Engineering and Applied Sciences
2025, Vol. 10, No. 5, pp. 114-122
https://doi.org/10.11648/j.eas.20251005.11

Research Article

Diagnostic Load Test of a Scaled Post-Tensioned Flat Plate Concrete Slab

Mohammed Faruqi*, Carlos Vargas

Department of Civil and Architectural Engineering, Texas Agricultural and Mechanical University, Kingsville, United States

Abstract

A flat plate floor system is a concrete system that has uniform thickness. They are generally cast-in-place or they may be casted at the ground level and lifted into their final position by the use of jacks at the columns. This system can be post-tensioned. Flat plate post tensioned concrete slabs are widely used in office buildings, institutional structures, parking structures, apartment buildings, and hotels. Therefore, it is important to have a good understanding of the behavior of these elements that form the fabric of the total structural system. The main goal of this work was to perform a design evaluation on a constructed scaled post-tensioned 4 ft x 4 ft flat plate concrete slab with American Concrete Institute (ACI) design provisions. The 28 days compressive strength of concrete was 5000 psi. The slab thickness was 1/2 in, and 1/16 in post-tensioning cables inside a plastic sheathing were used as the reinforcement. The slab was loaded using a designed water tank of 4 ft x 4 ft x 6 ft dimensions. The water depth generated the distributed load on the slab and a dial gauge measured the slab deflections. Distributed load and deflection data were collected. The design evaluations were carried out with respect to deflections, stresses, shear and flexural capacity using a developed ACI provisioned spreadsheet and experimentally obtained load and deflection data. The scaled constructed concrete slab satisfied the ACI design provisions.

Keywords

Load, Scaled, Post-Tensioned, Flat Plate, Concrete

1. Introduction

A flat plate floor system is a concrete system. This system has uniform thickness all around and it is supported by columns or walls that are load bearing in nature [1-4].

Flat plates are generally cast-in-place, they may also be casted at the ground level and lifted into their final position in the structure by jacks at the columns [5].

Flat slabs are used in parking garages, hotels, institutional structures, apartment complexes, office buildings, etc. [6, 7]. There are various types of slabs, namely: Basic flat slabs, flat slabs with drop panels, flat slabs with column heads, and flat slabs with both drop panels and column head [8]. Basic flat slabs have many advantages [9-11], such as:

1) Better appearance and diffusion of natural light,
2) Fire resistance,
3) Easy to handle and positioning them,
4) Provide faster construction time due to easier formwork,
5) Supported by columns and are therefore easy to use in residential and commercial buildings, and additionally,

*Corresponding author: m-faruqi@tamuk.edu (Mohammed Faruqi)

Received: 13 August 2025; **Accepted:** 22 August 2025; **Published:** 11 September 2025

6) Cost effectiveness.

The principal reinforcement in prestressed slabs consists of steel strand cables, typically spaced between about 2.0 and 5.0 ft center-to-center, depending on the loads, spans, and slab thickness. The American Concrete Institute (ACI) code recommends that the concrete protection for the cables should not be less than 1 in, if the surface is exposed to earth or weather and not less than ¾ in. if it is not exposed to weather or in contact with the ground [12]. The steel strand cables provide economic and construction considerations. They are generally greased and plastic-sheathed for slabs in post-tensioning construction.

2. Defining the Problem

The main goal of this work was to perform a design evaluation on a constructed scaled post-tensioned 4 ft x 4 ft flat plate concrete slab with (ACI) design provisions. The 28 days compressive strength of concrete was 5000 psi. The slab thickness was 1/2 in, and 1/16 in prestressed cables inside a plastic sheathing were used as the reinforcement. The slab was loaded using a designed water tank of 4 ft x 4 ft x 6 ft dimensions. The water depth generated the distributed load on the slab and a dial gauge measured the slab deflections. Distributed load and deflection data were collected. The design evaluations were carried out with respect to deflections, stresses, shear and flexural capacity using a developed ACI provisioned spreadsheet and experimentally obtained load and deflection data.

3. Laboratory Tests

3.1. Coarse and Fine Aggregates

Table 1 shows the properties of coarse and fine aggregates.

Table 1. *Physical Properties of Coarse and Fine Aggregates.*

Physical Properties	Coarse Aggregates	Fine Aggregates
Sieve Analysis	Passing sieve No.4 (3/16 in) and retained on sieve No.16 (3/64 in)	Passing sieve No.16 (3/64 in)
Unit Weight (dry)	98.61 lb/ft^3	95.02 lb/ft^3
Unit Weight (ssd)	100.20 lb/ft^3	103.53 lb/ft^3
Absorption	1.61%	8.96%
Specific Gravity	2.55	2.49
Fineness Modulus	------	2.50

3.2. Concrete Mixture Proportioning

Absolute volume method was used in concrete design.

The detailed procedure is shown below:

Conditions and specifications:

Concrete was required for a slab that is not exposed to any kind of aggressive environment, such as severe freeze-thaw climate or deicers. A specified compressive strength of 5,000 psi was required at 28 days, using Type I cement. The member thickness was 1/2 in, and 1/16 in post-tensioning cables inside a plastic sheathing were used as the reinforcement. The top and bottom cover was approximately 3/16 in. The minimum distance between reinforcing bars was approximately 7/8 in. No admixture was used. The materials used were as follows:

Cement: A Type I cement is used. This conforms to the standards of ASTM C150 [13].

Coarse aggregates: The maximum size was ¾ of the minimum clear space, which in this case is the concrete cover (3/16 in). Coarse aggregates retained between the sieves No.4 (3/16 in) and No.16 (3/64 in) were used. The unit weight is 100.2 lb/ft^3 at saturated surface dry (ssd) condition, and 98.61 lb/ft^3 at dry condition. Absorption = 1.61%. The specific gravity is 2.55.

Fine aggregates: Natural sand with particle sizes passing though the sieve No.16 (3/64 in) was used. This conforms to the standards of ASTM C33 [14]. The unit weight was 103.53 lb/ft^3 at ssd condition and 95.02 lb/ft^3 at dry condition. Absorption = 8.96%. The fineness modulus (FM) and the specific gravity were respectively 2.50 and 2.49.

The above mentioned information was used to proportion a trial mixture.

Strength: Since no statistical data was available. A rule of thumb was used [15]. Therefore, required compressive strength = 5000 + 1200 psi = 6200 psi.

Water to cement ratio: A compressive strength of 6200 psi requires a water to cement ration of 0.38 [15].

Coarse aggregate size: Aggregates passing sieve No.4 and retained on sieve No.16 (maximum particle size of 3/16 in) were used. This is almost the maximum limit of ¾ the concrete cover.

Slump: A slump of 3 in was used as a matter of practicality.

Air content: An approximate amount of entrapped air was about 4.25% [15].

Water content: A maximum-size aggregate of 3/16 in. and a slump of 3 in requires 445 lb of water per cubic yard of concrete [15]. This amount of water may be reduced by 45 lb/yd^3, if the particles of the coarse aggregate have a round shape; by 35 lb/yd^3, if they have a round shape with some crushed particles; and by 20 lb/yd^3, if they have subangular shape. In our case, we had coarse aggregates having particles with subangular shape. Then, our water content was 445 lb/yd^3 - 20 lb/yd^3 = 425 lb/yd^3.

Cement content: The cement content is based on the maximum water-cement ratio and the water content. Therefore, 425 lb of water divided by a water-cement ratio of 0.38 requires a cement content of 1,118.4 lb.

Coarse aggregate content: The bulk volume of coarse aggregates, when using a sand with fineness modulus of 2.50 is 0.15. The unit weight of coarse aggregates was 100.2 lb/ft^3 at saturated-surface-dry (ssd) condition. The ssd weight of coarse aggregates for 1 yd^3 (27 ft^3) of concrete was: 100.2 x 27 x 0.15 = 406 lb/yd^3.

Fine aggregate content: At this point, the amount of all ingredients except the fine aggregates are known. In the absolute volume method, the volume of fine aggregate is determined by subtracting the absolute volume of the known ingredients from 27 ft^3 (1 yd^3). The absolute volume of each ingredient was calculated as shown below:

Water = 425 / (1 x 62.4) = 6.81 ft^3

Cement = 1,118.4 / (3.15 x 62.4) = 5.69 ft^3

Air = 4.25% x 27 = 1.15 ft^3

Coarse aggregates = 406 / (2.55 x 62.4) = 2.55 ft^3

Total volume of known ingredients = 16.20 ft^3

The calculated absolute volume of fine aggregate was:

27 – 16.20 = 10.80 ft^3

The weight of the fine aggregates at SSD condition was:

10.80 x 2.49 x 62.4 = 1,678 lb

The mixture had the following proportions before trial mix ing for 1 yd^3 of concrete:

Water = 425 lb

Cement = 1,118.4 lb

Coarse aggregates (ssd) = 406 lb

Fine aggregate (ssd) = 1,678 lb

Total weight = 3,627.4 lb

Slump = 3 in.

Air content = 4.25% (entrapped)

Estimated unit weight (using ssd aggregate) = 3,627.4 / 27 = 134.35 lb/ft^3

Moisture: Corrections were needed to compensate for moisture in the aggregates. The mixing water added to the batch reduced according to the absorption capacity and moisture content of the aggregates. The coarse and fine aggregates were prepared at ssd condition.

Summary of mix design:

Concrete mix design = 5,000 psi

Absolute Ratio at ssd condition per volume

C: F.A.: C.A.: W

1: 1.90: 0.45: 1.26

C = Cement; F.A. = Fine aggregates; C.A. = Coarse aggregates; W = Water

3.3. Compression Tests

The compression and cylinder related tests provided the following results:

Specimen: Concrete cylinder with diameter of 4 in. and height of 8 in.

Area = 12.57 in.^{2}

Volume = 100.56 in.^{3} = 5.82 x 10^{-2} ft^3

Average weight of concrete cylinder = 7.924 lb

Unit weight of concrete = 136 lb/ft^3

Rate of loading = 16,000 lb/minute

Compression Tests @ 5 days

Cylinder No.	Compression Force (lb)
1	40,559
2	35,694
3	31,957 (Controls)

f'_c @ 5 days = 31,957 lb / 12.57 in.^{2} ≈ 2,550 psi

Compression Tests @ 7 days

Cylinder No.	Compression Force (lb)
1	42,161
2	43,842
3	37,790 (Controls)

f'_c @ 7 days = 37,790 lb / 12.57 in.^{2} ≈ 3,010 psi

Compression Tests @ 28 days

Cylinder No.	Compression Force (lb)
1	53,650
2	50,605
3	52,009 (Controls)

f'_c @ 28 days = 50,650 lb / 12.57 in.^{2} ≈ 4,030 psi

3.4. Tensile Tests of Cables

The cable tests provided the following results:

Nominal diameter of the cable = 1/16 in.

Number of wires per cable = 49

Diameter of each wire = 0.0075 in.

Effective area of the cable = 2.165 x 10^{-3} in^2.

Table 2 shows the results of tensile cable tests.

Table 2. *Tensile Cable Tests.*

Cable #	Ultimate load capacity (lb)	Observation
1	336.19	Sliding in anchor. It was not properly tightened
2	514.16	No failure at the anchor
3	553.72	No failure at the anchor
4	533.94	No failure at the anchor

3.5. Tensile Tests of Non-Prestressed Reinforcement

Tests on non-prestressed reinforcement provided the following results:

Diameter = 0.022 in.

Area = 3.801 x 10^{-4} in^2.

Ultimate load capacity = 25 lb

Ultimate strength capacity, f_{pu} = 25 / 3.801 x 10-4 = 65,760 psi ≈ 65 ksi

Yield stress capacity, fy = 70% f_{pu} = 46 ksi.

3.6. Formwork

The formwork included the construction of slab forms, water tank, and placement of reinforcement. The plan view and the reinforcement details of the slab are shown in Figures 1, 2, and 3. Non-prestressed steel was used at the top of the columns and around the perimeter to reduce overcrowding.

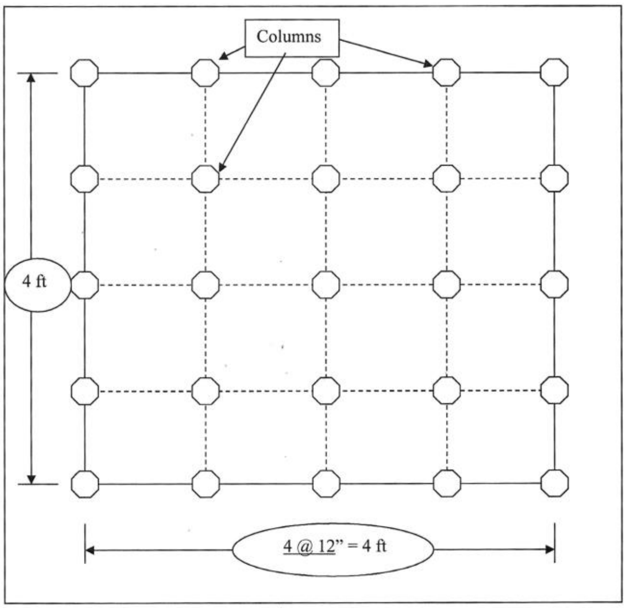

Figure 1. *Plane View of Scaled Flat Slab (Symmetric Spans).*

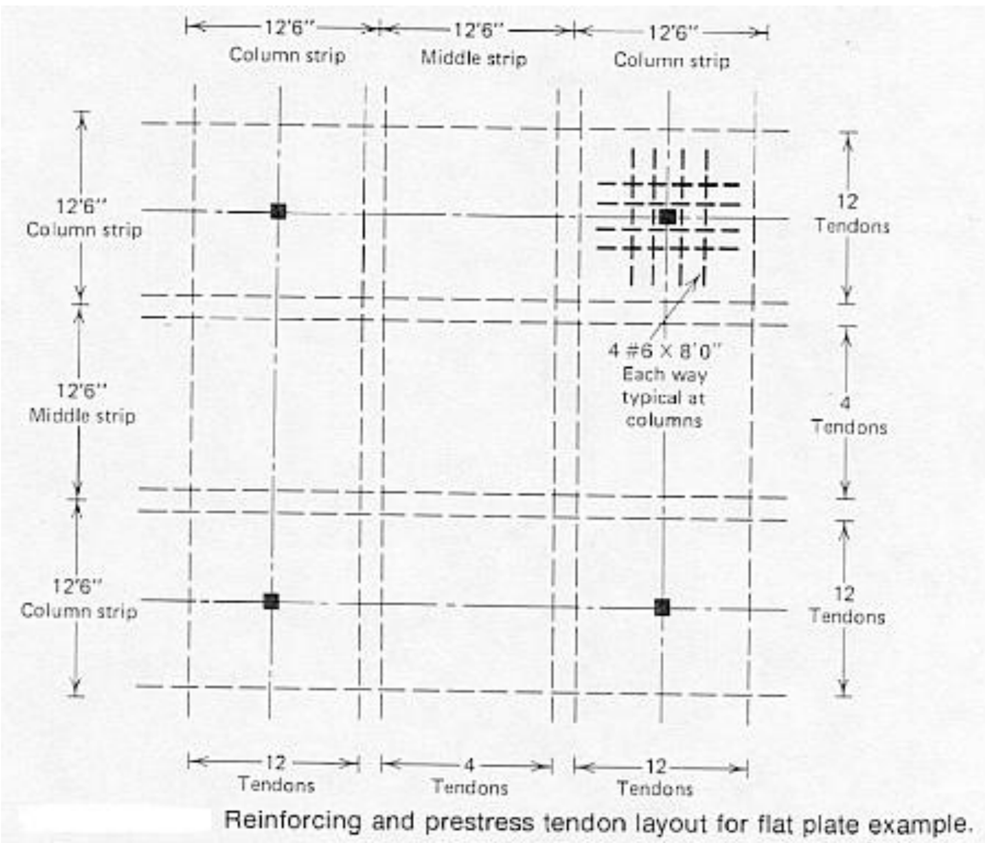

Figure 2. *Reinforcement and Tendon Layout of Scaled Flat Plate Slab.*

(i) (ii)

(iii) (iv)

(v)

Figure 3. Exploded View of Formwork and Reinforcement Layout of Flat Plate Slab.

3.7. Slab Testing

Figures 4 and 5 respectively show the plan view of the water tank and the total experimental setup.

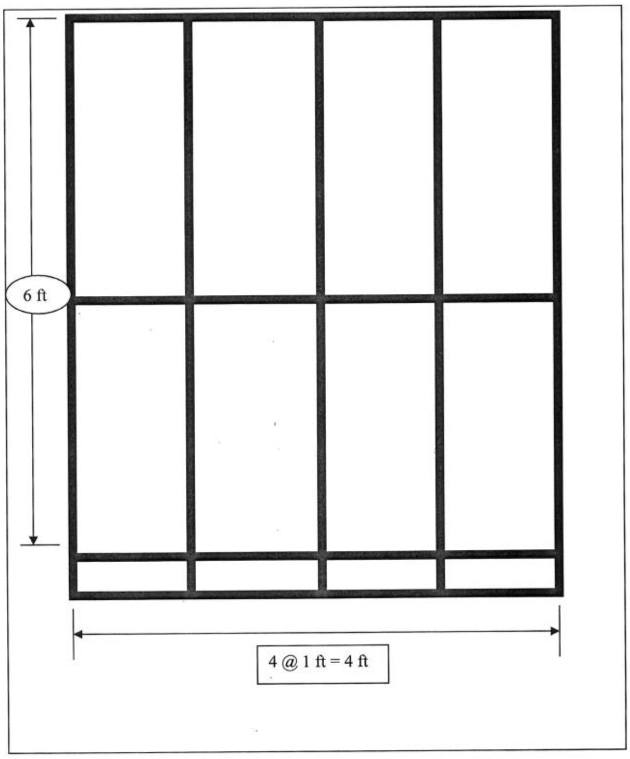

***Figure 4**. Plan View of Water Tank.*

***Figure 5**. Experimental setup showing water tank on the scaled flat plate slab.*

4. Experimental Results

Table 3 shows the experimental results with observations. The tank area = 13.57 ft^2, live load was water.
f'_c = 3,750 psi, ACI deflection limit = L/360 = 33.33 in/1000 = 0.33 in.

***Table 3**. Experimental Results.*

Depth of water (ft)	Distributed load (lb/ft^2)	Weight (lb)	Dial gauge reading (inches / 1000)	Observations
0.00	0	0	0.00	No leaks, no visible cracks
0.25	16	212	0.00	
0.50	31	423	0.00	No leaks, no visible cracks
0.75	47	635	0.50	
1.00	62	847	1.25	No leaks, no visible cracks
1.25	78	1058	3.00	
1.50	94	1270	4.00	No leaks, no visible cracks
1.75	109	1482	5.00	
2.00	125	1694	5.25	No leaks, no visible cracks
2.25	140	1905	5.50	
2.50	156	2117	5.75	No leaks, no visible cracks
2.75	172	2329	6.00	

Depth of water (ft)	Distributed load (lb/ft^2)	Weight (lb)	Dial gauge reading (inches / 1000)	Observations
3.00	187	2540	6.00	No leaks, no visible cracks
3.25	203	2752	7.50	
3.50	218	2964	8.00	No leaks, no visible cracks
3.75	234	3175	9.00	
4.00	250	3387	9.50	No leaks, no visible cracks
4.25	265	3599	11.00	
4.50	281	3810	12.25	No leaks, no visible cracks
4.75	296	4022	14.00	
5.00	312	4234	15.00	No leaks, no visible cracks
5.25	328	4446	17.00	

Note: a standard live load of 50 lb/ft^2 is usually used for designing apartment and office buildings.

5. Slab Evaluation with ACI Design Provisions

The design evaluations were carried out with respect to deflections, stresses, shear and flexural capacity using a developed ACI provisioned spreadsheet and experimentally obtained load and deflection data. Up to 4 ft of water (250 lb/ft^2), deflections, stresses, shear and flexural capacity satisfied the ACI design provisions. The stresses over 4 ft deviated. This is because the non-prestressed reinforcement around the corner was not considered in the allowable stress calculations. A factor of safety of 4 was obtained based on a distributed live load of 62 lb/ft^2 (1 foot water depth). It may noted again, that a a standard live load of 50 lb/ft^2 is usually used for designing apartment and office buildings. The capacity of our slab is five times as much. Therefore, this is a very safe slab. The evaluation is shown in Table 4.

Table 4. *Evaluation with ACI Design Provisions.*

Depth of water (ft)	Distributed Load (lb/ft^2)	Weight (lb)	Deflections	Stresses	Shear and Flexural Capacities	Factor of Safety (Due to live load)
0.00	0	0	Within ACI limit	Correlate	Correlate	__
0.25	16	212	Within ACI limit	Correlate	Correlate	__
0.50	31	423	Within ACI limit	Correlate	Correlate	__
0.75	47	635	Within ACI limit	Correlate	Correlate	__
1.00	62	847	Within ACI limit	Correlate	Correlate	1.00
1.25	78	1058	Within ACI limit	Correlate	Correlate	1.3
1.50	94	1270	Within ACI limit	Correlate	Correlate	1.5
1.75	109	1482	Within ACI limit	Correlate	Correlate	1.8
2.00	125	1694	Within ACI limit	Correlate	Correlate	2.0
2.25	140	1905	Within ACI limit	Correlate	Correlate	2.3
2.50	156	2117	Within ACI limit	Correlate	Correlate	2.5
2.75	172	2329	Within ACI limit	Correlate	Correlate	2.8
3.00	187	2540	Within ACI limit	Correlate	Correlate	3.0
3.25	203	2752	Within ACI limit	Correlate	Correlate	3.3

Depth of water (ft)	Distributed Load (lb/ft^2)	Weight (lb)	Deflections	Stresses	Shear and Flexural Capacities	Factor of Safety (Due to live load)
3.50	218	2964	Within ACI limit	Correlate	Correlate	3.5
3.75	234	3175	Within ACI limit	Correlate	Correlate	3.8
4.00	250	3387	Within ACI limit	Correlate	Correlate	4.0
4.25	265	3599	Within ACI limit	Correlate	Correlate	__
4.50	281	3810	Within ACI limit	Correlate	Correlate	__
4.75	296	4022	Within ACI limit	Correlate	Correlate	__
5.00	312	4234	Within ACI limit	Correlate	Correlate	__
5.25	328	4446	Within ACI limit	Correlate	Correlate	__

6. Conclusions

The main goal of this work was to perform a design evaluation on a constructed scaled post-tensioned 4 ft x 4 ft flat plate concrete slab with American Concrete Institute (ACI) design provisions. The 28 days compressive strength of concrete was 5000 psi. The slab thickness was 1/2 in, and 1/16 in post-tensioning cables inside a plastic sheathing were used as the reinforcement. The slab was loaded using a designed water tank of 4 ft x 4 ft x 6 ft dimensions. The water depth generated the distributed load on the slab and a dial gauge measured the slab deflections. Distributed load and deflection data were collected. The following conclusions were obtained from this work:

1) No leaks or cracks were observed in the experimental slab. This is because of strong shear and flexural design.
2) The stresses correlated well until 4 ft depth of water.
3) The stresses over 4 ft deviated a bit. This is because the non-prestressed reinforcement around the corner was not considered in the allowable stress calculations.

Abbreviations

ssd Saturated Surface Dry
f'_c Compressive Strength of Concrete
f_y Yield Strength of Steel
f_{pu} Ultimate Strength of Tendon

Author Contributions

Mohammed Faruqi: Conceptualization, Methodology, Project administration, Resources, Supervision, Visualization, Writing – review & editing

Carlos Vargas: Data curation, Formal Analysis, Investigation, Software Validation, Writing – original draft

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] The Constructor, "Flat Plate Floor System-Features and Advantages". Available from https://theconstructor.org/building/flat-plate-floor-system-features-advantages/36113/ [Accessed 6 July 2021].

[2] Mota, Mike., et, (2022), "High-Performance Concrete Flat-Plate Floor System," Concrete International.

[3] Buildings, "Concrete Floor-Two-Way, Plate". Available from https://www.dimensions.com/element/concrete-floor-two-way-plate [Accessed 3 June 2023].

[4] EB3 Construction, "A Deep Dive into Concrete Slab Systems and Construction Best Practices". Available from https://blog.eb3construction.com/construction/project-management/slab-construction/ [Accessed 7 July 2025].

[5] Structures Design Guidelines., (2023), "Structures Manual," Vol. 1, Florida Department of Transportation.

[6] Malta Chamber of Construction Management, "Usage of Flat Slab in Construction Industry". Available from https://mccm.org.mt/usage-of-flat-slab-in construction industry/ [Accessed 13 September 2023].

[7] Housing, "Flat slab: What is it, types advantages and disadvantages". Available from https://housing.com/news/flat-slab-why-should-you-build-with-a-flat-slab/ [Accessed 21 August 2025].

[8] The Constructor, "Flat Slab-Types of Flat Slab Design and its Advantages". Available from https://theconstructor.org/structural-engg/flat-slabtypes-design-advantages/13919/ [Accessed 5 June 2025].

[9] Hemali, P., (2024), Flat Slab: Types, Advantages, and Design Techniques," Construction Guide.

[10] Benchmark Fabricated Steel, "The Advantages of Flat Concrete Slab". Available from https://benchmarksteel.com/2023/08/the-advantages-of-flat-plate-concrete-slab/ [Accessed 27 August 2023].

[11] Brick and Bolt, "Types of Flat Slab-Benefits and Design Guide in Construction". Available from https://www.bricknbolt.com/blogs-and-articles/construction-guide/flat-slab [Accessed 3 March 2025].

[12] ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-23) and Commentary (ACI 318R-19)," American Concrete Institute, Farmington Hills, MI, 2023, 623 pp.

[13] Standard Specification for Portland Cement., (2024), ASTM C150/C150M-24 American Society of Testing Materials.

[14] Standard Specification for Portland Cement., (2023), ASTM C33/C33M-18 American Society of Testing Materials.

[15] Portland Cement Association., (2021), "Design and Control of Concrete Mixtures," 17th Edition.