Example 6.2 Verification of the iterative procedure

1 Description of problem

To verify the iterative procedure and evaluate its accuracy, a five-storey building resting on foundation through 36 columns is considered. The building is composed of five bays in both *x*- and *y*-directions, each bay is 5.0 [m] span. The height of the first storey is 4.0 [m] while the height of the other storeys is 3 [m]. The typical floor of the five storeys is chosen to be skew paneled beams as shown in Figure 6.11. The dimensions and loads of floor beams are shown in Table 6.4. The foundation is a grid type with 0.5 [m] thickness and 2.5 [m] breadth, Figure 6.12. The columns are square cross sections, the column models and dimensions for each storey are shown in Table 6.5.

The building material is reinforced concrete and has the following properties:

Young's modulus	E_b	= 3 × 107	[kN/m^2]
Poisson's ratio	ν_b	= 0.15	[-]
Shear modulus	G_b	= 1.3 × 10^7	[kN/m^2]

The soil mass below the foundation is idealized as *Winkler*'s medium. The modulus of subgrade reaction of the soil k_s is 40000 [kN/m^3].

Table 6.4 Dimensions and loads of floor beams

Beam type	Dimensions		Load [kN/m]
	Depth [m]	Breadth [m]	
Exterior beam B1	0.50	0.25	15
Interior beam B2	0.70	0.25	30

Table 6.5 Column models and dimensions

Storey	Column dimensions [m × m]		
	Model C1	Model C2	Model C3
1st & 2nd storey	0.40 × 0.40	0.50 × 0.50	0.60 × 0.60
3rd & 4th storey	0.30 × 0.30	0.40 × 0.40	0.50 × 0.50
5th storey	0.25 × 0.25	0.30 × 0.30	0.40 × 0.40

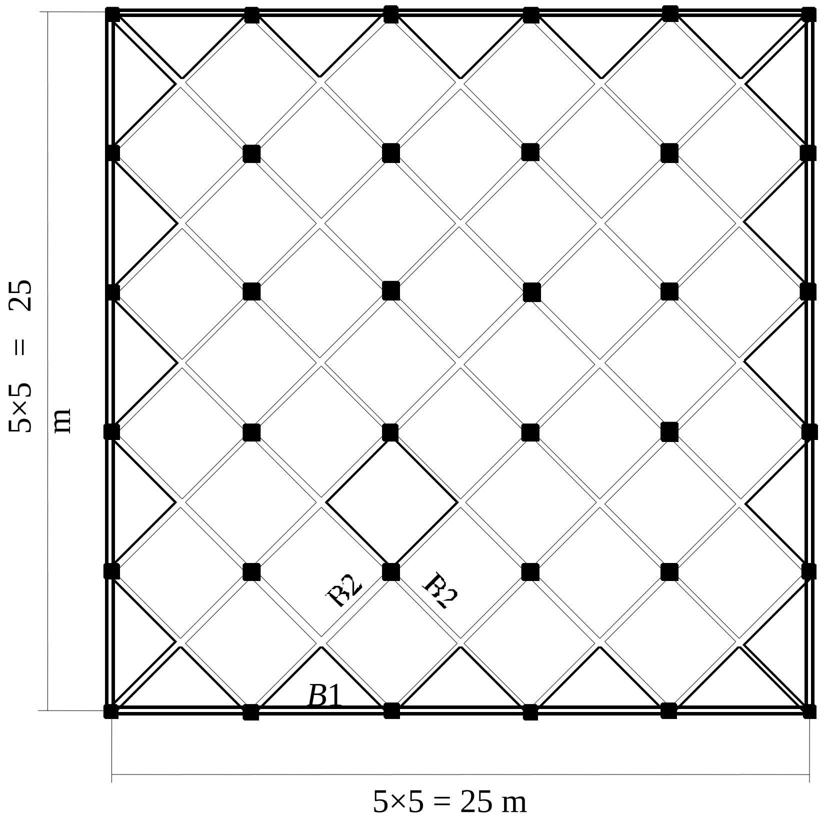

Figure 6.11 Typical floor in plan

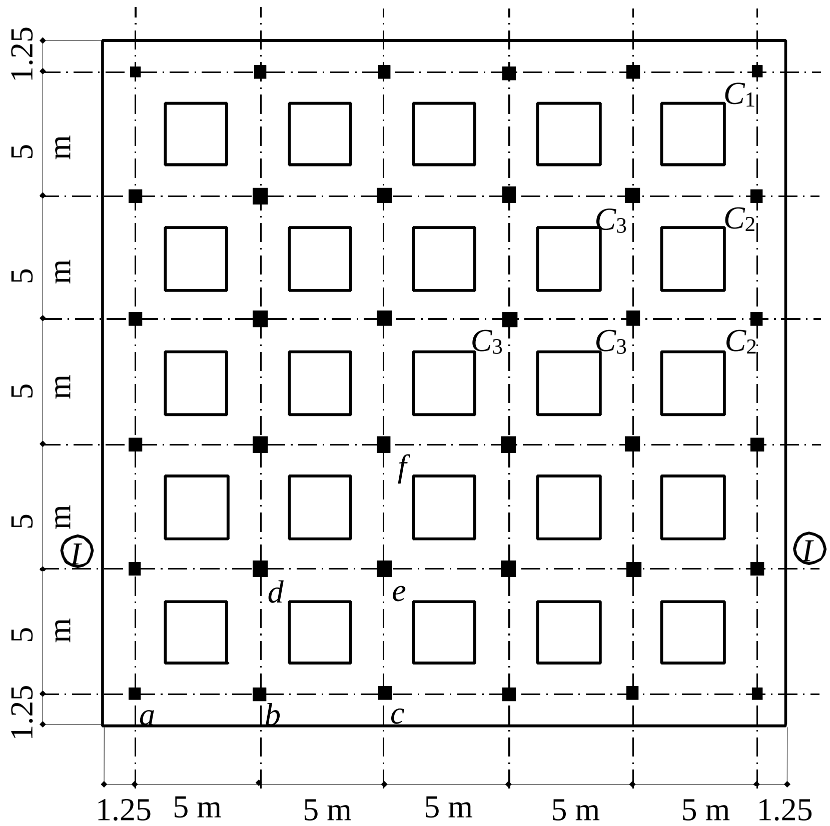

Figure 6.12 Foundation plan with column models

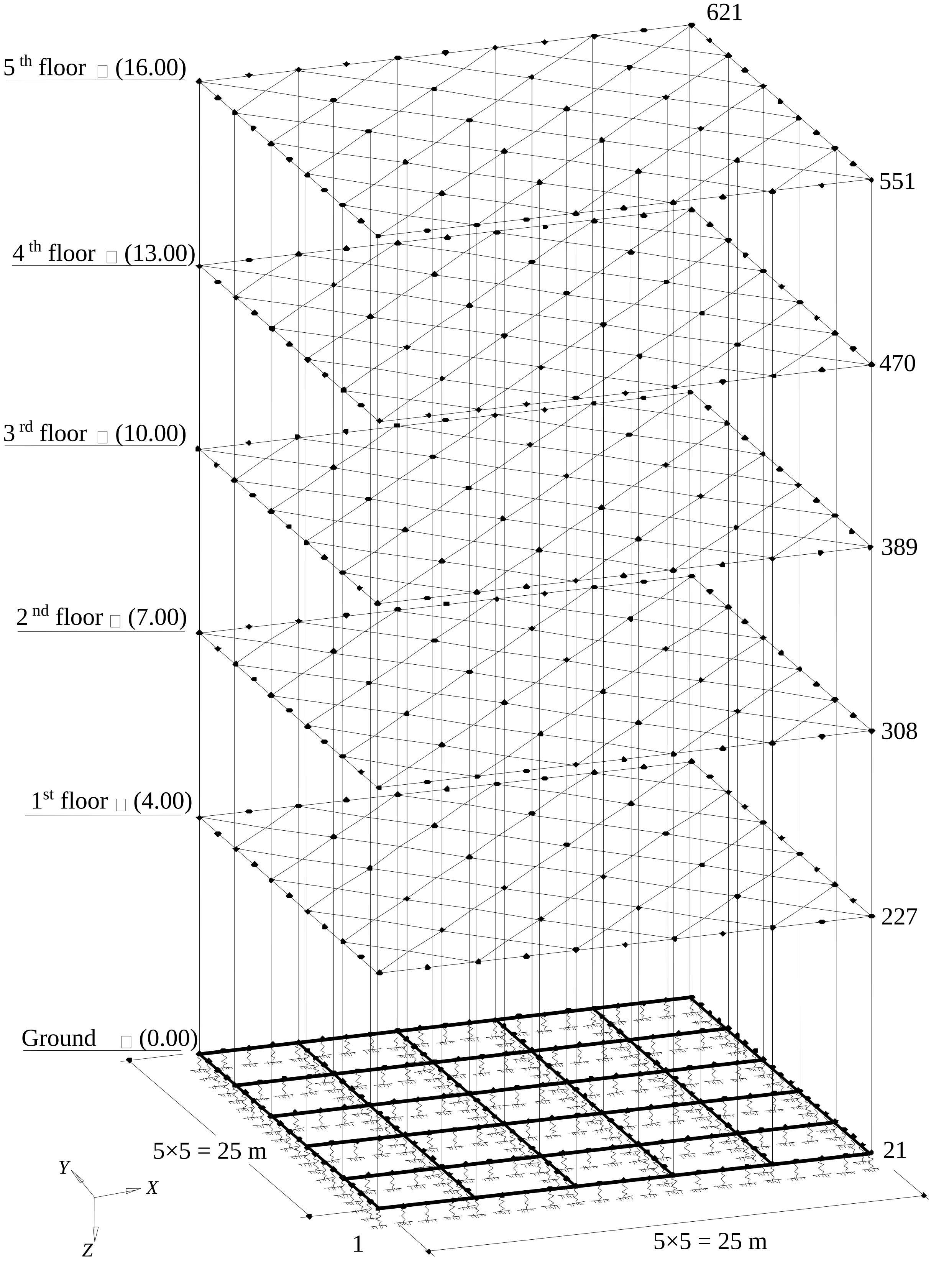

Figure 6.13 Statical system of space frame with foundation on elastic springs

2 Analysis

For the comparison between the results of building analysis using the proposed iterative procedure and that of traditional analysis without iteration, the building is modeled as a space frame supported by grid foundation resting on elastic springs. The element type for both the superstructure and foundation is a beam element as shown in Figure 6.13.

For the calculation based on the traditional analysis without iteration, the structure is divided into 1120 space frame elements yielding 621 nodes. Each node has six degree of freedom. This generates 3726 simultaneous equations. For the calculation based on the proposed iterative procedure, the structure is divided into three parts; floors, space frame (columns) and foundation. The number of elements is 140, 180 and 240, yielding 81, 216 and 216 nodes for floor, space frame and foundation, respectively. Because the structure subjects to symmetrical vertical loading, the effect of horizontal loads will be ignored. Therefore the horizontal translations (u, w) and stresses for the floors and foundation are not considered in the analysis.

For the calculation based on the traditional method, a three-dimensional space frame program is used to make the analysis of the structure. The horizontal translations and stresses in this case are ignored by assuming very small cross section areas for the floors and foundation elements. For the calculation based on the proposed iterative procedure, it is easy to use a two- or three-dimensional program whenever it is applicable to make the analysis of each part of the structure separately. A two-dimensional grid program is used to make the analysis of floors or foundation in order to omit the horizontal translations and stresses, and a three-dimensional space program is used to make the analysis of columns.

Due to symmetry in shape, dimensions, loading and supporting soil, it is possible to make the analysis for only one quarter of the structure. However, the analysis is carried out here for the whole structure and the conditions of symmetry are used to check the results.

3 Results and discussion

To verify the proposed iterative procedure, the results of deformations at six selected points (*a*) to (*f*) on the foundation are compared in Table 6.6 with those obtained by the traditional method without iteration.

Table 6.6 Comparison of deformations at selected points on the foundation obtained by iteration and those obtained by traditional method without iteration

Point	*w* [cm]		θ_x [-]		θ_y [-]	
	With iteration	Without iteration	With iteration	Without iteration	With iteration	Without iteration
a	0.214	0.213	0.00043	0.00042	-0.00043	-0.00042
b	0.229	0.229	0.00038	0.00037	0.00009	0.00008
c	0.219	0.219	0.00036	0.00035	-0.00003	-0.00003
d	0.308	0.308	-0.00011	-0.00009	0.00011	0.00009
e	0.291	0.291	-0.00011	-0.00009	-0.00004	-0.00003
f	0.269	0.270	0.00004	0.00004	-0.00004	-0.00004

The maximum difference between the vertical translations of floor slabs and columns and between those of columns and foundation at attached nodes is considered as an accuracy number

$$\varepsilon_w = \left(\frac{w_c - w_p}{w_c} \right) \times 100[\%]$$

where ε_w is the accuracy number for vertical translation in percentage, w_c = vertical translation of column and w_p is the vertical translation of floor or foundation.

The accuracy number ε_w is 0.6 [%] for translation after four cycles. It can be concluded from the comparison that the results of the proposed iterative procedure are in good agreement with those obtained by the traditional method without iteration with accuracy ε_w = 0.6 [%] for the whole structure which yields maximum settlement error 0.47 [%] of the foundation.

The computation time required for the iteration process used in Pentium 100 computer with 64 MB RAM is 39 minutes, while that, required for solving the system of linear equations by the traditional method without iteration is 6.5 hours. The computation time required for solving the system of linear equations by the traditional analysis without iteration is 10 times more than required for the iteration process using the proposed iterative procedure for this example. Another analysis using the iterative procedure for the same example was carried out using a plate-beam element program for floors and foundation (see case example 4.2), indicated that the processing time was 43 minutes. That means, the long computation time for the traditional method is referred to solving the overall matrix of the complete structure in one time, which normally, in this case, has large band width.