5. SEISMIC DESIGN PARAMETERS AND MODELING OF EXISTING RC STRUCTURES

5.1 General

An adequate seismic design is fundamental to ensure the safety of building occupants. The seismic design parameters, *viz.*, ductility, overstrength factor, response reduction factor are very important in the seismic evaluation of any structures. So, there is a need to calculate these parameters to understand the behavior of the structures. Modeling of existing reinforced concrete buildings from the Koyna-Warna region is done in the SeismoStruct software. Details of the seismic design parameters and this RC structure models are described in this chapter.

5.2 Response reduction factor (R)

The non-linear response of a structure through a response reduction factor (R-factor) is included in many current seismic design codes (Chaulagain *et al.* 2014). The response reduction factor is also named as response modification factor and behavior factor in various international codes. The response reduction factor (R-factor) is generally used to minimize elastic response to inelastic response structures. In other words, the response reduction factor is defined as the ratio of the elastic strength to inelastic design strength as shown in Figure 5.1. According to the ATC-19 code, the R-factor is mainly a function of three factors, viz. ductility reduction factor, overstrength factor, and redundancy factor. It is mathematically expressed as

$$R = R_d \times R_o \times R_R \quad (5.1)$$

where, R is the response reduction factor, R_d is the ductility reduction factor, R_o is the overstrength factor, and R_R is the redundancy factor. Figure 5.1 provides an explanation of all these factors. According to the BIS (Bureau of Indian Standards) code provisions, it is mathematically represented as follows (Chaulagain *et al.* 2014; Shendkar *et al.* 2020; Shendkar *et al.* 2021).

$$2R = R_d \times R_o \quad (5.2)$$

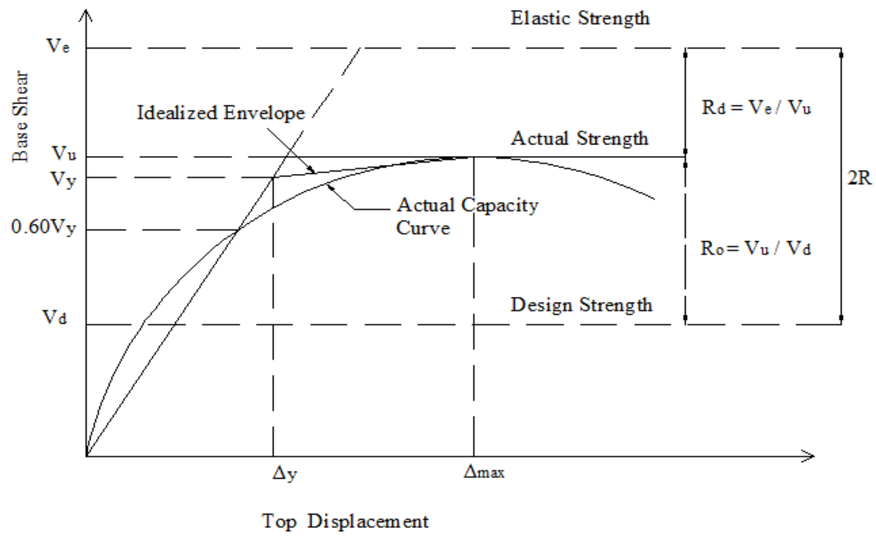


Figure 5.1 Interrelation between response reduction factor (R), overstrength factor (R_o), and ductility reduction factor (R_d)

The recommended values by the IS1893 (Part1): 2016 for the response reduction factor are given in Table 5.1.

Table 5.1 Response reduction factor recommended by IS 1893 (Part-1):2016

Frame System	R-factor
OMRF (Ordinary Moment Resisting Frame)	3
SMRF (Special Moment Resisting Frame)	5

5.3 Ductility reduction factor (R_d)

The ductility reduction factor provides a measure of the global nonlinear response of a structure. It mainly depends on, ductility and fundamental time period of structure. The ductility (μ) can be defined as the structure which undergoes an inelastic deformation without loss of significant strength and it is expressed as

$$\mu = \frac{\Delta_{max}}{\Delta_y} \tag{5.3}$$

Δ_{max} = maximum displacement corresponding to peak base shear, and Δ_y = yield displacement is calculated based on equal energy principle as shown in Figure 5.1. The equal energy principle means the area under the actual (real) curve is equal to area above the real curve. The bilinearization of pushover curve is done based on the ASCE 41-06 code. The relationship between the ductility and ductility reduction factor developed by the Newmark and Hall (1982) as follows:

If, Time period < 0.2 Seconds $\quad R_d = 1$

If, 0.2 seconds < Time period < 0.5 Seconds $\quad R_d = \sqrt{2\mu - 1}$ (5.4)

If, Time period > 0.5 Seconds $\quad R_d = \mu$

5.4 Overstrength factor (R_o)

The additional strength beyond the design strength is called the over strength. The main sources of overstrength are: (i) The difference between the actual and design material strength, (ii) load factors and their combination, (iii) participation of nonstructural elements such as infill walls, (iv) redundancy, (v) serviceability limit state provisions, (vi) member sizes, (vii) actual confinement effects. Overstrength factor is the ratio of ultimate strength to the design strength of structure as shown in Eq. (5.5)

$$R_d = \frac{V_u}{V_d} \tag{5.5}$$

Where, V_u is the ultimate strength, and V_d is the design strength of structure.

5.5 Redundancy (R_R)

The redundancy is usually defined as the gap between the local yield point to the global yield point of a structure. Any building should have a high degree of redundancy for the lateral resistance. In this study the redundancy factor is incorporated into the overstrength factor.

5.6 Performance point

In this study, the performance point is calculated according to the displacement coefficient method. This approach employs a direct numerical operation to calculate the expected displacement of the structures under earthquake impact. It is an approach that does not need to transform the capacity curve into spectral coordinates. Performance point is also called as a target displacement. The target displacements for structural models are calculated according to the ASCE 41-06.

$$\delta_t = C_0 C_1 C_2 S_a \frac{T_e^{\,2}}{4\Pi^2} g \tag{5.6}$$

where, δ_t is the target displacement; C_0 is the modification factor calculated from displacements of the building such as the roof displacement and the spectral displacement of an equivalent (SDOF) system; C_1 is also a factor for modification that used to relate the expected maximum inelastic displacement to the calculated displacement for the linear elastic response; C_2 is also a modification factor to correspond the impact of strength deterioration, cyclic stiffness degradation, and pinched hysteresis shape on the peak displacement response; S_a is the response spectra acceleration that obtained in the effective time period (T_e), T_e is the effective fundamental period of the structure; g is the gravitational acceleration. These modification factors are calculated from Table 3-2 in ASCE 41-06. The calculation of C_1 and C_2 is given in Eq. (5.7)

$$C_1 = 1 + \frac{R-1}{aT_e^2} g, \quad C_2 = 1 + \frac{1}{800}\left(\frac{R-1}{T_e^2}\right)^2, \quad R = \frac{S_a}{V_y / W} C_m \tag{5.7}$$

Where, α is the site class factor determined according to 3.3.3.3.2 of ASCE 41-06; V_y is the strength at yield point; W is the total seismic weight of building; C_m is the effective mass factor obtained from Table 3-1 in ASCE 41-06 and R is a ratio calculated from two parameters such as yield strength coefficient and demand elastic strength. The parameter S_a is expressed as:

$$S_a = S_{xs}\left[\left(\frac{5}{B_1} - 2\right)\frac{T}{T_s} + 0.4\right] \qquad 0 < T < T_0 \tag{5.8}$$

$$S_a = \frac{S_{xs}}{B_1} \qquad T_0 \leq T \leq T_s \tag{5.9}$$

$$S_a = \frac{S_{x1}}{(B_1 T)} \qquad T > T_s \tag{5.10}$$

where, T_s is the characteristic period of the response spectra, S_{xs} is a parameter that indicated as spectral response acceleration at 0.2sec; S_{x1} is a parameter that expressed as spectral response acceleration at 1sec; T is an effective fundamental period; T_0 is the period correlated with the variable acceleration segment of the spectra. T_S and T_0 expressions are given in Eq. (5.11) as per the ASCE 41-06.

$$T_s = \frac{S_{x1}}{S_{xs}}, \quad T_0 = 0.2T_S \tag{5.11}$$

The parameters S_{xs} and S_{x1} are calculated as per the design basis earthquake (DBE) & maximum considered earthquake (MCE) acceleration response spectrum of Koyna-Warna region for life safety and collapse prevention purpose respectively. The value for B_1 can be calculated from the Eq. (5.12).

$$B_1 = \frac{4}{\left[5.6 - \ln(100B)\right]} \tag{5.12}$$

where, B is the effective viscous damping.

5.7 Modeling of existing reinforced concrete structures

5.7.1 Model-1

The first building presented in this study is a residential ordinary moment-resisting RC framed building (Figure 5.2-5.4), located in Zone IV (Koyna-Warna Region). It is an open ground storey RC building. The plan dimensions of the building are 14.40 m × 9.10 m. Table 5.2 shows the material and sectional details, obtained from available structural drawings. Beam and column section details are shown in Figure 5.5

Figure 5.2 Front view of the three-storey RC building

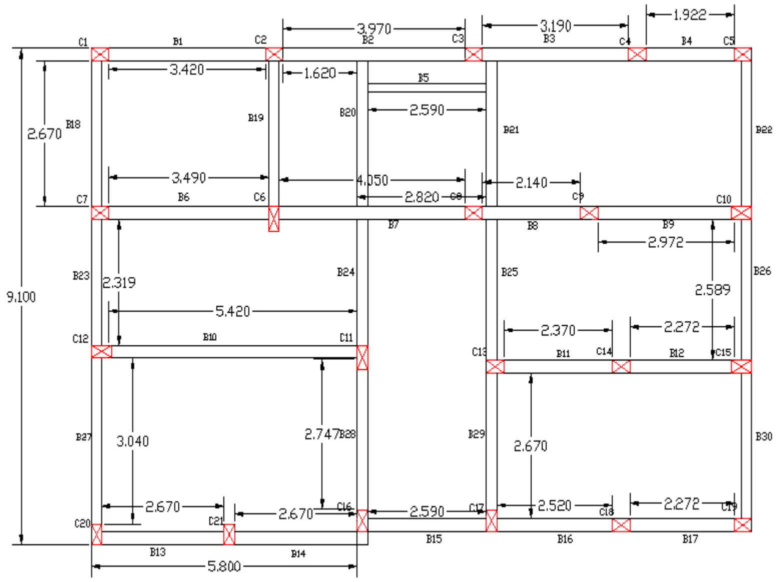


Figure 5.3 The plan of the three-storey RC building

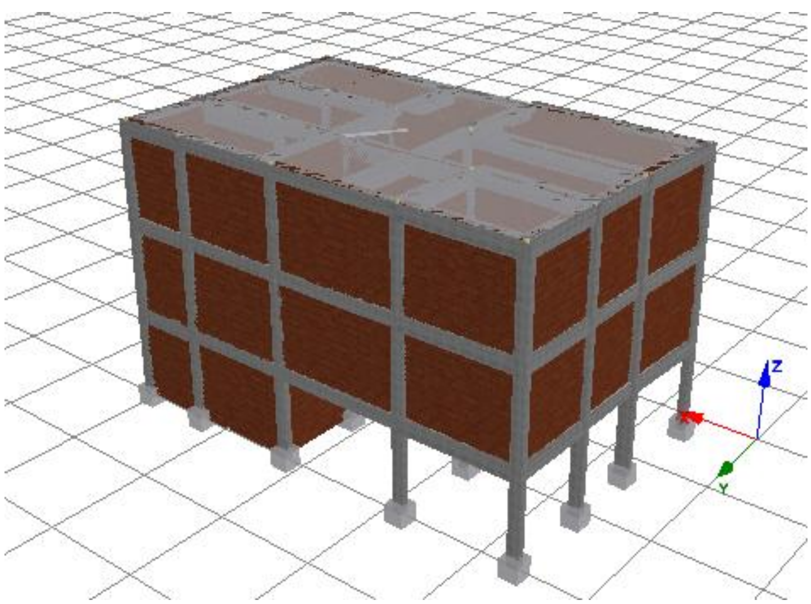
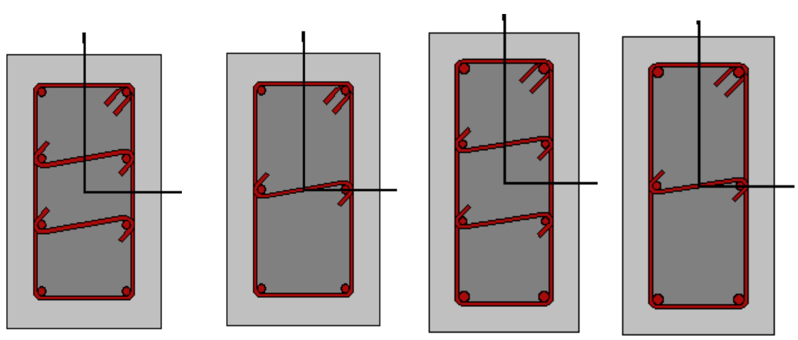


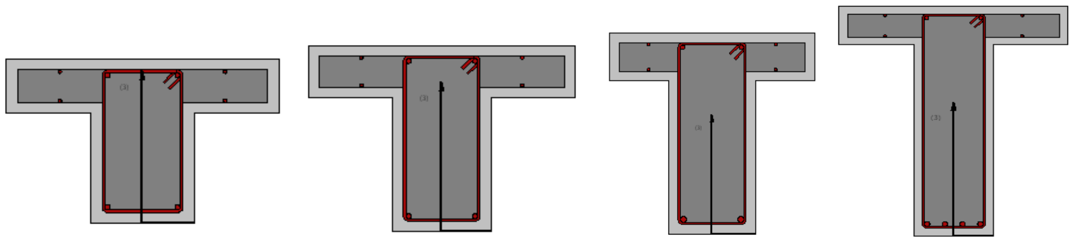
Figure 5.4 The model of the three-storey RC building

Table 5.2 Material and sectional details of the three-storey RC building	
Structural system	Ordinary moment resistant RC frame
Number of total storey	3 (G+2)
Height of stories (m)	3
Year of construction	2019
Name of building	Abdul Mukadam building (Residential)
Diagonal compressive strength of infill- f_m (MPa)	1.32
Thickness of infill (mm)	230 external , 115 internal
Concrete grade	M 20
Reinforcement grade	Fe-415
Size of columns (mm) Reinforcement	230×380, 230×450, 4-12 Ø at corners and, 4-12 Ø along longer side , 6 Ø @150 c/c 4-16 Ø at corners and, 4-12 Ø along longer side, 6 Ø @150 c/c
Size of beams (mm) Reinforcement	230×380, 230×450, 230×530, 230×750 2-12 Ø at top and bottom, 6 Ø @150 c/c, 2-12 Ø at top and bottom, 6 Ø @150 c/c, 2-16 Ø at bottom and 2-12 Ø at top, 6 Ø @150 c/c, 4-16 Ø at bottom and 2-12 Ø at top, 6 Ø @150 c/c
Thickness of slabs (mm)	125



(a) **(b)** **(c)** **(d)**

Figure 5.5 (a) cross section of 230×380 column at ground and first floor, (b) cross section of 230×380 column at second floor, (c) cross section of 230×450 column at ground and first floor, (d) cross section of 230×450 column at second floor.



(a) **(b)** **(c)** **(d)**

Figure 5.6 Cross section of beam (a) 230×380, (b) 230×450, (c) 230×530, and (d) 230×750

Similarly, the cross section of beams and columns of other buildings is shown in tabular form.

5.7.2 Model-2

The second building presented in this study is a four storey ordinary moment-resisting RC framed building (Figure 5.7-5.9), located in Zone IV (Koyna-Warna Region).The plan dimensions of the building are 14.40 m × 3.80 m. Table 5.3 shows the material and sectional details of the structure.

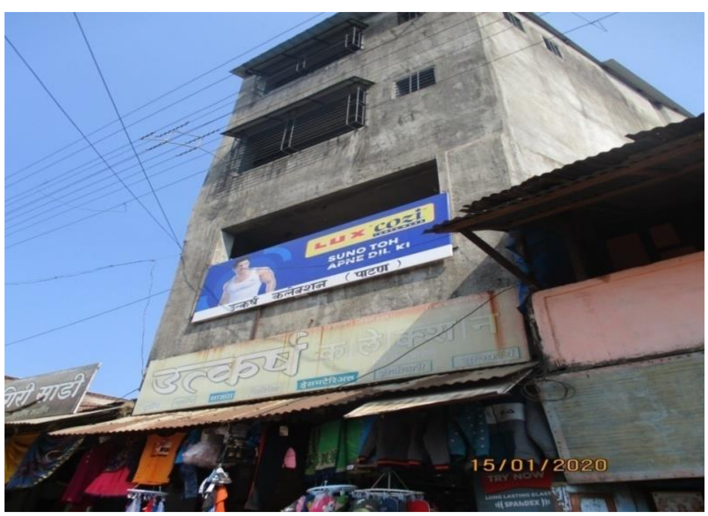


Figure 5.7 Front view of the four-storey RC building

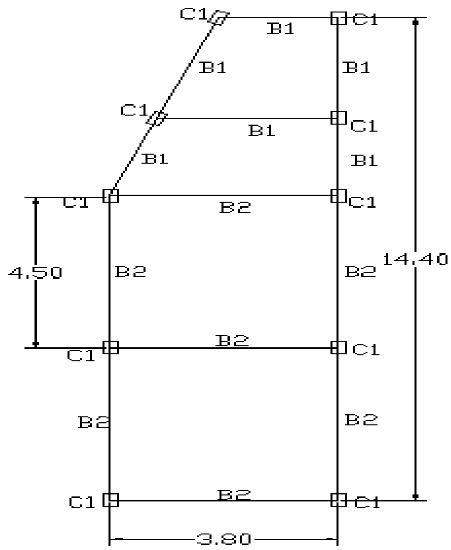


Figure 5.8 The plan of the four-storey RC building

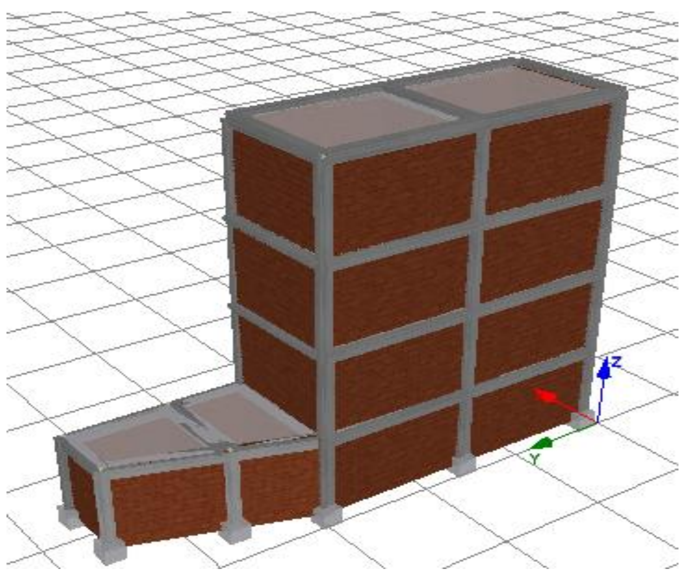


Figure 5.9 The model of the four-storey RC building

Table 5.3 Material and sectional details of the four-storey RC building

Structural system	Ordinary moment-resisting frame
Number of total storey	4 (G+3)
Height of stories (m)	3
Year of construction	2007
Name of building	Dnyandeep building (Residential)
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external) , 115 (internal)
Concrete Grade	M 20
Reinforcement Grade	Fe-415
Size of columns (mm) Reinforcement	230×380 4-16 Ø at corners and 4-16 Ø along longer side, 6 Ø @150 c/c
Size of beams (mm) Reinforcement	230×350, 230×400 2-16 Ø at bottom and 2-12 Ø at top, 6 Ø @ 200 c/c, 2-16 Ø at bottom and 2-12 Ø at top, 6 Ø @ 200 c/c
Thickness of slabs (mm)	125

5.7.3 Model-3

The third building presented in this study is a four storey ordinary moment-resisting RC framed building (Figure 5.10-5.12), located in Zone IV (Koyna-Warna Region). The plan dimensions of the building are 14.93m × 8.53m. Table 5.4 shows the material and sectional details of the structure.

Figure 5.10 Front view of the four-storey RC building

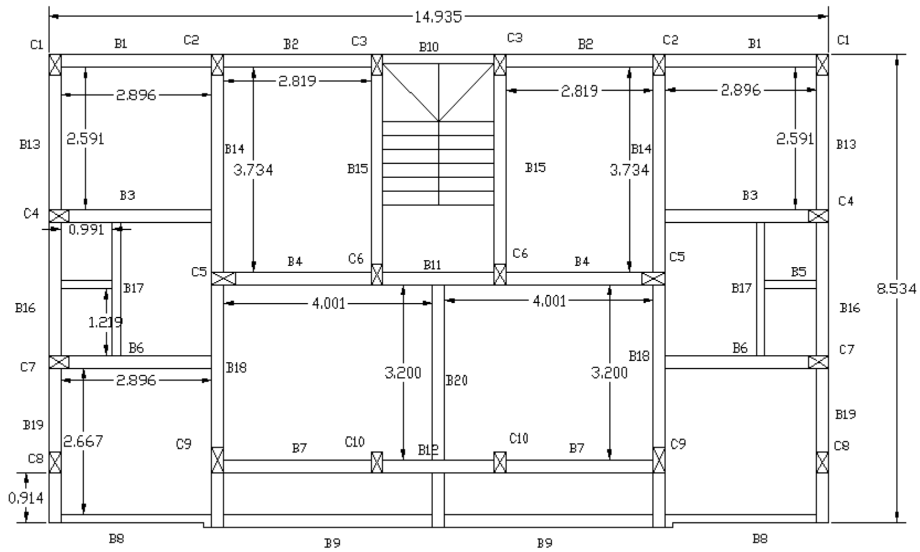


Figure 5.11 The plan of the four-storey RC building

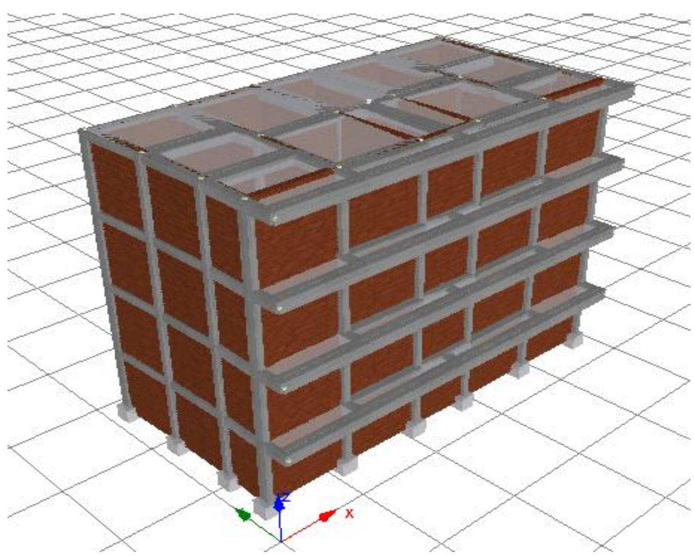


Figure 5.12 The model of the four-storey RC building

Table 5.4 Material and sectional details of the four-storey RC building	
Structural system	Ordinary moment-resisting frame
Number of total storey	4
Height of stories (m)	3
Year of construction	2018
Name of building	Ghadge Haribhau building (Residential)
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external) , 115 (internal)
Concrete Grade	M20
Reinforcement Grade	Fe-500
Size of columns (mm) Reinforcement	230×380, 230×450 4-12 Ø at corners and 2-12 Ø along longer side,6 Ø @150 c/c 4-16 Ø at corners and 4-16 Ø along longer side,6 Ø @150 c/c
Size of beams (mm) Reinforcement	230×300, 230×380, 230×450 2-12 Ø at bottom and 2-12 Ø at top, 6 Ø @ 150 c/c 2-12 Ø at bottom and 2-12 Ø at top, 6 Ø @ 150 c/c 2-12 Ø at bottom and 2-12 Ø at top, 6 Ø @ 150 c/c
Thickness of slabs (mm)	150

5.7.4 Model-4

The fourth building presented in this study is a single storey ordinary moment-resisting RC framed school building (Figure 5.13-5.15), located in Zone IV (Koyna-Warna Region). The plan dimensions of the building are 57.75m×19.60m. Table 5.5 shows the material and sectional details of the structure.

Figure 5.13 Front view of the single-storey RC building

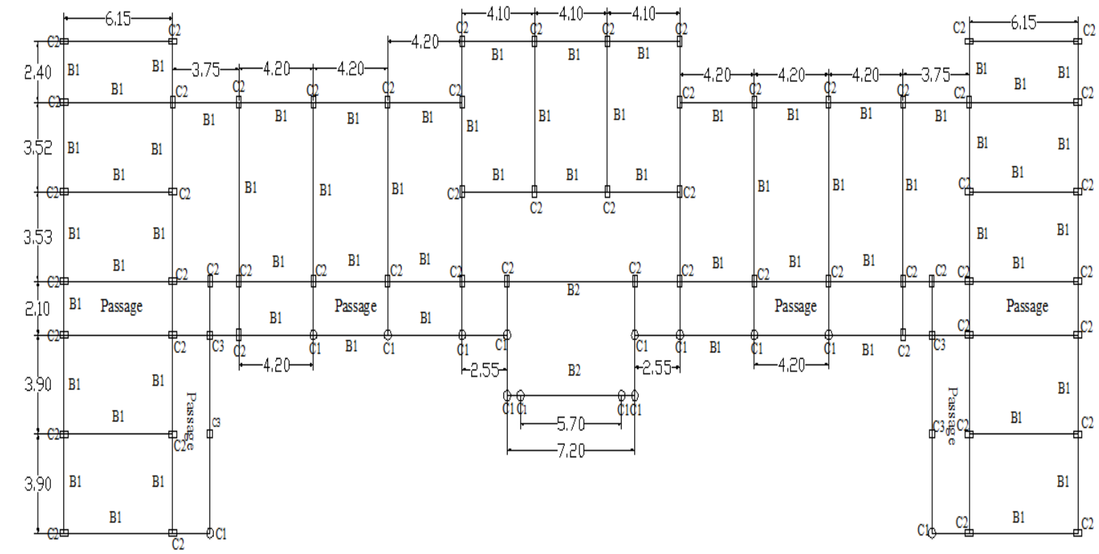


Figure 5.14 The plan of the single-storey RC building

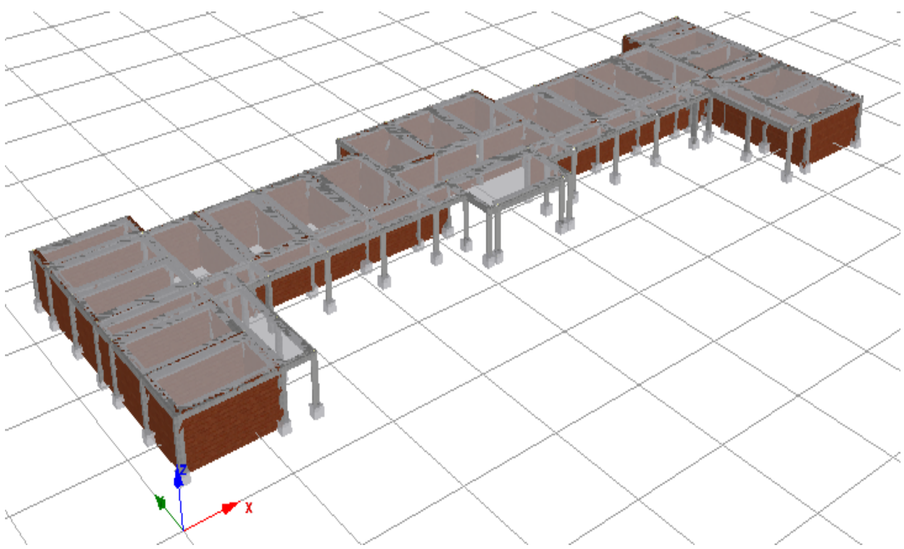


Figure 5.15 The model the single-storey RC building

Table 5.5 Material and sectional details of the single-storey RC building	
Structural system	Ordinary moment-resisting frame
Number of total storey	1
Height of stories (m)	3.1
Year of construction	2007
Name of building	Guruvarya Lalasaheb Patankar Vidyalay (School building)
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external), 115 (internal)
Concrete Grade	M20
Reinforcement Grade	Fe-415
Size of columns (mm) Reinforcement	250×450, 300×300, 400 mm dia. circular column 4-16 Ø at corners and 2-12 Ø along longer side,8 Ø @180c/c, 4-16 Ø at corners , 8 Ø @170 c/c, 8-18 Ø at peripheral, 8 Ø @150 c/c
Size of beams (mm) Reinforcement	250×300, 250×400 2-20 Ø at bottom and 2-12 Ø at top, 8 Ø @ 200 c/c, 2-20 Ø at bottom and 2-12 Ø at top, 8 Ø @ 200 c/c
Thickness of slabs (mm)	150

5.7.5 Model-5

The fifth building presented in this study is a three storey ordinary moment-resisting RC framed commercial building (Figure 5.16-5.18), located in Zone IV (Koyna-Warna Region). The plan dimensions of the building are 11.58m×11.49m. Table 5.6 shows the material and sectional details of the structure.

Figure 5.16 Front view of the three-storey RC building

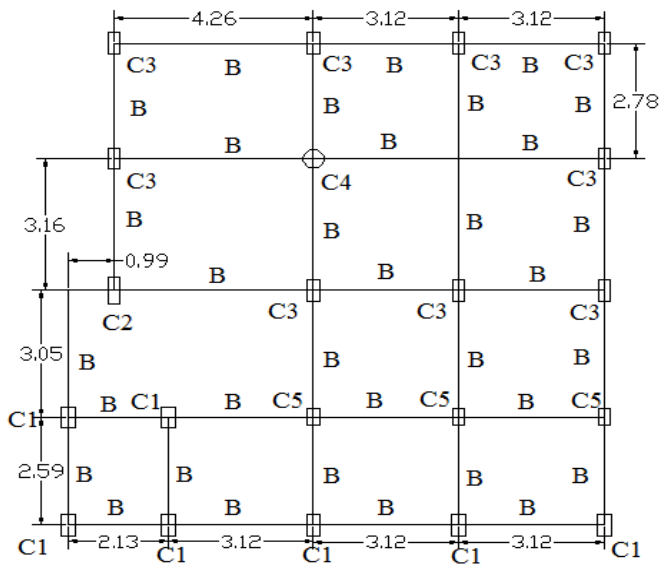


Figure 5.17 The plan of the three-storey RC building

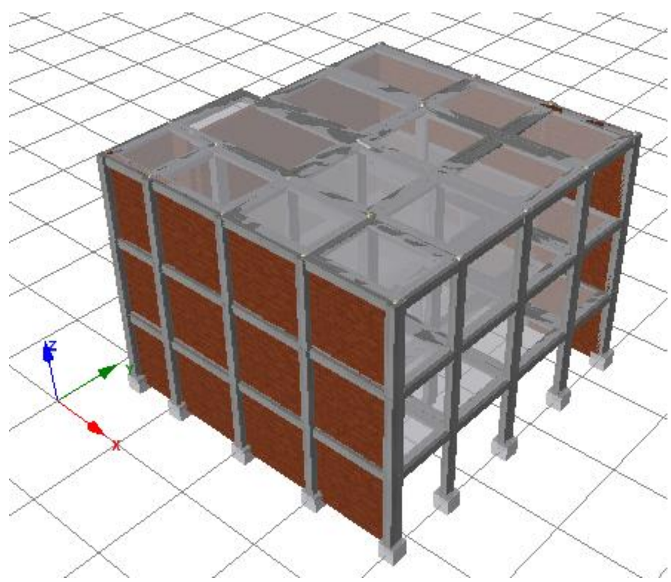


Figure 5.18 The model of the three-storey RC building

Table 5.6 Material and sectional details of the three-storey RC building

Structural system	Ordinary moment-resisting frame
Number of total storey	3 (G+2)
Height of stories (m)	3
Year of construction	2014
Name of building	Hero showroom (Commercial)
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external), 115 (internal)
Concrete Grade	M15
Reinforcement Grade	Fe-415
Size of columns (mm) Reinforcement	300×500, 250×630, 250×500, 250×450, 250×400, 440 mm dia. 4-25 Ø at corners and 4-16 Ø along longer side,6 Ø @160 c/c, 4-25 Ø at corners and 4-16 Ø along longer side, 6 Ø @180 c/c, 4-25 Ø at corners and 4-16 Ø along longer side, 6 Ø @180 c/c 4-25 Ø at corners , 6 Ø @180 c/c, 4-25 Ø at corners , 6 Ø @190 c/c, 12-25 Ø at peripheral, 6 Ø @135 c/c,
Size of beam (mm) Reinforcement	250×300 2-16 Ø at bottom and 2-12 Ø at top, 6 Ø @ 180 c/c
Thickness of slabs (mm)	150

5.7.6 Model-6

The sixth building presented in this study is a three storey ordinary moment-resisting RC framed building (Figure 5.19-5.21), located in Zone IV (Koyna-Warna Region). The plan dimensions of the building are 20m×3m. Table 5.7 shows the material and sectional details of the structure.

Figure 5.19 Front view of the three-storey RC building

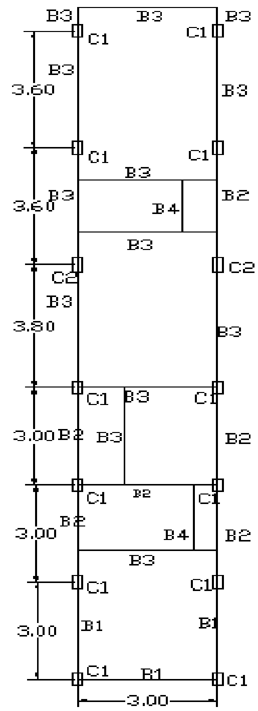


Figure 5.20 The plan of three-storey RC building

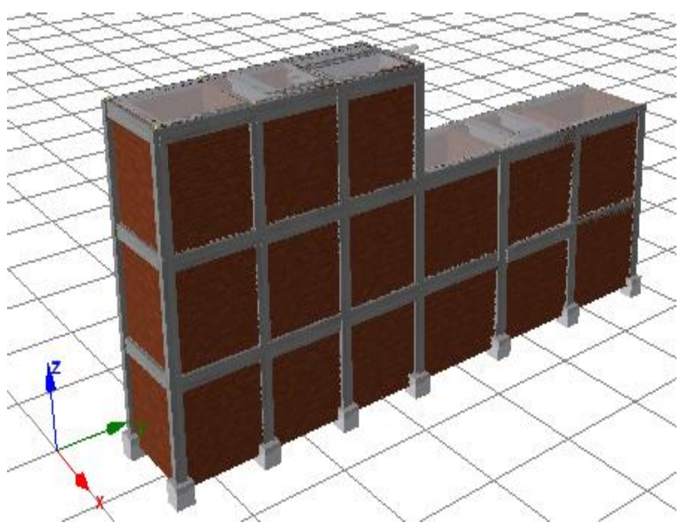


Figure 5.21 The model of three-storey RC building

Table 5.7 Material and sectional details of the three-storey RC building	
Structural system	Ordinary moment-resisting frame
Number of total storey	3 (G+2)
Height of stories (m)	3
Name of building	Khandke building
Year of construction	2020
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external), 115 (internal)
Concrete Grade	M20
Reinforcement Grade	Fe-415
Size of columns (mm) Reinforcement	230×380, 230×450 4-12 Ø at corners and 2-12 Ø along longer side,6 Ø @200 c/c 4-12 Ø at corners and 2-12 Ø along longer side,6 Ø @200 c/c
Size of beams (mm) Reinforcement	230×380, 230×450, 150×450, 150×380 2-12 Ø at bottom and 2-12 Ø at top, 6 Ø @ 200 c/c, 2-12 Ø at bottom and 2-12 Ø at top, 6 Ø @ 200 c/c, 2-12 Ø at bottom and 2-12 Ø at top, 6 Ø @ 200 c/c, 2-12 Ø at bottom and 2-12 Ø at top, 6 Ø @ 200 c/c
Thickness of slabs (mm)	125

5.7.7 Model-7

The seventh building presented in this study is a five storey ordinary moment-resisting RC framed building (Figure 5.22-5.24), located in Zone IV (Koyna-Warna Region). The plan dimensions of the building are 10.17m×7.32m. Table 5.8 shows the material and sectional details of the structure.

Figure 5.22 Front view of the five-storey RC building

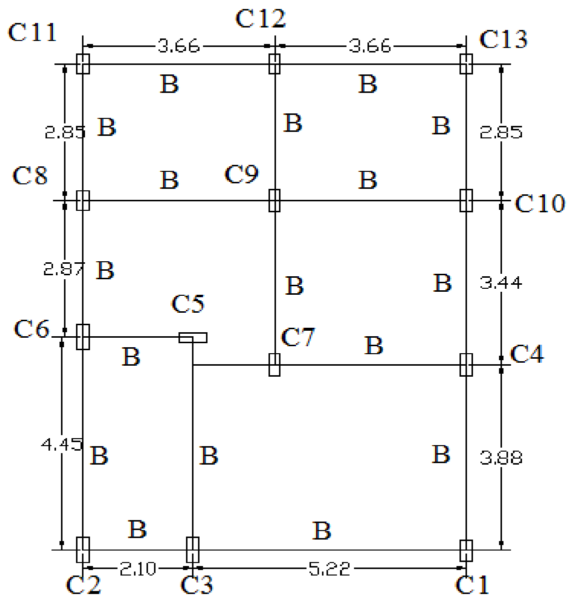


Figure 5.23 The plan of five-storey RC building

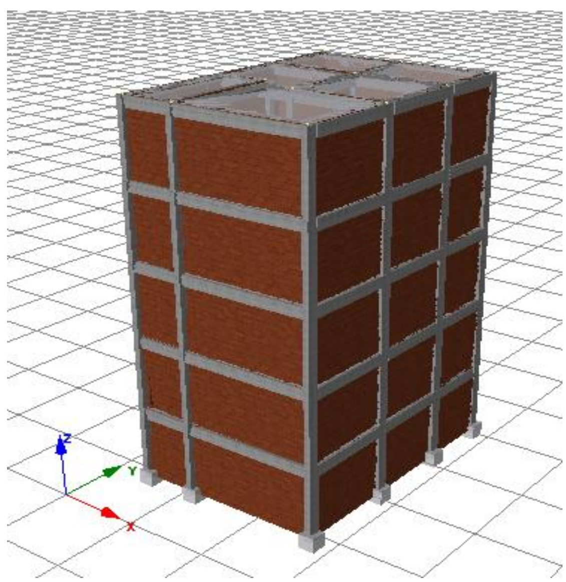


Figure 5.24 The model of five-storey RC building

Table 5.8 Material and sectional details of the five-storey RC building	
Structural system	Ordinary moment-resisting frame
Number of total storey	5 (G+4)
Height of stories (m)	3.1
Year of construction	2018
Name of building	Labdhe building
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external), 115 (internal)
Concrete Grade	M 20
Reinforcement Grade	Fe-500
Size of columns (mm) Reinforcement	230×525, 230×450, 230×400, 230×350 4-16 Ø at corners, 2-16 Ø along shorter , 6-12 Ø along longer side, 8 Ø @150 c/c, 4-16 Ø at corners, 6-12 Ø along longer side, 8 Ø @150 c/c, 4-12 Ø at corners, 6-12 Ø along longer side, 8 Ø @150 c/c, 4-12 Ø at corners, 2-12 Ø along longer side, 8 Ø @150 c/c
Size of beams (mm) Reinforcement	230×450 3-12 Ø at bottom and 2-12 Ø at top, 8 Ø @ 200 c/c,
Thickness of slabs (mm)	150

5.7.8 Model-8

The eighth building presented in this study is a three storey ordinary moment-resisting RC framed building (Figure 5.25-5.27), located in Zone IV (Koyna-Warna Region). It was in the constructing stage while doing the survey. The plan dimensions of the building are 16.45m×7.16m. Table 5.9 shows the material and sectional details of the structure.

Figure 5.25 Front view of the three-storey RC building

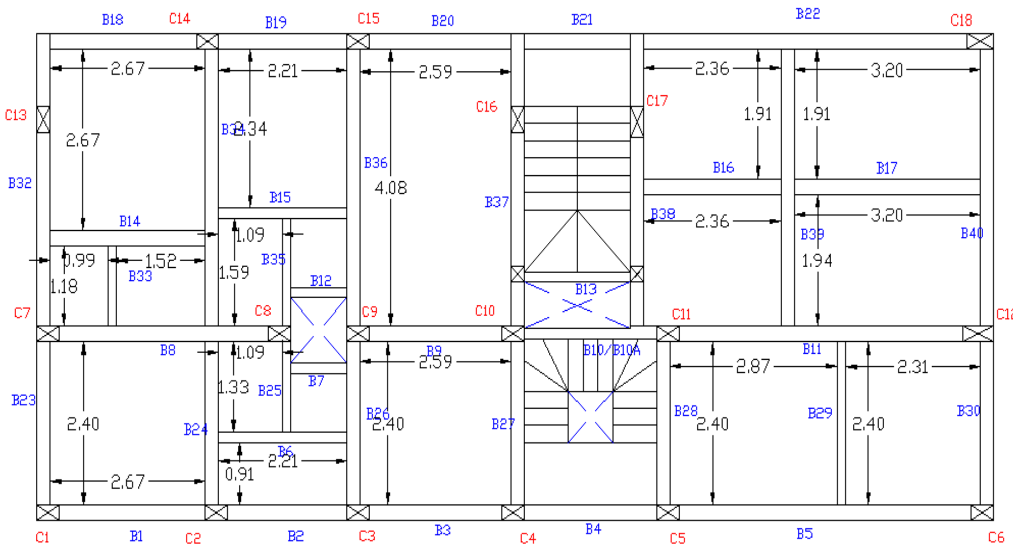


Figure 5.26 The plan of three-storey RC building

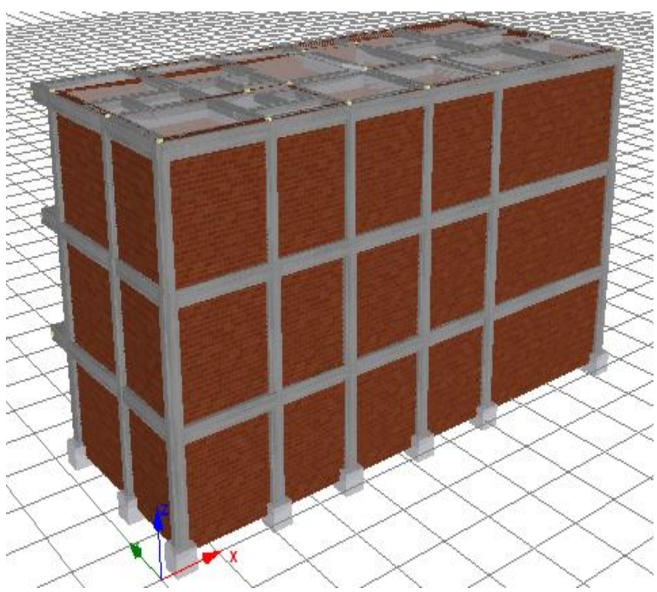


Figure 5.27 The model of three-storey RC building

Table 5.9 Material and sectional details of the three-storey RC building	
Structural system	Ordinary moment-resisting frame
Number of total storey	3 (G+2)
Height of stories (m)	3
Year of construction	2020
Name of building	Mane-Mahatne building
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external), 115 (internal)
Concrete Grade	M 20
Reinforcement Grade	Fe-415
Size of columns (mm) Reinforcement	230×380, 230×450, 230×530, 230×300 4-12 Ø at corners, 2-12 Ø along longer side, 6 Ø @150 c/c, 4-16 Ø at corners, 4-16 Ø along longer side, 8 Ø @150 c/c, 4-16 Ø at corners, 4-16 Ø along longer side, 8 Ø @150 c/c, 4-12 Ø at corners, 6 Ø @150 c/c
Size of beams (mm) Reinforcement	230×380, 150×380 2-12 Ø at bottom and 2-12 Ø at top, 6 Ø @ 150 c/c, 2-12 Ø at bottom and 2-12 Ø at top, 6 Ø @ 150 c/c
Thickness of slabs (mm)	125

5.7.9 Model-9

The ninth building presented in this study is a two storey ordinary moment-resisting RC framed building (Figure 5.28-5.30), located in Zone IV (Koyna-Warna Region). The plan dimensions of the building are 13.93m×9.98m. Table 5.10 shows the material and sectional details of the structure.

Figure 5.28 Front view of the two-storey RC building

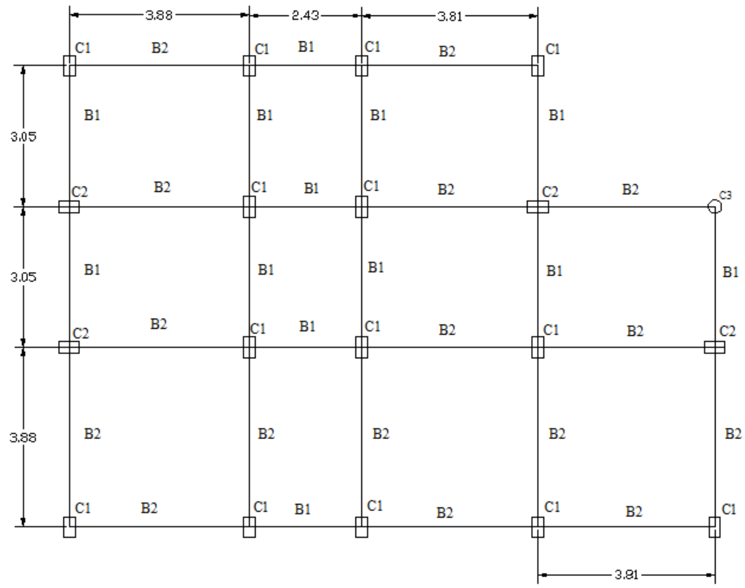


Figure 5.29 The plan of two-storey RC building

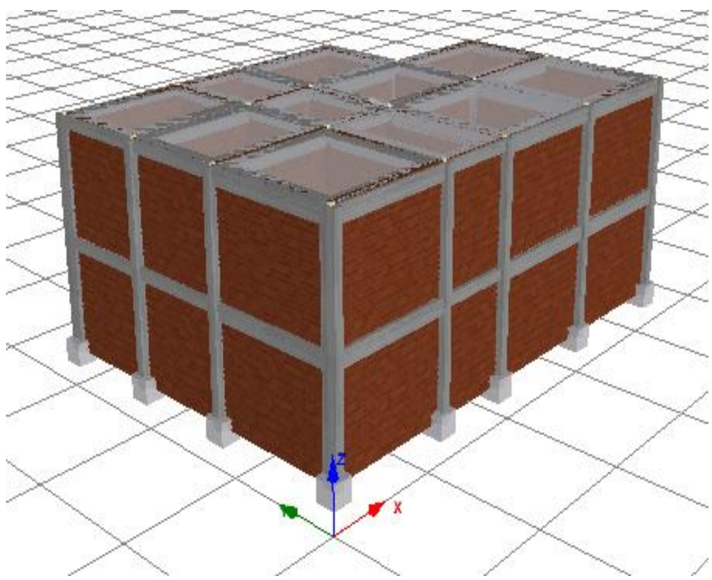


Figure 5.30 The model of two-storey RC building

Table 5.10 Material and sectional details of the two-storey RC building	
Structural system	Ordinary moment-resisting frame
Number of total storey	2 (G+1)
Height of stories (m)	3
Year of construction	2000
Name of building	Matru-Pitru Kunj
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external), 115 (internal)
Concrete Grade	M 15
Reinforcement Grade	Fe-415
Size of columns (mm) Reinforcement	250×450, 300 mm Dia. circular section, 4-18 Ø at corners, 4-16 Ø along longer side, 8 Ø @175 c/c, 6-16 Ø at peripheral, 8 Ø @140 c/c
Size of beams (mm) Reinforcement	250×300, 250×400 2-12 Ø at bottom and 2-12 Ø at top, 8 Ø @ 200 c/c, 2-12 Ø at bottom and 2-12 Ø at top, 8 Ø @ 200 c/c
Thickness of slab (mm)	150

5.7.10 Model-10

The tenth building presented in this study is a single storey ordinary moment-resisting RC framed building (Figure 5.31-5.33), located in Zone IV (Koyna-Warna Region). The plan dimensions of the building are 40.49m×10.35m. Table 5.11 shows the material and sectional details of the structure.

Figure 5.31 Front view of the single-storey RC building

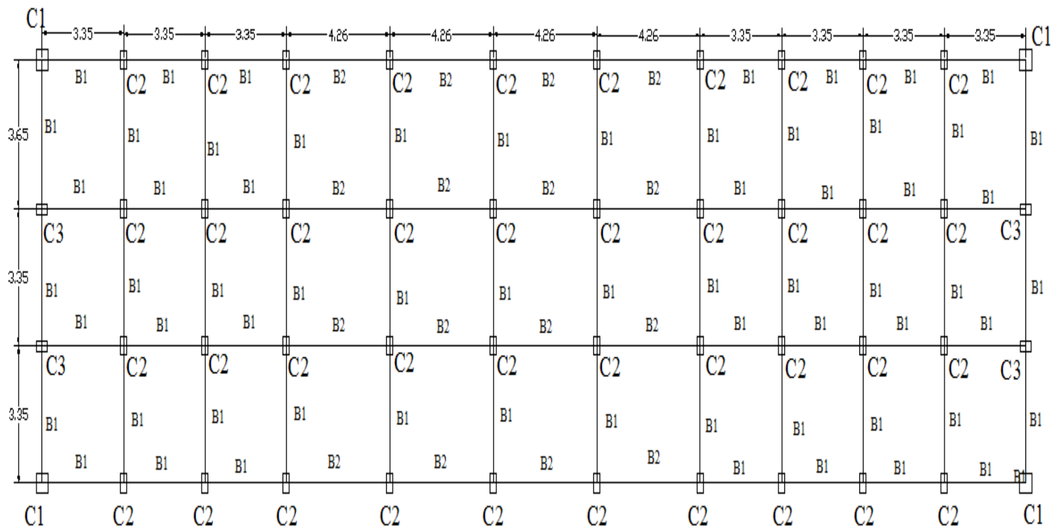


Figure 5.32 The plan of single-storey RC building

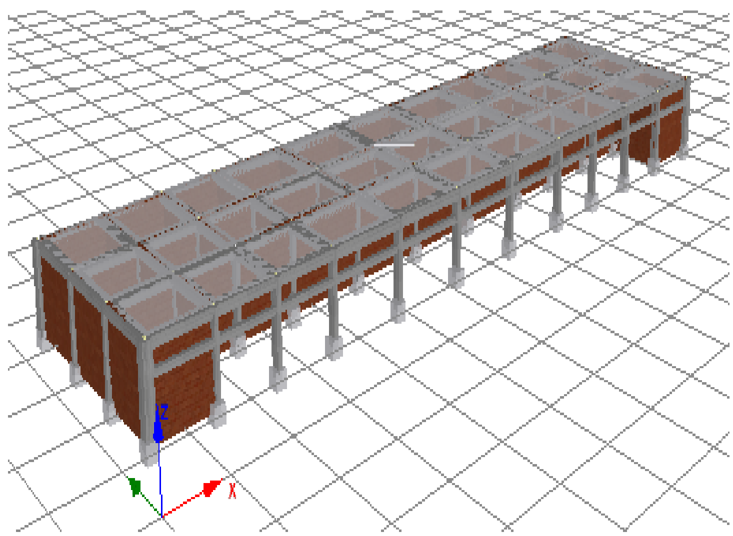


Figure 5.33 The model of single-storey RC building

Table 5.11 Material and sectional details of the single-storey RC building	
Structural system	Ordinary moment-resisting frame
Number of total storey	1
Height of stories (m)	3
Year of construction	2015
Name of building	New English School, Mirgaon
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external), 115 (internal)
Concrete Grade	M 15
Reinforcement Grade	Fe-415
Size of columns (mm) Reinforcement	500×500, 250×450 4-16 Ø at corners, 8-12 Ø at middle, 8 Ø @200c/c, 4-25 Ø at corners, 4-16 Ø at middle, 8 Ø @155c/c
Size of beams (mm) Reinforcement	250×350, 250×400, 250×250 2-12 Ø at bottom and 2-12 Ø at top, 8 Ø @ 200 c/c, 2-12 Ø at bottom and 2-12 Ø at top, 8 Ø @ 200 c/c, 4-10 Ø at corners, 8 Ø @ 220 c/c
Thickness of slab (mm)	125

5.7.11 Model-11

The eleventh building presented in this study is a three storey ordinary moment-resisting RC framed building (Figure 5.34-5.36), located in Zone IV (Koyna-Warna Region). The plan dimensions of the building are 30m×4.95m. Table 5.12 shows the material and sectional details of the structure.

Figure 5.34 Front view of the three-storey RC building

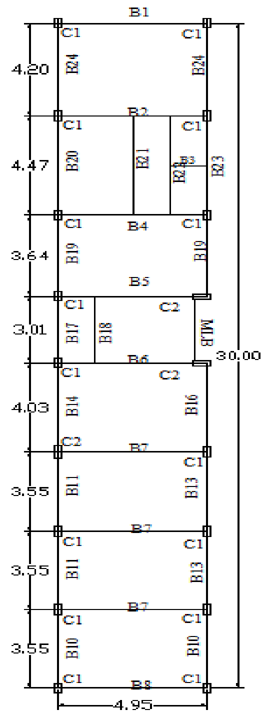


Figure 5.35 The plan of three-storey RC building

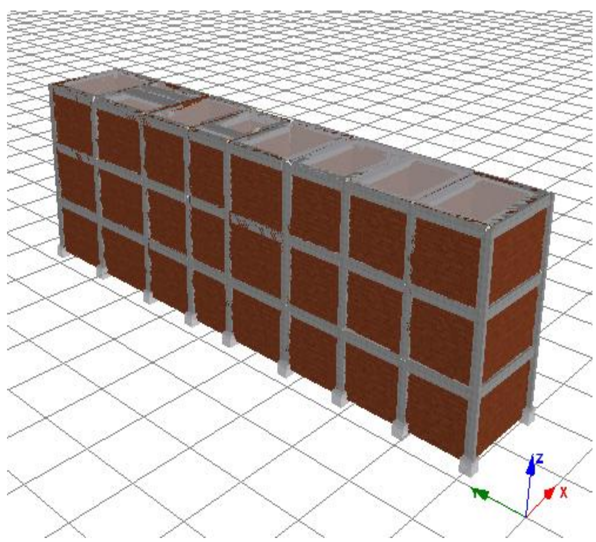


Figure 5.36 The model of three-storey RC building

Table 5.12 Material and sectional details of the three-storey RC building	
Structural system	Ordinary moment-resisting frame
Number of total storey	3 (G+2)
Height of stories (m)	3.1
Year of construction	2020
Name of building	Pooja Traders
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external), 115 (internal)
Concrete Grade	M20
Reinforcement Grade	Fe-500
Size of columns (mm) Reinforcement	230×450, 230×600, 230×530 4-12 Ø at corners, 6-12 Ø along longer side, 6 Ø @125c/c, 4-12 Ø at corners, 6-12 Ø along longer side, 6 Ø @125c/c, 4-12 Ø at corners, 4-12 Ø along longer side, 6 Ø @125c/c
Size of beams (mm) Reinforcement	150×450, 230×450, 150×250 3-12 Ø at bottom and 2-10 Ø at top, 6 Ø @ 150 c/c, 4-12 Ø at bottom and 2-10 Ø at top, 6 Ø @ 150 c/c, 3-12 Ø at bottom and 2-10 Ø at top, 6 Ø @ 150 c/c
Thickness of slabs (mm)	125

5.7.12 Model-12

The twelfth building presented in this study is a single storey ordinary moment-resisting RC framed building (Figure 5.37-5.39), located in Zone IV (Koyna-Warna Region). The plan dimensions of the building are 21.35m×15.25m. Table 5.13 shows the material and sectional details of the structure.

Figure 5.37 Front view of the single-storey RC building

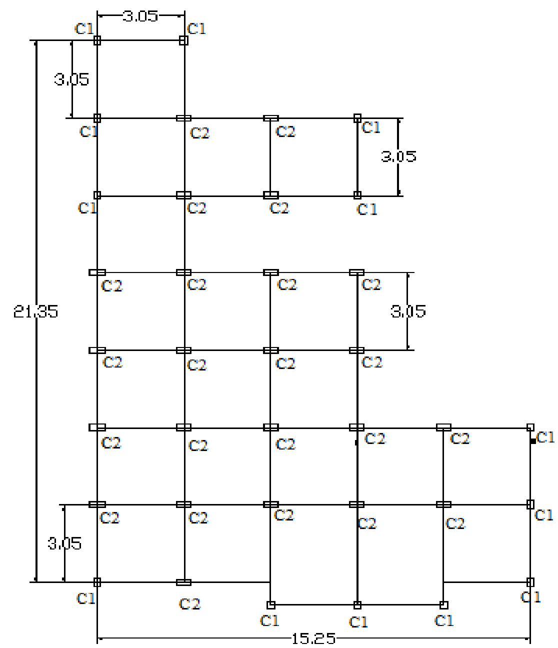


Figure 5.38 The plan of the single-storey RC building

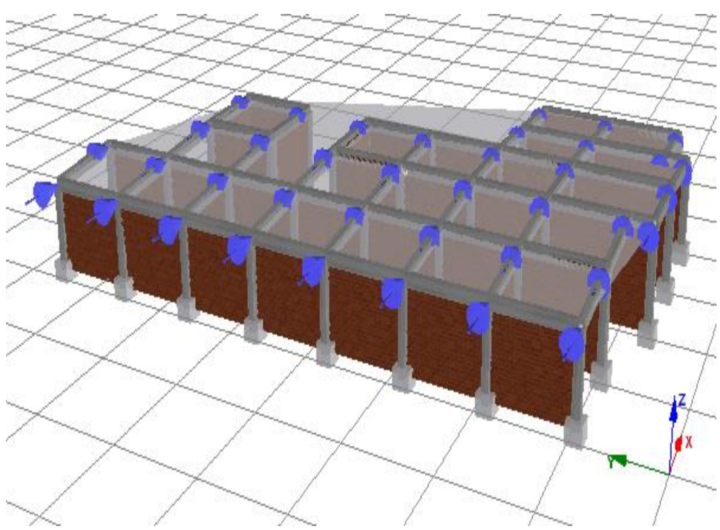


Figure 5.39 The model of single-storey RC building

Table 5.13 Material and sectional details of the single-storey RC building	
Structural system	Ordinary moment-resisting frame
Number of total storey	1
Height of stories (m)	2.55
Year of construction	1985
Name of building	Primary Health Center (PHC)
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external), 115 (internal)
Concrete Grade	M20
Reinforcement Grade	Fe-415
Size of columns (mm) Reinforcement	250×300, 250×500 4-16 Ø at corners, 8 Ø @160c/c 4-16 Ø at corners, 4-16 Ø along longer side, 8 Ø @200c/c
Size of beams (mm) Reinforcement	250×350 2-12 Ø at bottom and 2-12 Ø at top, 8 Ø @ 180 c/c
Thickness of slabs (mm)	125

5.7.13 Model-13

The thirteenth building presented in this study is a three storey ordinary moment-resisting RC framed building (Figure 5.40-5.42), located in Zone IV (Koyna-Warna Region). The plan dimensions of the building are 30.45m×13.40m. Table 5.14 shows the material and sectional details of the structure.

Figure 5.40 Front view of the three-storey RC building

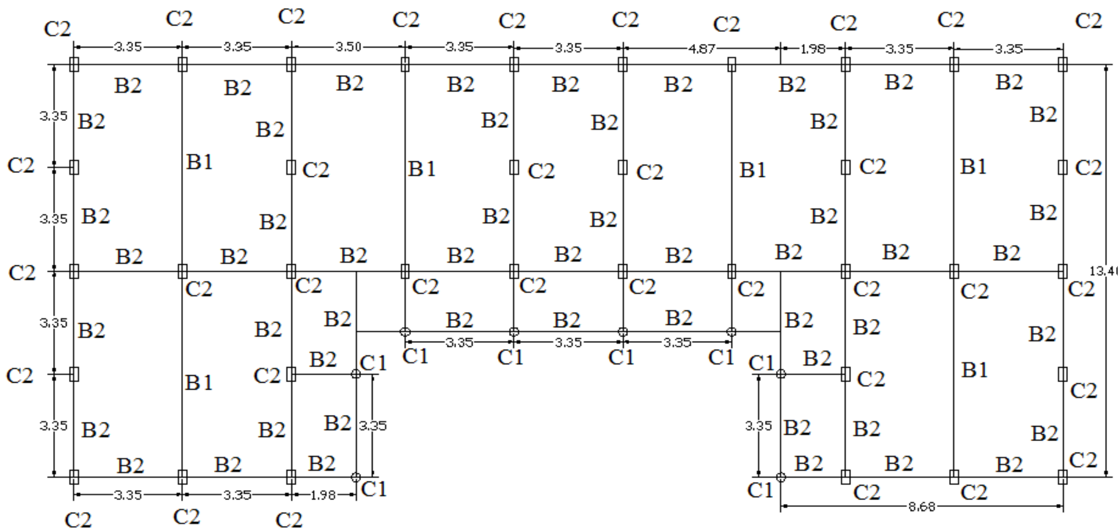


Figure 5.41 The plan of the three-storey RC building

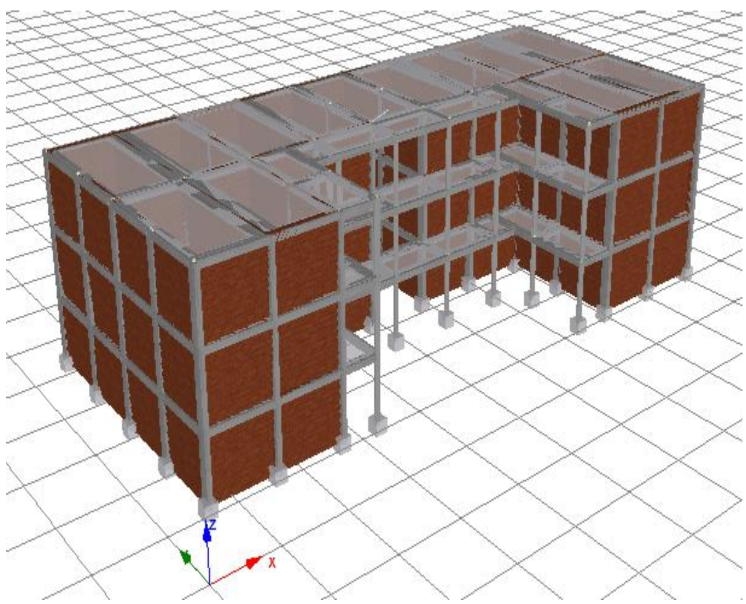


Figure 5.42 The model of three-storey RC building

Table 5.14 Material and sectional details of the three-storey RC building	
Structural system	Ordinary moment-resisting frame
Number of total storey	3(G+2)
Height of stories (m)	3
Year of construction	2000
Name of building	Shivanjali Shikshan Sanstha English Medium School
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external), 115 (internal)
Concrete Grade	M20
Reinforcement Grade	Fe-500
Size of columns (mm) Reinforcement	250×450, 280 mm Dia. circular column 4-12 Ø at corners, 2-12 Ø along longer side, 8 Ø @150 c/c, 6-12 Ø at peripheral, 8 Ø @175 c/c
Size of beams (mm) Reinforcement	250×400, 250×300 2-20 Ø at bottom and 2-12 Ø at top, 8 Ø @ 110 c/c 2-20 Ø at bottom and 2-12 Ø at top, 8 Ø @ 110 c/c
Thickness of slabs (mm)	125

5.7.14 Model-14

The fourteenth building presented in this study is a two storey ordinary moment-resisting RC framed building (Figure 5.43-5.45), located in Zone IV (Koyna-Warna Region). The plan dimensions of the building are 56.95m×7.30m. Table 5.15 shows the material and sectional details of the structure.

Figure 5.43 Front view of the two-storey RC building

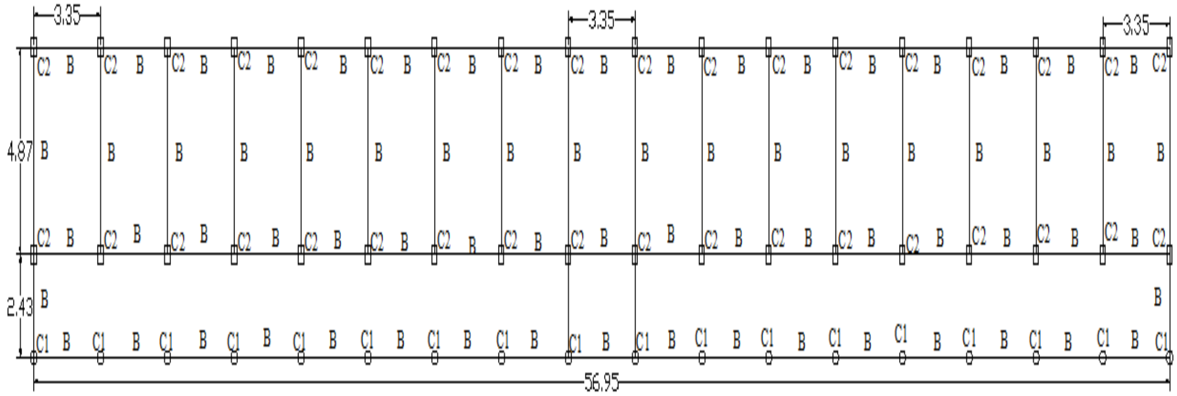


Figure 5.44 The plan of the two-storey RC building

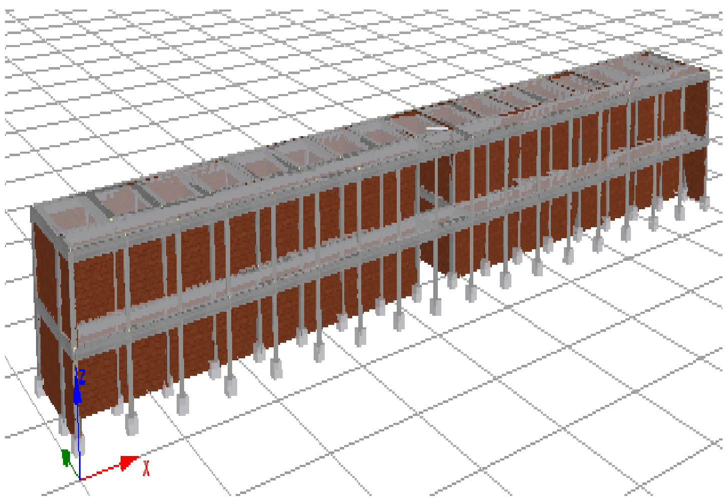


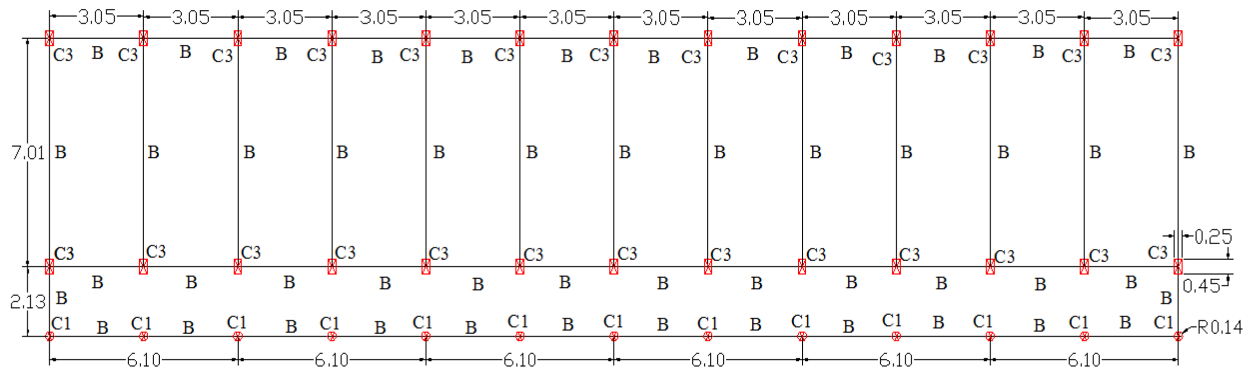
Figure 5.45 The model of two-storey RC building

Table 5.15 Material and sectional details of the two-storey RC building	
Structural system	Ordinary moment-resisting frame
Number of total storey	2 (G+1)
Height of stories (m)	3.1
Year of construction	2005
Name of building	Shri Shetrapal Vidyalay & Jr. College
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external), 115 (internal)
Concrete Grade	M15
Reinforcement Grade	Fe-415
Size of columns (mm) Reinforcement	250×450, 320 mm Dia. circular column 4-16 Ø at corners, 2-16 Ø along longer side, 8 Ø @150 c/c 6-16 Ø at peripheral, 8 Ø @150 c/c
Size of beams (mm) Reinforcement	250×400 2-20 Ø at bottom and 2-12 Ø at top, 8 Ø @ 170 c/c
Thickness of slabs (mm)	125

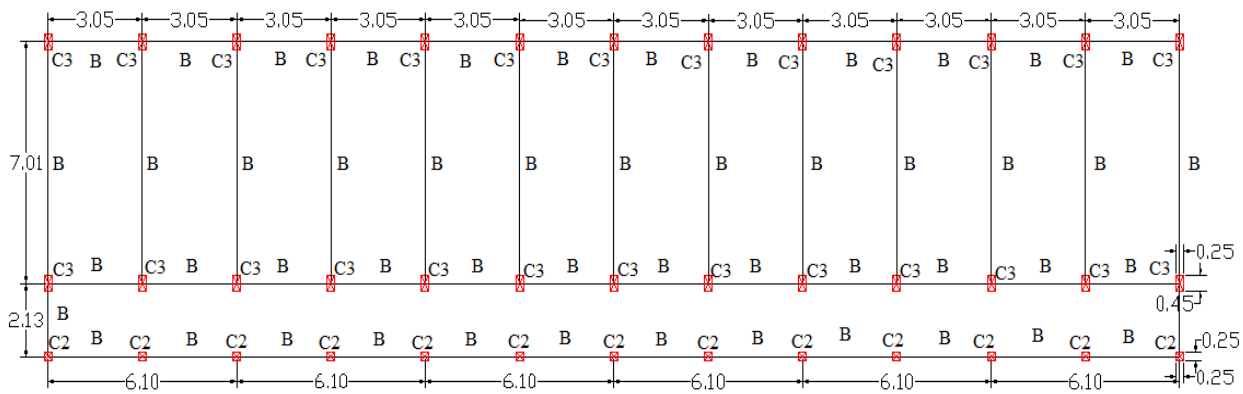
5.7.15 Model-15

The fifteenth building presented in this study is a two storey ordinary moment-resisting RC framed building (Figure 5.46-5.48), located in Zone IV (Koyna-Warna Region). The plan dimensions of the building are 36.60m×9.14m. Table 5.16 shows the material and sectional details of the structure.

Figure 5.46 Front view of the two-storey RC building



(a)



(b)

Figure 5.47 (a) Plan of ground floor, and (b) Plan of first floor of two-storey RC building

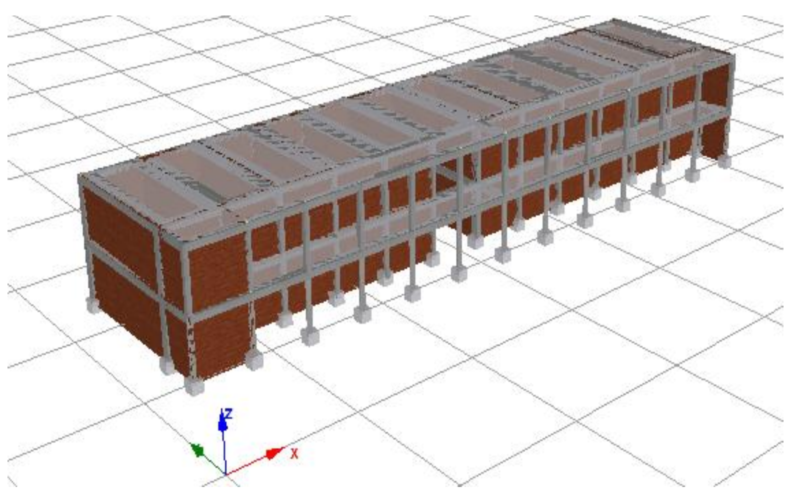


Figure 5.48 The model of two-storey RC building

Table 5.16 Material and sectional details of the two-storey RC building	
Structural system	Ordinary moment-resisting frame
Number of total storey	2 (G+1)
Height of stories (m)	3.1
Year of construction	1990
Name of building	Thakkar Bappa Vidyalay
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external), 115 (internal)
Concrete Grade	M15
Reinforcement Grade	Fe-415
Size of columns (mm) Reinforcement	250×450, 280 mm Dia. circular column , 250×250 4-12 Ø at corners, 2-12 Ø along longer side, 6 Ø @ 200 c/c 6-16 Ø at peripheral, 8 Ø @ 200 c/c 4-16 Ø at corners, 8 Ø @180 c/c
Size of beams (mm) Reinforcement	250×350 2-12 Ø at bottom and 2-10 Ø at top, 8 Ø @ 200 c/c
Thickness of slabs (mm)	125

5.7.16 Model-16

The sixteenth building presented in this study is a four storey ordinary moment-resisting RC framed building (Figure 5.49-5.51), located in Zone IV (Koyna-Warna Region). It was in constructing stage while doing survey. The plan dimensions of the building are 19.61m×15.16m. Table 5.17 shows the material and sectional details of the structure.

Figure 5.49 Front view of the four-storey RC building

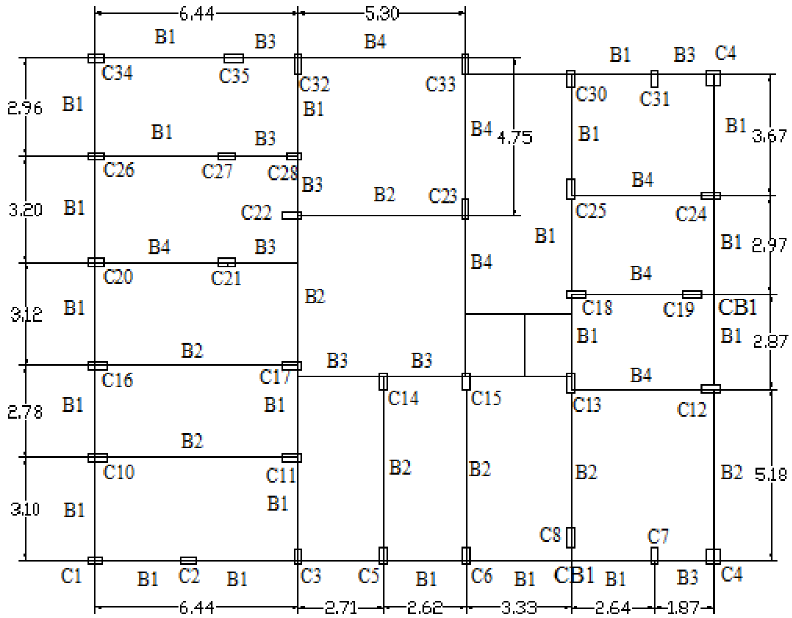


Figure 5.50 The plan of four-storey RC building

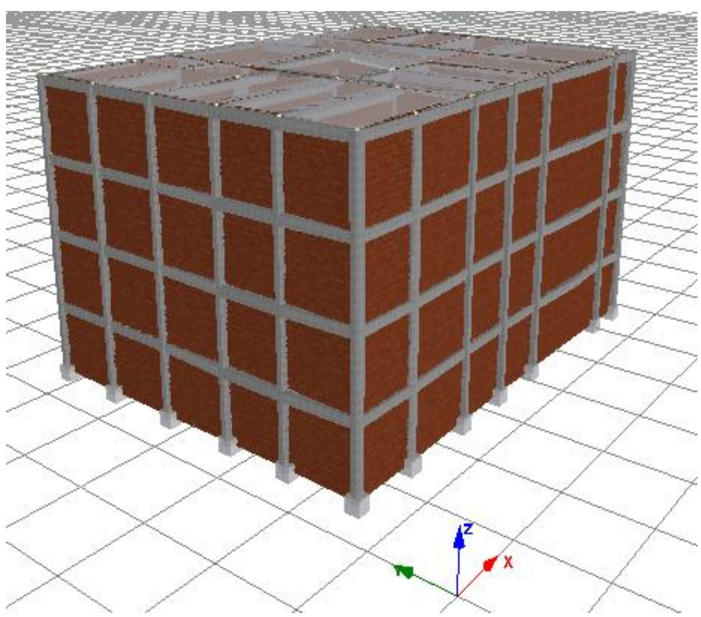


Figure 5.51 The model of four-storey RC building

Table 5.17 Material and sectional details of the four-storey RC building	
Structural system	Ordinary moment-resisting frame
Number of total storey	4 (G+3)
Height of stories (m)	3
Year of construction	2020
Name of building	Ram Niwas (Commercial)
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external), 115 (internal)
Concrete Grade	M20
Reinforcement Grade	Fe-500
Size of columns (mm) Reinforcement	230×450, 230×525, 230×600, 450×450 4-16 Ø at corners, 6-12 Ø along longer side, 8 Ø @180c/c, 4-16 Ø at corners, 6-12 Ø along longer side, 2-16 Ø along shorter side, 8 Ø @150c/c, 4-16 Ø at corners, 6-16 Ø along longer side, 8 Ø @130c/c, 4-16 Ø at corners, 2-16 Ø along longer side, 2-16 Ø along shorter side, 8 Ø @200c/c
Size of beams (mm) Reinforcement	230×375 2-12 Ø at bottom and 2-10 Ø at top, 8 Ø @ 250 c/c
Thickness of slabs (mm)	125

5.7.17 Model-17

The seventeenth building presented in this study is a two storey ordinary moment-resisting RC framed building (Figure 5.52-5.54), located in Zone IV (Koyna-Warna Region). The plan dimensions of the building are 88.47m×34.42m. Table 5.18 shows the material and sectional details of the structure.

Figure 5.52 Front view of the two-storey RC building

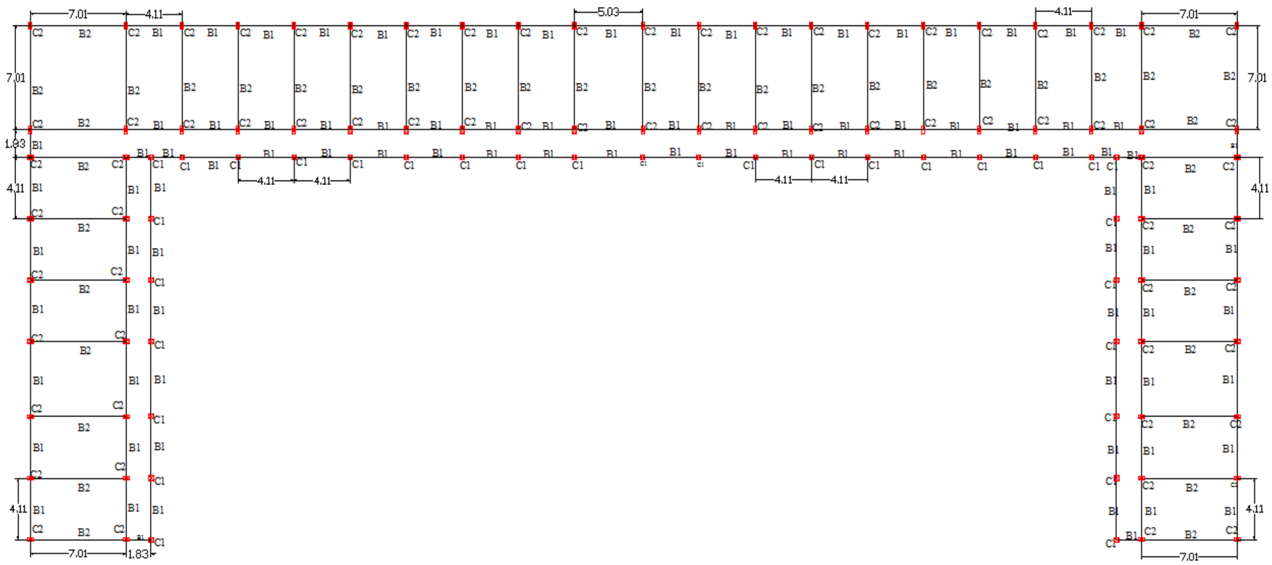


Figure 5.53 The plan of two-storey RC building

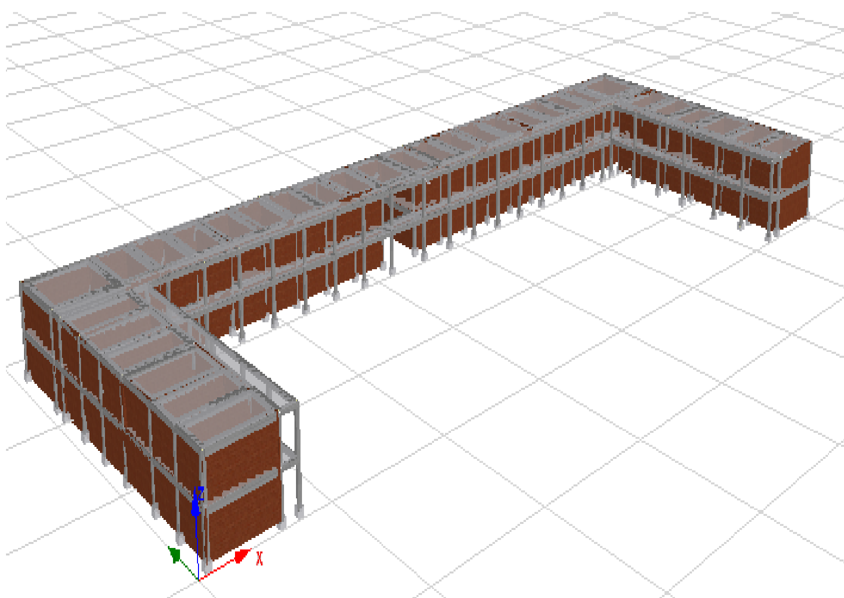


Figure 5.54 The model of two-storey RC building

Table 5.18 Material and sectional details of the two-storey RC building	
Structural system	Ordinary moment-resisting frame
Number of total storey	2 (G+1)
Height of stories (m)	3
Year of construction	2010
Name of building	New English School Pophali
Diagonal Compressive strength of infill (f_m) (MPa)	1.32
Thickness of infill (mm)	230 (external), 115 (internal)
Concrete Grade	M 15
Reinforcement Grade	Fe-415
Size of columns (mm) Reinforcement	300×350, 250×450 4-12 Ø at corners, 2-12 Ø along longer side, 6 Ø @200c/c, 4-12 Ø at corners, 2-12 Ø along longer side, 6 Ø @200c/c
Size of beams (mm) Reinforcement	250×350, 250×450 2-12 Ø at bottom and 2-12 Ø at top, 6 Ø @ 200 c/c, 2-12 Ø at bottom and 2-12 Ø at top, 6 Ø @ 200 c/c,
Thickness of slabs (mm)	125

5.8 Materials Models

5.8.1 Concrete Model

This model is a uniaxial nonlinear constant confinement model. The confinement effects provided by the lateral transverse reinforcement are incorporated through the rules proposed by Mander *et al.* (1988), in which constant confining pressure is assumed throughout the entire stress-strain range.

5.8.2 Steel Model

This is a uniaxial steel model initially programmed by Yassin (1994) on the basis of the stress-strain relationship proposed by Menegotto and Pinto (1973). Its employment should be confined to the modeling of reinforced concrete structures, particularly those subjected to complex loading histories. This model can be useful for the ribbed as well as smooth rebars.

5.8.3 Masonry infill panel element

Infill panel element is represented by four axial struts and two shear springs, as shown in Figure 5.55. Four node panel masonry elements were developed by the Crisafulli (1997). It separately accounts for compressive and shear behavior of masonry and adequately represents the hysteretic response. It shows the accuracy of the model to evaluate the nonlinear response of the structure. This model is also known as the "double strut nonlinear cyclic model". The diagonal compressive strength of masonry infill is calculated according to the Crisafulli (1997) thesis. The presence of an opening in infill will directly affect the structural integrity of the whole structural system and the effect can be incorporated by minimizing the width of the diagonal strut. The stiffness reduction factor to consider the opening effect in the infill in numerical modeling has been proposed by Mondal (2003).

$$W_{do} = (1-2.5A_r)W_d \tag{5.13}$$

Where, W_d is the width of the diagonal strut, W_{do} is the width of the diagonal strut with opening in infill, and A_r is the ratio of the opening area to the face area of infill. Eq.(5.13) is valid for openings in wall greater than 5% and lesser than 40%. In this study 15 % opening area is considered in the masonry infill for all building models.

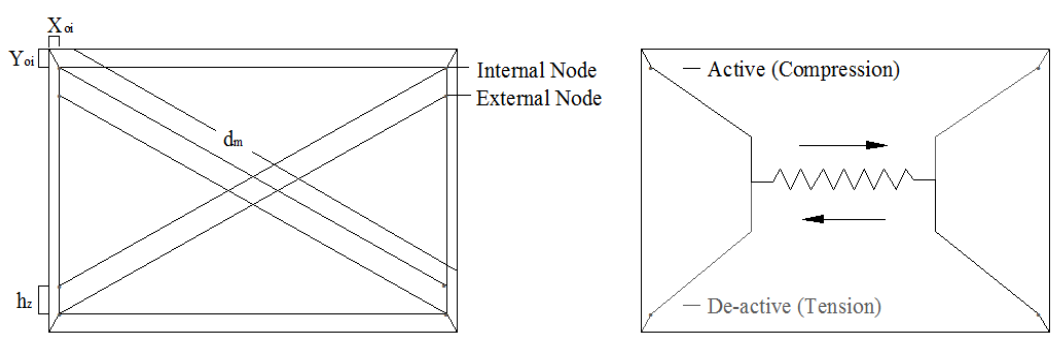


Figure 5.55 Inelastic Infill panel element

5.9 Concluding remark

This chapter gives the details of seismic design parameters and their calculation methodology. Also, we have discussed the different existing reinforced concrete structures from the Koyna-Warna region and their structural details.