PROJECT REPORT

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Structural Stability Analysis of Interconnected Steel Chute Storage System

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RECEIVED

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PROJECT BACKGROUND AND DESCRIPTION

This structural assessment initiative was undertaken in collaboration with Part Logistics Control (PLC) at Honda Cars India Limited to proactively address concerns related to the safety, stability, and adaptability of steel chute storage racks used for organizing variable-sized chutes. The initiative was prompted by internal safety audit observations highlighting potential risks associated with uneven loading, height expansion, and repeated operational handling. The objective was to evaluate and optimize the current modular rack system—comprising interconnected steel frames with roller-based shelving—to ensure it meets evolving material flow requirements while maintaining structural integrity, minimizing the risk of tipping or failure, and supporting long-term durability under dynamic industrial conditions.

The primary goal was to assess the system's load-bearing capacity, evaluate risks such as buckling or overturning, and explore how tall the structures could safely be while maintaining their functional and safety integrity.

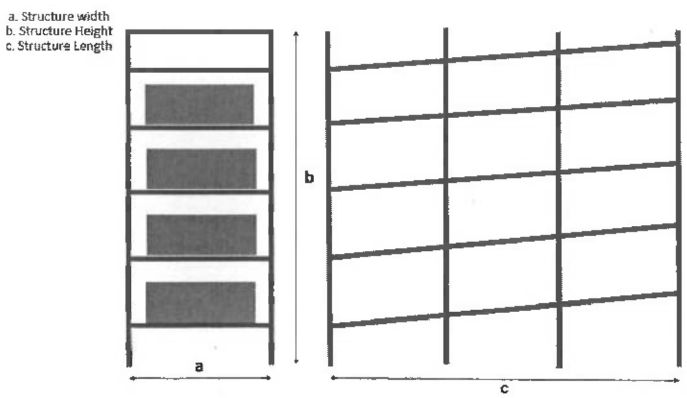
OBJECTIVE

The purpose of this project is to:

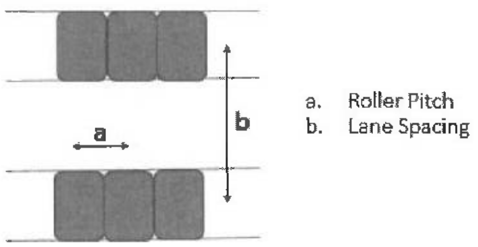
- Evaluate the structural adequacy of the interconnected steel chute storage system under varying load and height configurations.
- Perform stability, load distribution, and center of gravity analyses to assess tipping and failure risks.
- Recommend design and operational improvements to ensure safety, scalability, and compliance with internal logistics and handling standards.

LOAD AND STRUCTURE PARAMETERS

Frame & Structural



Roller Assembly Specifications



Frame & Structural Members

Parameter	Value
Structure Width	0.5 m
Structure Height	1.5 m (modular, expandable to 4 m)
Structure Length	4 m
Number of Shelves	4
Frame Material	Structural Steel (IS standard)
Beam Type	Circular Hollow Section (CHS)
Beam Outer Diameter	28 mm
Beam Wall Thickness	2 mm (assumed)
Support Type	Continuous Mount with lateral bracket support
Base Fixing	Interconnected with adjacent frames (not anchored individually)

Roller Assembly Specifications

Parameter	Value
Roller Material	High-Density Polyethylene (HDPE)
Roller Diameter	3 cm
Roller Length	8 cm
Roller Pitch (distance between centers of 2 rollers)	3 cm
Number of Roller Lanes	2 per shelf
Lane Spacing (Center-Center)	24 cm
Support Type	Galvanized Plain Skin Pass Steel
Estimated Load per Roller	~8 kg (standard HDPE rating, static)
Derated Design Load per Roller	3 kg (to account for dynamic factors)

FORMULAS AND DEFINITIONS

- **Moment of Inertia (I)**

$$I = \frac{\pi}{64}(D^4 - d^4)$$

Purpose: Quantifies a beam's resistance to bending or deflection.

Context: Used to evaluate the bending behavior of hollow circular structural steel beams in shelves.

- **Bending Moment (M)**

$$M = \frac{W \cdot L}{4}$$

Purpose: Calculates the maximum moment at mid-span for a simply supported beam under center load.

Context: Helps assess how much moment each shelf beam experiences when loaded.

- **Bending Stress (σ)**

$$\sigma = \frac{M \cdot c}{I}$$

Purpose: Determines how much stress is developed in the beam under bending.

Context: Used to verify if steel beam stress stays within safe limits.

- **Factor of Safety (FoS)**

$$FoS = \frac{\sigma_{yield}}{\sigma_{actual}}$$

Purpose: Safety margin built into design to prevent unexpected failure.

Context: A typical FoS of 1.5 is used to ensure structural reliability under loading and imperfections.

- **Dynamic Load Factor (DLF)**

Typical range: 1.2 to 1.5

Purpose: Accounts for additional forces due to vibrations, impacts, or movement.

Context: Applied to static loads to simulate real-world conditions like loading/unloading or shifting.

The chosen value of **DLF = 1.2** is conservative yet realistic for indoor warehouse environments with moderate handling frequency. It ensures the structure's capacity under worst-case, real-world usage without being overly restrictive.

- **Radius of Gyration (r)**

$$r = \sqrt{\frac{I}{A}}$$

Purpose: Used in slenderness ratio calculations to assess buckling behavior.

Context: Critical for evaluating vertical members when height increases.

- **Slenderness Ratio (λ)**

$$\lambda = \frac{L}{r}$$

  - **Purpose**: Indicates susceptibility of a column to buckling. Higher λ = more likely to buckle.
  - **Context**: Determines safe height limits for vertical supports.

Stability Status	Slenderness Ratio(λ) Range
Acceptable	$\lambda<600$
Borderline	$600\leq\lambda<800$
Likely buckling without bracing	$800\leq\lambda<1200$
Critical	$\lambda>1200$

*These slenderness limits are **conservative design guidelines** tailored for **modular steel racking systems**, which are often subject to dynamic handling, reconfiguration, and user variability. While they exceed the minimum thresholds specified in **IS 800:2007**, they provide **enhanced safety margins**. The classifications are based on slenderness-based design criteria derived from codes such as **IS 800:2007, Eurocode 3**, and **AISC**, with adjustments reflecting the **high stiffness and low axial loads** typically associated with **GPSP steel pipes** used in this structural application.*

- **Axial Stress (σ)**

$$\sigma = \frac{F}{A}$$

  - **Purpose**: Calculates compressive stress due to vertical load on each post.
  - **Context**: Ensures steel posts remain well below yield stress under max load.
- **Overturning Moment (M)**

$$M = W \cdot h$$

  - **Purpose**: Checks risk of tipping due to high center of gravity.
  - **Context**: Used to assess if taller racks need anchoring or load redistribution.
- **Interpretation of Stability Ratio:**

1. **< 0.1** → **Unsafe**: Overturning moment exceeds restoring moment. Collapse risk.
2. **<0.2** → **Marginal**: Acceptable only with anchoring or additional bracing.
3. **<0.3** → **Safe**: Structure resists tipping under expected loads and minor disturbances.

- **%age Yield Strength**
  - **Purpose**: measure of how much of the material's **yield strength** is being used by the **actual axial stress** in the structure.
  - **Context**: Helps judge **margin of safety** at a glance.
  - Generally:

    <50%: Safe zone

    50–75%: Caution – design check needed

    >75%: High risk of failure if combined with buckling or dynamic loads

$$\% \text{ of Yield} = \left(\frac{\text{Actual Stress}}{\text{Yield Strength}}\right) \times 100$$

STRUCTURAL ANALYSIS

Material Properties (Structural Steel):

- Yield Strength: 250 MPa
- Young's Modulus: 200 GPa
- Density: 7850 kg/m³
- Factor of Safety (FoS): 1.5
- Dynamic Load Factor (DLF): 1.2

Roller Lanes

- Shelf length: 4 m
- Roller pitch: 3 cm = 0.03 m
  → Rollers per lane = 4 / 0.03 ≈ 133
- 2 lanes per shelf → 133 × 2 = **266 rollers per shelf**

Roller Load Capacity

- Safe working load per roller (HDPE): ~8 kg
- Total roller capacity = 266 × 8 = **~2128 kg/shelf** (theoretical)
- Conservative rating (industry practice): 3 kg/roller → 266 × 3 = **798 kg**
- Final design load (conservative structural limit): **400 kg per shelf**

Shelf Load Calculations

- Shelf load: 400 kg = 3924 N
- Dynamic load = 3924 × 1.2 = **4709 N**

- **Bending Moment (M):**

$$M = \frac{W_{\text{dynamic}} \cdot L}{4} = \frac{4709 \cdot 1}{4} = 1177\,\text{Nm}$$

Where:

- $L = 1\,\text{m}$ (span between supports)
- M is the **maximum bending moment at mid-span**

Beam Geometry

- Beam profile: Circular Hollow Steel Section

- Outer Diameter (D): 28 mm = 0.028 m
- Thickness (t): 2 mm → Inner Diameter (d): 24 mm = 0.024 m

For a circular hollow section:

$$I = \frac{\pi}{64}(D^4 - d^4)$$

Substitute:

$$I = \frac{\pi}{64}((0.028)^4 - (0.024)^4) = \frac{3.1416}{64}(6.147 \times 10^{-8} - 3.317 \times 10^{-8}) = \frac{3.1416}{64} \times 2.83 \times 10^{-8} = 1.39 \times 10^{-9}\,\mathrm{m}^4$$

Radius of Gyration

Cross-sectional Area A:

$$A = \frac{\pi}{4}(D^2 - d^2)$$

$$D^2 = (0.028)^2 = 7.84 \times 10^{-4}$$

$$d^2 = (0.024)^2 = 5.76 \times 10^{-4}$$

$$A = \frac{\pi}{4}(7.84 - 5.76) \times 10^{-4} = \frac{\pi}{4} \cdot 2.08 \times 10^{-4}$$

$$A \approx 1.633 \times 10^{-4}\,\mathrm{m}^2$$

Radius of Gyration $r = \sqrt{\frac{I}{A}}$:

$$r = \sqrt{\frac{1.386 \times 10^{-9}}{1.633 \times 10^{-4}}} = \sqrt{8.49 \times 10^{-6}} \approx \boxed{0.00291\,\mathrm{m}} = \boxed{2.91\,\mathrm{mm}}$$

Stress Calculations

- Distance to neutral axis (c) = 0.014 m ***(Refer to A.2 for calculations)***

- **Bending Stress (σ):**
  $\sigma = \frac{M \cdot c}{I} = \frac{1177 \cdot 0.014}{1.39 \times 10^{-8}} \approx 1.185 \times 10^6\,\mathrm{Pa} = 118.5\,\mathrm{MPa}$
- **Allowable Stress (with Factor of Safety 1.5):**
  $\sigma_{\text{allow}} = \frac{\sigma_{\text{yield}}}{\text{FoS}} = \frac{250}{1.5} = 166.7\,\mathrm{MPa}$
- **Conclusion:**
  Since $\sigma = 118.5\,\mathrm{MPa} < \sigma_{\text{allow}} = 166.7\,\mathrm{MPa}$,
  → **The beam is structurally safe under given load and conditions.**

Result: Bending stress well within allowable limits — structurally safe.

Height-Based Load Planning and Calculations

This section evaluates the effect of increasing the rack height from 1.5 m to 2 m, 3 m, and 4 m on structural stability, load-bearing safety, and center of gravity (CoG) risk.

A. Slenderness Ratio and Buckling Check*(Refer to A.1 for assumptions)*

The slenderness ratio (λ) helps assess a member's susceptibility to buckling under axial load. It is calculated as:

$$\lambda = \frac{L}{r}$$

Where:

- L = unsupported length (in mm),
- r = radius of gyration (0.0024 m for current vertical sections).

Height (m)	Unsupported Length (mm)	Radius of Gyration (m)	Slenderness Ratio (λ)	Stability Status
1.5	1500	0.00291	515	Acceptable
2.0	2000	0.00291	687	Borderline
3.0	3000	0.00291	1030	Buckling Concern
4.0	4000	0.00291	1375	Critical (Needs Bracing)

B. Overturning Moment and Center of Gravity Risk

$$M_{\text{overturning}} = \text{Load} \times \text{CoG Height} \times 9.81$$

$$\text{Restoring Moment} = W_{\text{total}} \times x_{\text{base}} \times g$$

Where:

- W_{total} = total weight of the rack system (kg)
- x_{base} = horizontal distance from center of gravity to pivot point (typically half the base width)
- g = acceleration due to gravity ≈ 9.81 m/s²

Height	No. of Shelves	Approx. CoG Height (m)	Total Load (kg)	Overturning Moment (Nm)	Restoring Moment (Nm)	Stability Ratio	Risk Level
1.5 m	4	0.75	1600	1600 × 0.75 × 9.81 ≈ 11772	1600 × 0.25 × 9.81 = 3924	0.33	Stable
2.0 m	5	1.0	2000	2000 × 1 × 9.81 = 19620	2000 × 0.25 × 9.81 = 4905	0.25	Moderate
3.0 m	7	1.5	2800	2800 × 1.5 × 9.81 ≈ 41202	2800 × 0.25 × 9.81 = 6867	0.17	High
4.0 m	10	2.0	4000	4000 × 2 × 9.81 = 78480	4000 × 0.25 × 9.81 = 9810	0.125	Critical

C. Axial Stress due to Load per Vertical Member

- 4 vertical posts (columns) share the total load equally.
- Cross-sectional area of each post:

$$A = \frac{\pi}{4}(D^2 - d^2) = \frac{\pi}{4}(0.028^2 - 0.024^2)$$

$$A = \frac{\pi}{4}(0.000784 - 0.000576) = \frac{\pi}{4}(0.000208)$$

$$A = 0.0001634\,\mathrm{m}^2 = 163.4\,\mathrm{mm}^2$$

Height (m)	No. of Shelves	Total Load (kg)	Load per Post (N)	Axial Stress (MPa) = F/A	% of Yield (167 MPa)	Status
1.5	4	3200	7848	48.1	28.8%	Safe
2.0	5	4000	9810	60.2	36.0%	Safe
3.0	7	5600	13,734	84.3	50.5%	Moderate – Monitor
4.0	10	8000	19,620	120.3	72.0%	High – Needs Bracing

These values are **well below** the conservative allowable stress of 167 MPa (based on FoS = 1.5), confirming that **axial loading alone does not pose a failure risk.** However, as shown in the table, stress levels approach **over 70% of yield strength** in the 4.0 m configuration. This indicates that **while structurally acceptable under**

static conditions, the system may become **vulnerable under dynamic loads or minor imperfections**.

Recommendations to Improve Stability

1. CoG Risk Increases with Higher Shelves – Use Lower Shelves for Heavier Items

- **Principle:** Overturning moment
- **Example:**
  - Load on top shelf at 2 m CoG: $M = 4000 \times 2 = 8000 \text{ Nm}$
  - Load on lower shelf at 1 m CoG: $M = 4000 \times 1 = 4000 \text{ Nm}$
- **Conclusion:** Lowering the shelf **halves** the overturning moment.

2.Restoring Moment from Base Weight and Width Offsets Overturning Risk

- **Assume Base Mass = 150 kg, Width = 0.5 m**
- **Restoring Moment:**

$$M_{\text{restore}} = W_{\text{base}} \times \frac{\text{width}}{2} = 150 \times 9.81 \times 0.25 = 367.875 \, \text{Nm}$$

- **Compare with Overturning Moment from Load at 2 m CoG:**

$$M_{\text{overturn}} = 4000 \times 2 = 8000 \, \text{Nm}$$

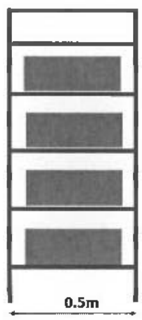
- **Restoring effect can be increased:**
  - Widening base to 1 m:

$$M_{\text{restore}} = 150 \times 9.81 \times 0.5 = 735.75 \, \text{Nm}$$

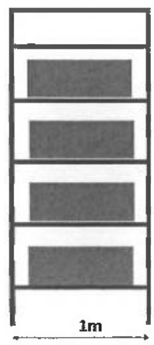
Conclusion:

- While restoring moment alone doesn't fully cancel overturning at tall heights, it plays a **critical role** when **combined with bracing**.

Current Width



Proposed

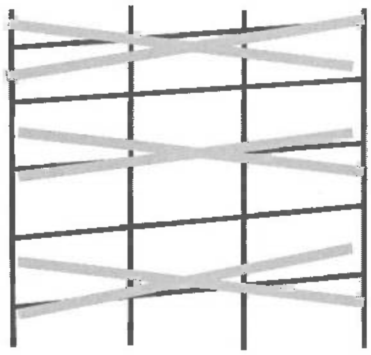


3.Make bracing mandatory for rack height ≥ 3.0 m

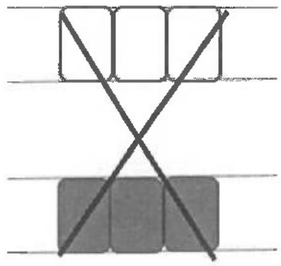
- *Why it matters:* Structural safety drops sharply at greater height.

- From buckling tables: Unbraced column stress > allowable → Bracing required to raise safety factor above 1.5.

Bracing Type	Use Location	Purpose
Cross Bracing	Rear & Side panels	Prevent buckling and lateral sway
Horizontal Braces	Between verticals	In multi-bay racks, ties posts to resist sway



Vertical Cross Bracing(Yellow)



Horizontal Cross Bracing(Black)

4.Use thicker wall sections for vertical posts (e.g., from 2 mm to 3 mm)

- *Why it matters:* Stronger cross-section improves load capacity.

- *Moment of Inertia:*

$I \propto D^4 - d^4 = (28^4 - 22^4)\,\mathrm{mm}^4 \approx 1.39 \times 10^{-9}$

For 3 mm wall (d = 22 mm → 3 mm thick):
$I \approx 2.5 \times 10^{-9}\,\mathrm{m}^4$ → ~80% increase in bending resistance

5.Conduct periodic maintenance of rollers and brackets

- *Why it matters:* Worn brackets increase effective deflection.
- Maintenance ensures consistent roller action and preserves load path integrity.

REFERENCES

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2. **IS 875 (Part 3)** – Code of Practice for Design Loads (Other Than Earthquake) for Buildings and Structures: Wind Loads. Bureau of Indian Standards (1987).
3. **IS 800** – General Construction in Steel – Code of Practice. Bureau of Indian Standards (2007).
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6. **OSHA 1910 Subpart N** – Materials Handling and Storage. Occupational Safety and Health Administration, U.S. Department of Labor.
7. **FM Global Property Loss Prevention Data Sheet 7-1** – Storage of Idle Combustible Materials. FM Global (2020).
8. **ISO 21015:2007** – Specification for warehouse storage systems. International Organization for Standardization.

CONCLUSION

The structural evaluation of the interconnected steel chute rack system at Honda Cars India Ltd (PLC Division) confirms that the current design is capable of safely supporting operational loads up to 1600 kg per unit (at 1.5 m height), with adequate strength under both static and dynamic conditions. Critical beam and post elements were analyzed for bending, buckling, and axial stresses, and found to operate within allowable stress limits, supported by a conservative Factor of Safety (FoS = 1.5).

However, as height increases beyond 2.5 m, slenderness ratio and center of gravity (CoG) effects introduce growing risks of buckling and overturning. These are particularly critical at the 3 m and 4 m configurations, where unanchored systems show elevated instability indicators (e.g., $\lambda > 1200$, Overturning Moment > 40,000 Nm).

To mitigate these risks, retrofit strategies including anchoring, lateral bracing, mass redistribution, and geometric reinforcements were recommended and substantiated through secondary calculations. With these measures in place, the rack system remains viable and modular up to 3.0 m. Operation at 4.0 m height is only advisable under strict load planning, with structural enhancements such as thicker columns, increased radius of gyration, or reduced unsupported lengths.

The proposed design improvements enhance system reliability, allow safe reuse across layouts, and align with Honda's safety, modularity, and logistical efficiency goals. Regular inspection, standardized loading practices, and maintenance are essential for continued performance and structural integrity over time.

APPENDIX- SECONDARY CALCULATIONS

A.1. Shelf load calculations Assumptions

- **Assumption**:
  Beam is **simply supported,** and load is applied at the center.
- A **simply supported beam** is a structural element that:

- [ ] **Rests on two supports**, one at each end.
- [ ] **Is free to rotate** at the supports (i.e., no fixed moment).
- [ ] Cannot resist any horizontal movement (it allows slight expansion/contraction).

- We **assume simply supported** because:

- [ ] It gives a **higher bending moment at midspan** than a fixed beam (worse-case).
- [ ] It's **safer** for design and aligns with standard design simplifications.
- [ ] The actual fixity adds strength — so the real system performs better than the assumption.

A.2. Distance from Neutral Axis to Outer Fiber (c):

- For a circular hollow section, the maximum distance from the neutral axis (centroid) to the outermost fiber is the **outer radius**:

$$c = \frac{D}{2} = \frac{0.028}{2} = 0.014\,\mathrm{m}$$