

Volume 11
Issue 1
July 2022

ISSN - 1857 - 839X

SJCE
SCIENTIFIC
JOURNAL
OF CIVIL
ENGINEERING

SJCE
SCIENTIFIC
JOURNAL
OF CIVIL
ENGINEERING



SS CYRIL AND METHODIUS UNIVERSITY
FACULTY OF CIVIL ENGINEERING

SS CYRIL AND METHODIUS UNIVERSITY
FACULTY OF CIVIL ENGINEERING

FOUNDER AND PUBLISHER

Faculty of Civil Engineering
Partizanski odredi 24, 1000
Skopje, N. Macedonia

PRINT

This Journal is printed in Mar-saz
DOOEL Skopje

EDITORIAL OFFICE

Faculty of Civil Engineering
Partizanski odredi 24, 1000
Skopje, N. Macedonia
tel. +389 2 3116 066
fax. +389 2 3118 834
prodekan.nauka@gf.ukim.edu.mk

EDITOR IN CHIEF

Assoc. Prof. PhD **Marijana Lazarevska**
University "Ss. Cyril and Methodius"
Faculty of Civil Engineering
Partizanski odredi 24, 1000
Skopje, N. Macedonia
marijana@gf.ukim.edu.mk

EDITORIAL ADVISORY BOARD

Prof. PhD **Elena Dumova-Jovanoska**
University "Ss. Cyril and Methodius", Skopje, N. Macedonia

Assoc. Prof. PhD **Zlatko Bogdanovski**
University "Ss. Cyril and Methodius", Skopje, N. Macedonia

TECHNICAL EDITORS

MSc **Milica Jovanoska**
Assistant, University "Ss. Cyril and Methodius", Skopje, N. Macedonia

PhD **Kristina Milkova**
Assistant, University "Ss. Cyril and Methodius", Skopje, N. Macedonia

MSc **Riste Volcev**
Assistant, University "Ss. Cyril and Methodius", Skopje, N. Macedonia

ISSN: 1857-839X

EDITORIAL BOARD

Rita Bento, PhD
Instituto Superior Técnico,
Universidade de Lisboa,
Department of Civil Engineering,
Architecture and Georesources,
Lisbon, Portugal

Zlatko Bogdanovski, PhD
University "Ss. Cyril and Methodius", Faculty of Civil Engineering, Skopje, N. Macedonia

Heinz Brandl, PhD
Vienna University of Technology,
Institute for Geotechnics, Vienna,
Austria

Maosen Cao, PhD
Hohai University, Department of Engineering Mechanics, Nanjing, China

Eleni Chatzi, PhD
ETH Zurich, Chair of Structural Mechanics & Monitoring, Zurich, Switzerland

Tina Dasic, PhD
University of Belgrade, Faculty of Civil Engineering, Belgrade, R. Serbia

Ljupco Dimitrievski, PhD
University "Ss. Cyril and Methodius", Faculty of Civil Engineering, Skopje, N. Macedonia

Katerina Donevska, PhD
University "Ss. Cyril and Methodius", Faculty of Civil Engineering, Skopje, N. Macedonia

Elena Dumova-Jovanoska, PhD
University "Ss. Cyril and Methodius", Faculty of Civil

Engineering, Skopje, N. Macedonia

Michael Havbro Faber, PhD
Aalborg University, Department of Civil Engineering, Aalborg, Denmark

Massimo Fragiaco, PhD
University of L'Aquila, Department of Civil, Construction-Architectural & Environmental Engineering, L'Aquila, Italy

Tomas Hanak, PhD
Brno University of Technology, Faculty of Civil Engineering, Brno, Czech Republic

Nenad Ivanisevic, PhD
University of Belgrade, Faculty of Civil Engineering, Belgrade, R. Serbia

Milos Knezevic, PhD
University of Montenegro, Faculty of Civil Engineering, Podgorica, Montenegro

Andrej Kryzanowski, PhD
University of Ljubljana, Faculty of Civil and Geodetic Engineering, Ljubljana, Slovenia

Stjepan Lakusic, PhD
University of Zagreb, Faculty of Civil Engineering, Zagreb, Croatia

Marijana Lazarevska, PhD
University "Ss. Cyril and Methodius", Faculty of Civil Engineering, Skopje, N. Macedonia

Peter Mark, PhD
Ruhr University, Faculty of Civil and Environmental Engineering, Bochum, Germany

Marc Morell
Institute des Sciences de l'Ingénieur de Montpellier, France

Impressum

Vlastimir Radonjanin, PhD

University of Novi Sad, Faculty of
Technical Sciences, Novi Sad, R.
Serbia

Marina Rakocevic, PhD

University of Montenegro, Faculty
of Civil Engineering, Podgorica,
Montenegro

Resat Ulusay, PhD

Hacettepe University, Faculty of
Engineering, Ankara, Turkey

Joost C. Walraven, PhD

Delft University of Technology,
Department of Civil Engineering,
Delft, Netherlands

Zlatko Zafirovski, PhD

University "Ss. Cyril and
Methodius", Faculty of Civil
Engineering, Skopje, N.
Macedonia

Ales Znidaric, PhD

ZAG – Slovenian National Building
and Civil Engineering Institute,
Ljubljana, Slovenia

COVER DESIGN:

Prof. PhD **Mitko Hadzi Pulja**
Mr. Arh **Darko Draganovski**
Faculty of Architecture
University "Ss. Cyril and
Methodius", Skopje, N. Macedonia

ORDERING INFO

SJCE is published bi-annually.
All articles published in the journal
have been reviewed.
Edition: 100 copies

SUBSCRIPTIONS

Price of a single copy:
for Macedonia (500 den);
for abroad (10 EUR + shipping
cost).

**BANKING DETAILS
(NORTH MACEDONIA)**

Narodna banka na RNM
Account number:
160010421978815
Prihodno konto 723219,
Programa 41

**BANKING DETAILS
(INTERNATIONAL)**

Correspond bank details:
Deutsche Bundesbank Zentrale
Address: Wilhelm Epstein Strasse
14 Frankfurt am Main, Germany
SWIFT BIC: MARK DE FF
Bank details:
National Bank of the RNM
Address: Kompleks banki bb 1000
Skopje North Macedonia
SWIFT BIC:NBRM MK 2X
IBAN: MK 07 1007 0100 0036 254
Name: Gradezen fakultet Skopje

V. Gacevski, V. Zileska Pancovska, M. Lazarevska ASSESSMENT OF RISKS IN A ROAD TUNNEL CONSTRUCTION USING TREE ANALYSIS	7
T. Gegovski, Z. Bogdanovski, F. Kasapovski A REVIEW OF INSAR TECHNOLOGY FOR DETERMINATION OF SURFACE DEFORMATION	13
D. Memedi, D. Popovski, M. Partikov, A. Nasufi ANALYTICAL MODEL OF NON-SWAY STEEL FRAME WITH SEMI-RIGID CONNECTIONS	21
V. Mickovski, G. Iannace, M. Jovanoska-Mitrevska, T. Samardzioska REBONDED POLYURETHANE FLEXIBLE FOAM AS SOUND ABSORBING MATERIAL	27
A. Nasufi, D. Popovski, M. Partikov, D. Memedi OPTIMIZATION OF STEEL FRAMES USING SEMI-RIGID CONNECTIONS	35
M. Naumovski, M. Lazarevska, D. Dimkovski COMFORT, AS AN ASPECT OF LIFE CYCLE ASSESSMENT (LCA) ANALYSIS TOWARD SUSTAINABLE BUILDINGS	41
I. Nedevska, Z. Zafirovski, M. Lazarevska, R. Ristov, V. Gacevski TRACK GEOMETRY DEGRADATION AND MAINTENANCE OF THE RAILWAYS	55
H. Pasternak, N. Živaljević-Luxor THE COLOSSUS OF PRORA – BUILDING HISTORY AND NEW BEGINNING	61

Albnor Nasufi

MSc, Civ. Eng.
North Macedonia
nolinasufi@live.com

Denis Popovski

PhD, Associate Proffesor
Ss. Cyril and Methodius University
Faculty of Civil Engineering – Skopje
popovski@gf.ukim.edu.mk

Mile Partikov

PhD, Assistant Proffesor
Ss. Cyril and Methodius University
Faculty of Civil Engineering – Skopje
partikov@gf.ukim.edu.mk

Ditar Memedi

MSc, Assistant
South East European University
Faculty of Contemporary Sciences and
Technologies Tetovo, North Macedonia
ditarm2@gmail.com

OPTIMIZATION OF STEEL FRAMES USING SEMI-RIGID CONNECTIONS

The true behavior of the connections is usually semi-rigid. Neglecting the real behavior of the connection in the analysis may lead to unrealistic predictions of the response and reliability of steel frames. In this paper the methodology for determination of rotational stiffness of semi-rigid connection in steel constructions according to Eurocode 3 componential method has been analyzed. By application of this concept the determination of rotational connection response comes down to determination of geometrical characteristic of different connection components. This paper considers the effects of semi-rigid behavior of the connections in analysis for steel frames and ways for global optimization of structural members and optimization of joint especially. In this paper, steel frames are analyzed by using computer program. Having the same geometry and cross-section, the static analysis for frames is examined for three different type of connections. The first frame is analyzed with ideally rigid connection, second one with semi-rigid connection and third one with ideally pinned connection.

Keywords: semi-rigid, joint, moment resistance, steel frame, rotational stiffness

1. INTRODUCTION

A steel frame as a plane of linear members, such as beams and columns, joined together by connections. These joints between members play an important role. From an economic point of view the costs for design and fabrication form a considerable part of the total cost. From a structural point of view the properties of the joint essentially influence the response of the structure to actions. Traditionally, in the design and analysis of steel frames it is assumed that all structural beam-to-column connection behave either as: simply pinned or fully rigid.

Simply pinned, which implies that no moment will be transmitted between the beam and the column and thus the connection is only capable of transmitting shear and axial force. As far as rotation is concerned, the beam and the column that are jointed together by a pin will behave independently.

Fully rigid, which implies that no relative rotation will occur between the adjoining members and the beam end-moment is transmitted to the

column. The angle between the beam and the column remains unchanged as the frame deforms.

Existing methods of design and analysis of steel frames still firmly rely on these simplified idealized models, despite the fact that it has been recognized for more than half a century that connection behavior lies somewhere between the two extreme idealizations. Thus the design of the structure is not fully based on the actual load-deformation characteristic of the joint. This is due to a member of factors, two of which are the relative complexity of the necessary design calculations and lack of comprehensive information on the performance of the full range of modern days connections. This has resulted in a rapid growth of investigation on this topic, leading to continuous innovations in the analysis and design of steel frames and the testing of beam-to-column connections. Experiments carried out during the last decades have shown that the behavior of real bolted connection is neither rigid nor pinned; rather, they possess some degree of rotational restraint which depend on type of connection used. The term "Semi-rigid" is used to describe such connections. In addition to the classification by rigidity beam-to-column connection may be classified as well by strength with respect to the design moment resistance. Under such classification beam-to-column connection behave wither as: nominally pinned, full-strength; partial-strength connection.

2. GENERAL DESCRIPTION OF ANALYTICAL MODEL

In this paper is analyzed a single span steel frame with dimensions 6.00x4.00m (L x H). Two columns are with cross-section HEA 180, beam with cross-section IPE 270. Base support for columns are ideally rigid connecting with concrete foundation. For this study connection beam-column is taken in three ways: ideally rigid, semi-rigid, ideally pinned. Frame is analyzed by two type of load. First load, include self-weight and uniform linear load 8.00kN/m'. Second load include vertical support displacement in column support for 5.0cm. Base support displacement is taken into account because this load can best determinate the behavior of frames in dependence of real connection rotation. In real situation non uniform foundation displacement shows in a lot of forms. For example, when we have to build very close to another building. In this situation

in that older building is done soil consolidation, that's mean a foundation for new building who is close to that have to do less consolidation in comparison on another foundation in same new building (in another column).

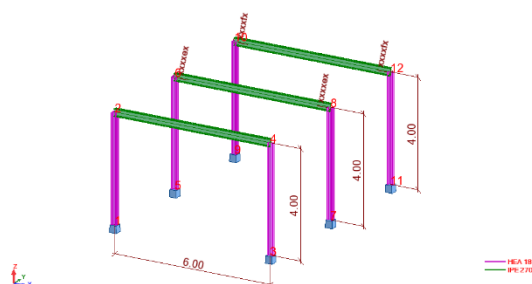


Figure 1. Steel frame, dimensions, cross-sections

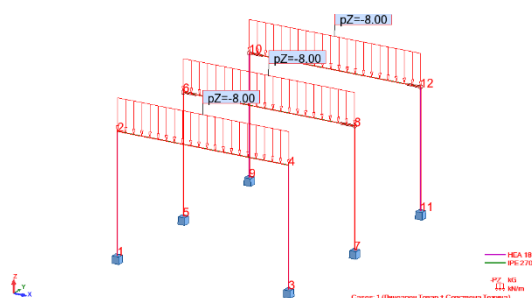


Figure 2. First load, self-weight and uniform linear load

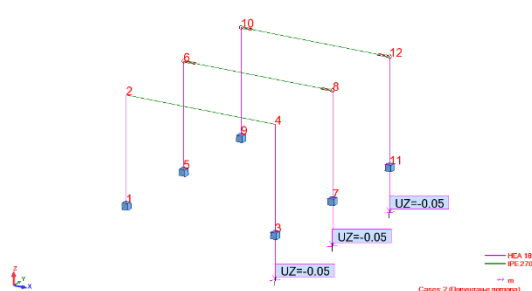


Figure 3. Second load, base support displacement

3. RESPONSE OF JOINT AND DESIGN TOOLS

Beside the need for background information the engineer requires simple design tools to be able to design joint in an efficient way. Three different types of design aids can be provided: -design tables; -design sheet; -software. Response of the joints in terms of stiffness, resistance and ductility is a key aspect for design purposes. From this point of view, three main approaches may be followed:

- experimental;
- numerical;
- analytical

In this paper is used the analytical approach. Analytical procedures enable a prediction of the joint response based on the knowledge of

the mechanical and geometrical properties of the so-called “joint components”. Component method applies to any type of steel joint whatever the geometrical configuration, the type of loading (axial force and/or bending moment, ...) and the type of member cross sections.

However, the analysis of a frame with semi-rigid connections is difficult to perform unless the exact moment-rotation relation of such joint is known.

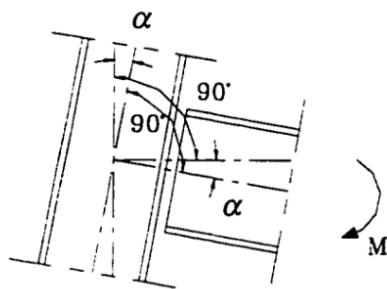


Figure 4. Loaded rigid connection

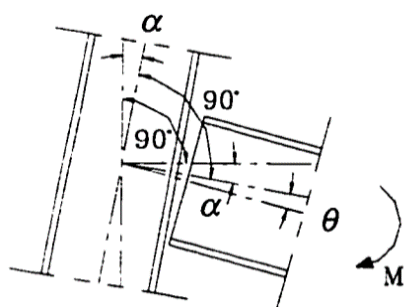


Figure 5. Loaded semi-rigid connection

At rigid connection moment-rotation relation is known before starting design of joint, at loaded rigid connection relative rotation between elements in elastic area is always 90°. Relative rotation between elements in elastic area at semi-rigid connection is shown with moment - rotation curve.

$$\theta_r = \frac{M}{S_{j,ini,s}} \quad (1)$$

where:

- θ_r : relative rotation between elements
- M: bending moment
- $S_{j,ini,s}$: Initial stiffness

3.1 DESIGN OF JOINTS ACCORDING EC3

Identification of the active components in the joint are regulated in EC3 part .1-8 (table 6.10). In this joint in figure 5, active components are:

1. Column web panel in shear; 2. Column web in compression; 3. Column web in tension; 4. Column flange in bending; 5. End-plate in bending; 10. Bolts in tension. For this connection in analytical way is calculated bending resistance, secant and initial stiffness.

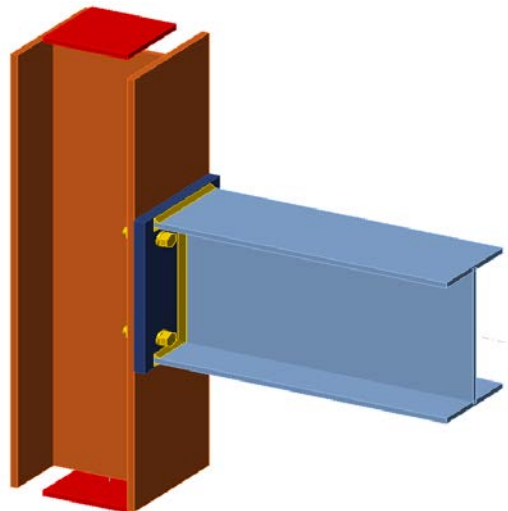


Figure 6. Single-sided bolted end plate connection used in this paper

Identification of the active components in the joint are regulated in EC3 part .1-8 (table 6.10). In this joint in figure 5, active components are:

1. Column web panel in shear; 2. Column web in compression; 3. Column web in tension; 4. Column flange in bending; 5. End-plate in bending; 10. Bolts in tension. For this connection in analytical way is calculated bending resistance, secant and initial stiffness.

Table 1. Joint components

Component	Stiffness coefficient k_i (mm)	Design Resistance $\min F_{Rd,i}$ (kN)
1. Column web panel in shear	2.374	177.30
2. Column web in compression	5.700	181.85
3. Column web in tension	6.540	199.6
4. Column flange in bending	3.419	115.13
5. End-plate in bending	11.320	180.86
10. Bolts in tension. 4M16	4.567	180.86

3.1.1 Design moment resistance:

$$M_{j,Rd} = F_{Rd} * z = 27.05 \text{ kN/m}' \quad (2)$$

3.1.2 Design elastic moment resistance:

$$M_{j,el,Rd} = \frac{2}{3} F_{j,Rd} = 18.03kN/m' \tag{3}$$

3.1.3 Initial stiffness:

$$S_{j,ini,s} = \frac{Eh^2}{\sum k_i} = 8614.12kNm/rad \tag{4}$$

3.1.4 Secant stiffness:

$$S_j = \frac{S_{j,ini,s}}{2} = 4307kNm/rad \tag{4}$$

3.1.5 EC3 classification of connections by stiffness:

$$k = \frac{S_{j,ini}L_b}{EI_n} = 4.250 \tag{5}$$

4. DESIGN OPPORTUNITIES FOR OPTIMISATION OF FRAMES

The various approaches can be used to design steel frames with due attention being paid to the behave of the joints. For the design of steel frames, the designer can follow one of the following design approaches: 1. Traditional design approach; 2. Consistent design approach; 3. Intermediate design approach.

In this paper is used consistent design approach, the global analysis is carried out in full consistency with the presumed real joint response. Both members of steel frame and joint properties are accounted for when starting the global frame analysis.

In the pre-design phase, joints are selected by the practitioner based on his experience. Proportions for the joint components are determined: end-plate or cleat dimensions, location of bolts, number and diameter of bolts, sizes of column and beam flanges, thickness and depth of column web, etc. First the joints are characterized with the possible consequence of having a non-linear behave. This characterization is followed by an idealization, for instance according to a linear or bi-linear joint response curve, which becomes a part of the input for global frame analysis. For the purpose of global frame analysis, any joint structural response is assigned to a relevant spring in the frame model.

5. NUMERICAL MODEL AND RESULTS

In this case study, the numerical analysis of steel frame is made with Autodesk Robot

Structural Analysis Professional). Globally speaking, four main analysis approaches may be contemplated according to Eurocode 3:

- linear elastic first order analysis;
- plastic first order analysis;
- linear elastic second order analysis;
- plastic second order analysis;

In this case study analysis is made with: linear elastic first order. Results for bending moments are shown in Combination of first load type together with second load type.

5.1 BENDING MOMENTS

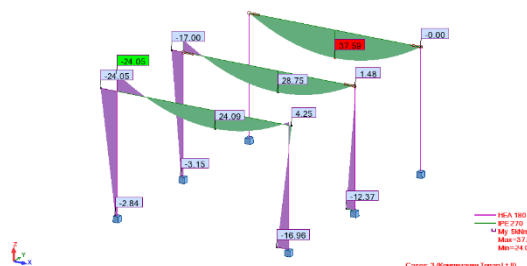


Figure 7. Bending moment on steel frame

Table 2. Bending moments

	Bending moments "My" from combination I+II (kN/m')		
	Negative moment "left joint"	Positive moment in middle of beam	Negative moment "right" joint"
Frame with rigid connection	-24.05	23.44	-4.25
Frame with semi-rigid connection	-17.00	28.75	-1.48
Frame with pinned connection	0.00	37.59	0.00

From the results at table 2. we can see that the maximum negative moment is at frame with rigid connection and maximum positive moment is at frame with pinned connection.

Joint designed in chapter 3 has elastic moment resistance 18.03kN/m'. From the table we can see that frame with rigid connection has negative moment value more than elastic moment resistance of joint. Also frame with pinned connection has higher positive bending moment than frame with semi-rigid and rigid connection.

5.2 DISPLACEMENTS

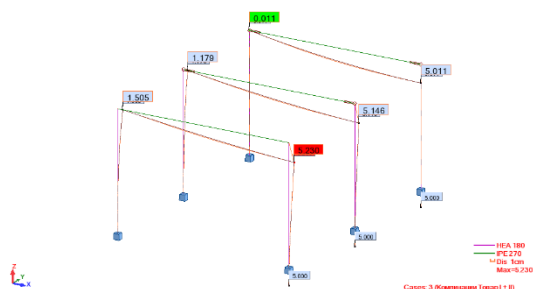


Figure 8. Deformation on steel frame

Table 3. Displacements

Frame	No de	Case	UX (cm)	UZ (cm)
Steel frame with "rigid" connection	1	3 (C)	0.000	0.000
	2	3 (C)	1.505	-0.012
	3	3 (C)	0.000	-5.000
	4	3 (C)	1.501	-5.009
Steel frame with "semi-rigid" connection	5	3 (C)	0.000	0.000
	6	3 (C)	1.179	-0.012
	7	3 (C)	0.000	-5.000
	8	3 (C)	1.177	-5.010
Steel frame with "pinned" connection	9	3 (C)	0.000	0.000
	10	3 (C)	0.000	-0.011
	11	3 (C)	0.000	-5.000
	12	3 (C)	0.000	-5.011

From the results at table 3. We can see that maximum node displacement (nodes where are connecting beam-column) has frame with rigid connection.

5.3 RELATIVE ROTATION BETWEEN MEMBERS

Table 4. Relative rotation between members

Frame	No de	Bending Moment (kN/m')	Initial stiffness (kNm/rad)	θ_r (rad)
Steel frame with "semi-rigid" connection	6	-17.000	8614.12	-0.00197
	8	-1.480	8614.12	-0.0001718

At rigid connection relative rotation between elements in elastic area is always 90°. At pinned connection there are no developing significant moments which might adversely affect members of the frame.

6. CONCLUSION

Based on the numerical results the following can be concluded:

1. In general designers when have to design a frame with support displacement goes with pinned connection, due the fact frame can rotate and not showing extra bending moments and lateral displacement. In this case frame with pinned connection have higher positive bending moments, which brings larger cross-section of beam.
2. Frame with rigid connection are more usually used in steel industries. From the table we can see that frame with rigid connection has negative moment value more than elastic moment resistance of joint (18.03kN/m'), which brings design a new joint detailing, more complex, more stiffener that brings increasing fabrication cost.
3. From the table we can see frames with rigid connection have higher lateral displacement, the higher lateral displacement can bring in more complex analysis (second order analysis)
4. Using semi-rigid connection shows a real optimization of steel frames. From the tables we can see, lower positive moments compare with pinned connection, and lower negative moments compare with rigid connection. Lateral displacement are lower compare with rigid connection.

5. A real advantage of using semi-rigid connection is taking relative rotation of members in joint for global displacements in frames. Which members can rotate and not showing extra bending moments.
6. Consistent design approach is more complex, need more time and work, but using this design we can bring more reliable results with taken care a real joint response. Consistent design approach brings optimization of joints components and cross-sections of members.

7. REFERENCES

- [1] EN 1993-1-1: Eurocode 3: Design of steel structures – Part 1-1: General rules and rules for buildings
- [2] EN 1993-1-8: Eurocode 3: Design of joints
- [3] Wai-Fah, Chen Norimitsu, Kishi Masato Komuro: “*Semi-rigid connections handbook*” (2011); ISBN: 978-1-932159-99-8
- [4] Jean-Pierre Jaspart Klaus Weynand; “Design of joints in steel and composite structures” (2016) ISBN (ECCS): 978-92-9147-132-
- [5] Zoubir Benterkia; “End-plate connections and analysis of semi-rigid steel frames” (PhD dissertation, 1991) University of Warwick
- [6] Mahmoud Hassan El-Boghdadi; “Elastic plastic analysis of semi-rigid industrial frames” (PhD dissertation, 1997)
- [7] Chen, W. F. (editor), *Practical analysis for semi-rigid frame design*, World Scientific, Singapore, 2000