was used and extended. From Ref [1], PC4.15.100 Test No is chosen for evaluating of ColumnBase's results.

3.1 Test Setup

For all tests, a general configuration as shown in Figure 3-1 was conducted. For technical reasons the tests was carried out with a compressive force F1 in the column acting horizontally, whereas the force F2 generating bending moment was acting vertically.

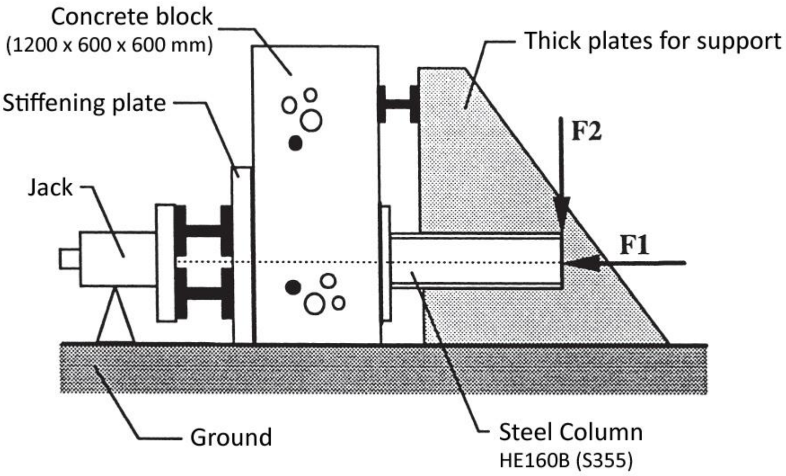


Figure 3-1, Typical test setup

3.2 Material Properties

Material properties of all parts in the test model are shown in the table below.

Part	Material Properties	
Base Plate	Grade	S235
	Modulus of Elasticity	210000 MPa
	Yielding Stress	280 MPa (Test)
	Ultimate Stress	412 MPa (Test)
Column	Grade	S355
	Modulus of Elasticity	210000 MPa
	Yielding Stress	464 MPa (Test)
	Ultimate Stress	580 MPa (Test)
Anchor Rods	Grade	10.9
	Modulus of Elasticity	200000 MPa
	Yielding Stress	900 MPa
	Ultimate Stress	1000 MPa
Footing	Modulus of Elasticity	35000 MPa
	Cube Strength	45.29 MPa

3.3 Geometry Properties

For the chosen test (PC4.15.100), the base plate and footing dimensions are 220x340x15 mm and 1200x600x600 mm respectively. The column section is HE160B and height of the column is 1035 mm from the point of application of the load to the top of the base plate. Four hooked anchor bolts (M20) with the embedded length of 250 mm are used. Although installation of a thin layer of grout has been mentioned in Ref [1], because of having no more information, modeling of the grout layer is ignored. Plate geometry for chosen test (PC4.15.100) is shown in Figure 3-2.

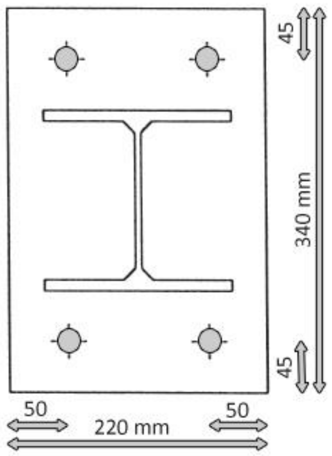


Figure 3-2, Plate geometry for PC4.15.100

3.4 Loading

At first an axial compression load equal to 100 KN (F1 in Figure 3-1) is applied at the top of the column and then monotonically shear force (F2 in Figure 3-1) is applied at the mentioned point. Details of loading are shown in the table below.

Load Combination	Axial Force (F1)	Shear Force (F2)
LoadCombo3	-100 KN	35 KN
LoadCombo2	-100 KN	25 KN
LoadCombo1	-100 KN	15 KN

3.5 Setting Program Parameters

1) Set column section to HE160B and it's height to 1035 mm.

2) In 'Analysis Options' set 'Total Defined Height' for 'Set Height of Column to be modeled' option.

3) In input interface > Loading tab, click 'Specified by User' in 'Loading Preferences' and set 'Apply Shear Forces at Level' to 'Top of Column'.

3.6 Results

The below equation defines the moment on the column base, that D_1 is displacement transducer described in Ref [2].

$$M = 1.05F_2 + 0.114F_1.D_1$$

According to the above equation and by using ColumnBase's results, base moments for all load combinations are obtained.

Load Combination	Base Moment
LoadCombo3	15.777 KN.m
LoadCombo2	26.303 KN.m
LoadCombo1	36.829 KN.m

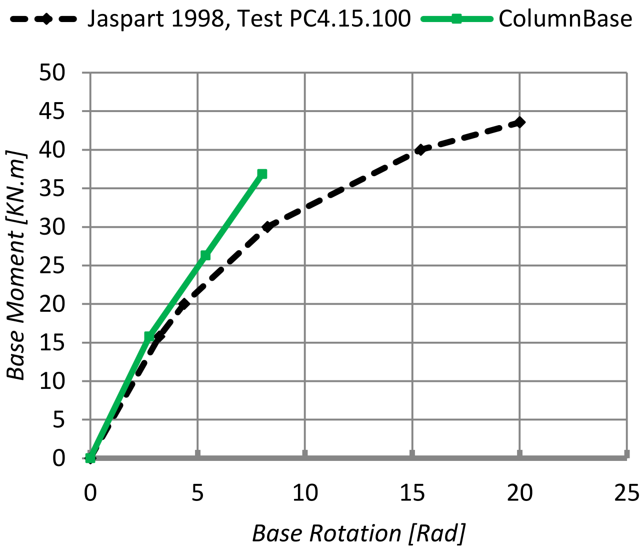


Figure 3-3, M-ϕ curves for test PC4.15.100

Base rotation vs. base moment curve is plotted in Figure 3-3. In the elastic zone, the comparison of ColumnBase's results with experimental tests clarifies the acceptable accuracy and confidential results of it.

3.7 References

[1] Jaspart, J. P. and Vandegans, D. (1998). "Application of component method to column bases." Journal of Constructional Steel Research, 48, pp. 89-106. [CrossRef]

[2] Guisse S, Vandegans D, Jaspart JP. Application of the component method to column bases—experimentation and development of a mechanical model for characterization. Report no. MT195. Liege: Research Centre of the Belgian Metalworking Industry, 1996.

[3] EUROCODE 3. Revised Annex J. Joints in Building Frames. Document CEN/TC250/SC3-N419E. Brussels: European Committee for Standardization, 1994.