

Seismic Performance Evaluation of Post-Tensioned Flat-Slab Building Systems with TMT and GFRP Reinforcement

¹Mahesh Arun Fulsoundar, ²Dr. A.G. Dahake

^{1,2}Department of Civil Engineering, G H Raisoni College of Engineering and Management Wagholi, Pune

Mail id - mahesh.fulsoundar@gmail.com

Abstract—This paper presents an analytical evaluation of a post-tensioned/reinforced concrete flat-slab building system under seismic loading. The study is based on a basement + Ground + four typical floors + attic structural prototype having an overall plan dimension of 23.40 m x 16.60 m, flat slab thickness of 200 mm, 600 mm x 600 mm columns and drop-panel regions at slab-column joints. ETABS-based response spectrum analysis and IS code-based checks are used to compare TMT and GFRP reinforced flat-slab alternatives. The adopted post-tensioning calculation uses a 12.7 mm low-relaxation strand with an effective force of 108.1 kN after losses, producing an equivalent upward balancing load of 3.75 kN/m², approximately 62.5% of the service dead load. Results show that GFRP reinforcement increases X-direction top displacement from 20.992 mm to 30.734 mm and X-direction drift from 0.001660 to 0.002325, while reducing X-direction seismic force attraction from 1110.8523 kN to 794.9928 kN. Punching shear demand-capacity ratios remain within safe limits for both systems. The study concludes that TMT provides superior deformation control, whereas GFRP offers durability benefits that require careful drift and connection safety verification.

Keywords— post-tensioned flat slab; ETABS; GFRP reinforcement; TMT reinforcement; punching shear; response spectrum analysis; IS 1893; seismic performance.

I. INTRODUCTION

Flat-slab structural systems eliminate deep beams and transfer gravity loads directly from slab panels to columns. This arrangement improves architectural flexibility, reduces floor-to-floor height, simplifies formwork and accelerates construction. Post-tensioned flat slabs further improve serviceability by inducing precompression and by balancing part of the gravity load through draped tendon profiles. However, the same structural efficiency that makes flat slabs attractive under gravity loading can make them vulnerable under lateral earthquake effects.

The absence of beams reduces frame action and lateral stiffness. Earthquake forces may therefore produce larger storey displacement, interstorey drift, unbalanced moment and punching shear demand at slab-column connections. The slab-column region becomes the governing local safety zone, particularly when flat slabs are used without adequate walls, perimeter beams or other lateral load-resisting systems. For this reason, seismic evaluation of PT/flat-slab systems must combine global response parameters with local punching shear checks.

This paper converts the supplied dissertation data into an IEEE-style analytical research paper. The main objective is to compare TMT and GFRP reinforced flat slabs with drop panels using displacement, drift, base shear, post-tensioning load balancing and punching shear demand-capacity indicators.

II. STRUCTURAL MODEL AND MATERIALS

The structural prototype consists of Basement + Ground + four typical floors + attic, giving seven levels in total. The plan dimensions are 23.40 m in the X direction and approximately 16.60 m in the Y direction. Non-uniform bay spacing is used to represent a realistic residential or institutional building layout. The ETABS model consists of

columns modelled as frame elements, slabs and drop panels modelled as shell elements and rigid diaphragm action assigned at floor levels.

TABLE I. BUILDING GEOMETRY AND SECTION DETAILS

Item	Adopted value
Structural configuration	Basement + Ground + 4 Floors + Attic
Plan dimension	23.40 m x 16.60 m
X-direction bay spacing	4.80, 4.80, 3.60, 4.75, 4.95 m
Typical storey height	3.00 m
Column size	600 mm x 600 mm
Beam size for reference frame	400 mm x 400 mm
Flat slab thickness	200 mm
Frame slab thickness	140 mm

Concrete grade M30 and Fe500 steel are adopted for conventional reinforced concrete modelling. GFRP bars are considered as an alternative reinforcement to improve durability and corrosion resistance. The major mechanical distinction is the significantly lower modulus of elasticity of GFRP compared with steel, which directly affects displacement and drift response.

TABLE II. MATERIAL PARAMETERS USED IN THE ANALYSIS

Material parameter	Concrete / TMT / GFRP value
Concrete grade	M30, f _{ck} = 30 MPa, E _c = 27.4 GPa
Steel reinforcement	Fe500, f _y = 500 MPa, E _s = 200 GPa
GFRP reinforcement	f _u approximately 800 MPa, E _f approximately 50-60 GPa
Concrete unit weight	25 kN/m ³
Poisson ratio	Concrete = 0.20; steel = 0.30

III. METHODOLOGY

The methodology follows an analytical and numerical workflow. First, the grid system, storey levels, material properties, shell slab elements, frame columns, drop panels and diaphragm constraints are defined in ETABS. Dead load, live load and response spectrum earthquake cases are assigned. Second, the TMT and GFRP reinforced flat-slab models are analysed for modal and response spectrum

responses. Third, maximum storey displacement, storey drift, base shear, modal time period, frequency and punching shear demand-capacity values are compared.

The adopted response spectrum calculation follows the design horizontal seismic coefficient method:

$$A_h = (Z/2)(I/R)(S_a/g)$$

where Z is the zone factor, I is the importance factor, R is the response reduction factor and S_a/g is the spectral acceleration coefficient. The supplied model uses $Z = 0.24$, $I = 1.0$, $R = 5$, medium soil and 5% damping. For consistency with IS 1893, $Z = 0.24$ is treated as the adopted zone factor in the numerical study.

Post-tensioning is represented through equivalent load balancing. For a parabolic tendon, the equivalent upward load is evaluated as:

$$w_{bal} = 8Pe e / L^2$$

For one 12.7 mm strand, the jacking force is 137.7 kN and the effective prestressing force after 21.5% losses is 108.1 kN. With $e = 0.10$ m and $L = 4.80$ m, $w_{bal} = 3.75$ kN/m² for 1.0 m tendon spacing. This balances nearly 62.5% of the service dead load of 6.00 kN/m².

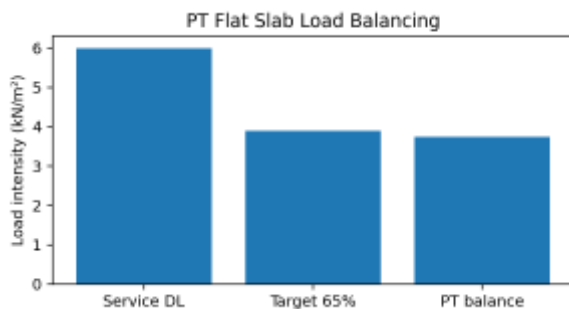


Fig. 1. PT flat-slab load balancing adopted for representative tendon calculation.

IV. RESULTS AND DISCUSSION

The comparative structural response indicates a clear stiffness-based difference between the two reinforcement systems. In the X direction, the GFRP model develops greater top displacement and drift due to its lower elastic modulus. In contrast, the TMT model attracts higher base shear because its greater stiffness mobilizes larger lateral seismic forces. The Y-direction response is comparatively small for both systems, indicating that the selected plan and load-resisting path govern more critically in the X direction.

TABLE III. COMPARATIVE SEISMIC RESPONSE OF TMT AND GFRP FLAT SLABS

Parameter	TMT	GFRP
Top displacement X	20.992 mm	30.734 mm
Top displacement Y	0.047 mm	0.036 mm
Max drift X	0.001660	0.002325
Max drift Y	0.000004	0.000003
Base shear X	1110.8523 kN	794.9928 kN
Base shear Y	1.5678 kN	0.5067 kN

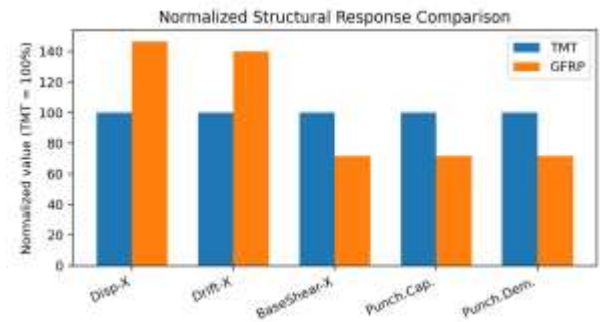


Fig. 2. Normalized structural response comparison of TMT and GFRP systems.

The drift check is satisfied for both systems because the maximum X-direction drift ratios, 0.001660 for TMT and 0.002325 for GFRP, are below the IS 1893 limit of 0.004. However, code compliance alone is not sufficient for performance interpretation. The GFRP drift is approximately 40% higher than the TMT drift, showing that deformation control must be treated as a governing design requirement when GFRP reinforcement is used in seismic flat-slab systems.

V. PUNCHING SHEAR AND CODE CHECKS

The punching shear check is critical because flat slabs transfer vertical and lateral actions directly into columns. For a 600 mm x 600 mm column and a 200 mm slab with effective depth $d = 165$ mm, the critical perimeter is approximately 3720 mm. The nominal punching shear stress is evaluated using:

$$\tau_{u_v} = V_u / (b_o d)$$

Using the TMT demand value of 1110.85 kN gives τ_{u_v} approximately 1.81 N/mm². The demand-capacity comparison remains safe for both reinforcement systems, but the TMT slab provides a larger absolute strength reserve. The GFRP slab remains safe because its demand is lower; however, the lower capacity and brittle material behaviour require careful design detailing at slab-column connections.

TABLE IV. PUNCHING SHEAR DEMAND-CAPACITY COMPARISON

System	Capacity	Demand	D/C
TMT	1277.48 kN	1110.85 kN	0.87
GFRP	914.24 kN	794.99 kN	0.87

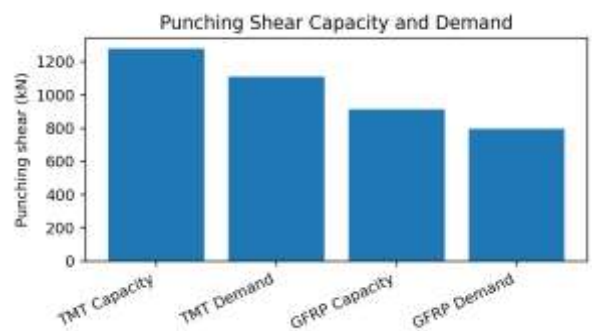


Fig. 3. Punching shear capacity and demand for TMT and GFRP flat slabs.

VI. CONCLUSION

The study shows that PT/flat-slab systems are efficient for architectural planning and gravity load resistance, but their seismic performance must be evaluated through both global

and local response parameters. The absence of beams increases the importance of lateral stiffness and slab-column connection safety. TMT reinforcement provides superior displacement and drift control because of its higher modulus of elasticity. GFRP reinforcement offers corrosion resistance and lower seismic force attraction, but produces higher deformation and therefore requires strict drift, ductility and punching shear verification.

For the analysed building, both TMT and GFRP systems satisfy the IS drift limit and punching shear demand-capacity requirements. The TMT model is more suitable where lateral stiffness and deformation control govern. GFRP may be adopted where durability and corrosion resistance are important, provided adequate stiffness-enhancing measures such as drop panels, RC walls, perimeter beams or core walls are included. Future work should include nonlinear time history analysis, shake table testing, soil-structure interaction and cost-durability optimization of PT/GFRP flat-slab systems.

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