EXPERIMENTAL MODELS OF REINFORCED CONCRETE (RC) BUILDING WITH SETBACK

1. Introduction

1.1. Background

Setbacks vertical irregularities in the building is one condition where there is a sudden change of upper stories bays because it has a smaller number of bays than the lower stories. The upper part is regarded as tower structure, while the lower part is regarded as base structure. The setbacks could influence the discontinuities in the mass, stiffness, and structural strength distributions. Hence, the analysis on setback buildings is necessary because its existence has considerable effect on structural response under seismic excitations. In this example, two sets of experimental tests setback RC buildings were modelled to show the accuracy of STERA_3D [1]. These two specimens are representing two type of setback buildings, namely towered setback and stepped setback.

1.2. Introduction of Tower Model

The towered model was experimentally tested by Wood [2] in 1985, which is the part of doctoral dissertation in University of Illinois at Urbana-Champaign, USA. The structure consists of 9 stories, where the first story has a slightly taller elevation. The setback location is in between level two and three. The tower structure has 1 bay, and the base part has 3 bays. The specimen scale is 15 times smaller than the real building dimension. It consisted of two 2D beam-column frames, and the mass was attached to both frames by supporting structures. The first and second stories' total weight is 5.04 kN, while the tower part is 1.73 kN for each level. The concrete compressive strength was 42.33 MPa, and the beam and column longitudinal rebar yielding strengths are 380.59 MPa and 388.17 MPa, respectively.

The input motion is only one direction parallel to the 2D frame. The original tests were using a set of successive earthquake acceleration input motions based on the scaled 1940 El Centro NS with different magnitude. In this study, only the first input of scaled 1940 El Centro NS with the peak acceleration of 382.8 cm/s^2 was implemented. The raw data of this experimental tests were retrieved from DataCenterHub repository [3].

1.3. Introduction to Stepped Model

The stepped model was experimentally tested by Shahrooz and Moehle [4] in 1987, which is the report from Earthquake Engineering Research Center, University of California at Berkeley (UCB), USA to the National Science Foundation (NSF). The structure consists of 6 stories: three stories tower part and three stories base part. The base part has two bays while the tower part consists of only one bay. The specimen scale is 4 times smaller than the real building dimension. The model is in three dimensions with 2 × 2 bays of 1143 mm × 1905 mm floor panel size. The design concrete strength was 27.5 MPa, and all reinforcement had minimum yield stress of 413 MPa. The weight of structures is 72 kN per level for base structure and 41 kN per level for tower structure, and the inter story height is 914.4 mm.

The specimen was experimentally subjected to two input motions sequentially: unidirectional and bidirectional. In this study, the numerical analysis only focuses on the longitudinal study and neglects the bidirectional simulation. The unidirectional input motions consist of three different scaled 1940 El Centro NS ground motions. The raw data of this experimental tests were retrieved from DataCenterHub repository [5].

2. Purpose of Study

The purposes of this study are:

a. To model the setback RC buildings with STERA_3D [6], both of towered type and stepped type by performing numerical analysis of two sets of scaled building which experimentally tested with shaking table tests by Wood [2] and Shahrooz and Moehle [4].
b. To verify the accuracy of frame analysis response by using STERA_3D [6] by comparing experiment responses and analysis responses in terms of displacement and acceleration.

3. Detail of Structure

3.1. Towered model

a. Elevation (x-z view)

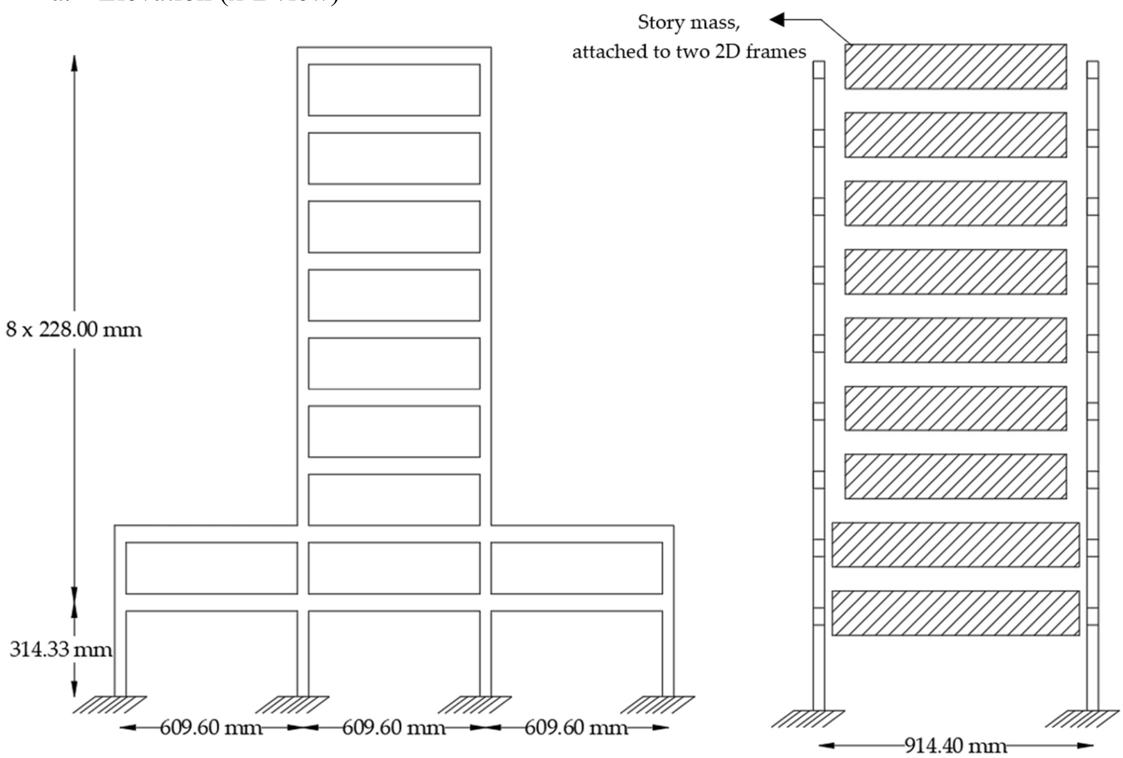


Figure 1. Front view and side view [1]

b. Floor plan (x-y view)

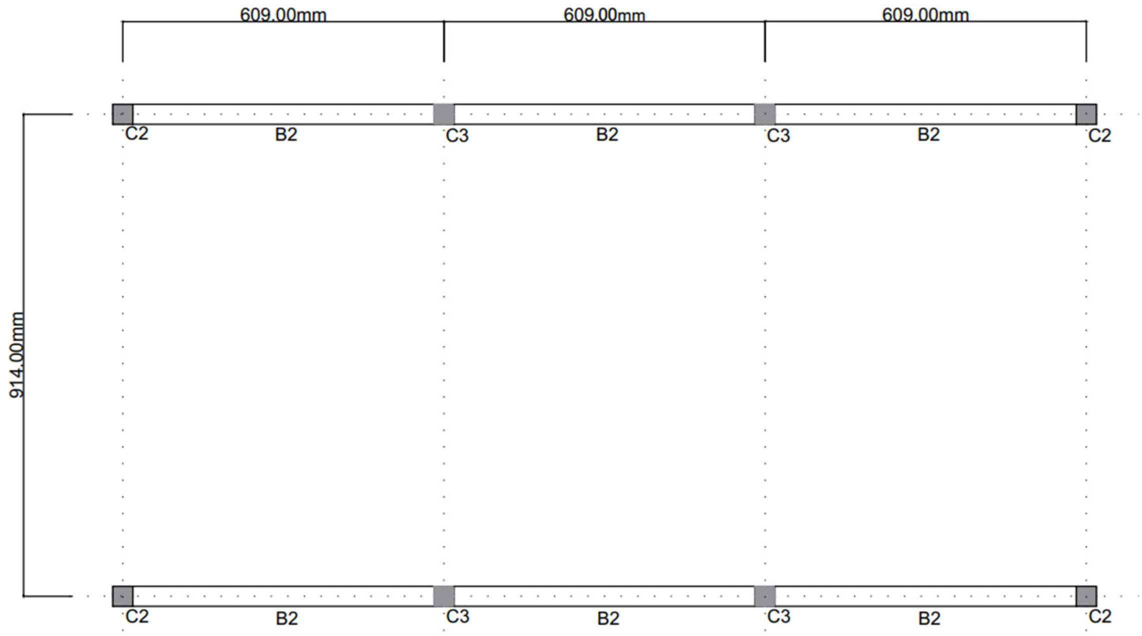


Figure 2. First floor

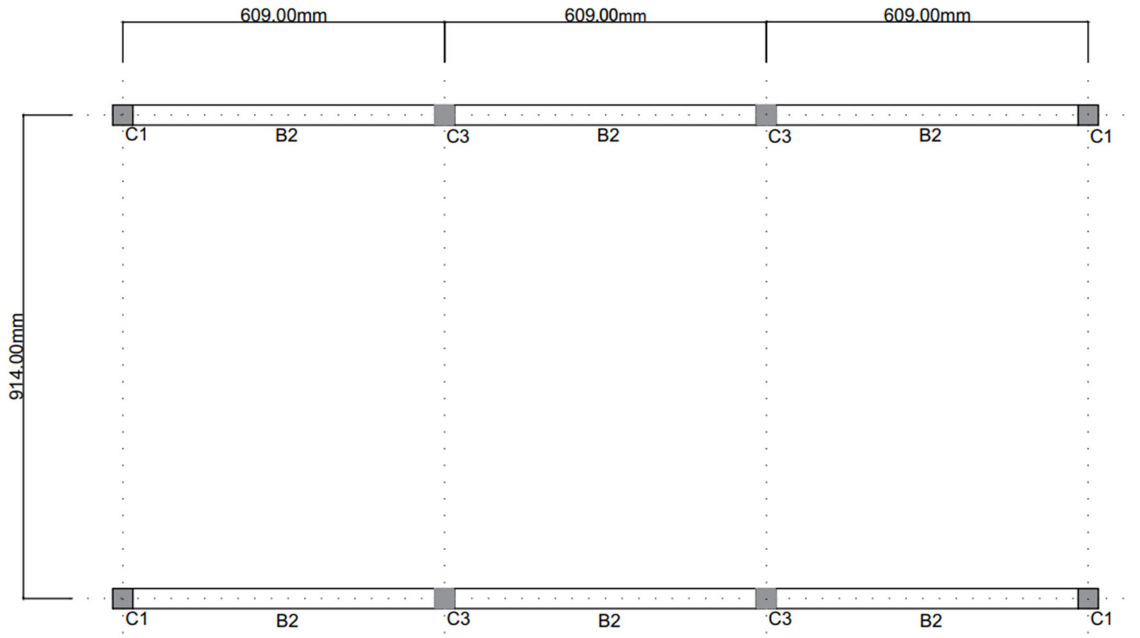


Figure 3. Second floor

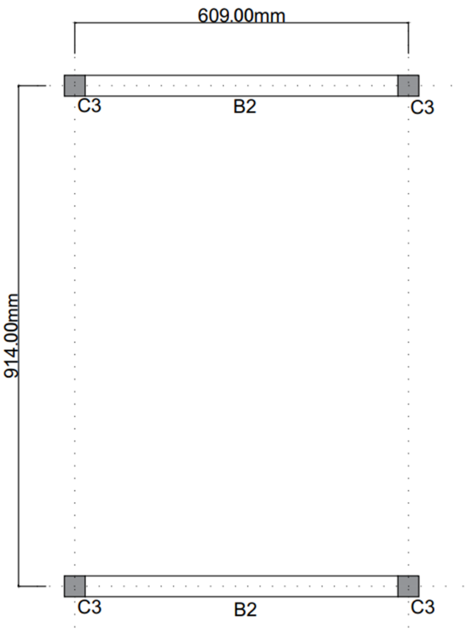


Figure 4. 3rd floor

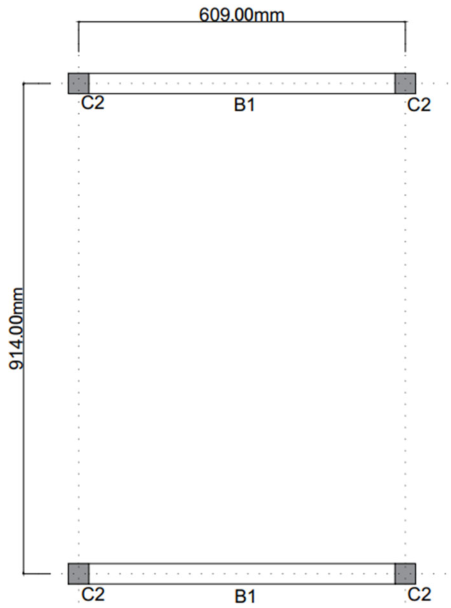
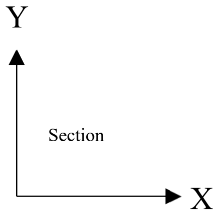
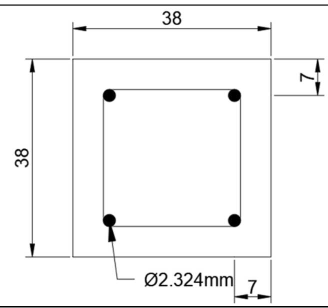
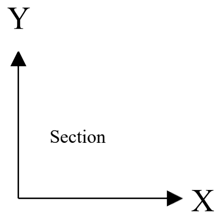
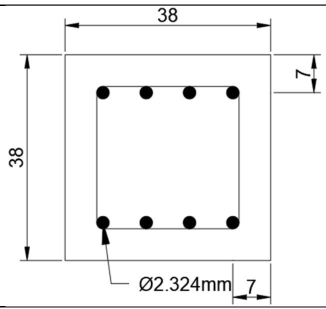
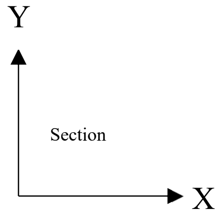
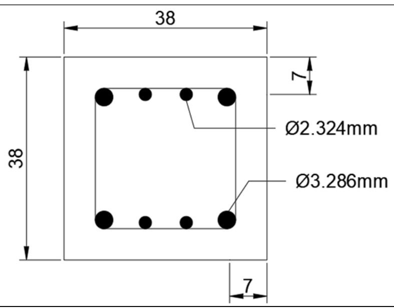


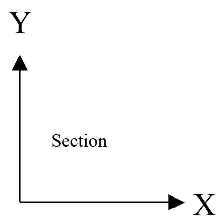
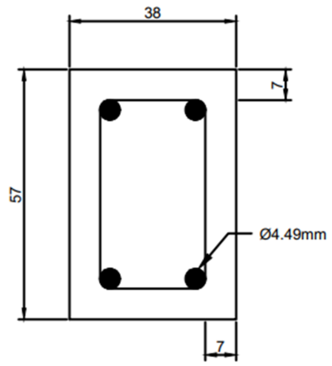
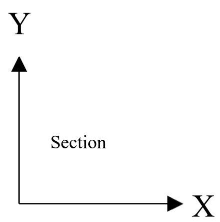
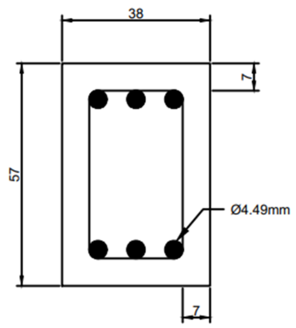
Figure 5. 4th – 9th floor

c. Column list

<table>
<tr><td colspan="2">Type</td><td>C1</td></tr>
<tr><td>See floor plan</td><td>
</td><td>
</td></tr>
<tr><td rowspan="3">F’c = 42.33 N/mm²</td><td>B x D</td><td>38 mm x 38 mm</td></tr>
<tr><td>Main bar</td><td>4-D 2.324 mm</td></tr>
<tr><td>Hoop</td><td>2-D 1.588 mm @ 10.16 mm</td></tr>
<tr><td colspan="2">Type</td><td>C2</td></tr>
<tr><td>See floor plan</td><td>
</td><td>
</td></tr>
<tr><td rowspan="3">F’c = 42.33 N/mm²</td><td>B x D</td><td>38 mm x 38 mm</td></tr>
<tr><td>Main bar</td><td>8-D 2.324 mm</td></tr>
<tr><td>Hoop</td><td>2-D 1.588 mm @ 10.16 mm</td></tr>
<tr><td colspan="2">Type</td><td>C3</td></tr>
<tr><td>See floor plan</td><td>
</td><td>
</td></tr>
<tr><td rowspan="3">F’c = 42.33 N/mm²</td><td>B x D</td><td>38 mm x 38 mm</td></tr>
<tr><td>Main bar</td><td>Corner: 4 × 2D 2.324 mm,
modelled as 4× D 3.286 mm
X-side: 4 D 2.324 mm</td></tr>
<tr><td>Hoop</td><td>2D1.97@10.16</td></tr>
</table>

The tensile strength of main reinforcement is 388 N/mm².
The tensile strength of shear reinforcement is 772 N/mm².

d. Beam list

<table>
<tr><td colspan="2">Type</td><td>B1</td></tr>
<tr><td>See floor plan</td><td>
</td><td>
</td></tr>
<tr><td rowspan="3">F'c = 42.33 N/mm²</td><td>B x D</td><td>38 mm x 57 mm</td></tr>
<tr><td>Main bar</td><td>4 D 4.496 mm</td></tr>
<tr><td>Hoop</td><td>2 D 1.588 mm @ 10.16 mm</td></tr>
<tr><td colspan="2">Type</td><td>B2</td></tr>
<tr><td>See floor plan</td><td>
</td><td>
</td></tr>
<tr><td rowspan="3">F'c = 42.33 N/mm²</td><td>B x D</td><td>38 mm x 57 mm</td></tr>
<tr><td>Main bar</td><td>6 D 4.496 mm</td></tr>
<tr><td>Hoop</td><td>2 D 1.588 mm @ 10.16 mm</td></tr>
</table>

The tensile strength of main reinforcement is 388 N/mm².
The tensile strength of shear reinforcement is 772 N/mm².

e. Structural height and weight

Plan Size			
Story	Height (mm)	Mass (lb.)	Weight (kN)
9	228.60	390	1.73
8	228.60	390	1.73
7	228.60	390	1.73
6	228.60	390	1.73
5	228.60	390	1.73
4	228.60	390	1.73
3	228.60	390	1.73
2	228.60	1134	5.04
1	314.33	1134	5.04
total	2143.13	4998	22.23

f. Input acceleration

Table 1. Detail of input motion properties

No	Year	Event, Station	Component	Max. Acc. (cm/s²)	Abbreviation	Input Direction
1	1940	scaled Imperial Valley, El Centro	NS	382.89	EC382.8L	Longitudinal

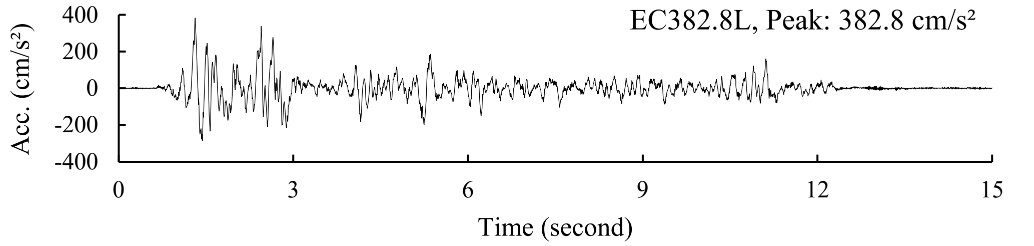


Figure 6. Time history acceleration of input ground motion

g. Comparison results

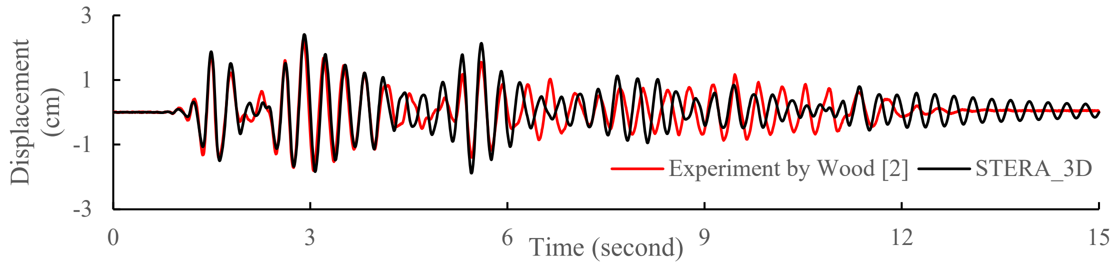


Figure 7. Roof displacement history responses of Experiment by Wood [2] compared with STERA_3D [1]

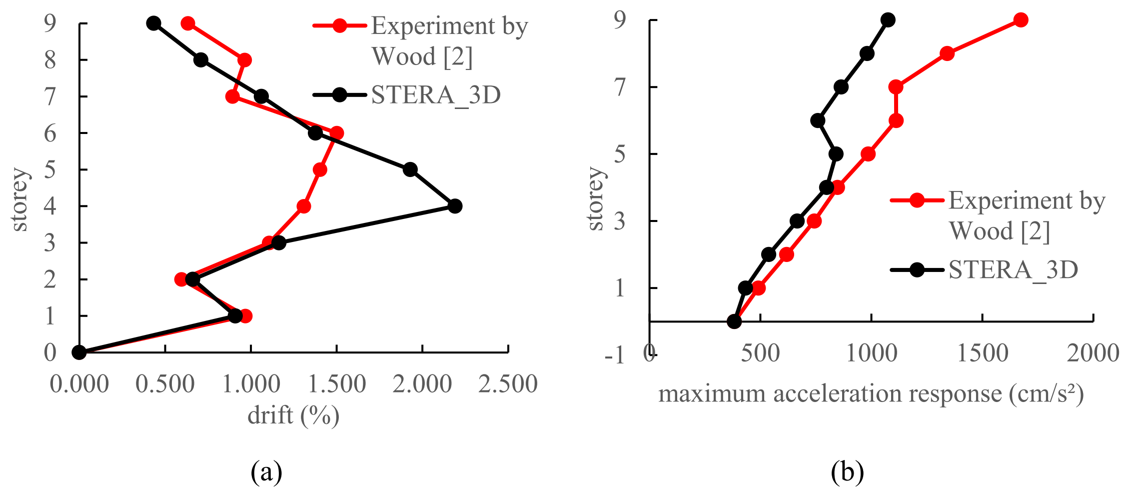


Figure 8. Comparison of experiment by Wood [2] specimen with STERA_3D response [1]: (a) interstory drift; (b) maximum acceleration

3.2. Stepped model

a. Elevation (x-z view)

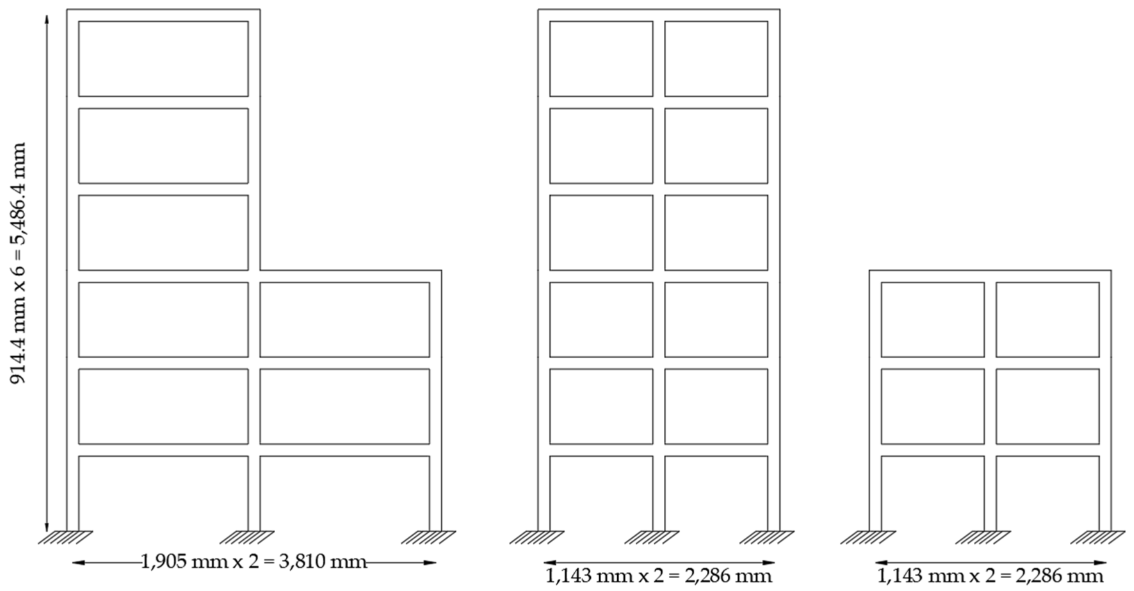


Figure 9. Elevation view of setback experimental model [1]: front view, side left view, and side right view

b. Floor plan (x-y view)

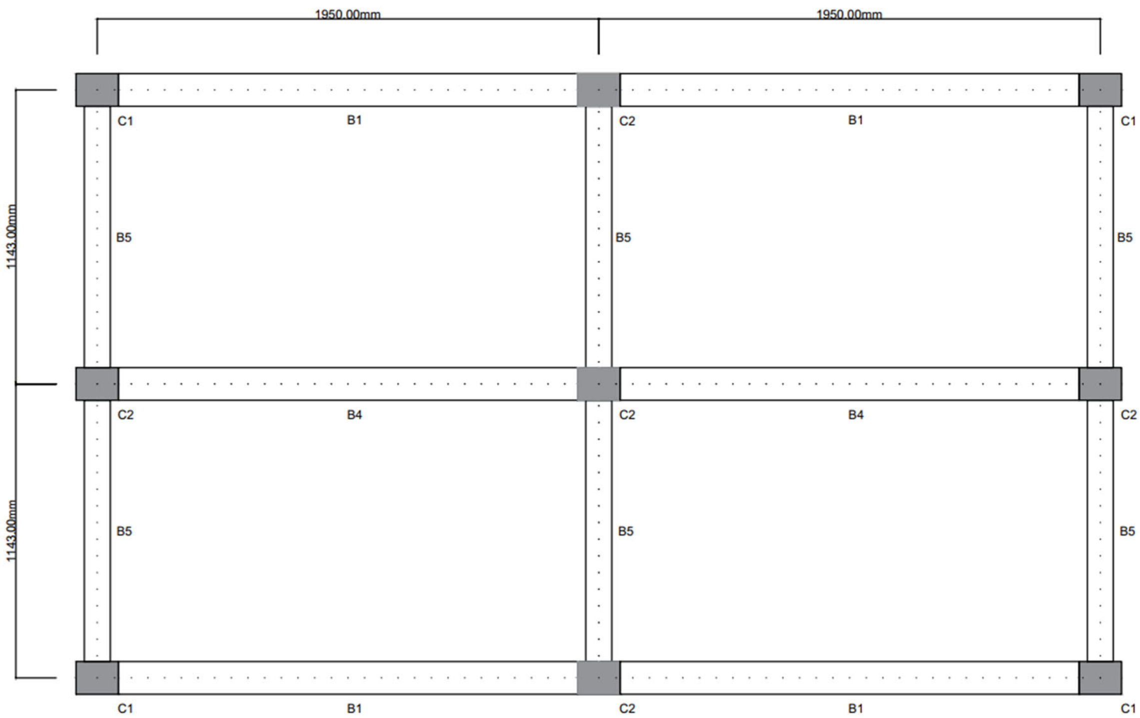


Figure 10. 1st and 2nd floor

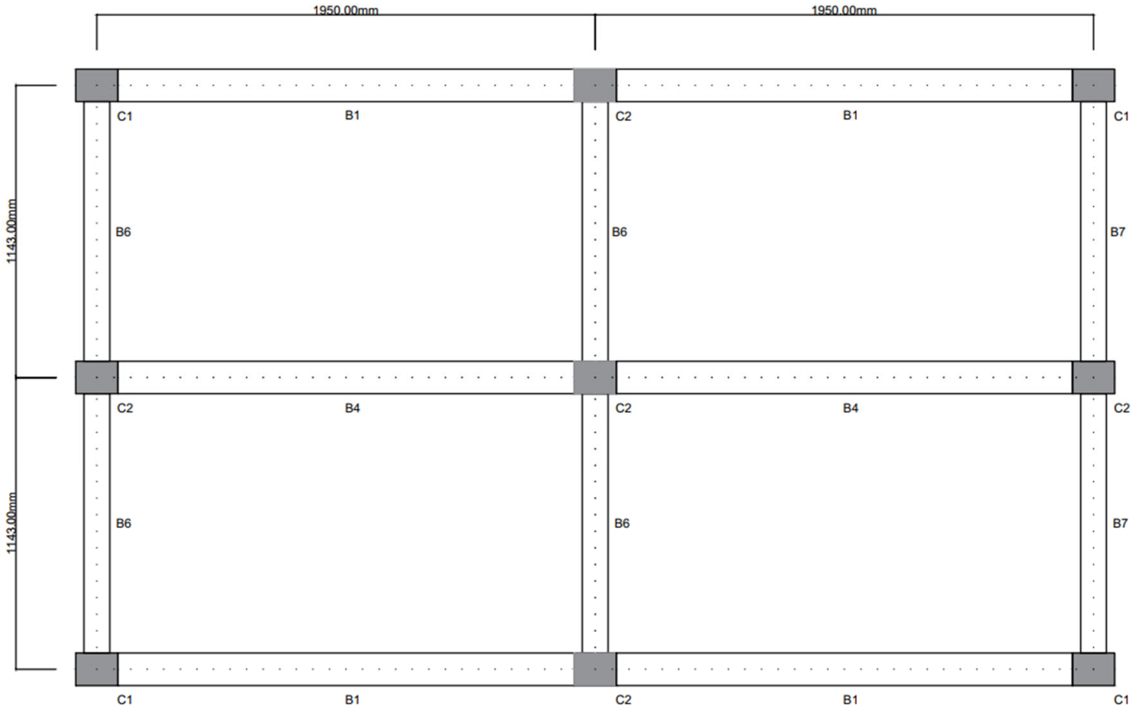


Figure 11. 3rd floor

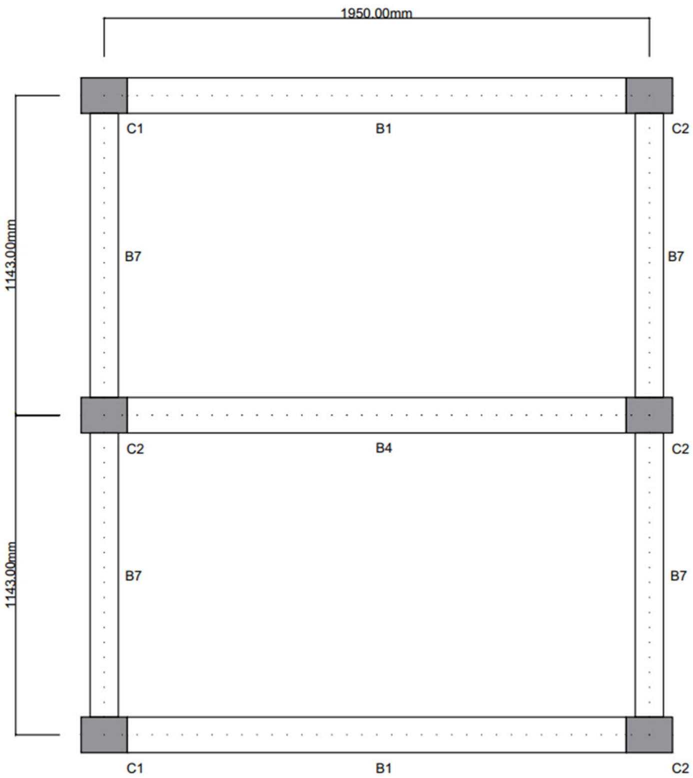


Figure 12. 4th floor

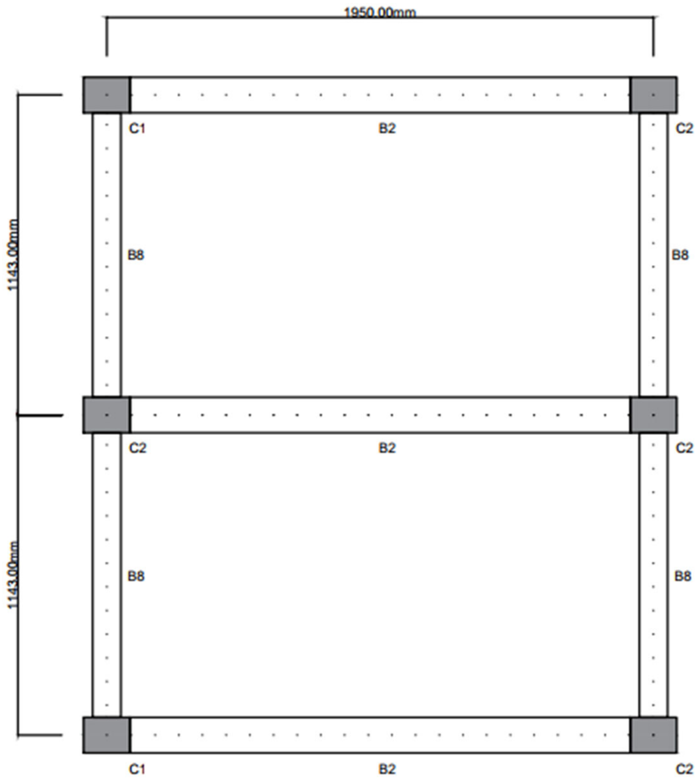


Figure 13. 5th floor

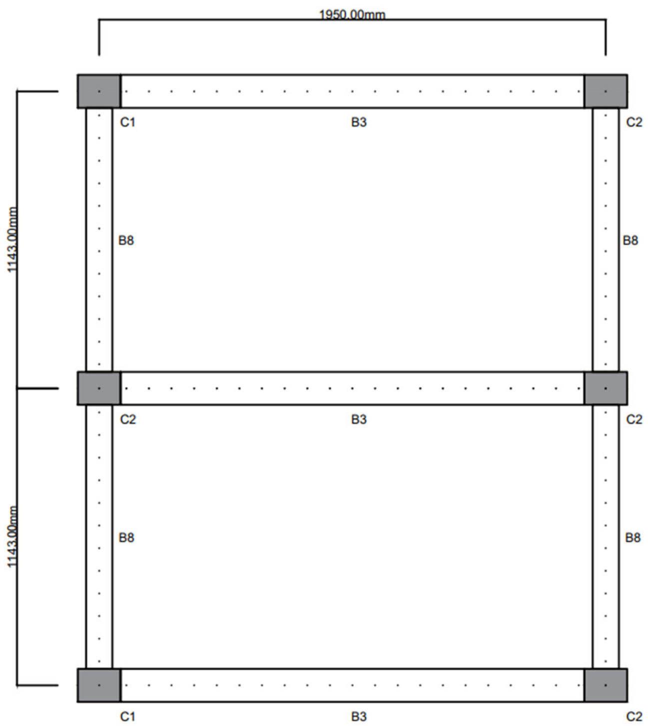
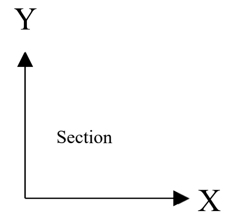
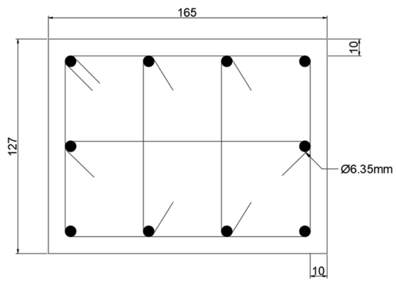
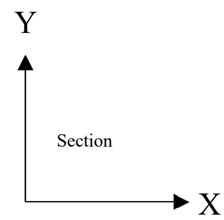
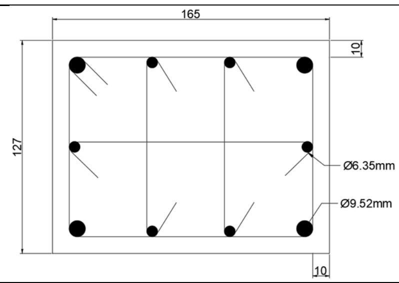


Figure 14. 6th floor

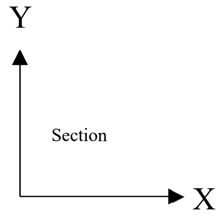
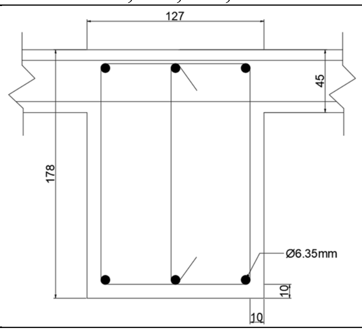
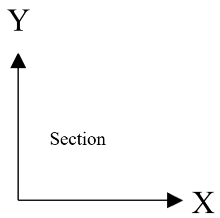
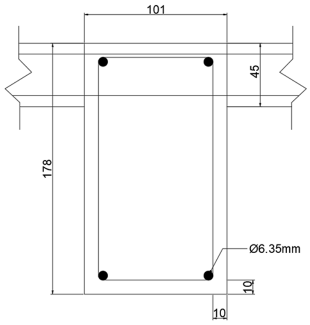
c. Column list

<table>
<tr><td colspan="2">Type</td><td>C1</td></tr>
<tr><td>See floor plan</td><td>
</td><td>
</td></tr>
<tr><td rowspan="3">F’c = 28.95 N/mm²</td><td>B x D</td><td>127 mm x 165 mm</td></tr>
<tr><td>Main bar</td><td>Corner: 4 D 6.35 mm
X-side: 4 D 6.35 mm
Y-side: 2 D 6.35 mm</td></tr>
<tr><td>Hoop</td><td>X-side: 4 D 3.76 @ 38 mm
Y-side: 2 D 3.76 @ 38 mm</td></tr>
<tr><td colspan="2">Type</td><td>C2</td></tr>
<tr><td>See floor plan</td><td>
</td><td>
</td></tr>
<tr><td rowspan="3">F’c = 28.95 N/mm²</td><td>B x D</td><td>127 mm x 165 mm</td></tr>
<tr><td>Main bar</td><td>Corner: 4 D 9.52 mm
X-side: 4 D 6.35 mm
Y-side: 2 D 6.35 mm</td></tr>
<tr><td>Hoop</td><td>X-side: 4 D 3.76 @ 38 mm
Y-side: 2 D 3.76 @ 38 mm</td></tr>
</table>

The tensile strength of main reinforcement is 650 N/mm².

The tensile strength of shear reinforcement is 386 N/mm².

d. Beam list

Type		B1, B2, B3, B4
See floor plan		
F'c = 28.95 N/mm²	B x D	127 mm x 178 mm
	Main bar	6 D 6.35 mm
	Hoop	3 D 3.05 mm @ 44 mm
	Plate thickness	45 mm
	Slab reinforcement	2 D 3.76 mm @ 44 mm
Type		B5, B6, B7, B8
See floor plan		
F'c = 28.95 N/mm²	B x D	127 x 178
	Main bar	2D6.35
	Hoop	2D3.05@44
	Plate thickness	45 mm
	Slab reinforcement	2 D 3.76 mm @ 44 mm

The tensile strength of main reinforcement is 650 N/mm².

The tensile strength of shear reinforcement is 386 N/mm².

The difference between B1, B2, B3 and B4 is that they are in different location in the model (end or middle cross section). The condition is same with B5, B6, B7 and B8.

e. Structural data

Plan Size			
Story	Height (mm)	Mass (kg)	Weight (kN)
6	950.0	410	41
5	950.0	410	41
4	950.0	410	41
3	950.0	720	72
2	950.0	720	72
1	950.0	720	72
total	5700.0	3390	339

f. Input acceleration

Table 2. Detail of input motion properties

No	Year	Event, Station	Component	Max. Acc. (cm/s²)	Abbreviation	Input Direction
1	1940	scaled Imperial Valley, El Centro	NS	76.10	EC7.7L	Longitudinal
2				163.00	EC16.6L	
3				484.00	EC49.3L	

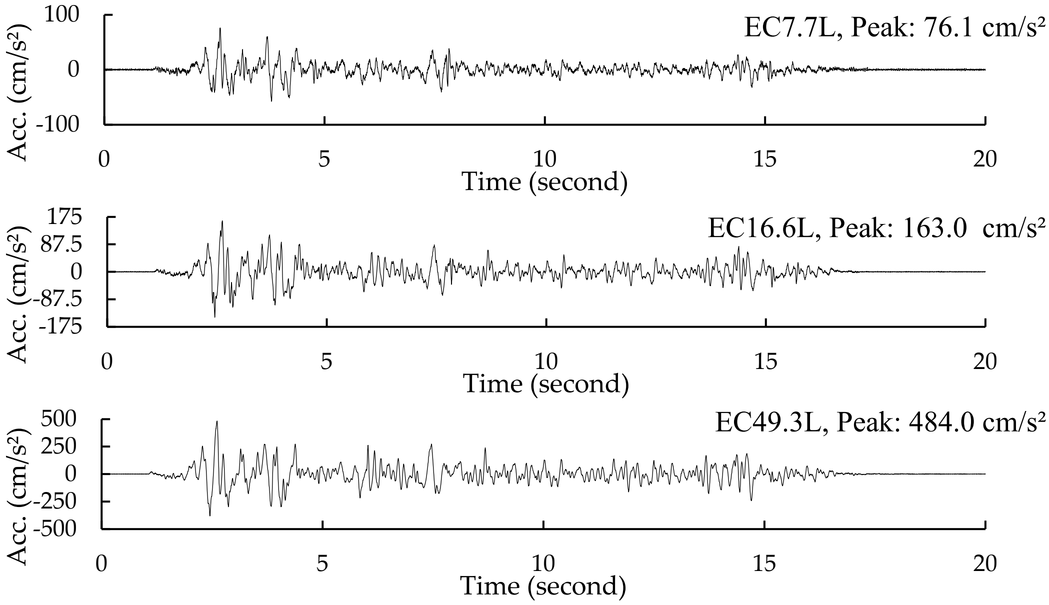


Figure 15. Time history acceleration of input motions

g. Comparison results

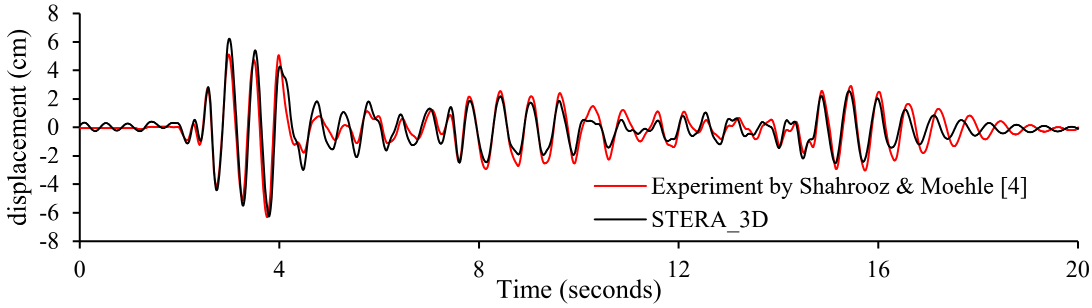


Figure 16. Roof displacement history responses of experiment compared with STERA_3D [1]

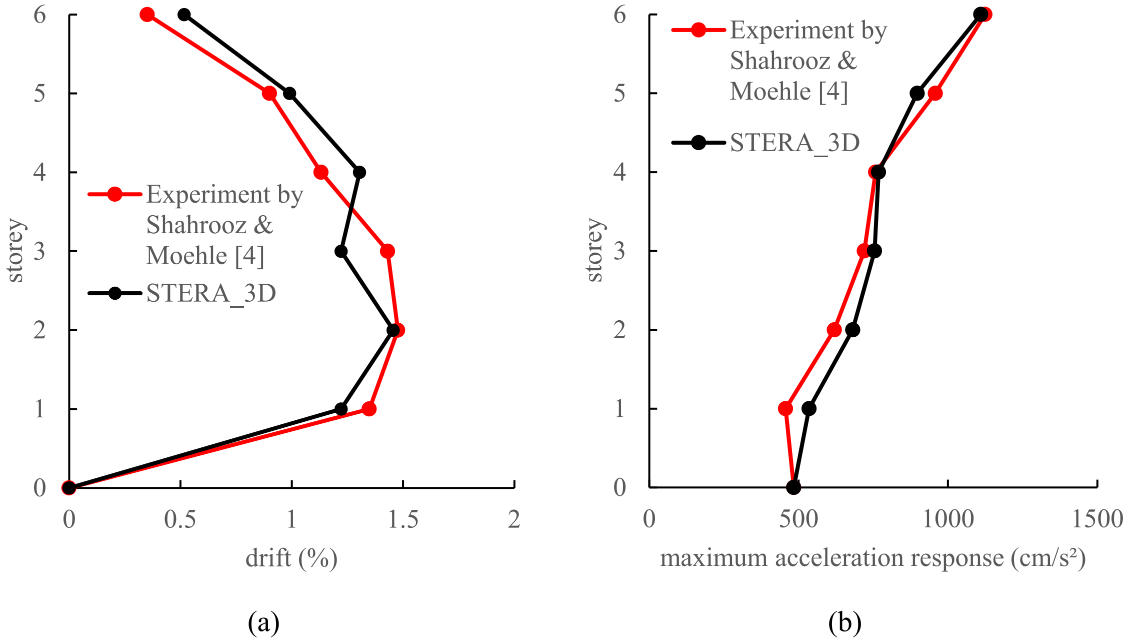


Figure 17. Comparison of experiment of Shahrooz and Moehle [4] specimen with STERA_3D response [1]: (a) interstory drift; (b) maximum acceleration

4. STERA_3D modelling

4.1. Naming rule of model:

Year_Specimen Owner_Type of Setback.stera

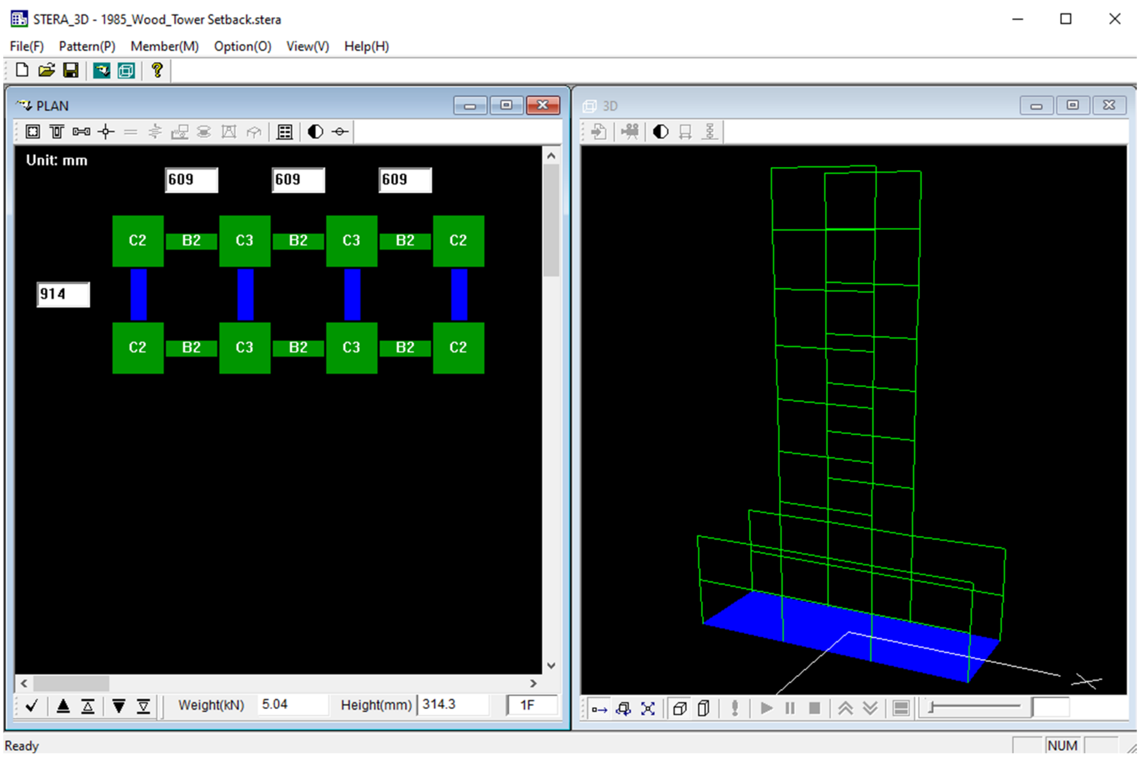
No	Name	Remarks
1	1985_Wood_Towered Setback.stera	Model based on Specimen of Wood [2]
2	1987_Shahrooz&Moehle_Stepped Setback.stera	Model based on Specimen of Shahrooz and Moehle [4]

4.2. Naming rule of input motions:

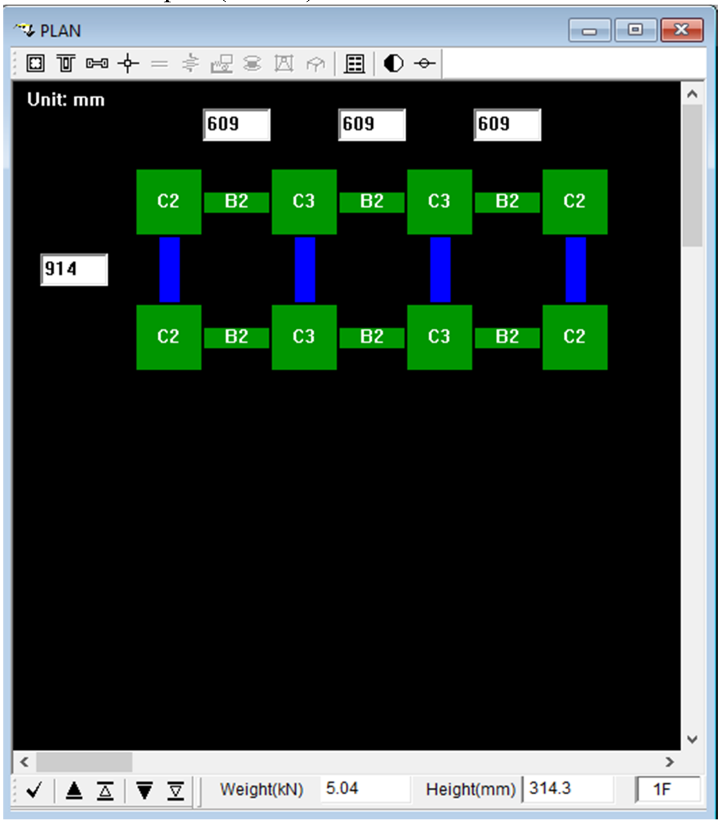
No	Name	Remarks
1	1985_Wood_EC382.txt	Scaled 1940 El Centro NS
2	1987_Shahrooz&Moehle_1_EC77.txt	Scaled 1940 El Centro NS, initial earthquake
	1987_Shahrooz&Moehle_2_EC166.txt	Scaled 1940 El Centro NS, successive earthquake
	1987_Shahrooz&Moehle_3_EC493.txt	Scaled 1940 El Centro NS, final earthquake

4.3. Towered Setback Model adopted from Wood [2]

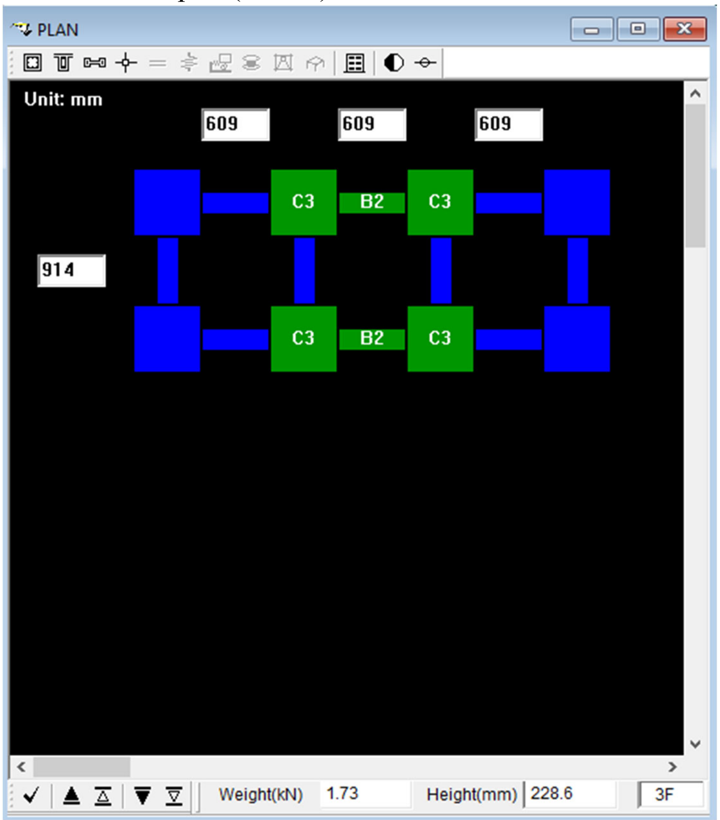
a. Overall view



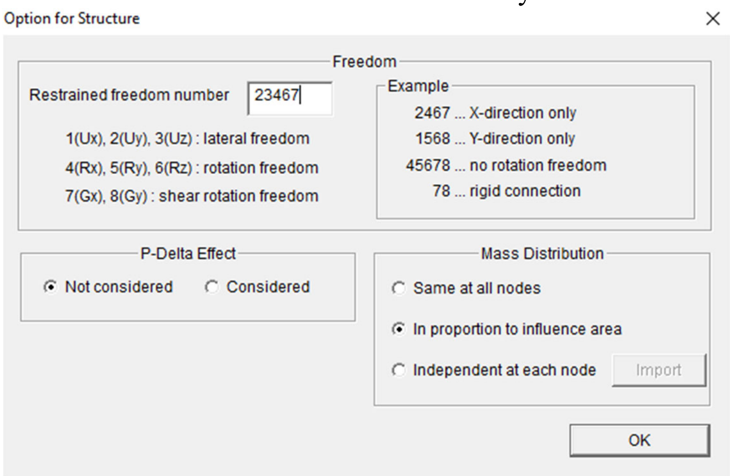
b. Plan for base part (level 1)



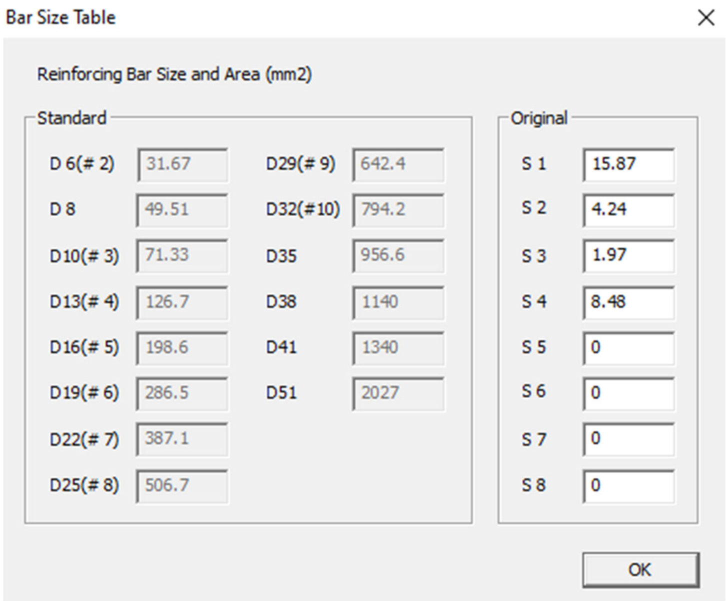
c. Plan for tower part (level 3)



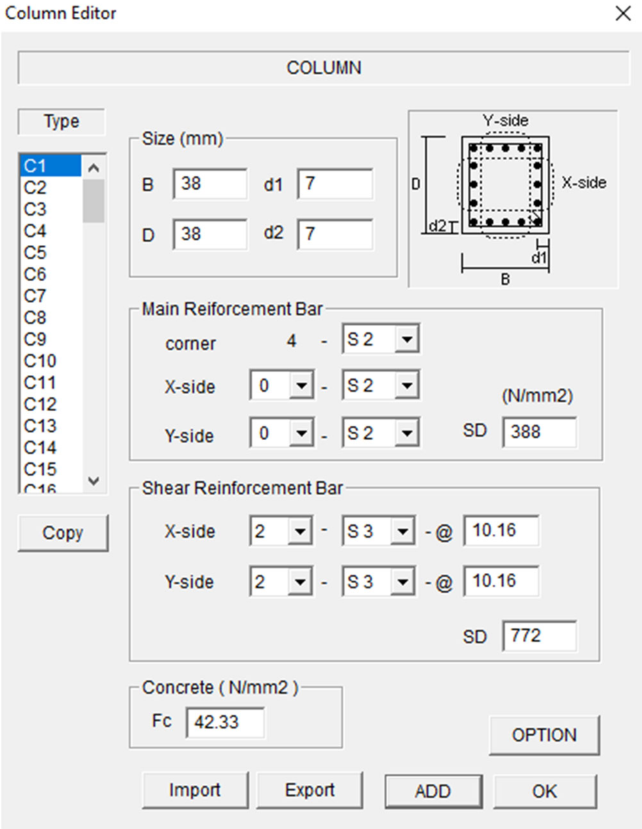
d. Restriction freedom for one directional analysis



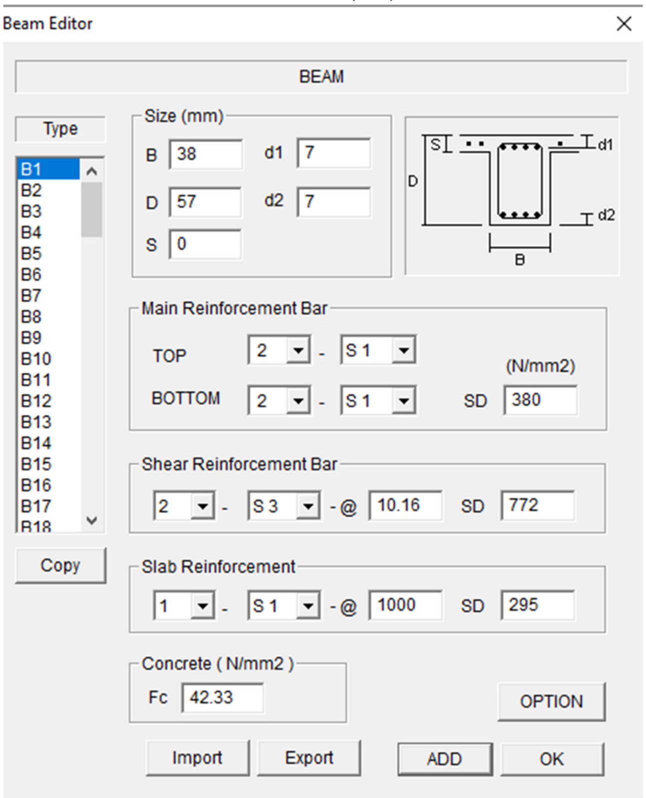
e. Definition of Custom Area Rebar



f. Definition of Column Member (C1)

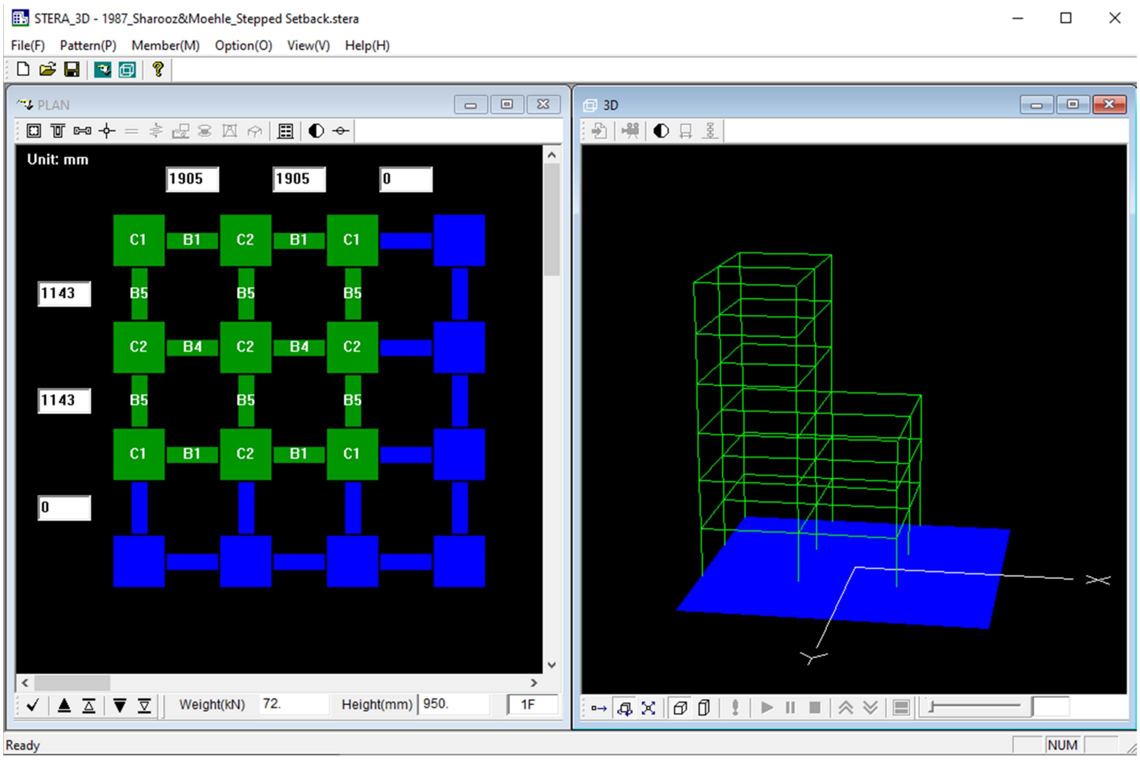


g. Definition of Beam Member (B1)

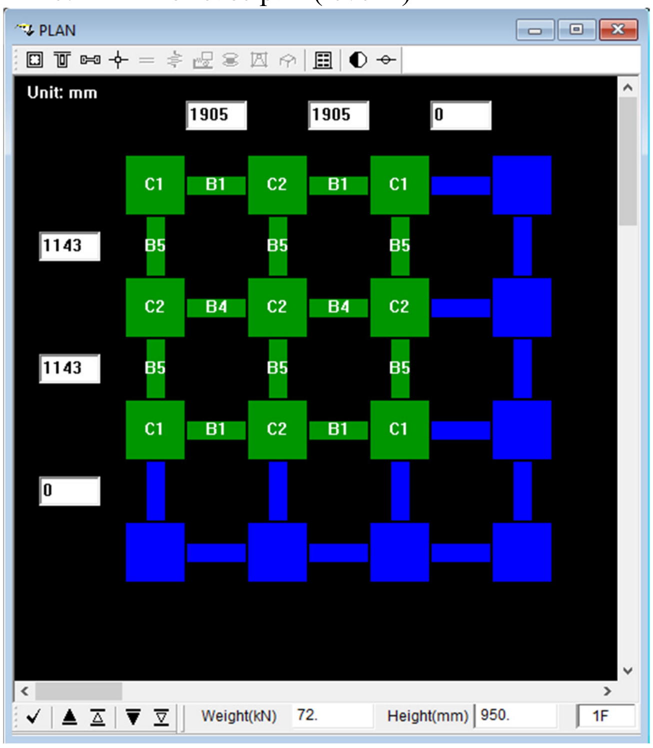


4.4. Stepped Setback Model adopted from Shahrooz and Moehle [4]

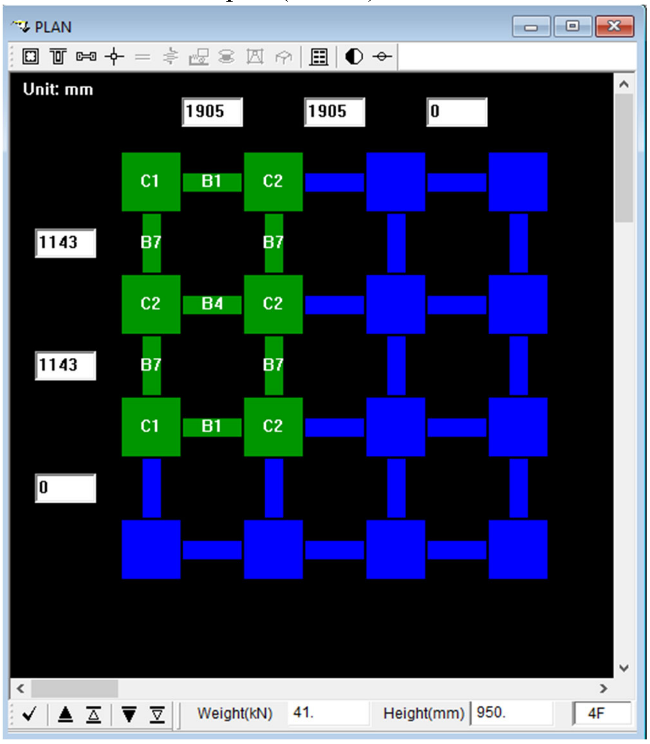
a. Overall view



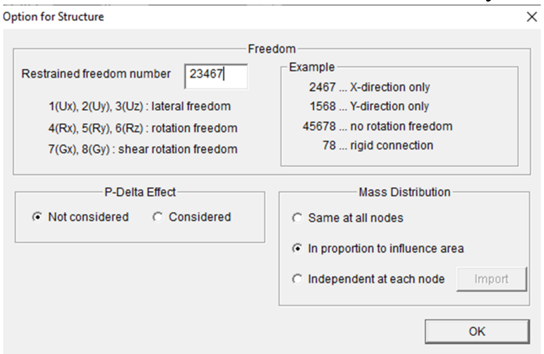
b. Plan for base part (level 1)



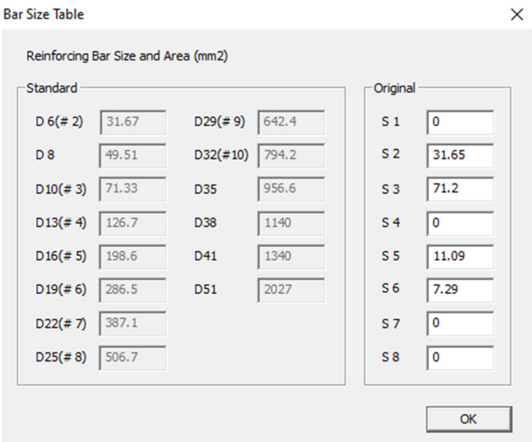
c. Plan for tower part (level 4)



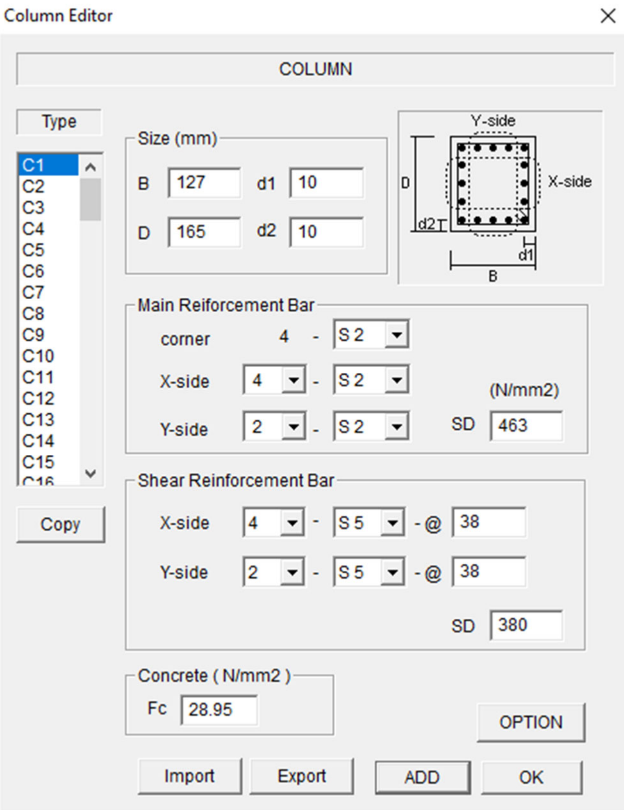
d. Restriction freedom for uniaxial analysis



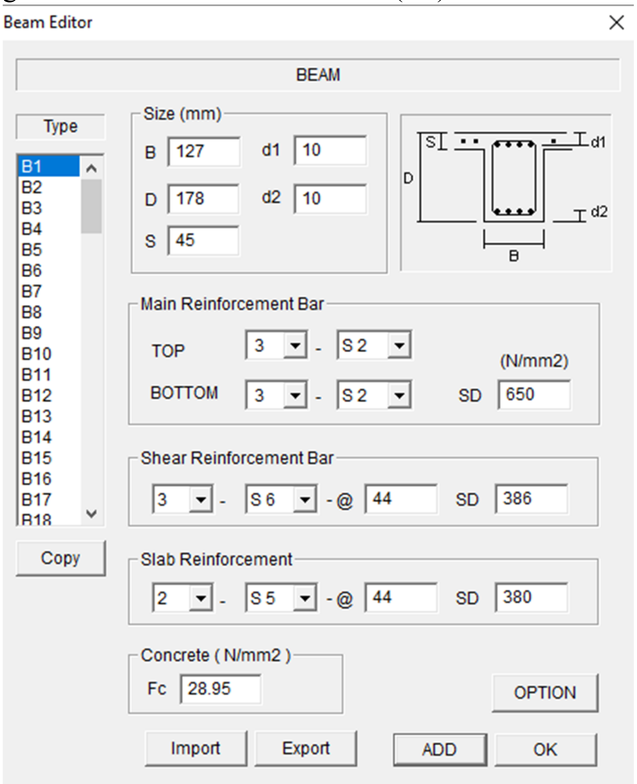
e. Definition of Custom Area Rebar



f. Definition of Column Member (C1)



g. Definition of Beam Member (B1)



5. References

1. Maulana, T. I., Enkhtengis, B., & Saito, T. (2021). Proposal of Damage Index Ratio for Low-to Mid-Rise Reinforced Concrete Moment-Resisting Frame with Setback Subjected to Uniaxial Seismic Loading. Applied Sciences, 11(15), 6754. [CrossRef]
2. Wood, S.L. Experiments to Study the Earthquake Response of Reinforced Concrete Frames with Setbacks. Doctoral dissertation, University of Illinois at Urbana-Champaign, IL, USA, 1985.
3. Wood, S.L.; Sozen, M. Experiments to Study the Earthquake Response of Reinforced Concrete Frames with Setbacks (NEES-2011-1068). Available online: https://datacenterhub.org/deedsdv/publications/view/285 (accessed on 1 October 2020).
4. Shahrooz, B.M.; Moehle, J.P. *Experimental study of seismic response of RC setback buildings*; National Science Foundation Report; UCB: CA, USA, 1987.
5. Shahrooz, B.M.; Moehle, J.P. Experimental Study of Seismic Response of Reinforced Concrete Setback Buildings. Available online: https://datacenterhub.org/deedsdv/publications/view/293 (accessed on 1 October 2020).
6. Saito, T. Structural Earthquake Response Analysis, STERA_3D Version 10.8. Available online: http://www.rc.ace.tut.ac.jp/saito/software-e.html (accessed on 1 October 2020).