FAILURES OF STEEL STRUCTURES WITH EMPHASIS ON PRE-ENGINEERED BUILDING (PEB)

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ABSTRACT: *Day by day the use of steel structures is increasing in a vast pace, so there is need to design the structure in the correct standards. This research presents Findings of various types of collapse cases occurs in PEB structures. With Pre-engineered Steel Buildings industry recording growth of Compounded Annual Growth Rate (CAGR) of 15% over past decade, manufacturers and suppliers of PEB are mushrooming across India. With absence of regulatory framework, failures of PEB buildings are happening with increasing frequency. study shows that these failures may be attributed to poor engineering (design and construction), mismatch and/or absence of details in substructure and superstructure, poor manufacturing standards, use of substandard materials and most predominant being faulty erection procedures. Study of failures or impending failures show a grim picture for the industry as a whole, with all the stake holders to share their part of blame.*

Failures may be categorized in two broad categories i.e. during construction and during service life. For these structures, apart from foundation, superstructure failures are due to primary (frame) members, connections, secondary members like bracing and purlins. During service failures are infrequent due to reasons of improper loads or service conditions envisaged or forces beyond human controls like fire or corrosion. These failures, collapse or impending, are due to omission or commission or poor engineering practices. Also remedial measures are recommended here for every stage of project execution.

INTRODUCTION

India is now one of the fastest growing economy in the world, notwithstanding the fact that steel consumption per capita being among lowest, 45 kg/capita as compared to 140 kg/capita of China. Pre-engineering Steel Buildings, PEB, industry applications in various sectors has led its growth by CAGR 15% and more. PEB manufacturers have mushroomed across India to more than 2000 from just few of them about a decade earlier. This phenomenal growth in numbers may not be attributed its positive features of optimum design, aesthetics, economy or earlier time of completion, giving earlier return on investment (ROI). The growth is primarily because of shift in user perception, leading to shift in construction techniques and non-availability of labour, least technical barriers, easy supply of steel, our indigenous ways of frugal engineering, imitation and lack of defined standards. The worst casualty of cancerous growth is quality, severe shortage of skilled and trained professionals. The obvious outcome of this increasing incidences of failures, an overview of it is being recounted as rightly termed forensic study.

This study presents few cases of failures and deemed failures where standards/ conventions are apparently overstretched.

PEB FAILURES - COLLAPSE

CASE I: PACK OF CARDS

Figure 1 shows incident happened near Nagpur about a decade ago. The building was 45 m wide and 112 m long.

Incident was reported to have happened due to mild wind for few minutes during erection. Site visit showed that cross bracing rods were not provided either on roof or wall and comprised of only 12mm diameter rods lying on ground. On one sidewall, only portal columns were erected without beams, making them redundant.

Failure was along the ridge due to insufficient stability in longitudinal direction, what is termed as pack of cards failure

Fig.1 Pack of Cards Failure – Building Collapsed In Direction of Ridge.

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CASE II: CONNECTIONS

Figure 2 presents a case happened near Bengaluru. Building was about 66m wide clear span and was under erection. Collapse was due to failure of rafter splice next to knee, leading to caving in of the erected structure.

For wide span buildings with pin-based support, staging is recommended to be used for supporting rafter for frame erection.

CASE III: TRAGEDY OF ERRORS

Figure 3 presents a case where collapse of a building near Nagpur, @56m wide multi-span with one interior column(BC-1). Cantilevers of about 10m length on either sidewall along roof were modelled, though were not yet erected. Collapse happened during erection and can be attributed to multiple reasons like erection of half frame, insufficient bracing and base pate of frame being above pedestal top by more than 100 mm.

Fig. 2. Failure in Plane of Due to Rafter Splice

Fig. 3. Building Collapse along Ridge and Unbraced Free Standing Columns

Figure 4 show many facts such as inappropriate and insufficient welding, building modelling and section size limits conventions adopted by the industry, mismatch in design and detailing and cross bracing.

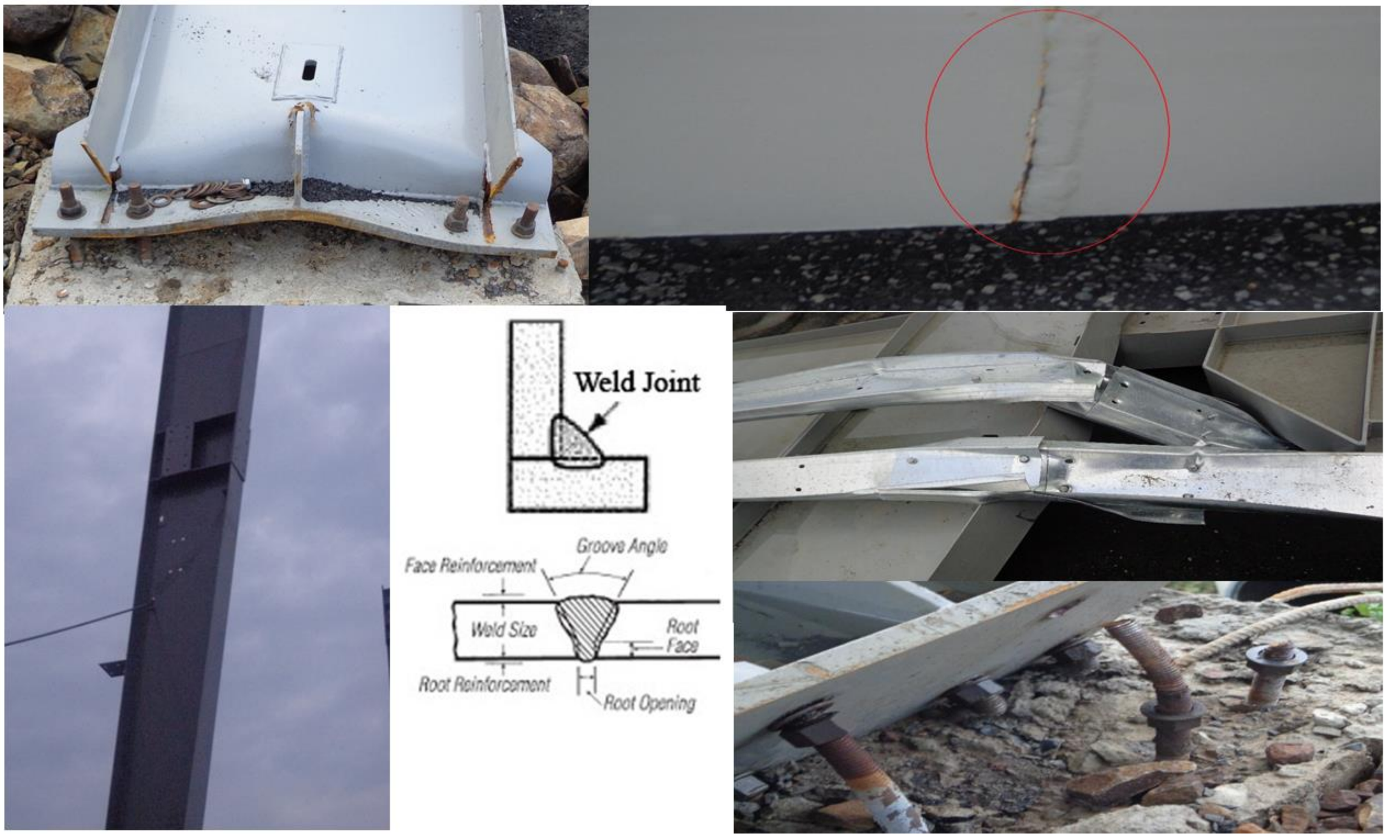

Fig. 4 Insufficient Welding, Inconsistent Detailing, Level Difference in Pedestal & Baseplate

Figure 5 shows rehabilitation of building in progress. Support braces are now added to cantilevers.

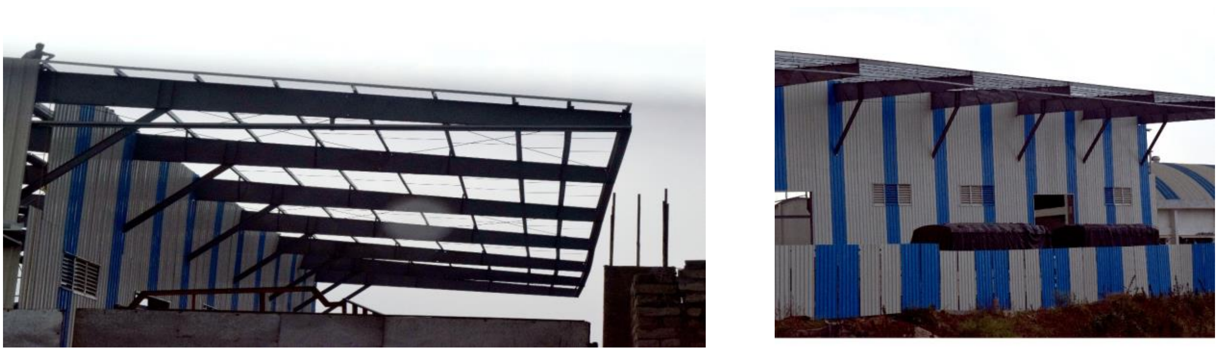

Fig. 5. Rehabilitation in Progress – Braces Added For Cantilevers

CASE IV:PSEUDO PEB .

This metal building collapsed near Nagpur in 2014 and was about 30 m wide multi-span with one Design engineer, supplier of plates, fabricator of primary frame, supplier of coldformed sections and sheeting, were all different. Multiple erectors tried to erect the building, eventually it collapsed. Figure 6 interior column (BC-1) with provision for one crane of 5 MT in each isle and lean-to extension. shows the collapsed building and also rehabilitated one.

Figure 7 shows level of baseplate of column above pedestal by about 300 mm, welding strip on flange, web and flange butt welding at same cross section and member to be connected to stub with large eccentricity. bilitated structure used same material and still had a lot to be desired on structural stability. It is a classical case to define urgent need of structural audit of the buildings.

Fig. 6 Collapsed Metal Building And Partially Rehabilitated Building

Fig. 7. Level Difference in Pedestal and Baseplate, Poor Welding Standards

CASE V:OMISSION OF VITALS

Figure 8 shows failure of another major building 57.5m wide clear span with eave height of 15m. Building collapsed in longitudinal direction, however columns deflected at the level where section properties changed. Collapse was due to delay in fixing bracing in first bay due to site conditions and next braced bay was only seventh. For walls, three tier bracing was required.

Other non-conformities were observed as flange butt weld just above base plate stiffeners, distorted base plate and flange braces not fixed.

Fig. 8. Collapse of Wide and Tall Building along Ridge above Column Section Change

CASE VI: CASE OF COLLAPSE : STABILITY

Figure9
shows collapse of a building due to similar errors like erecting columns only without bracing, frames without bracing and may be also poor engineering of frame.

Fig. 9 Collapse of a Building in Plane of Frame and Unbraced Free Standing Columns

CASE VII: FIRE ACCIDENT/NATURAL DISASTER

Figure 10 show pictures of few cases of dilapidated due to fire incidents. It may be observed that flange braces, sag rods get snapped easily and cross bracing rods may lose tensile strength, thus compromising the stability of the building. And cross bracing rods may lose tensile Most of the projects do not specify fire rating of the building. Also due to forbidding cost of fire retardant intumescent paint, only specialized applications use them.

Fig. 10 Building Collapse – Partial and Complete Due to Fire Accidents, Sagging Roof

CASE VIII:IMPENDING FAILURE

Figure 11

Fig. 11. Case of Impending Failure, project drawings and Final New Building

Figure 11 shows metal buldig which may be termed as impending collapse on left top while right top is pictiure ew and replace oe. The building is in the palghar clear span of 26m and height of 7.5m.
There wew not even technical documents to assess the requirement and what was erected as PEB

Figure 12 shows poor knee splice where stiffeners were of smaller size, gap in splice plates, bolts of different sizes, crane bracket welded on edge of flanges and endwall column connected to rafter at

endwall column was directly supported on brick wall ad pirlins welded on clear or rafter without lap or sag rods etc.

top by welding scraps. There was no record of strength of material used. This case is a symbol of lack of awareness about structural stability in industrial buildings.

Figure 12 Poor Splice, Crane Bracket Detail and Endwall Column Top Splice with Rafter

CASE IX: DEEMED FAILURE .

Figure 13 presents a case from Bhilai, Chhatisgarh where the structure was reported vibrations under crane operations of 10MT. The work order showed that the single slope building was supposed to be engineered for future expansion along width with crane load of 20MT in each module. Base plates do not have stiffeners and column did not have bracket for future crane. Rafter section at knee is less than that of section at centre span of rafter. There were no angle bracing for longitudinal forces of the crane. Documents showed that building was designed for winds loads as closed building and not partial open case.

Fig. 13 Single Sloped Building Scheduled For Expansion – Deemed Failure

CASE X: SECTIONS BEYOND CODES/INDUSTRY STANDARDS .

Figure 14 presents a cross section of a frame of 24.0 m width and 12.15m eave height near Bengaluru. Web depth of column was increased from 300 to 1884 mm with thickness only 5mm. Similarly for rafter having web thickness of 5 mm only, web depth reduced from 1615mm to 284 mm, in about 4.5 meter. For column, web depth to thickness ratio was 377 while for rafter it was 323. Similarily flange of 300x8 mm is used with b/t ratio of 37.5[2,3].

These slenderness ratios are far more than that of codes. For webs, d/t ratio of 180 is adopted as maximum in practice. For flanges b/t ratio of 30 is used in industry as maximum. Also taper angle provider for rafter was more than 15^0 as recommended by AISC[2,3].

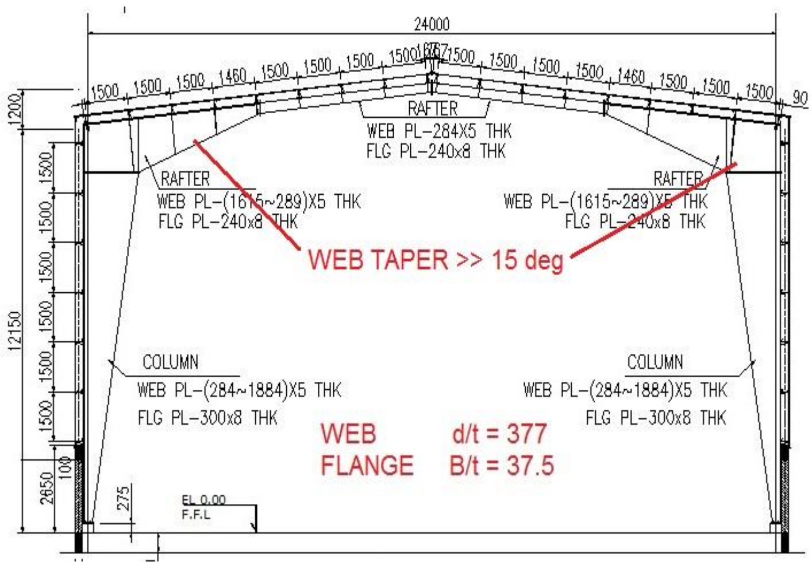

Figure 14 Frame Cross section showing section sizes with d/t and b/t ratios exceeding limits.

CASE XI: CHANGE IN PROJECT DEFINITION-MIDWAY .

Figure 15 shows the details of a building near wardha of width 12m and height 6m.building specifications were changed after complete engineering of PEB building was over, like shifting of plinth beam inwards and addition of crane beams. However re-engineering of PEB building was not done before execution. Column flange at base plate was cut to accommodate anchor bolt, crane bracket was added without modifying bracing in walls. Splice plate at knee from rafter did not overlap column splice plate, leaving only two pairs of connection bolts. Purlins supplied and erected were of about 6 meter length, whereas bay spacing was about 8 meters. This led to purlin overlaps falling mid-span with single purlin section over the rafter. Bracing rods were erected without hillside washer.

Fig. 15 Outer Flange Cut, Mismatch in Knee Splice Plate, Wrong Bracing and Midspan Purlin Laps

MATERIAL SPECIFICATIONS

With entry of unorganised fabricators, termed here as pseudo PEB suppliers, instances are being reported with increasing frequency for use of grade of material compromised during fabrication. Figure 16 shows test material certificate of where material is tested for grade E250 but bought and used as high strength steel plate.

For coldformed structural components used in solar module mounting structures, steel is being used having yield stress, Fy, 550 Mpa. AISI recommends this material only for sheeting and not for structural members and also with reduction in design Fy by 25%. Besides test reports of this grade of steel show that ultimate tensile stress, Fu, is almost equal to Fy and elongation far below 10%. This material may have little ductility. Figure 17 shows test certificate of such material.

Test Certificate No :ESH/TC/D/02062/60/2012/004661 Date: 19.11.2012
Sales Order No :2120184511 Date:18.11.2012
Equivalent
Specification :IS 2062 E 250 BR 2011
Essar Grade :SRCGEN02
Invoice No :168196
V ˙.cle No :GJ05YY8009

WE CERTIFY THAT THE MATERIAL DESCIBED BELOW FULLY CONFORMS TO IS:2062-2011. CHEMICAL COMPOSTTION AND MECHENICAL PROPERTIES OF THE PRODUCT, AS TESTED IN ACCORDANCE WITH THE SCH
NSPECTION CONTAINED IN THE BIS CERTIFICATION MARKS LICENCE NO. CM/L :7090365 ARE AS INDICATED BELOW AGAINST EACH ORDER NO. ETC.(PLEASE REFER TO IS:2062-2011 FOR DETAILS OF SPECIFICATI

Item No.	Section/Size T X W X L (mm)	Coil No.-Pack No.	Cast No.	No of Sheet	Quantity(mt) Net. Wt.	C	Mn	S	P	Si	Al	Cu	Mo	N	MAE	CE	YS	UTS	EL	E
						%	%	%	%	%	%	%	%	%	%	%	MPA	MPA	%	
010	5.000 X 1500 X6300	93370B200D	12203082	14	5.200	0.175	0.684	0.002	0.014	0.190	0.036	0.004	0.000	0.006	0.000	0.29	321	461	31	OK
010	5.000 X 1500 X6300	93370B300D	12203082	14	5.210	0.175	0.684	0.002	0.014	0.190	0.036	0.004	0.000	0.006	0.000	0.29	321	461	31	OK

(Cast Analysis: C to CE; Mechanical Properties: YS to E)

Fig. 16. Material Test Certificate (TC) for Plates

Test Certificate

Order Specifications				Dimensions						Mechanical Properties							
Batch	Heat No	Surface Trt/ Passvation/ Oiling	Sales Specifications	Thick (mm)	Width (mm)	Length (mm)	Length (mtr)	No Of Pieces / Slit	Qty (MT)	Bend Test	Hard HRB	Coating g/m2	ECV MM	Y.S. MPa	UTS MPa	EL% (GL)	(%
TBQA5J0022	15302681	NSTL/AFP/N	ASTM/A_792_2010/ G_80_550_CLASS_1	1.200	202	NA	911.000	6	10.225	Pass	94	158	NA	666	675	10.00	(
TBQA5J0021	15302681	NSTL/AFP/N	ASTM/A_792_2010/ G_80_550_CLASS_1	1.200	202	NA	947.000	6	10.695	Pass	93	150	NA	666	666	2.00	(
					Total Quantity				20.920								

Fig. 17 Material Test Certificate (TC) For Fy = 550 Mpa For Coldformed Section.

For sheeting also, grade of steel widely being used is with Fy being 550 Mpa and with galvalume or Aluzinc coating of 70 GSM only. Though this does not affect structural integrity of the structure, it may compromise sheeting life against corrosion to a great extent.

ERECTION

Most of the cases show that erection procedures were not followed. Few of common errors are as below.

- All the cases of collapse show that the guidance of starting the erection with braced bay was not followed.
- Safety standards are not followed, even helmets are not used.
- Crashed project time schedules, sometimes due to delay in civil works, often make them to resort to adopt erection procedures which compromise stability of structure.

PROCESS OF METAL BUILDING PROJECT – PLANNING & EXECUTION

Irrespective whether PEB supplier is selected by competitive bidding or captive relation, guidelines for documentation for every phase and process are recommended by Newman[1]. These documents include specifications, typical contract between owner and PEB supplier, designer's certificate, material test certificates, check list to be submitted by PEB supplier etc. Owner should insist upon submission of all such documents during contract signing.

OBSERVATIONS

From above cases, there are obvious instances of omissions and commissions as below.

1. Most of the cases of collapse indicate that cross bracing is most commonly neglected and reason of collapse.

2. Connection failure is the most often the reason for collapse in plane of frame.
3. Structures, which are categorised here as impending and deemed failures, are often executed by unorganized fabricators. These also show symptoms of violating codes, norms and conventions for fabrication of primary sections.
4. Lack of project co-ordination among stake holders during execution can also become a reason for collapse or failure.
5. In case of collapse, erection was done without proper procedure or supervision.
6. Pseudo PEB suppliers do not invest on inventory and often buy plates for fabrication of primary frame components which do not have recommended yield stress Fy as designed.
7. Safety standards are not followed by majority of PEB erectors.

CONCLUSIONS

From above cases, few conclusions are enumerated below.

1. Investigations in case of collapse normally do not get beyond insurance requirement.
2. Framework for structural audit of collapsed structure does not exist.
3. In absence of such framework for audit, there is no mechanism for collection of data of such instances and comprehensive studies thereof.
4. In most of the cases, same mutilated structural material or components are used for rehabilitation of the structure or is used for different project.
5. Guidelines for use of such material for structural work do not exist.
6. Use of same design equations of virgin steel for already yielded material to be reused should be widely debated across technical forum.
7. Excessive competition among PEB suppliers and pseudo PEB suppliers is leading to excessive optimization, overstretching norms in all phases of project execution.

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