Comparative Study of Foundation System for Building in Soft Soil Condition

Chayan Biswas, Augnik Chakraborty, Shahidul Islam, Piyush Kumar, Debagni Singha

[1] Assistant Professor, [2, 3,4, 5] UG Student
[1, 2, 3, 4, 5] Department of Civil Engineering
[1, 2, 3, 4, 5] Global Institute of Management and Technology, Krishnanagar, Nadia, W.B., India.
[1]chayanbiswas7@gmail.com, [2] chakrabortyaugnik@gmail.com, [3] shahidulislam57275@gmail.com, [4] cpiyushkr@gmail.com, [5] debagnisingha03@gmail.com

***Abstract*— Foundation selection is crucial for the safety, durability, and cost efficiency of multi-storey buildings. Rising land values and construction expenses make economical design essential. This study investigates foundation options for a medium-height building with a lift, shear wall, and water tank on soft soil, comparing pile and open foundations using software tools such as AutoCAD, STAAD Pro, and MS Office. Results show that, with proper analysis and design, MAT (raft) foundations can safely replace pile foundations in soft soil for such buildings, offering significant economic advantages.**

***Index Terms*—Mat Foundation, Pile Foundation, Soft Soil, Cost Efficiency.**

I. INTRODUCTION

Post-COVID economic challenges have increased the demand for affordable housing, especially among middle- and lower-income groups. Since foundation design significantly affects construction cost, selecting an appropriate foundation can make buildings more economical without compromising safety. While many studies analyzed building behavior using software tools, most focus on single foundation types, high-rise structures, or seismic effects, with limited work on medium-height buildings typically built for MIG and LIG buyers

This paper examines a realistic G+6 residential building (approx. 15m × 15.6m; 45 m² flats) on low-bearing-capacity soil (10 T/m²), using common materials like M25 concrete and Fe500 steel. Structural drawings were prepared in AutoCAD, and analysis/design was conducted using STAAD Pro (v8i SS6) and STAAD Foundations. Slabs, shear walls, and other components were designed using Excel for accuracy. Both pile foundations and mat (raft) foundations were analysed under identical loads and soil conditions following BIS codes. Cost estimates, considering only material costs for concrete and steel, were compared to determine the more economical system.

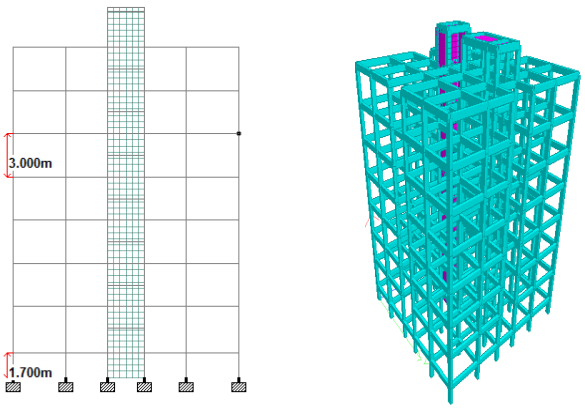


Fig. No.: 1 Skeletal Structure of the Building Model 2D and 3D from STAAD File

II. LOADING CRITERIA AND COMBINATIONS

All the basic loading criteria's including Dead Load, Live Load, Wind Load and Seismic Load have been considered as per the BIS codal provisions. Load combinations were done as per IS 875 Part-V and IS 1893 Part-I 2002. A total number of 17 load combination cases was generated. Table-1 below provided with the input parameters of loads in the software and some loading calculations which were made separately manually.

TYPE OF LOAD	REFERENCE CODE	INPUT PARAMETERS
DEAD LOAD	IS 875 PART-I	Floor Slab Thickness = 125mm
		Roof Slab Thickness = 125mm
		Mumpty Room Roof Slab Thickness = 200mm
		Waist Slab thickness = 150mm
		Tread = 300mm
		Riser = 150mm
		Width of Landing slab = 1.2m
LIVE LOAD	IS 875 PART-II	Floor Load For Building= 2 kN/m2
		Roof Load (Accessible) = 1.5kn/m2
		Roof Load (Non Accessible) = 1.5kn/m2
		Stair Case Load= 3 kN/m2
WIND LOAD	IS 875 PART-III	Location of Structure = Kolkata
		Basic Wind Speed: = 50m/sec
		Building Class = B
		Terrain Category = III
		K1 = 1.0
		K3 = 1.0
SEISMIC LOAD	IS 1893 Part-I, 2016	Location of Structure = Kolkata
		Zone Factor = III (0.16)
		Importance Factor = 1.2
		Response Reduction Factor = 3
		Type Of Soil = Soft Soil
		Damping Ratio = 5%
		Rock and Soil Site Factor = 3

Table. No.: 1 Input Parameters of Loads

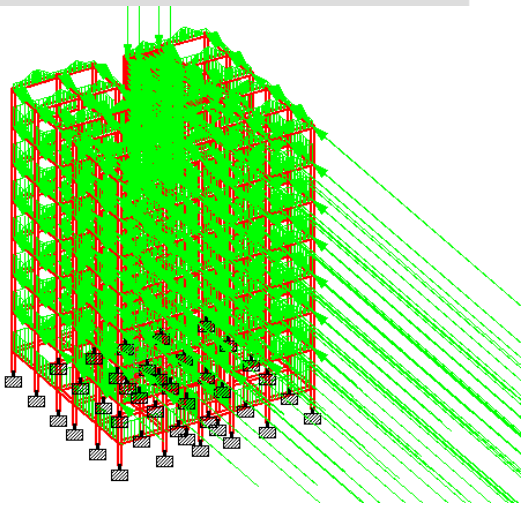
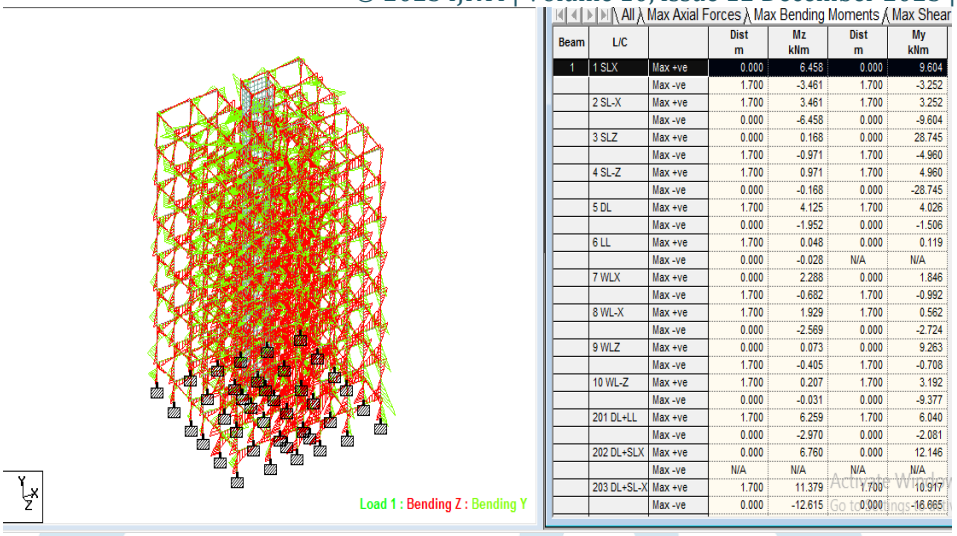


Fig. No.: 2 Effect of all Load Combinations on the Building Model

III. ANALYSIS AND DESIGN OF RC MEMBERS

The analysis of the structure has been done in STAAD Pro. and from the output results of analysis, design was performed. Some RCC elements like Beam, Column were design in RC Design Plug in of STAAD and other element like Slab, Shear Wall was designed in MS Excel to obtain better economic result.



Beam	L/C		Dist m	Mz kNm	Dist m	My kNm
1	1 SLX	Max +ve	0.000	6.458	0.000	9.604
		Max -ve	1.700	-3.461	1.700	-3.252
	2 SL-X	Max +ve	1.700	3.461	1.700	3.252
		Max -ve	0.000	-6.458	0.000	-9.604
	3 SLZ	Max +ve	0.000	0.168	0.000	28.745
		Max -ve	1.700	-0.971	1.700	-4.960
	4 SL-Z	Max +ve	1.700	0.971	1.700	4.960
		Max -ve	0.000	-0.168	0.000	-28.745
	5 DL	Max +ve	1.700	4.125	1.700	4.026
		Max -ve	0.000	-1.952	0.000	-1.506
	6 LL	Max +ve	1.700	0.048	0.000	0.119
		Max -ve	0.000	-0.028	N/A	N/A
	7 WLX	Max +ve	0.000	2.288	0.000	1.846
		Max -ve	1.700	-0.682	1.700	-0.992
	8 WL-X	Max +ve	1.700	1.929	1.700	0.562
		Max -ve	0.000	-2.569	0.000	-2.724
	9 WLZ	Max +ve	0.000	0.073	0.000	9.263
		Max -ve	1.700	-0.405	1.700	-0.708
	10 WL-Z	Max +ve	1.700	0.207	1.700	3.192
		Max -ve	0.000	-0.031	0.000	-9.377
	201 DL+LL	Max +ve	1.700	6.259	1.700	6.040
		Max -ve	0.000	-2.970	0.000	-2.081
	202 DL+SLX	Max +ve	0.000	6.760	0.000	12.146
		Max -ve	N/A	N/A	N/A	N/A
	203 DL+SL-X	Max +ve	1.700	11.379	1.700	10.917
		Max -ve	0.000	-12.615	0.000	-18.665

Fig. No.: 3 STAAD result showing Bending along Z-direction (Red Colour) and Y-direction (Green Colour) of the Model

	Beam	L/C	Node	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
Max Fx	801	203 DL+SL-X	329	**3281.221**	-164.480	-57.865	-0.301	18.375	-114.880
Min Fx	801	1 SLX	329	**-1497.548**	113.135	33.500	0.162	-10.603	80.306
Max Fy	372	205 DL+SL-Z	160	43.791	**179.425**	-6.042	0.010	5.178	265.750
Min Fy	371	204 DL+SLZ	338	18.320	**-234.219**	-3.735	-7.212	-10.737	261.623
Max Fz	1646	205 DL+SL-Z	798	493.564	-34.574	**159.503**	-6.981	14.544	23.254
Min Fz	2299	205 DL+SL-Z	88	-227.258	-15.970	**-146.391**	-4.939	63.619	-19.100
Max Mx	1687	203 DL+SL-X	830	10.570	-49.304	-19.228	**32.673**	-2.967	14.191
Min Mx	1334	202 DL+SLX	558	10.457	-49.715	19.173	**-32.545**	2.972	14.232
Max My	410	204 DL+SLZ	170	521.852	2.728	-59.634	-0.245	**89.311**	4.079
Min My	410	204 DL+SLZ	206	511.249	2.728	-59.634	-0.245	**-89.590**	-4.104
Max Mz	372	205 DL+SL-Z	160	43.791	179.425	-6.042	0.010	5.178	**265.750**
Min Mz	271	204 DL+SLZ	123	-45.895	-84.471	-6.346	0.289	5.918	**-151.897**

Fig. No.: 4 STAAD result showing Max and Min. Shear Forces and Bending Moments in X, Y and Z directions along with their corresponding nodes and beams

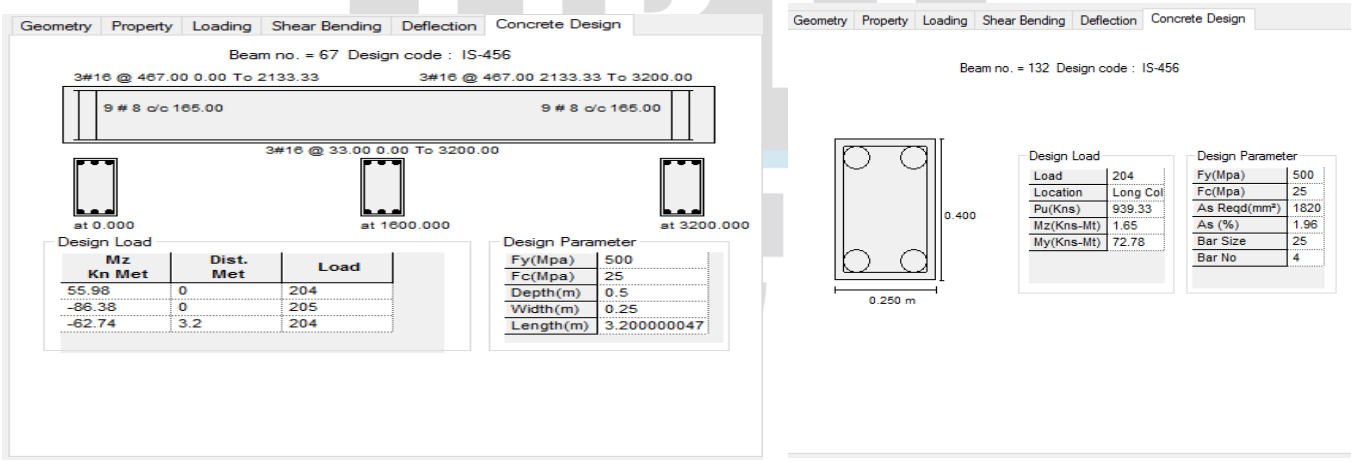


Fig. No. 5 Detail Section of Beam and Column from STAAD file.

IV. ANALYSIS AND DESIGN OF FOUNDATIONS

In this structure two types of foundations have been considered. Pile Foundation and Mat Foundation. The soil considered to be soft soil and accordingly bearing capacity of the soil is provided as mentioned earlier.

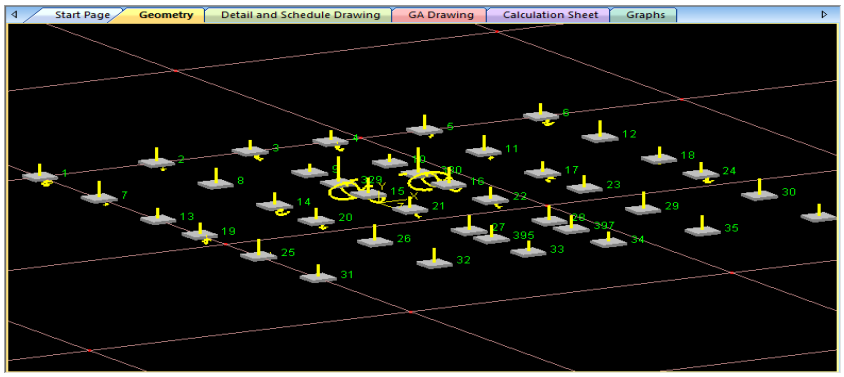


Fig. No. 6 Column Markings from STAAD file for Foundation Design

V. ANALYSIS AND DESIGN OF PILE FOUNDATION

Design of Pile Foundation has been done manually in Excel because of various limitations of STAAD and for better economical results. Analysis and Pile Cap design although is done with STAAD Foundation and rest done in Excel by considering worst load cases has been taken from STAAD Output file. As per reactions of Column, Pile Cap for 2, 3, 8 and 12Pile group came from STAAD result.

Column Markings	Pile Cap Group	Details of Area of Reinforcement for Pile cap.
C3, C4, C9, C10, C13, C14, C19, C20, C17, C18, C23, C24, C33, C34	2 Pile Cap Group.	6Nos. 25mm dia at bottom along X-direction , 12mm dia @150mm C/C at top along X-direction & 12mm dia. @ 150mm C/C at top and bottom in Z-direction.12mm dia @250mm C/C at side face.
C1, C2, C5, C6, C7, C8, C11, C12, C25, C26, C29, C30, C31, C32, C35, C36, C21, C22	3 Pile Cap Group	8 Nos. 25mm dia bar at bottom along Z-direction, 8 Nos. 12mm dia at top along Z-direction, 12mm dia bar @ 150mm C/C in top and bottom along X- direction and 12mm dia bar @ 250mm C/C at side face.
C27, C28, C395, C397	8 Pile Cap Group	20mm dia bar @ 150mm C/C at bottom in both ways, 16mm dia bar @ 150mm C/C at top in both ways and 12mm dia bar @ 250mm C/C at side face.
C15, C16, C329, C330	12 Pile Cap Group	20mm dia bar @ 150mm C/C at bottom in both ways, 16mm dia bar @ 150mm C/C at top in both ways and 12mm dia bar @ 250mm C/C at side face.

Table No. 2 Reinforcement details of Pile Cap along with column markings

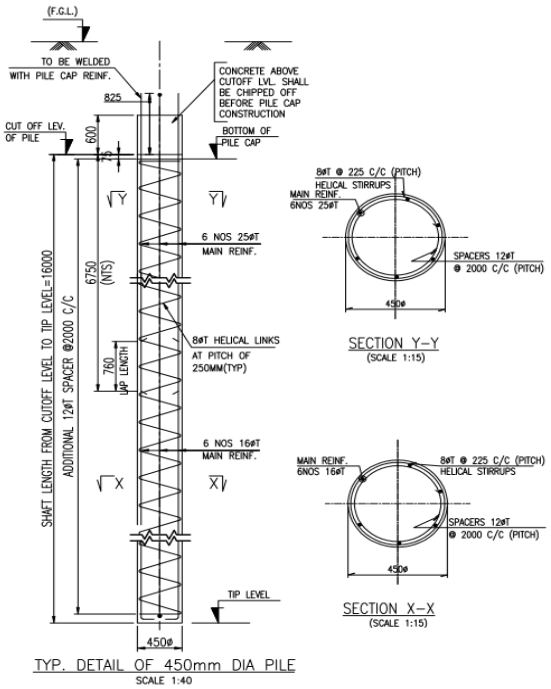


Fig. No. 7 Reinforcement details of a Pile

VI. ANALYSIS AND DESIGN OF MAT FOUNDATION

Entire analysis and design of Mat foundation have been done in STAAD Foundation software. Details of input and stress distribution patterns have been given in the figures below.

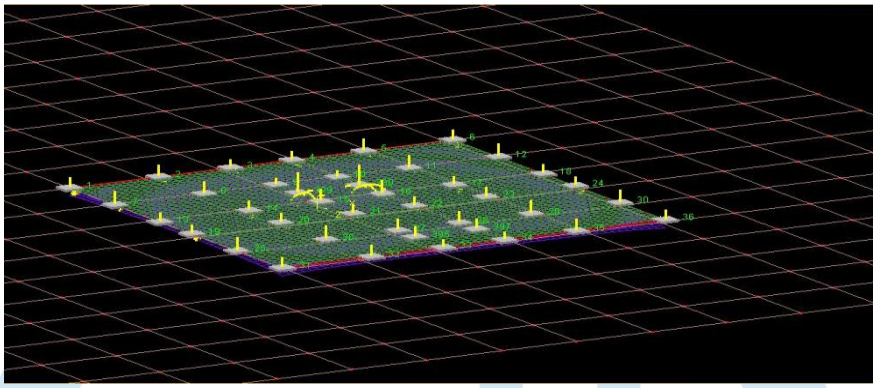


Fig. No. 8 Generation of Slab for Mat foundation after complete analysis

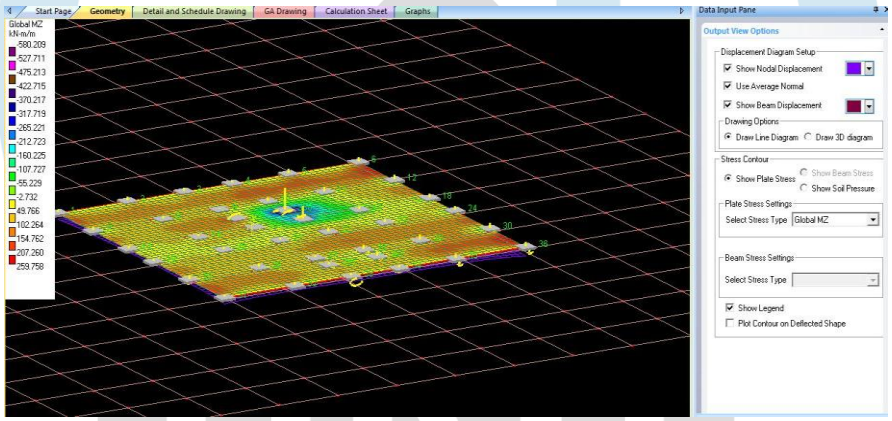


Fig. No. 9 Stress variation on Mat slab due to combination effect of dead load and seismic load

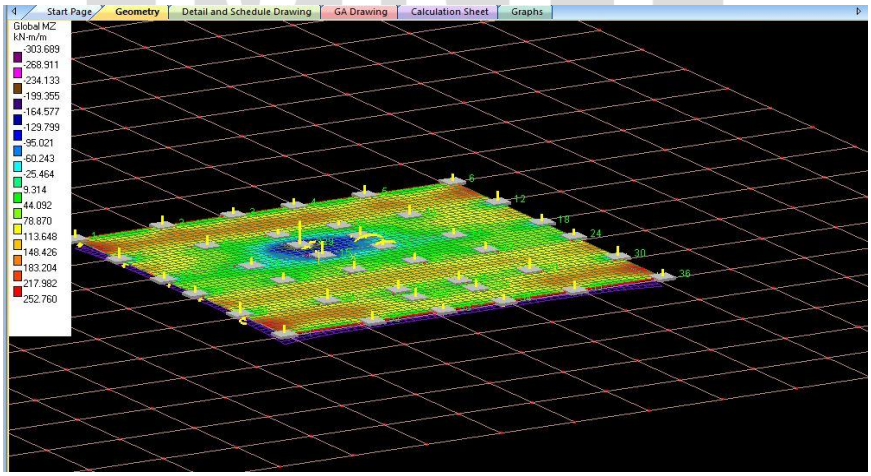


Fig. No. 9 Stress variation on Mat slab due to combination effect of dead load and wind load

Zone Reinforcement Summary -Longitudinal Top

Zone	Moment kN-m/m	Load Case	X (m)	Z (m)	Area Reqd.mm²/m	Area Prod.mm²/m	Bar Detail
1	174.223	106	3.173	6.356	722.221	722.566	20 @ 450"c/c
2	388.149	102	6.346	4.322	1665.708	1668.814	16 @ 120"c/c
3	457.133	102	6.346	4.831	1985.447	1990.513	12 @ 50"c/c
4	775.982	108	0.264	15.000	3587.456	3599.008	16 @ 50"c/c

Fig. No. 10 Reinforcement Details of Mat Foundation for Longitudinal Top

Zone Reinforcement Summary -Longitudinal Bottom

Zone	Moment kN-m/m	Load Case	X (m)	Z (m)	Area Reqd.mm²/m	Area Prod.mm²/m	Bar Detail
1	-165.687	102	10.312	5.085	720.000	722.566	20 @ 450"c/c
2	-564.728	106	8.725	5.847	2643.325	2650.718	25 @ 180"c/c
3	-1046.783	107	6.610	4.831	4596.459	4614.214	25 @ 100"c/c

Fig. No. 11 Reinforcement Details of Mat Foundation for Longitudinal Bottom

Zone Reinforcement Summary -Transverse Top

Zone	Moment kN-m/m	Load Case	X (m)	Z (m)	Area Reqd.mm²/m	Area Prod.mm²/m	Bar Detail
1	170.522	109	1.851	6.102	722.522	722.566	20 @ 450"c/c
2	898.563	108	0.000	14.746	4405.413	4417.864	25 @ 110"c/c

Fig. No. 12 Reinforcement Details of Mat Foundation for Transverse Top

Zone Reinforcement Summary -Transverse Bottom

Zone	Moment kN-m/m	Load Case	X (m)	Z (m)	Area Reqd.mm²/m	Area Prod.mm²/m	Bar Detail
1	-161.434	107	5.024	4.831	720.000	722.566	20 @ 450"c/c
2	-876.638	107	6.610	4.831	4574.921	4586.725	20 @ 60"c/c

Fig. No. 13 Reinforcement Details of Mat Foundation for Transverse Bottom

VII. RATE ANALYSIS OF PILE AND MAT FOUNDATION

Sl no.	Item	Cost
1	Reinforcement in Pile Cap	Rs. 63000
2	Concrete in Pile Cap	Rs. 7,17,015
3	Pile	Rs. 1, 10,40, 000
Total Cost for Pile Foundation Construction (Excluding Labor, Machinery Charges and other Contingencies):		**Rs. 1,18,20,015.00 /-**
1	Reinforcement in Mat Foundation	Rs. 2,28,000
2	Concrete in Mat Foundation	Rs. 9,50,000
Total Cost for Mat Foundation Construction (Excluding Labor, Machinery Charges and other Contingencies):		**Rs. 11,78,000.00/-**

Table No. 3 Cost Comparison of Pile and Mat Foundation

After completing the full estimate, it is evident that, from a cost point of view, a mat or raft foundation can be adopted for a multi-storied building on soft soil, provided the analysis and design are carried out correctly. Since various software tools have inherent limitations, calculations and analysis must be performed judiciously. Where necessary, certain computations should be carried out in MS Excel using the results obtained from the software, in order to achieve safe yet economical sections. All calculations should be performed in accordance with the relevant codal provisions wherever applicable.

VIII. CONCLUSIONS

Since construction cost is a major factor—especially in the post-COVID market for apartments—it was necessary to compare the costs of different foundation types. The study shows that mat foundation is more economical. However, foundation selection for multi-storey buildings must be based on thorough analysis and design, not cost alone. Although some engineers mix foundation types to reduce expenses, this can complicate construction. For multi-storey buildings up to about G+5 to G+7, a properly designed mat foundation can be a suitable and economical option.

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