FAILURES IN STEEL STRUCTURES : A COLLECTION OF CASE STUDIES

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ABSTRACT

Structural steel is a very versatile material and a very common material of construction in the industrial world. Structural steel has high initial cost than RCC and is used as the material of construction because of its

- STRENGTH
- EASE AND SPEED OF CONSTRUCTION
- EASY CONNECTION OF SERVICES AT A LATER DATE

In the recent times, there have been few cases failures reported in the industry. This paper presents the findings from the study of failures in steel structures and the analysis of the probable reason for the failures and suggestions to avoid them.

Case study 1 - Failure of a steel coal storage bunker in a power plant

INTRODUCTION

A coal fired power plant having circular coal storage bunkers had failure in one of the coal bunkers of one unit. The bunker cone or hopper got detached from bunker cylinder and entire cone along with around 450 MT of coal had come down resulting inplant outage and damage to equipment. A site visit was made by the design Consultant along with the plant engineers and thereafter the design of the bunkers was checked and found to be in order. When it was clear that the reason for the failure was not due to faulty designs, a detailed study was carried out to understand the reason for the failure. The study revealed that the most possible reason for the failure was faulty erection procedure adopted by the contractor. The Owner's of the plant were apprehensive of more such failures as all the bunkers in the project were erected using the same faulty procedure, and wanted a rectification scheme to be developed by the consultant where the other bunkers could be rectified by giving alternative support to the hoppers, thereby preventing hopper detachment. In fact a second bunker hopper failed later in a similar way before rectification could be carried out.

LAYOUT AND GEOMETRY

COAL BUNKERS

The power plant where the failure occurred has six (6) circular steel bunkers per unit housed in the mill and bunker bay or mill and bunker building. The steel bunkers have a top cylindrical portion and a bottom conical portion caller hopper. The cylindrical top has an internal diameter of 8m with an approximate height of 10m, and is fabricated with 12 mm thick MS plates. The thickness of this plate was designed for internal coal pressure. This thickness also included the required corrosion allowance. The cylindrical portion of the bunker is provided between EL 38.50m and EL 28.50m. The bottom portion of the bunker is a conical portion of approximate 10m height and with internal diameter varying between 8m at top to 900mm at bottom. The conical portion is provided between EL 28.50m and EL 18.50m. The conical portion has a transition piece at the bottom for a height of

4.25m with a hyperbolic profile to help easy flow of coal. The conical portion is fabricated using 8mm thick stainless steel (SS) plates- SS409M. As stainless steel is used corrosion allowance is not provided.

MILL & BUNKER BAY

The mill and bunker building (Figure 1) which houses the bunkers is a structural steel building 12m wide, 47.5m high and 57m long. This building has portal frames in the transverse direction at 9m centers with last frame at 12m centers. Each portal frame has two columns along grids C and D at 12m centers. All the columns along grids C and D are vertically braced. The building has two major RCC floors and a RCC roof. The RCC floors and roof are cast on structural steel floor beams. The floor at EL 12.7m is the feeder floor which supports the gravimetric feeders. Coal stored in the bunkers above this floor is taken to the mills below through the gravimetric feeders. At EL 39.95m is the Tripper floor. Coal is dropped into the bunkers placed below the tripper floor with the help of coal trippers that move on this floor. The roof for this building is at EL 47.5m.The Mill and bunker building also has structural steel floor framing beams at EL 25.75m which is the bunker supporting floor.

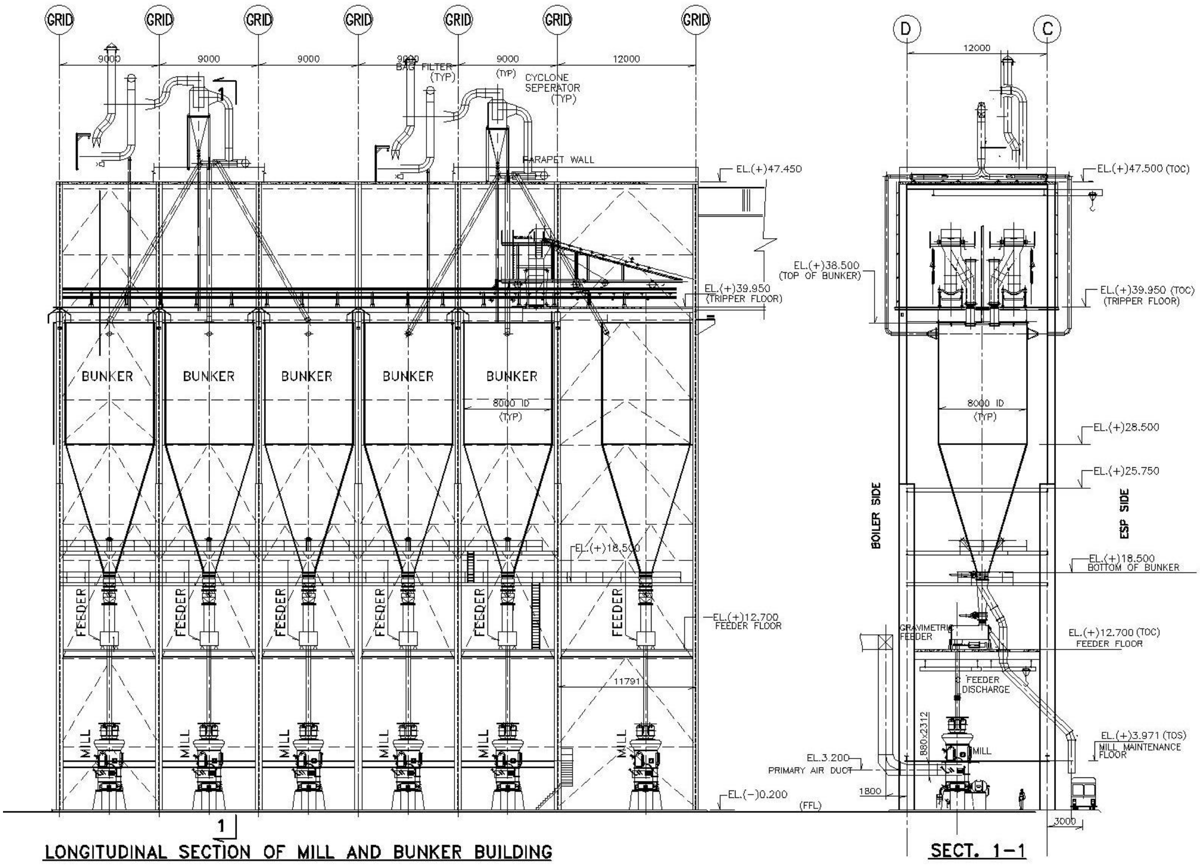

Figure 1: General Arrangement of Mill and Bunker Building

Figure 2: Picture showing the Mill and Bunker Building

BUNKER SUPPORTING ARRANGEMENT

General arrangement and details of the bunker is shown in Figure 3. The bottom of the cylindrical portion of the bunker shell between EL 27.0m and EL 29.1m is fabricated from 20mm thick MS plates instead of 12mm MS Plates. At EL29.1m a horizontal flange of 400mm width and 32mm thickness is provided and welded to the 20mm cylindrical shell. The 20mm cylindrical web and the 32 mm flange form a skirt girder.The circular flange plate of the skirt girder is seated on 6 stub columns which rise from the mill and bunker building framing beams at EL 25.75m. These stub columns transfer the entire bunker vertical loads due to self weight and due to the weight of coal stored in the bunker to the Mill and bunker building through the framing beams at EL 25.75m.The top cylindrical portion of the bunkers is connected to the mill and bunker building framing at three elevations with plan bracings so as to transfer horizontal wind and seismic loads from the bunker to the building frames.

HOPPER SUPPORTING MECHANISM

The conical bottom portion of the bunker is welded to the 20mm cylindrical shell internally at EL 28.5m. Externally at this elevation a T shaped ring beam is welded to the cylindrical shell. As the bunker is around 20m in height and 8m in diameter, single piece erection of the bunker would be difficult. The bunker was to be erected in two pieces - Cylindrical shell first and hopper portion next. To help with the site erection of the bottom conical portion or the hopper, a circular sloping 16mm thick plate, 750mm wide and whose slope matches the slope of the hopper is shop welded to the inside bottomportion of the cylindrical shell. This sloping annular plate acts as a seating bracket plate for the hopper shell to be placed on after lowering from top through the cylindrical shell and then held in position during erection till the hopper can be site butt welded to the top cylindrical portion of the bunker. The topmost piece of the SS conical hopper shell which is around 160mm wide, 8mm thick is shop welded to the cylindrical shell just above the seating plate. This is done so that the top diameter of the loose conical shell piece which has to be site erected by lowering through the top cylindrical shell can be less than 8m, which is the diameter of the cylindrical shell, and so that the hopper can be easily lowered through the cylindrical shell. The conical shell piece is site butt welded to this top 160mm wide piece of the conical shell plate. The seating plate will also act as a backing strip for this weld. This weld is a very important weld and needs to be carried out carefully and has to be radiographically tested to ensure its strength, as the entire hopper load gets transferred to the skirt girder through this weld. In other words the hopper actually hangs from the skirt girder through this weld.

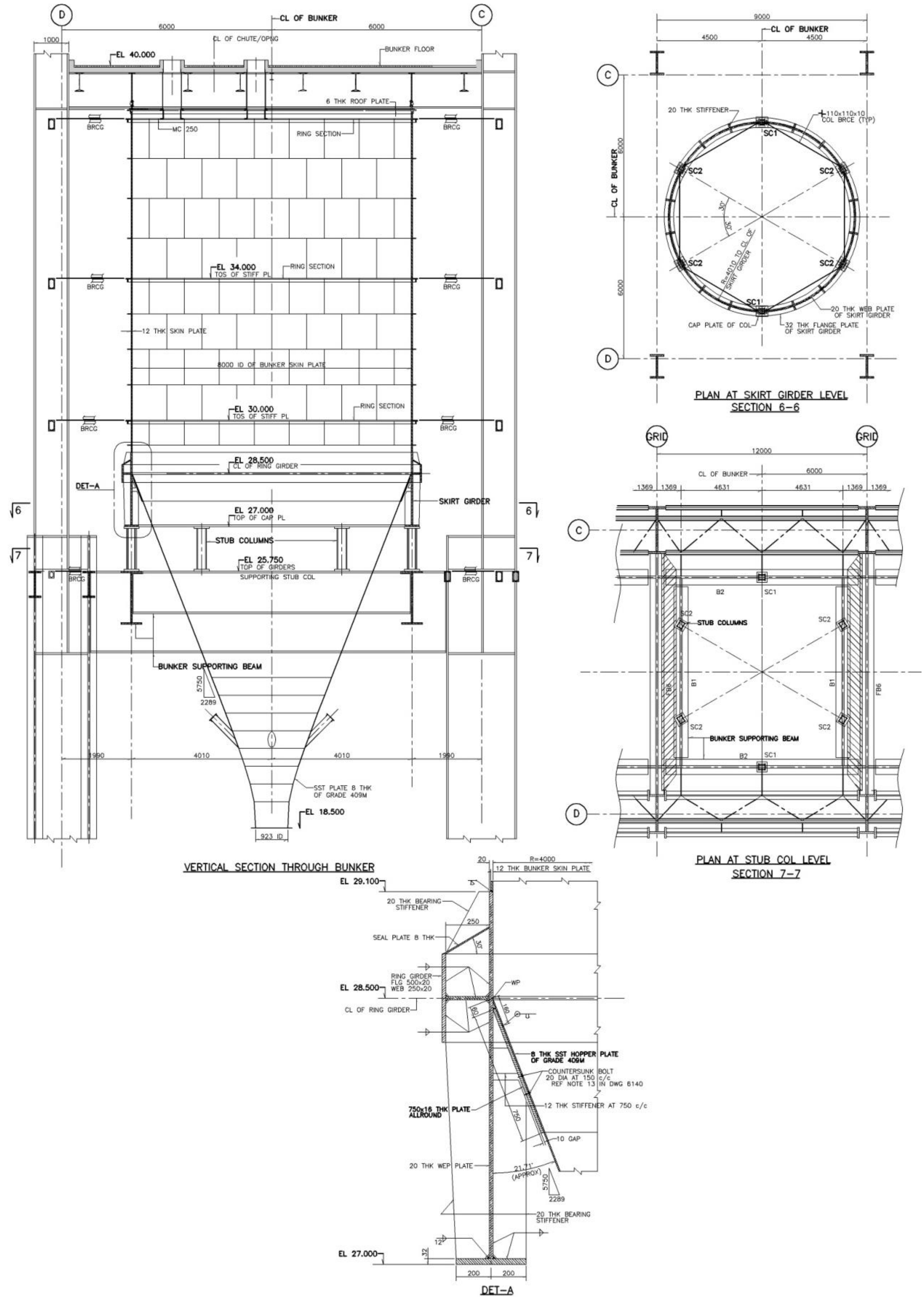

Figure 3: Structural Details of Coal Bunker

ERECTION PROCEDURE

These bunkers were erected in two pieces. The top cylindrical shell was fabricated in one piece and the bottom conical hopper in one piece. The cylindrical shell was erected first and placed on the six load transferring stub columns.The hopper portion was to be lowered from top through the cylindrical portion, placed on the seating plate, and then the hopper was to be joined to the cylindrical shell with a site butt weld.

The erection procedure proposed is explained below:

1. The Mill building framing should be completed.
2. The six stub columns for transferring the bunker load to the Mill building structure should be erected on the mill building beamsat EL 25.75m.
3. The top cylindrical bunker portion with the ring beam shop welded externally and with seating bracket plate and top 160mm wide SS conical shell plate welded at shop internally to the cylindrical shellshould be placed on the six stub columns.
4. The conical shell should be lowered from top through the cylindrical shell and placed on the seating plate.
5. The gap between the 160mm SS shop welded plate and the conical shell plate should be welded at site with square butt weld. The seating plate should act as backing strip for this weld. For this continuous contact of conical shell with bracket plate should be checked and ensured.
6. This site square butt weld should be radiographically tested.
7. The plan bracings between the bunker cylindrical shell and building structure should be completed.

However during actual erection, the bunker hoppers were erected from below instead of from the top.

REASONS FOR FAILURE

During the site visit it was noted that the conical hopper portion of the bunker was found detached from the top cylindrical portion of the bunker at the location of the square groove field butt weld that was carried out between the two SS 8mm hopper plates. It was also noted that the MS 16mm thick seating plate and the top 160mm wide SS 8mm thick plate were found intact and welded to the cylindrical portion of the bunker after the failure. During the site visit it was also noted that the top portion of the conical hopper had vertical cut marks that were welded. After discussion with the site engineers, it was established that the contractor had erected the conical hopper portion from bottom and not from top. While following this erection procedure it was difficult to push in the larger diameter of the conical shell into the smaller diameter of the seating plate that had come shop welded to the inside of the cylindrical portion of the bunker. Hence the contractor had vertically cut the top of the conical hopper at a few locations and crimped the conical shell at top so as to push the conical shell inside the annular bracket plate. Later the conical shell was opened and welded. This resulted in the conical shell not sitting properly on the seating plates and thereby not properly aligning to the top 160mm wide SS plate. The contractor most likely would have held the bunker conical piece from below and then would have carried out the square butt weld between the two unaligned shell pieces. There would have been gaps between the seating plate and the conical shell. This was observed at site for the other bunkers that had not failed by the team of engineers that visited site after the failure of the first bunker. Due to this gap, carrying out the square butt weld would have been very difficult as the backing strip which was the seating plate was not in position. Due to this faulty welding the weld had given way and the conical portion got detached from the cylindrical portion.

CONCLUSION

The reason for failure was due to faulty erection of the bunker which resulted in faulty welding between the hopper and bunker shell plates. From this case study it becomes quite clear that very often there is a disconnect between Engineers who are conceiving and designing structures in the office and the Engineers who are fabricating and erecting these structures at site. This disconnect could lead to collapses and failures and needs to be narrowed or removed.

Case study 2 - Failure of a steel conveyor gallery in a power plant

INTRODUCTION

In one of the coastal power plants, coal was brought by ships and unloaded at the jetty next to the power plant, and conveyors housed in galleries were used to transport coal from the jetty to the coal storage yard. The conveyor galleries were to run very close to the boundary wall. During the structural erection of the gallery a collapse was reported. The consultant’s team visited the site of the collapse along with site engineers and EPC contractor’s engineers and tried to establish the reason for the failure.

LAYOUT AND GEOMETRY

The conveyor gallery which had collapsed was around 24m in span and was an inclined gallery. The lower end of the gallery was to take support on a trestle and the higher end was to rest on a junction tower. The height of the gallery was around 40m and the collapsed portion of the gallery was very close to the sea and exposed to strong sea winds. The collapsed gallery was exactly at a right angled bend in the conveyor and very close to the boundary wall.

Conveyor galleries have two latticed girders with top and bottom chord bracings. The top chord bracings are a part of the roofing system and the bottom chord bracings are a part of the conveyor support and walkway system.The top and bottom chord bracings transfer horizontal loads due to wind and earthquake to the end portals and also provide lateral restraint to the lattice girders thereby helping to reduce the size of the girders.Both the lattice girders are connected to end portals which rest either on the trestle columns or on the junction tower and transfer loads to them.

ERECTION PROCEDURE

It is preferable to lift the entire gallery (two lattice girders with top and bottom bracings in place and connected to the two end portals) in one piece and place one end portal on the trestle and the other end portal on junction tower so as to ensure box action and maintain the design conditions of lateral restraint to lattice girders and provide paths for horizontal wind forces to flow easily to the end portals.

At this site, as the gallery was very close to the boundary wall on one side and as there were other constraints on the other side the contractor had decided to go in for piece erection. The following procedure was followed:-

1. End portals were erected first. One on the trestle and one on the junction tower
2. One lattice girder was erected and connected to the gusset welded to the webs of the two end portals with erection bolts and left.
   This work was completed on a Saturday afternoon. Sunday being a holiday further erection work was to be continued on Monday. The erected girder was left without any lateral support/ guying for nearly two days.
3. The first thing that the contractor did on Monday on resumption of work was to start welding the erected lattice girder to the end portal, instead of lifting the second lattice girder and trying to erect the top and bottom chord bracings to achieve box action.
4. On Monday, late in the morning the erected lattice girder fell down.

SITE OBSERVATIONS

During site visit the following were observed:-

- The end portals were still in position. One was on the junction tower and the other was on the trestle.
- The lattice girder had torn away from the web of the end portals and fallen down.
- The gussets that were shop welded to the web of the end portals had torn away from the web of the end portal column and had come down connected to the lattice girder.
- There was a hole in the web of the end portal column at the location where the gussets (for lattice girder connection) were provided welded to the end portal column web.

REASONS FOR FAILURE

- The lattice girder was connected to the end portals at four locations through gussets.
- Apart from self-weight of the girder and wind load on the girder there was no other load acting on the erected girder.
- The erected girder was around 2.5m high and was very stiff in the vertical direction. As no chord bracings were erected the girder was very slender in the horizontal/ lateral direction.
- The single lattice girder that was erected and left for two days at around 40m height was continuously exposed to sea winds. In fact it was like a sheet of paper continuously fluttering laterally in the wind.
- The end portals were MB 250 with a web thickness of 6.9mm only. 12mm thick gusset plates were welded to the 6.9mm web with 6mm welds on two sides.
- When the wind load was acting on the lattice girder the lattice girder was fluttering- moving horizontally in the wind. As a result the gusset plates were also moving laterally in the wind.
- Since the gussets were welded to the web of the MB250 end portal column, the web of the column was subjected to local bending. As a result the 6.9mm web was being bent in one direction at one instant of time and very next moment in the opposite direction due to the fluttering action of the girder.
- As the web of the portal was very thin and as it was subjected to this alternate bending, the material of the web went into fatigue and failed.
- This was the reason for a hole in the web of the end portals around the gusset connection location.

CONCLUSION

It is always better to lift the entire conveyor gallery in one piece so as to maintain the design conditions of the lattice girder. If one piece lifting is not possible then, suitable guying to be done so

that lateral restraints are provided. Erection program should be so scheduled that erection is completed as quickly as possible. Leaving part erected structures for too long should be avoided.
It is a good engineering practice to provide a stiffener to the web of columns at points of load transfers. This is done to stiffen the web. Generally in conveyor galleries, stiffeners are usually provided welded to web/ flanges of the portal column behind the lattice girder connecting gussets. These stiffeners were not provided in the galleries. This was observed in the remaining erected galleries during the site visit. If this stiffener would have been provided, the web of the end portal column would not be flexible and would not have gone into bending leading to fatigue.
Hence good erection procedures which try to maintain design assumptions/ conditions along with good detailing practices can very often avoid failures.

Case study 3 - Failure of a steel Junction towers in a power plant

INTRODUCTION

In one of the power plants under construction where erection work was in progress in the coal handling area, two junction towers and an erected portion of conveyor gallery attached to one of the junction tower collapsed along with a trestle when high velocity winds hit the site during monsoons.

SITE OBSERVATIONS

During a site visit after the collapse the team of engineers noticed that one of the collapsed junction towers had been erected with only the top level vertical bracings between the tower columns in position. The lower level bracings were not connected to the tower columns. The various floors of the tower were erected along with the first span of conveyor gallery supported on the junction tower. The tower was nearly complete except for lower level bracings and some minor works. During the winds as there was no path for the wind forces to reach ground / foundation level, the wind forces had bent the columns and the whole tower had come down. The anchor bolts connecting the steel columns to the concrete foundation pedestals were badly damaged and cracks were observed in the top portion of concrete pedestals around the bolts. Some pedestals were even found crushed below base plate.

The second tower that had collapsed was erected with columns and floor beams in position but with no vertical bracings erected. The un-braced columns were not guyed also. Hence during winds the columns got bent and collapsed and fell on the adjacent erected trestle and damaged it also.

REASONS FOR FAILURE

Junction towers have columns which are vertically braced from top to bottom of the tower. The bracings give lateral support to the tower columns and provide a path for horizontal forces due to wind/ earthquake/ equipment acting at various levels of the tower to reach the foundation level by inducing axial forces in the bracing/ column system there by giving a light effective structural system. If the bracings are not provided at any level, the horizontal forces will induce bending in the columns instead of axial tension/ compression. The columns are not designed for bending and will fail under such conditions. Due to bending induced in the columns there could be bending tensions induced in anchor bolts connecting the steel columns to the foundation pedestals and which may fail by cracking/ crushing the pedestal concrete.The following erection scheme should be followed:-

- The columns are erected first and held in position and guyed.
- The bracings are erected.

- The tower columns are checked for verticality and anchor bolts are tightened.
- Only after this is completed, the other elements like floor beams/ flooring/ conveyor galleries / any other loads are erected on the tower.

CONCLUSION

It is very important for all parties to understand the basic design principles involved in conceiving any structure. Probably the erection team was not aware of this. The failure occurred because high velocity winds induced horizontal forces on the structure which damaged the towers. If the wind had not occurred, probably the tower would have stood as no major horizontal forces would be generated. Many erection teams hope that major winds would not strike during the erection activity and they would be able to complete erection of the structure.

SITE PHOTOS OF CRUSHED FOUNDATION PEDESTALS AND OF COLUMNS ERECTED WITHOUT BRACINGS

OVERALL CONCLUSION AND SUGGESTIONS

From the above three cases it is seen that all the three failures have taken place due to change in erection procedure/sequence. There appears no interaction between site team and design teams on the aspect of changed erection procedure/sequence. The interaction could have led to some improvements in designs/details, to factor the stresses in various structural components to allow the new erection procedure proposed due to any site constraints.

Suggestions

1. It is necessary to establish a “ONE TEAM” approach between all team members of project i.e. Owner, PMC, DEC, Contractors, subcontractors etc. A continuous communication forum between design and construction teams need to be established through regular site review/coordination meetings not only to review/expedite progress but also on trivial issues, change notices requested in design, A systematic process for Change management need to be put in place.
2. Increasing awareness in design and construction engineers about the overall concept of the project, criticalities, and common issues in such projects. This could be achieved through joint concept review meetings, capturing all such info in standard presentations and any new team member goes through small induction to understand the same.
3. Rigorous safety management processes, reviews and monitoring to be established right from start of project to review Safety in Design as well as safety during construction.
4. The stage by stage clearances, inspections need to be insisted to curb damages.
5. All such structures need to be jointly visited by Site and Design teams before commissioning of the plant to identify and address in advance any issues about stability and safety.
6. In today’s world of “TIME” overruling other deciding factors, there is a need for sensitization on the degree of detailing of designs, construction procedures required. Though this will take little more time in initial phase but will avoid the major loss of life, property and TIME at a later stage.

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