

INDIAN METAL BUILDING FORUM

IMBF

Connecting India's Metal Building Ecosystem

5C FRAMEWORK: CONNECT • COLLABORATE • CREATE • CONSTRUCT • CERTIFY+

RESOURCE CENTRE

Technical Knowledge Series

STEEL STRUCTURE FAILURE & LESSONS LEARNED

Metal Building Warehouse Distress: Stored-Product Pressure and Column Bases Built Fixed but Modelled as Hinged

Two cottonseed storage warehouses (manufactured metal buildings) | Location not named in source

Learn from Failure
Improve the System
Prevent Recurrence

CASE STUDY NO:	IMBF-SF-010
COUNTRY:	Not stated in source (study published in the USA)
YEAR:	Not established (study published 2002)
STRUCTURE TYPE:	Manufactured (pre-engineered) metal building warehouses
TECHNICAL CATEGORY:	PEB / Design assumption versus as-built detail / Stored-product loads

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IMBF publishes this educational case study. IMBF was not the designer, builder or investigator of the structure.

A DOCUMENT CONTROL AND STATUS

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Technical review status

- ☒ Research Draft (compiled from referenced public sources; not yet reviewed)
- ☐ Technical Review
- ☐ IMBF Approved for Publication

This draft must not be marked approved until an authorised IMBF reviewer has checked it against the primary investigation report listed in the Source Register.

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The technical explanations and lessons presented are intended for general educational and professional-development purposes. They shall not be used as a substitute for: project-specific structural design; engineering calculations; site investigation; competent structural-engineering review; statutory approval; manufacturer instructions; applicable codes and standards; independent inspection; accredited testing or certification.

Readers must verify project-specific requirements with qualified professionals and the applicable statutory and code requirements. Where facts are uncertain or disputed, this document identifies them as such.

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How to read the references. Tags such as [S1] point to the Source Register on the last page. Text marked "IMBF interpretation" is engineering commentary by this series and is not a finding of the original investigators.

1 EXECUTIVE SUMMARY

Question	Answer
What happened?	Two metal building warehouses bulged outward when filled to the roof with cottonseed. Floor slabs cracked badly and the steel frames were left permanently deformed. [S1]
Where?	Two towns about 32 km (20 miles) apart; not named in the source. [S1]
When?	Not established in the available source. The damage came in the third season of use; the study was published in 2002. [S1]
What structure?	Manufactured metal buildings bought and erected as bulk storage warehouses, filled by a blower from one end and emptied through a door at the other. [S1]
What failed?	The frames and the concrete floor slab at the column bases. [S1]
Why?	The stored product pushed outward on the walls. The column bases were built as fixed connections, but the structural model treated them as hinged, so the moment at the base was designed for by neither the building engineer nor the foundation engineer. [S1]
Consequence?	Serviceability failure and permanent damage, not a collapse. No casualties reported. At least three warehouses of this kind are reported to have failed in the same way. [S1]
Main lesson	What is built must behave as the calculation assumed. A base, a brace or a connection detailed differently from the model moves forces to places no one designed.

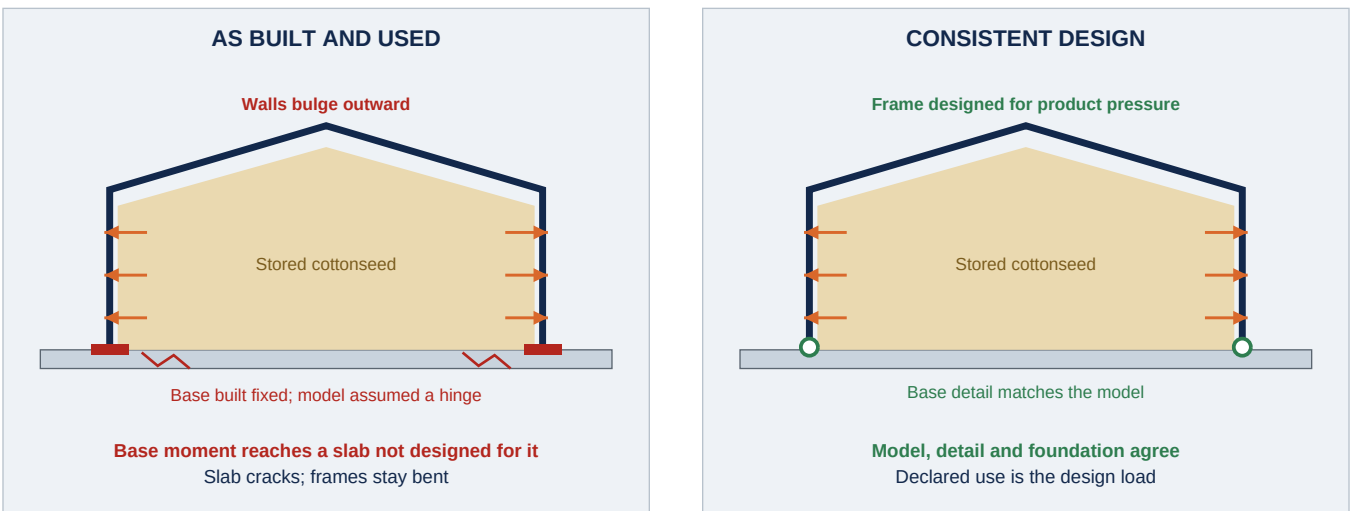


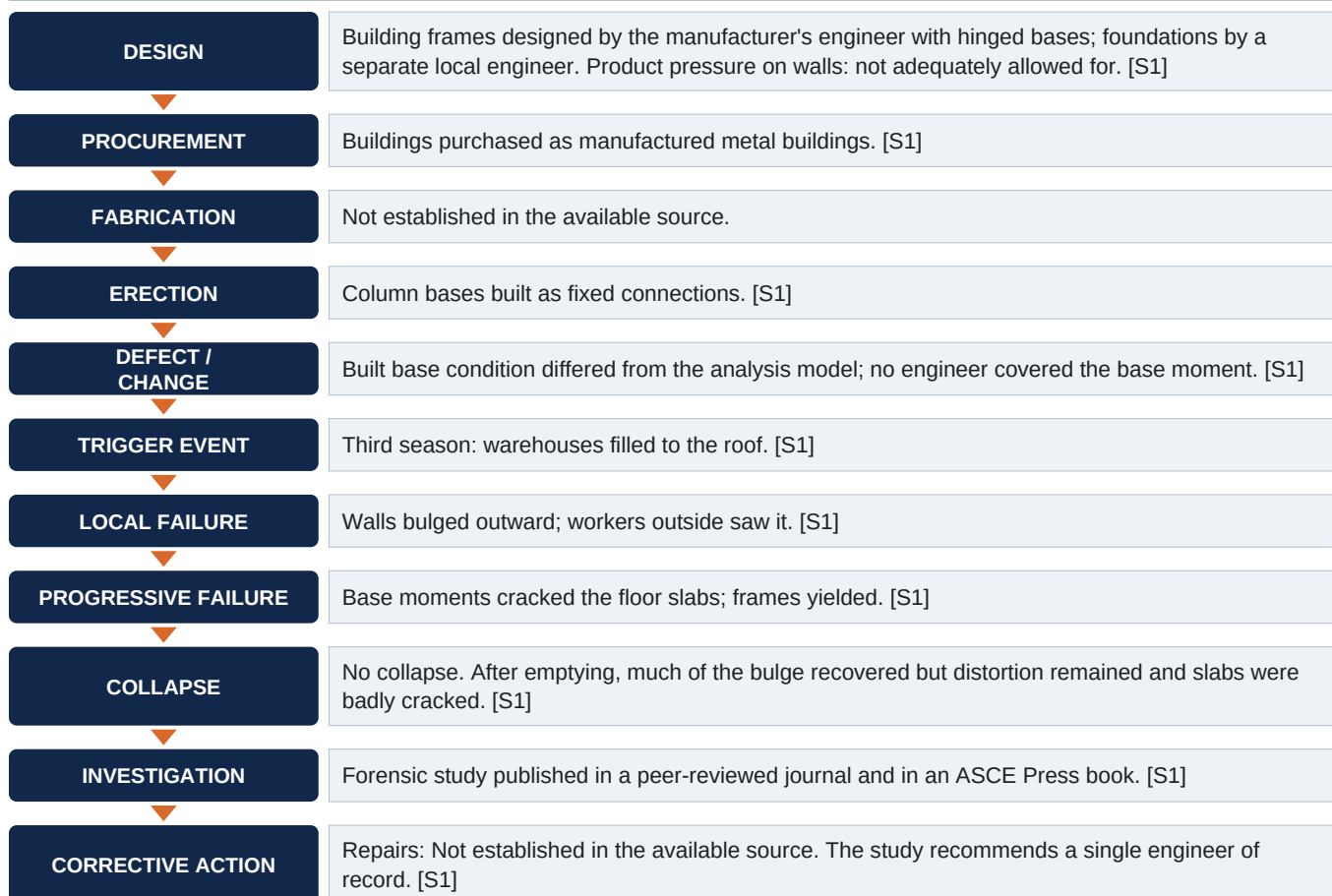
Figure 1. Mismatch between the analysis model and the built column base under stored-product pressure. Original IMBF schematic; conceptual, not to scale.

2 PROJECT BACKGROUND

Only data found in the consulted sources is listed. Missing data is stated as not established rather than estimated.

Item	Verified data	Source
Purpose	Storage of cottonseed after ginning, to hold stock for a better price.	[S1]
Building type	Manufactured metal buildings.	[S1]
Filling	Blown in from one end; a roof-mounted auger moved the product toward the door once the pile reached the roof peak.	[S1]
Intended use	Warehouses were intended to be loaded full.	[S1]
Loading history	Partly filled for two years; filled to the roof in the third season.	[S1]
Column bases	Connections were fixed, but modelled as hinged.	[S1]
Design responsibility	Split between the building manufacturer's structural engineer and a local foundation engineer.	[S1]
Dimensions, frame type, steel grades, design loads	Not established in the available source.	-

3 FAILURE TIMELINE



4 WHAT FAILED?

Element	Identification
Primary failed component	Primary frames (columns and walls) deformed outward. [S1]
Secondary failed components	Concrete floor slab at the column bases, cracked by base moment. [S1]
Connection involved	Column base connection: fixed as built, hinged in the model. [S1]
Load path involved	Stored product -> wall sheeting and girts -> columns -> column base -> slab and foundation.
Failure mode	Excessive deflection and yielding under lateral product pressure; cracking of slab by unaccounted moment. [S1]

5 ENGINEERING FAILURE MECHANISM

Product pressure. Bulk materials such as cottonseed push sideways on walls much as soil does on a retaining wall. The pressure can be estimated with standard soil-mechanics formulas and grows with depth of fill. [S1]

Unbalanced fill. Filling from one end leaves the pile higher on one side or one bay than another, so the frame also sees out-of-balance load. The study stresses overall stability under unbalanced product load. [S1]

Model and detail mismatch. A hinged base sends no moment to the foundation; a fixed base does. The frame was analysed one way and built the other. The real base moment went into a slab that was never designed for it. [S1]

Divided responsibility. The building engineer did not know the site and use; the foundation engineer did not know metal-building behaviour. The gap between them was the base. [S1]

Mechanism considered	Role in this case
Lateral pressure from stored product	Load not adequately designed for (reported). [S1]
Design assumption versus as-built detail (base fixity)	Direct cause of slab cracking (reported). [S1]
Yielding / permanent deformation of frames	Reported. [S1]
Buckling, weld or bolt failure, corrosion, wind, snow	Not reported as factors.

6 ROOT-CAUSE ANALYSIS

Area	Finding	Basis
Design	Lateral product pressure and unbalanced fill not properly considered; base assumption inconsistent with detailing.	Reported [S1]
Material	Not reported as a factor.	-
Fabrication	Not established in the available source.	-
Welding	Not established in the available source.	-
Bolting	Base connection behaved as fixed.	Reported [S1]
Erection	Not established in the available source.	-
QA/QC	No check that the built base matched the design model.	IMBF interpretation of [S1]
Operation	Filled to the roof, as the owner intended.	Reported [S1]
Maintenance	Not reported as a factor.	-
Management / communication	Responsibility split between manufacturer's engineer and local foundation engineer; poor communication.	Reported [S1]

Level	Statement
Immediate cause	Outward product pressure on walls when the warehouses were filled to the roof. [S1]
Contributing causes	Product load underestimated; fixed base modelled as hinged; base moment undesigned; unbalanced filling. [S1]

Level	Statement
Root cause	No single engineer of record owned the whole structure, its use and its interface with the foundation. [S1]

7 FIVE-WHY ANALYSIS

IMBF interpretation built on the findings reported in the cited sources.

WHY 1	Why did the walls bulge and the slabs crack? Because the frames were pushed outward by the stored product and the bases put moment into the slab.
WHY 2	Why were the frames not strong and stiff enough? Because the lateral pressure of the product was not properly designed for.
WHY 3	Why did the slab take moment? Because the bases were built fixed while the design assumed hinges.
WHY 4	Why did no one design for that moment? Because the building engineer assumed none and the foundation engineer was given none.
WHY 5	Why was this not coordinated? Because design was split between two engineers with no one responsible for the whole.
ROOT SYSTEMIC / CAUSE	Standard building supplied for a non-standard load, with divided design responsibility and no check of built detail against model.

8 CORRECTIVE ACTION

Immediate corrective action (as reported)

- Product removed; damage surveyed and studied. [S1]
- Repair or strengthening carried out: Not established in the available source.

Permanent corrective action (engineering remedy, IMBF interpretation)

- Design bulk-storage buildings for lateral product pressure, including unbalanced fill, or keep the product off the walls with separate retaining structures.
- Make the base detail and the analysis model agree, and design the foundation for the resulting reactions, including moment where the base is fixed.
- Appoint one engineer of record for building and foundation.
- State the permitted fill height and filling pattern on the drawings and on a sign in the building.

9 PREVENTIVE ACTION (CAPA)

Problem	Root cause	Corrective action	Preventive action	Responsible party
Walls bulged	Product pressure not designed for	Strengthen frames or add retaining walls	Owner states stored material and fill height in the order; designer confirms loads	Owner; building designer
Slab cracked	Fixed base, hinged model	Redesign base or foundation	Check of base detail against analysis model before release	Building designer; detailer
Moment undesigned	Split responsibility	Joint review	Single engineer of record; reactions issued and acknowledged in writing	Owner; engineers
Unbalanced load	Filling from one end	Control filling	Operating instructions for filling and emptying	Owner; operator
Problem unseen for two years	No inspection as load rose	Monitor	Inspection at first full loading	Owner; designer

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QA/QC FAILURE ANALYSIS: WHAT SHOULD QA/QC HAVE DETECTED?

Original QA/QC records are not available in the consulted sources. The table shows what a robust system should check on a similar structure (IMBF interpretation).

QA/QC area	Check relevant to this type of failure
Material certificates	Grades on certificates match the design assumption.
Traceability	Members, bolts and anchors traceable to their position.
WPS / PQR and welder qualification	Qualified procedures and welders for load-path welds.
Welding inspection and NDT	Critical welds inspected and tested to the specified extent.
Bolt certificates and installation	Bolts, nuts, washers and anchors as specified; tightening recorded.
Dimensional inspection and alignment	Column plumb and wall line surveyed empty and at first full load.
Bracing	All permanent and temporary bracing installed and connected before load is applied.
Coating	Protection complete; connections still inspectable.
Drainage	Roof falls, drains and overflows as designed and working.
Erection sequence	Work follows the approved sequence; changes approved in writing.
As-built verification	Base, bracing and connection details as built compared with the assumptions in the design model; differences returned to the designer.

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IMBF OPTIMIZATION STRATEGY

Area	Optimisation
Design	Order form captures actual use: stored material, fill height, filling method. Model and details reviewed together.
Fabrication	Detailers confirm base type (pinned or fixed) against the design basis report.
QA/QC	Add hold points for the items that govern stability and load path to the Inspection and Test Plan.
Erection	Follow a written erection sequence with temporary stability designed by an engineer.
Digital traceability	Link inspection records, changes and approvals to each member in the model.
Inspection	Risk-based plan: non-redundant members and connections get the most attention.
Maintenance	Fill-height limit marked in the building; inspection after first full loading.
Cost	The cost of a check, a brace or an extra bolt is small against the cost of a collapse.
Safety	Higher review level where people work under or occupy the structure.
Productivity	Standard, pre-checked details reduce redesign, site improvisation and rework.

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DIGITALIZATION

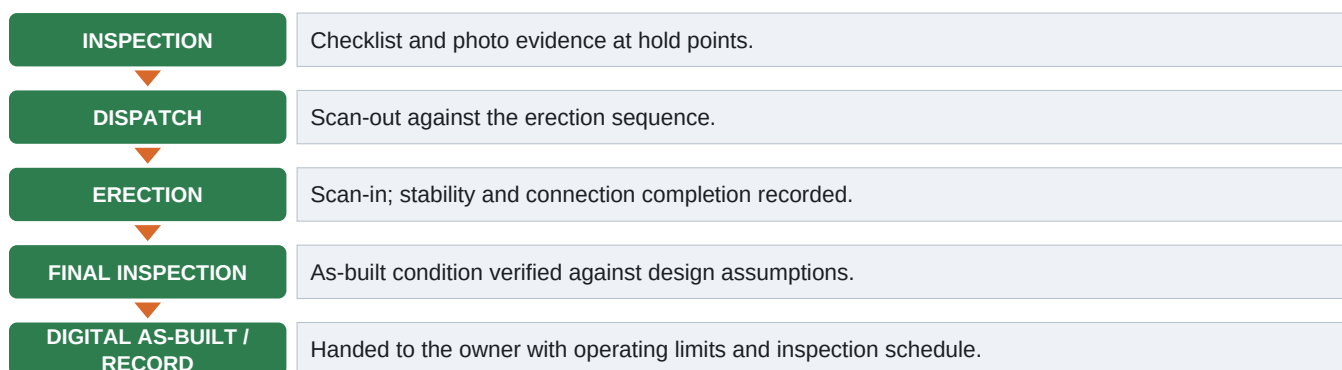
- Design basis report, including use and load assumptions, stored with the building model and handed to the owner.
- Reactions and base type issued to the foundation designer through a tracked transmittal.
- QR code or barcode on main members linking to drawings, certificates and inspection records.
- Heat-number and lot traceability for steel, bolts and anchors.
- Mobile inspection checklists with photographs at each hold point.

DESIGN

Assumptions, critical items and limits recorded in the model.

FABRICATION

Parts marked and traced; changes raised formally.



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INDIAN CONTEXT: WHAT SHOULD INDIA LEARN FROM THIS FAILURE?

- PEB sheds are widely used for bulk storage of grain, sugar, fertiliser, cement, cotton and seed, often with product stacked or heaped against the walls.
- A standard PEB wall is designed for wind, not for bulk-material pressure. The buyer must declare the stored material and height; the supplier must ask.
- In India the PEB supplier usually designs the steel and issues reactions, while the client's consultant designs foundations. Pinned or fixed, and the reactions for each, must be explicit and acknowledged.
- Anchor bolt layout and base plate thickness decide whether a "pinned" base really behaves as one.
- Change of use after handover, for example from general warehouse to bulk storage, needs a structural review.

Reference	Subject	Relevance to this case
IS 800	General construction in steel: code of practice	Member, connection and stability design.
IS 875 (Part 2)	Imposed loads	Loads from stored materials.
IS 9178 and IS 4995	Bins and silos for bulk materials	Pressure from stored bulk solids.
IS 456	Plain and reinforced concrete	Design of slab and foundations for base reactions.
IS 2062	Hot-rolled structural steel	Material conformity.
Project specification and ITP	Contract documents	Where responsibilities, hold points and limits must be written.

Clause numbers are deliberately not cited. Standard titles and current editions must be confirmed against Bureau of Indian Standards publications at technical review.

14 IMBF PREVENTION CHECKLIST

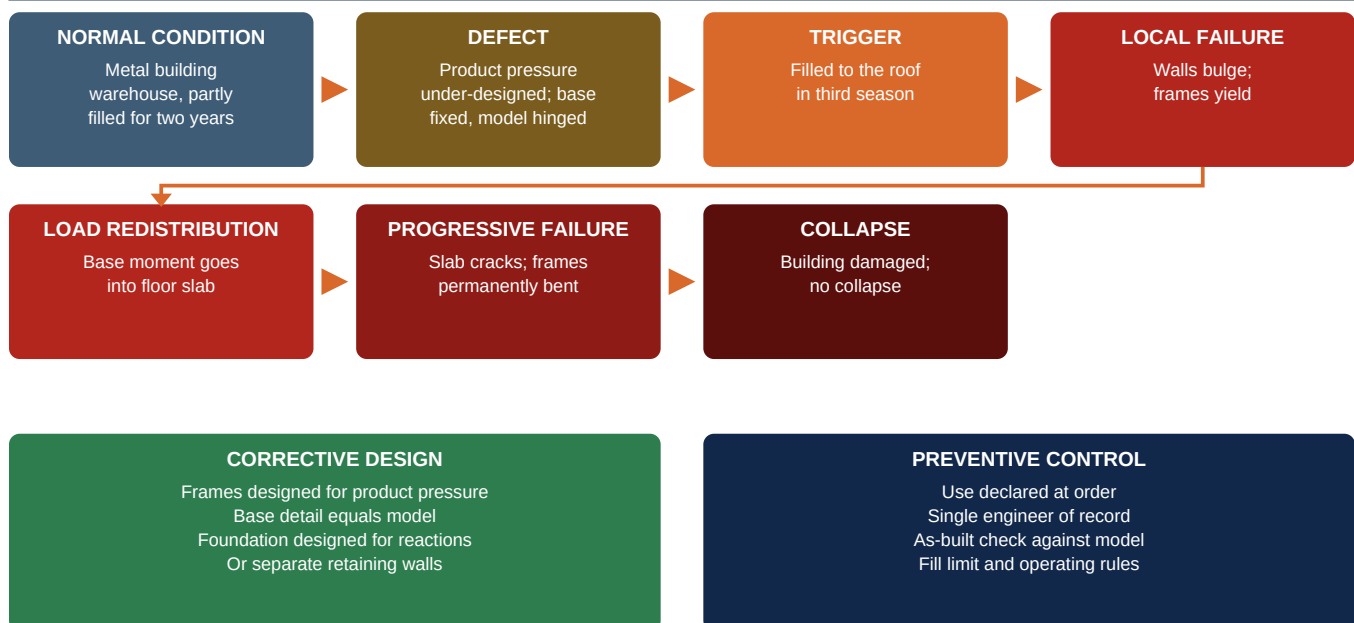
Inspection point	Required check	Status	Remarks
Design review	Stored material, fill height and filling pattern declared and designed for; one engineer of record	☐	
Connection review	Column base type as built matches the analysis model; foundation designed for the issued reactions	☐	
Material traceability	Certificates on file; items traced to position	☐	
Welding	Qualified WPS and welders	☐	
NDT	Critical welds tested	☐	
Bolting	Bolts and anchors as specified; tightening recorded	☐	
Dimensional inspection	Geometry within tolerance	☐	
Bracing	All bracing installed and connected	☐	
Erection sequence	Approved sequence followed; temporary stability checked	☐	
Coating	Protection complete	☐	
Drainage	Drains and overflows clear and working	☐	
Final inspection	Fill-height limit displayed; inspection planned at first full load	☐	
As-built documentation	As-built records and maintenance manual handed to owner	☐	

15 PHOTOGRAPHS

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Photo source	Copyright	License	Permission
None reproduced	Not applicable	Not applicable	Not applicable

16 ORIGINAL IMBF FAILURE DIAGRAM



Original IMBF schematic. Conceptual, not to scale.

17 LESSONS LEARNED

5 engineering lessons

1. Bulk materials load walls like soil.
2. Check unbalanced fill.
3. A base must be built as it was modelled.
4. Design the foundation for the real reactions.
5. Serviceability failure can write off a building.

5 management lessons

1. Appoint one engineer of record.
2. Tell the supplier exactly what will be stored.
3. Make reactions a signed deliverable.
4. Review the structure on change of use.
5. Do not treat a standard building as fit for any load.

5 QA/QC lessons

1. Compare base details as built with the design basis.
2. Check anchor layout against the pinned or fixed assumption.
3. Survey wall line at first full load.
4. Record the declared use on the drawings.
5. Report deformation early.

5 preventive actions

1. Add stored-material questions to enquiry forms.
2. Issue a design basis report with every building.
3. Display fill-height limits.
4. Inspect at first full loading.
5. Share this case with PEB buyers and sales teams.

18 IMBF KEY MESSAGE

"These buildings were made correctly and still failed, because the building that was calculated was not the building that was built or the way it was used. Declare the real load, build the detail the model assumes, and give one engineer the whole picture."

19 SOURCE REGISTER

Ref	Source and organisation	Date	Used for	Consulted?
S1	Building Failure Cases: Agricultural Product Loads. University of North Carolina at Charlotte with the ASCE TCFE Education Committee; summary of Delatte (2002) and of chapter 4 of Beyond Failure (ASCE Press). https://engineering.charlotte.edu/research/areas/case-studies/asce-failure-case-studies/building-failure-cases/	Accessed 4 Oct 2026	All facts in this document	Yes, in full
S2	Agricultural Product Loads and Warehouse Failures. N. J. Delatte. ASCE Journal of Performance of Constructed Facilities, vol. 16, no. 3, pp. 116-123.	2002	Original study, cited by S1	No

Limits of this draft: this case rests on one university summary of a journal paper; the paper itself [S2] was not read. The source does not name the location or date, and gives no dimensions or design loads. This is a damage and serviceability case, not a collapse, and it concerns a design-to-as-built mismatch more than a fabrication error; a second case of fabrication deviation may be added to the series.

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