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# Roof Slab Safety Index (Rssi): A Framework for Evaluating Structural Adequacy of RC Roof Slabs with Rooftop Antennas

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## Abstract
*The growing deployment of satellite antenna systems atop low-rise reinforced concrete (RC) buildings introduces concentrated loads that the original slab design did not account for. This study introduces and validates the Roof Slab Safety Index (RSSI) a practical performance-based metric to assess RC roof slab structural adequacy under combined antenna and building loads. A G+1 RC residential building integrated with an S/Ka-band satellite antenna pedestal was modelled and analyzed using STAAD.Pro 2024 in compliance with IS 456:2000, IS 875 (Parts 1–3), and IS 1893 (Part 1):2016. The RSSI is defined as the minimum ratio of slab capacity to imposed demand across two failure modes: flexure, and shear. For the modelled 300 mm thick roof slab (M25 concrete, Fe500 steel, 10 mm bars at 100 mm c/c both ways), the governing flexural safety index was 2.21 and the shear safety index was 1.33, yielding an overall RSSI of 1.33. All serviceability checks, including span-to-depth ratio (l/d = 15.79 vs. permissible 32), were satisfied. An RSSI ≥ 1.33 confirms that the slab is structurally safe without requiring redesign, despite carrying the combined weight of the RC pedestal and the 145kN antenna assembly. The RSSI framework offers practitioners a concise diagnostic index for screening existing roof slabs prior to antenna installation, directly supporting safe and economical communication infrastructure integration in urban environments.*

***Keywords:*** *Flexural safety, Roof Slab Safety Index, Rooftop installation, reinforced concrete slab, Shear capacity.*

## 1. Introduction
As the use of satellite communication keeps growing, adding antenna systems on top of existing RC buildings has become quite common. In busy urban areas where space is already tight, this feels like a practical and affordable solution compared to building separate structures. However, this convenience often comes with a downside—these installations can place extra demands on the structure that weren't considered in the original design, especially on the roof slab. Once an antenna system is placed on the roof, the slab has to carry additional concentrated loads from the antenna dish, the supporting RC pedestal, and related equipment. These loads act along with the regular dead and live loads defined in IS 875, and in many cases, the slab was never designed to handle such heavy, localized forces. If not checked properly, this can put extra strain on the structure and may lead to safety issues. The slab's response to these loads is mainly controlled by three types of failures: bending (flexural failure), one-way shear, and punching shear due to concentrated reactions. To bring all these checks together in a simple and clear way, the Roof Slab Safety Index (RSSI) is introduced. It compares the slab's available strength with the applied loads, where a value of 1.0 or more indicates a safe condition as per IS 456:2000.

## 2. Literature Review
Most of the studies on rooftop telecommunication towers looks at overall behaviour of building, but don't really go into what's happening at the roof slab. Katare and Chincholikar (2024) point out the challenges that as cities grow and space becomes limited, these installations are increasing, yet no clear guidelines on tower placement are still missing, especially in critical cases. Chouhan et al. (2021) and Patil et al. (2019) indicate that even change in the tower's location can influence how a building

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responds during an earthquake. Malviya and Jamle (2019) also note that small shifts in position can lead to visible differences in behaviour. Zala and Patel (2020) further point out that the simplified models we often use may not fully reflect actual behaviour of real structures [1-5]. At the same time, Patidar and Vyas (2021) point out that using base isolation can help lower the impact of earthquakes and make the building more stable overall. Azeem et al. (2018) further point out the lack of clear design guidelines and suggested better ways to estimate seismic amplification. Faria and Quadir (2017) observed that rooftop towers are often treated as minor additions, without properly checking their structural impact. Overall, while these studies give a good understanding of the building's overall behaviour—such as drift and displacement—they don't really address the safety of the roof slab under concentrated loads. This gap highlights the need for a parameter like the Roof Slab Safety Index (RSSI) to better assess slab-level safety.

## 3. Methodology

### 3.1. Performance Parameter

***Roof Slab Safety Index (RSSI)*** is used as a parameter to check whether the roof slab is capable of safely carrying the additional loads coming from the rooftop antenna system. RSSI is the ratio of the available capacity of the slab to the corresponding applied demand, and is given by:

$$RSSI = \frac{\text{Slab Capacity}}{\text{Total Demand}} \quad (1)$$

Capacity is simply how much load the slab can safely handle (in bending, shear, or punching), while demand is the load actually acting on it from analysis.

RSSI compares these two: RSSI above 1.0, the slab is safe. RSSI equal to 1.0, it's just at its limit RSSI below 1.0, the slab isn't safe and needs redesign. For slabs supporting antenna loads, the type of failure depends on how the stresses develop within the slab.

- Flexure Failure: Due to the excessive bending moments in the slab under applied loads.

$$Flexural\ Index = \frac{M_{capacity}}{M_{demand}} \quad (2)$$

- Shear Failure: Due to transverse shear forces acting within the slab thickness.

$$Shear\ Index = \frac{V_{capacity}}{V_{demand}} \quad (3)$$

The overall safety of the slab is governed by the minimum value among all indices:

$$RSSI = \min\left(\frac{M_c}{M_d}, \frac{V_c}{V_d}\right) \quad (4)$$

### 3.2. Model Parameters

The G+1 RC building model was coupled with the antenna system by incorporating it at the roof level. The dimensions of the building considered are as follows shown in Table 1 and Figure 1.

**Table 1 Dimensions of the Building Model**

| Parameter | Description / Value |
|---|---|
| Software | STAAD.Pro 2024 |
| Structural System | Special RC Moment-Resisting Frame (SMRF) |
| Number of Storeys | G + 1 (1 storey) |
| Storey Height | 3.3 m (typical) |
| Beam Size (B1) | 450 mm × 650 mm |
| Column Size (C1) | 450mm × 750 mm |
| Column Size (C2) | 300 mm × 450 mm |
| Antenna pedestal thickness | 420mm |
| Rigid link | 300mm × 300mm |
| Slab Thickness | 300 mm (roof slab) |
| Grade of Concrete | M25 |
| Grade of Steel | Fe 500 |
| Seismic Zone | Zone II (as per IS 1893) |
| Importance Factor (I) | 1.0 |
| Response Reduction Factor (R) | 5.0 (SMRF) |
| Soil Type | Medium Soil (Type II) |

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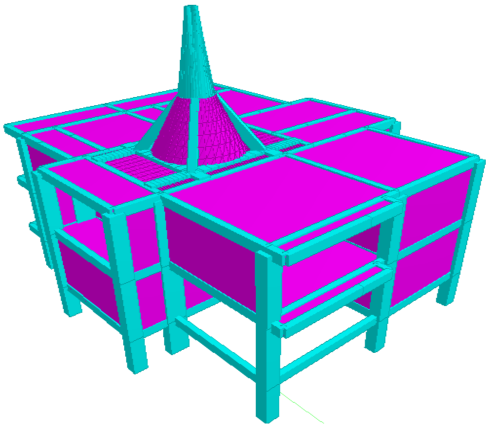

**Figure 1 3D Model of Building with Rooftop Antenna System**

### 3.3. Loading on Roof Slab

The roof slab of the antenna support structure is a two-way restrained interior panel with all four edges continuous (IS 456:2000, Annex D, Case 1). Its aspect ratio ly/lx = 6.945 m / 4.845 m = 1.455, confirming two-way behavior shown in Table 2.

**Table 2 Geometric and Material Parameters of the Roof Slab**

| PARAMETERS | VALUE |
|---|---|
| Shorter effective span ($l_x$) | 4.845 m |
| Longer effective span ($l_y$) | 6.945 m |
| Aspect ratio ($l_y/l_x$) | 1.455 → Two-Way Slab ✓ |
| Overall slab thickness (D) | 300 mm |
| Clear cover | 20 mm |
| Main bar diameter (φ) | 10 mm |
| Effective depth – (d) | 275 mm |
| Concrete grade ($f_{ck}$) | 25 N/mm² |
| Steel grade ($f_y$) | 500 N/mm² |
| Edge condition (IS 456 Annex D) | Case 1 – Interior Panel (All four edges continuous) |

The roof slab's factored load is calculated by combining dead load (including slab, pedestal, and antenna) with live load, as per IS 456:2000.

**Table 3 Load Acting on Roof Slab**

| Load Component | Value |
|---|---|
| Self-weight of slab (SW = D/1000 × 25) | 7.500 kN/m² |
| Miscellaneous loads (pedestal + antenna) | 11.044 kN/m² |
| Total Dead Load (DL) | 18.544 kN/m² |
| Live Load (LL – IS 875 Part 2) | 3.000 kN/m² |
| Partial load factor for DL ($\gamma_{f_{DL}}$) | 1.5 |
| Partial load factor for LL ($\gamma_{f_{LL}}$) | 1.5 |
| Factored load ($w_u = \gamma_{f_{DL}} \times DL + \gamma_{f_{LL}} \times LL$) | 32.316 kN/m² |

The detailed calculation of the miscellaneous loads (antenna pedestal and antenna assembly)

**Table 4 Pedestal Geometry and Input Parameters**

| Parameter | Value | Unit | Remarks |
|---|---|---|---|
| Antenna Load | 145 | kN | — |
| Floor Finish (F.F) | 1.1 | kN/m² | — |
| lx / ly | 4.845 / 6.945 | m | Effective spans |
| D1 / D2 (Outer Dia.) | 1 / 3.4 | m | Top / Bottom |
| D1' / D2' (Inner Dia.) | 0.16 / 2.56 | m | Top / Bottom |
| Height (h) | 3 | m | Pedestal height |

**Table 5 Volume Calculations**

| Parameter | Formula | Value (m³) |
|---|---|---|
| V_outer | π/3 · h · (R1² + R1·R2 + R2²) | 12.535 |
| V_inner | π/3 · h · (R1'² + R1'·R2' + R2'²) | 5.489 |
| V_pedestal | V_outer – V_inner | 7.046 |

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**Table 6** Load Distribution on Slabs

| Load Component | Formula | Value (kN/m²) |
|---|---|---|
| Pedestal Load | γ · V_pedestal / (lx · ly) | 5.235 |
| Antenna Load | Antenna Load / (lx · ly) | 4.309 |
| Antenna System Total | Pedestal + Antenna | 9.544 |
| Total Misc. Load | Antenna System + F.F | 11.044 |

## 4. Demand Assessment: Design Bending Moments

The design bending moment at a section is evaluated using the formula: Mu = α · wu · lx2 which depends on the load acting on the slab, the span length and moment coefficient [6-10].

**Table 7** Design Bending Moments

| Direction | Location | Coeff (α) | Mu (kN·m) |
|---|---|---|---|
| Short Span | Support (Hogging) | 0.05210 | 39.523 |
| Short Span | Midspan (Sagging) | 0.04010 | 30.420 |
| Long Span | Support (Hogging) | 0.03200 | 24.275 |
| Long Span | Midspan (Sagging) | 0.02400 | 18.206 |

The required effective depth from the governing moment (Mu,max = 39.523 kN·m at the short-span support) was calculated as:

$$dreq = \sqrt{\frac{M_{u_{max}} \times 10^6}{(Ru \times 1000)}} \quad (5)$$

$$dreq = \sqrt{\frac{39.523 \times 10^6}{(3.3402 \times 1000)}} = 108.78 \text{ mm}$$

which is well below the provided depth d = 275 mm, confirming adequacy of the slab depth.

## 5. Capacity Calculations

**Table 8** Calculation of Flexural Capacity

| Parameter | Short Span (X) | Long Span (Y) | Unit |
|---|---|---|---|
| Bar diameter (φ) | 10 | 10 | mm |
| Spacing (s) | 100 | 100 | mm |
| Provided Ast | 785.39 | 785.39 | mm² |
| $Ast_{min}$ (0.12%·b·D) | 360 | 360 | mm² |
| Adequacy ($Ast \geq Ast_{min}$) | ✓ OK | ✓ OK | – |
| Neutral axis depth ($x_u$) | 37.96 | 37.96 | mm |
| Limiting $x_{u_{max}}$ (0.46·d) | 126.5 | 126.5 | mm |
| Section type | Under-Reinforced | Under-Reinforced | – |
| Moment Capacity ($M_{u_{capacity}}$) | 87.469 | 87.469 | kN·m |

**Table 9** Calculation of Shear Capacity

| Parameter | Value |
|---|---|
| Design Shear ($V_u = w_u \times \frac{l_x}{2}$) | 78.286 kN/m |
| Nominal shear stress $\tau_v = \frac{V_u \times 1000}{(b \times d)}$ | 0.285 N/mm² |
| % Tensile steel ($p_t = \frac{100 \times Ast}{(b \times d)}$) | 0.143 % |
| Design shear strength ($\tau_c$) – IS 456 Table 19, M30 | 0.379 N/mm² |
| Depth factor k – IS 456 Cl. 40.2.1.1 | 1.0 (D = 300 mm) |
| Enhanced shear strength ($k \cdot \tau_c$) | 0.379 N/mm² |
| Max shear stress ($\tau_{c_{max}}$) – IS 456 Table 20 | 3.10 N/mm² |
| Shear Capacity ($V_{u_{capacity}} = k \times \tau_c \times b \times d$) | 104.225 kN |
| Shear Check ($\tau_v \leq k \cdot \tau_c$) | 0.285 ≤ 0.379 N/mm² → SAFE ✓ |

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## 6. Results & Discussion: RSSI Evaluation

The flexural safety index at the governing section (short-span support, highest demand)

$$SI_{flexure} = \frac{87.469}{39.52} = 2.21 \text{ (From eq no: 2)}$$

The shear safety index:

$$SI_{shear} = \frac{104.225}{78.29} = 1.33 \text{ (From eq no: 3)}$$

$$RSSI = \min(SI_{flexure}, SI_{shear}) = \min(2.21, 1.33) = 1.33 \geq 1.0 \checkmark \text{ SAFE (From eq no: 4)}$$

**Table 10 Summary of RSSI Results**

| Critical Section | Demand | Capacity | Status |
|---|---|---|---|
| Short Span – Support Hogging | 39.523 | 87.469 | SAFE |
| Short Span – Midspan Sagging | 30.420 | 87.469 | SAFE |
| Long Span – Support Hogging | 24.275 | 87.469 | SAFE |
| Long Span – Midspan Sagging | 18.206 | 87.469 | SAFE |
| Shear (Short Span) | 78.286 | 104.225 | SAFE |
| OVERALL ROOF SLAB SAFETY INDEX | | SI = 1.33 | SAFE ✓ |

An RSSI of 1.33 indicates that the 300 mm thick roof slab is structurally adequate to carry the combined loading from the RC frustum pedestal (effective volume 7.046 $m^3$, unit weight 25 $kN/m^3$) and the 145 kN antenna assembly. The slab response is mainly governed by shear rather than flexure under a factored UDL of 32.316 $kN/m^2$ and a moderate lx/d ratio. Although the flexural capacity shows a higher reserve of about 121%, the shear reserve is relatively lower at around 33%, making shear the critical design consideration for such antenna-supported slabs. This observation supports concerns regarding concentrated load effects from antenna bases. In the present study, the pedestal load is idealized as a uniformly distributed load over the slab panel. However, in practice, the load is transferred as concentrated reactions at pedestal supports [11-15]. Therefore, future studies should adopt detailed plate or finite element modelling to better capture local stress concentrations, particularly punching shear around pedestal supports, which are not addressed in simplified IS 456 slab design methods.

## Conclusions

The structural safety evaluates of the roof slab yields the following key findings:

- Flexure: All four critical sections (short-span and long-span, at support and midspan) exhibit Safety Indices greater than 1.0. The governing flexure SI = 2.21 is found at the short-span support under hogging, which is the most critically loaded section. This means that at the most critical section, the slab has about 121% additional capacity.
- Shear: The shear safety index of 1.33 shows that the slab is safe against diagonal tension failure, with roughly 33% reserve capacity. No shear reinforcement is required as confirmed by $\tau_v$ (0.285 $N/mm^2$) < $k \cdot \tau_c$ (0.379 $N/mm^2$) per IS 456:2000, Cl. 40.2.
- Overall Safety: The critical (governing) safety index for the roof slab is SI = 1.33, controlled by shear. This confirms the slab is structurally adequate under all design loading combinations at the Limit State of Collapse in accordance with IS 456:2000.
- Deflection: The calculated span-to-depth ratio (l/d = 15.79) is much below than the permissible limit of 32, showing that the slab satisfies the deflection requirements under the Limit State of Serviceability.
- Steel Adequacy: The reinforcement provided (Ast = 785.39$mm^2$) is greater than the minimum required steel area of Astmin = 360 $mm^2$/m calculated as 0.12% × b × D as per IS 456:2000, Cl. 26.5.2.1 this confirms that the sufficient steel is provided in both directions.

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