MAI-2012-12

UNITED STATES
DEPARTMENT OF LABOR
MINE SAFETY AND HEALTH ADMINISTRATION
Metal and Nonmetal Mine Safety and Health

REPORT OF INVESTIGATION

Surface Nonmetal Mine
(Hydraulic Cement)

Fatal Falling Material Accident
August 17, 2012

Tarmac America, LLC
PENNSUCO Cement Plant
Medley, Miami-Dade County, Florida
Mine ID No. 08-00051

Investigators

Scott Johnson, P.E.
Supervisory Mine Safety and Health Inspector

Sonia Conway
Mine Safety and Health Inspector

Jose Figueroa
Supervisory Mine Safety and Health Inspector

Terence Taylor, P.E.
Senior Civil Engineer

Originating Office
Mine Safety and Health Administration
Southeastern District
135 Gemini Circle, Suite 212
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Doniece Schlick, Acting District Manager

OVERVIEW

On August 17, 2012, Pierre (Sonny) Mezidor, Cement Equipment Operator, age 58, was killed when the silo roof he was working on collapsed. The cement roof slab, beams, and the grout in the beam pockets failed causing the roof and the equipment on the roof to fall into the 3/4 full silo. Rescuers responded and Mezidor was recovered from the silo on September 4, 2012.

Mezidor was on top of Silo 12 to measure the level of material in the silo. Miners had to manually check the silo levels several times each shift because the radio transmitter level indicator and the high level indicators for the silo were not functional.

The accident occurred due to management's failure to correct defects on the silo where the victim was working. The roof decking on Silo 12 was inadequately attached to the roof beams, causing the beams to become unstable and buckle; the grout under the beam ends was too thick and some of the grout in the beam pockets had cracked and delaminated; and the shear stirrups were placed too far below the beam ends to prevent the grout in the beam pockets from failing in shear. Also, in 2004 a roof beam was cut when a penetration was made into the roof to install an automatic level detecting device. This cut significantly reduced the load carrying capacity of the beam. These defects led to the collapse of the silo roof slab that was supporting the victim. In addition, adjacent Silo 11 had experienced a partial roof failure in 2011 that caused the roof to bulge and caused significant cracking in the reinforced concrete. Management did not adequately investigate the causes and conditions surrounding the Silo11 partial roof failure and therefore did not identify similar conditions existing under the roof of Silo 12.

Management also allowed the silos to operate with defective aeration systems and the presence of a large rathole (partly caused by those defective systems). When the cement would bridge over the rathole and then collapse during discharge, this would create significant suction loading and detrimental vibrations on the roof slab, beams, grout in the beam pockets, and welds. In addition, other equipment including high level indicators and an automatic level detection device were inoperable, making manual measurement necessary and the over pressure events more likely. The over pressurization in the silo resulted in upward pressures on the silo roof slab and its support system (puddle welds and beams), and damage to those components.

When combined, these equipment-related defects and structural deficiencies contributed to the collapse of the roof slab.

GENERAL INFORMATION

PENNSUCO Cement Plant, a hydraulic cement facility operated by Tarmac America, LLC, and owned by Titan Cement Company SA, is located in Medley, Miami-Dade County, Florida. At the time of the accident, the principal operating official at the plant was Kevin Baird, General Plant Manager. The plant operates 24 hours a day, 7 days a week. Total employment is 132 persons. An adjacent quarry, PENNSUCO Quarry, supplies the plant with raw material. PENNSUCO Quarry employs 164 persons.

A series of belt conveyors transport the raw material to the kiln, where the rock is crushed, sized and mixed with the other raw materials. The kiln heats the mixture to about 2,700 degrees F to produce the clinker. The clinker is conveyed to another part of the plant where it is ground with a small amount of gypsum into a powder. This powder, or Portland cement, is then fed into one of 12 silos.

The Mine Safety and Health Administration (MSHA) completed the last regular inspection at the plant on August 2, 2012.

DESCRIPTION OF THE ACCIDENT

On the day of the accident, Pierre (Sonny) Mezidor started his shift at 7:00 a.m. Following a routine 15 minute safety meeting, Mezidor talked with Dolores Otero, Control Room Operator, who briefed Mezidor on the status of the silos. Mezidor then went to the maintenance trailer and gave a fan, that needed repair, to Alejandro Ortiz, Cement Shift Repairman.

About 7:40 a.m., Otero called Mezidor on his radio and told him to go to Silo 12 to confirm a measurement of material in the silo. The mine operator’s inventory record showed the silo to be nearly full, but a measurement taken one hour before the collapse showed the silo to be nearly empty. Mezidor stopped at the loadout control room at the base of Silos 1-9, talked with the miners there, and then used the elevator to travel to the top of Silos 1-9 at 8:05 a.m. Mezidor walked across Silos 1-9 and climbed the ladder on the side of Silo 10. He crossed Silos 10 and 11 and reached Silo 12 shortly before 8:10 a.m. Silo 12 collapsed soon after

Mezidor reached the silo. Surveillance video showed the collapse occurred at 8:11 a.m.

Lazaro Sainz, Cement Repairman, and Reynerio Martinez, Cement Repairman, were working on a conveyor at the new plant when they saw the dust collector fall into Silo 12. Martinez called Otero at the control room to let her know the dust collector on the roof of Silo 12 fell into the silo. Otero informed Martinez that Mezidor was measuring Silo 12. Sainz tried unsuccessfully calling Alberto Hernandez, Maintenance Supervisor. Otero tried contacting Mezidor several times on the radio.

Otero began telling miners over the radio that there was a problem on Silo 12 and that Mezidor was missing. At approximately 8:20 a.m., Otero called Kevin Baird, General Plant Manager, to report the roof of Silo 12 had collapsed and that Mezidor was on the silo when it collapsed. Baird went to the loadout and met with Hernandez, Jeff Harris, Assistant Cement Production Manager, and other miners, and took the elevator to the top of Silos 1-9. They reached the top of Silo 11 at approximately 8:30 a.m.

Harris contacted Marco Burgoa, Technical Manager, soon after reaching the top of Silo 11. Burgoa arrived on top of Silo 11 approximately 8:40 a.m. The fire department was already on-site when Burgoa made it to Silo 11 and rescue efforts began.

INVESTIGATION OF THE ACCIDENT

MSHA was notified of the accident about 8:30 a.m. on August 17, 2012, when Burgoa initially called MSHA's national office in Arlington, Virginia. MSHA's National Call Center was notified at 8:45 a.m. by a telephone call from Rene Hernandez, PENNSUCO Cement Plant. The National Call Center notified Patrick Sharp, Southeastern Health Specialist, and an investigation started the same day. At 9:31 a.m., MSHA issued an order under the provisions of 103(j) of the Mine Act to ensure the safety of the miners. At 2:55 p.m., soon after the first Authorized Representative (AR) arrived at the mine, this order was modified to section 103(k) of the Mine Act.

MSHA sent two inspectors from the Bartow Field office to secure the accident scene until the accident investigation team could arrive. Before the end of the day, the first two members of MSHA's accident investigation team, from Kentucky, arrived at the mine and made a physical inspection of the accident scene. The following day additional accident investigation team members arrived on the mine site. During the course of the next 28 days, the accident investigation team assisted in the recovery of the miner, interviewed employees, inspected recovered debris, and reviewed documents and work procedures relevant to the accident. MSHA conducted the investigation with the assistance of mine management and employees.

The Miami-Dade Police Department and Fire Department had members on the property from the time they were notified until the victim was recovered on September 4, 2012. Throughout the investigation, these two local Departments participated in the daily discussions with MSHA and assisted the mine operator in moving forward with the rescue and recovery efforts.

DISCUSSION

The conclusions in the body of this report are compiled from the interview findings and the technical investigations. Details of the engineering and technical investigation that support the findings of this report are located in Appendix C.

Location of the Accident

The accident occurred on Silo 12. It was one of three silos (10, 11and 12) that were constructed in 1981. These three silos were interconnected and oriented in a line. Silo 11 was the middle silo and it shared a common wall with Silo 10 on its northern side and Silo 12 on its southern side.

Surveillance and Time of Collapse

Security cameras monitoring the plant captured the collapse from a distance. The time of the collapse, ascertained from viewing the footage, indicated the roof failed at 8:11 a.m. Based on the footage, it appeared that a majority of the dust plume, once the roof collapsed, came from the east side of the silo. Just prior to the collapse, there appeared to be a haze in the vicinity of the dust collector. It was not clear whether this was sun reflections off the east side of the collector or a localized haze of dust leaking near the collector that was being illuminated by the rays of sunlight.

Weather

The weather on the day of the accident was clear with a slight breeze and a temperature about 85 degrees Fahrenheit. Weather was not considered a contributing factor to the accident.

Rescue and Recovery

After the collapse, the cement product level near the silo walls was approximately 35 feet below the roof. The victim was found at a depth of approximately 51 feet below the top of the silo in the region of the silo slightly north of the center. He was below most of the debris, indicating that he likely fell off the slab as it was tilting into the silo, but before it pulled completely free from the ends of the perimeter vertical reinforcing bars that were bent into the silo. The depth to the recovery point was in stark contrast to the depth of 148 feet measured about an hour before the collapse. This information suggested that the taped reading of 148 feet was into a flow channel, which then filled in once the peaked perimeter of cement build-up collapsed into the channel void at the time of the failure.

PENNSUCO contracted G&R Minerals, a construction company from Birmingham, Alabama, to manage the recovery operations. Two cranes were on site by the end of the first day of the recovery. One crane was used to lift debris out of the silo. The second one had a man basket attached that could lower persons in and out of the silo. For the first eight days of the debris removal, the process involved cutting and breaking large pieces of material to a size the crane could lift out of the silo.

Several times during the first eight days of the recovery, the Miami-Dade Fire Department lowered their cadaver dog and trainer into the silo to search for Mezidor.

After the eighth day of debris removal, a clam shell was used to remove the loose material. The clam shell had the capacity to remove up to 15 cubic yards (around 15 tons of cement) per lift. As the extraction progressed, the center portion of the silo material moved down at a constant rate. However, the outer edge of the material remained firm. On the eleventh day, the operator lowered a Brokk machine into the silo to break the hardened material from the outside edges. In two days, hardened material was scaled down to the center material.

During the clam shell extraction phase of the recovery, an average of 10 tons of material per 30 minute cycle was removed from the silo. This cycle included the removal of the material from the silo, dumping the material into a waiting dump truck at the base of the silo, and delivering the material to a flattened area to be dumped on the ground. A crew of miners was at the dump site with rakes and shovels moving the debris around to locate the victim. Cadaver dogs and their trainers were at the dump site during this entire process.

At the end of August, 2012, tropical storm Isaac dropped more than 10 inches of rain at the accident site. The excessive wind speeds and rain from the storm stopped the use of the cranes and slowed recovery efforts for two days.

At approximately 2:30 a.m. on September 4, 2012, 18 days following the accident Mezidor was located. The Miami-Dade Medical Examiner pronounced the victim dead at the mine site.

General Information Silos 10, 11, 12

Silos 10, 11, and 12 were cement storage silos designed by R.S. Fling and Partners, Inc.[1] in 1980 and built by S&W Construction Company[2] using reinforced concrete. The silo was constructed in 1981 for the original plant owners, Lone Star Industries, Inc. Law Engineering Testing Company was engaged to serve as the owner's representative for the foundation construction phase of the three silos. The silos were partially interconnected and oriented in a line. Silo 11 was the middle silo and shared a common wall with Silo 10 on its northern side and Silo 12 on its southern side. The silos were approximately 189 feet high, as measured between the foundation and the top of the silo roof. They had an approximately 56 foot outside diameter (photo 1). The silo walls were 14 inches thick and reinforced vertically with 2 layers of No. 4 bars at 14 inches on centers. The horizontal reinforcing hoops varied in size from No. 4 to No. 8 bars and spacing from 6 to 12 inches on centers from the top of the silo to the bottom. At each elevation there were two layers (an inner and outer hoop).

The internal storage of the silo was less than the overall volume of the cylinder, because in each of the silos there was a 34.6-foot-high conically-shaped steel hopper supported by an elevated reinforced concrete floor. The floor was supported by 14 internal columns varying from 36 to 42 inch diameter. The

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[1] R.S. Fling and Partners is no longer in business.
[2] S&W Construction Company is no longer in business.

hoppers were sloped at a 55° angle and had a single 6 foot diameter bottom discharge. The hopper plates were 3/16 inch thick at the top of the hopper and 3/8 inch thick at the bottom. The plates were ½ inch thick where they passed through the elevated floor. While the elevated floor supported the hopper plate directly as it passed through the floor, the hopper was supported above the floor by a lean concrete fill material that formed to the conical shape of the hopper plates. The lean fill rested on the elevated floor. The actual live cylindrical storage area above the hopper was 135.2 feet high. The combined volume of the live cylinder and conical hopper as per the calculations by R.S. Fling was 327,451 cubic feet. Each silo could store 16,147 tons of Type I/II cement powder, as per the silo inventory datasheet provided by the mine operator. The cement powder had a stored density of 94 pounds per cubic foot.

The silo roof was a reinforced concrete slab with a varying thickness (photo 2). The slab was designed to be 4½ inches thick at the edge and 11½ inches at the center to create a slope for drainage. These thicknesses included the 1½ inches of depth of the corrugated metal floor decking (specified as 16/16 GA) that supported the wet concrete while it hardened during initial construction. The gauge ratio referred to the thickness of the top hat plate and the thickness of the flat bottom sheet of the embossed cellular decking, which were both 16 gauge (equal to 0.06 inches). The center to center spacing of the corrugations in the roof decking was 6 inches. The top hat geometry was B-LOK. The decking sheets were as much as approximately 31 feet long and spanned north to south over multiple roof beams. The roof slab was reinforced by four layers of reinforcing steel, with two of the layers being oriented north to south and the other two layers east to west. The bars were specified as No. 4 bars on 18 inch centers. The concrete compressive strength was specified at 3,500 psi and the reinforcing steel at 60,000 psi yield strength. The roof slab was designed for its self-weight plus 50 psf[3] live loading. The slab was tied to the silo walls via continuity of the vertical reinforcing steel bars. Specifically, the two layers of vertical bars in silo walls were extended three feet above the top elevation of the wall. These extensions were then bent over into the roof slab to become part of the slab pour. Aside from this continuity of the wall reinforcing into the roof slab and the bearing around the perimeter, the primary means of support for the slab came from the six underlying steel roof beams.

The silo roof beams spanned east/west and rested in wall pockets left open at the top of the wall (figure 1). Within the pocket, a bearing plate was installed. The

[3] psf = pounds per square foot

beams' ends transferred their reactions to the bearing plates and ultimately into the silo wall. There were a total of twelve pockets, six on the east side and six on the west side. During the investigation, these pockets were labeled as East 1 (E1) though East 6 (E6) and West 1 (W1) through West 6 (W6). The beams were likewise labeled as Beams 1 through 6, with Beam 1 being the southernmost and Beam 6 the northernmost. For consistent nomenclature, Beam 1 was supported by E1 and W1. Likewise, Beam 2 was supported by E2 and W2, etc. All the structural steel was grade A36. Beams 1 and 6 were W24x55 sections. Beams 2 and 5 were W27x84 sections and Beams 3 and 4 were W30x99 sections. The outer Beams 1 and 6 were shallower beams, since they only spanned 39.2 feet. The middle two deepest Beams 3 and 4 spanned 54.8 feet, whereas intermediate Beams 2 and 5 spanned 50.2 feet.

A pair of short extension channels was bolted to the ends of each of the beams using between six to nine A325 high strength bolts. These channel extensions then rested on the bearing plates cast inside the beam pockets. The channels at the ends of Beams 1 and 6 were C10x15.3 and the channels at the ends of Beams 2 through 5 were C12x20.7. These deeper channels were needed for the middle four beams, since they were carrying higher end force reactions (shears). In addition, each of the ends of the six roof beams was coped (notched) near the location of the bolted connection with the channels. The length of the channel extensions was 13 to 16 inches.

<u>Factors Causing the Collapse</u>

As evident in the photos taken when the silo was being drawn down during recovery and based on disparities with the silo measurements, Silo 12 had a considerable amount of non-flowing static material that was partially cohesive and somewhat compacted. The non-flowing material occupied a considerable amount of the stored material and formed a large rathole (an area created in the silo where material moved mostly through the center and accumulated around the edges). With the restricted flow channel, the cement powder was able to bridge/arch over the opening during drawdown. When the arch collapsed, it created a large dynamic suction of the roof. Erratic flow over the life of the silo created dynamic suction and rebound loads (vibration) on the silo roof slab, roof beams, puddle welds and beam pockets.

Several factors contributing to the buildup of material and flow problems were attributed to the aeration piping system on the sides of the hopper, which was intended to help prevent rathole formation but had not worked for a long time.

The silo was full for over three weeks prior to the accident, which allowed the material to settle and compact. Additionally, the air blaster at the hopper outlet was using ambient air exposed to moisture, rather than thermally dried air. The ambient air contained humidity, which caused the cement particles to begin to hydrate and stick together, thereby helping form a rathole.

The radio transmitter level indicator and the high level indicators were not functional, causing additional exposure to workers who had to measure the silo depths manually each day. On the morning of the accident, flow from Silo 12 unexpectedly stopped, even though the silo was found to contain a large amount of cement product. The truck loading operator could no longer fill customers from Silo 12.

The dust collector on Silo 12 was running constantly even though no new material was being pumped into the silo. This condition created a negative suction of 35 psf on the roof and the cement material, which was then partly lost when the silo port was opened for measurement. This change in pressure likely caused the cement powder in the upper reaches of the silo to destabilize and fall into the flow channel creating a significant suction load on the roof.

Although the original contractor generally provided the roof deck puddle welds on 12-inch centers, many of the welds were not of good quality. Specifically, while the weld metal was deposited on the top flange of the beam, the weld material had porosity and did not fuse with the steel in the beam in many instances. In some cases, it appeared that the burn holes in the decking did not penetrate both layers of decking. Therefore, the decking was not adequately attached at these areas. Both downward loading and previous instances of over pressurizing the silo (upward loading), likely caused the puddle weld connections to fail either through the weld, at the base of the weld, or through the decking material surrounding the weld. Aside from overload of the welded connections, fatigue (suction and rebound vibration loadings during flow) may have also contributed to some of the connection failures of the decking to the beams. Once the welded connections were lost, the beams were then not adequately braced to prevent lateral torsional buckling from downward loading, which likely occurred prior to the day of the collapse. Also, as mentioned above, if the welds were able to transmit the tension from the underside of the slab to the beams during an overpressure event, then the bottom flanges of the beams would be in compression. Since the bottom flanges were un-braced, the beams could fail in lateral torsional buckling, even from this upward direction of loading.

Post collapse investigation of the condition of identical Silos 10 and 11 found several roof beams buckled and detached from the roof slab. In addition, hardened cement was found on the top flanges of Silo 12 beam numbers 1, 2, 3, 4, and 6 near the buckled areas, indicating these beams were most likely buckled to some extent prior to the day of the collapse. A deflected buckled beam was unable to carry as much of the load as it did prior to the buckle, particularly if the buckle was severe enough to lose contact with the roof slab.

The top flange of Beam 3 in Silo 12 had been cut when a penetration was made after the silo was built. The cut reduced the section modulus by 30%, the compression flange cross sectional area by nearly 50%, and the general resistance to lateral torsional buckling. Hardened cement on the top flange of the beam and within the bent torch cut marks on the flange appeared to indicate that the beam had buckled some time prior to the day of the collapse.

In the original design, the 35 psf dust collector suction pressure should have been considered as a separate load in addition to the 50 psf live loading, rather than incorporating, by default, the suction within the 50 psf live loading. The original design did not specify supplemental bracing or minimal puddle weld connection strength to prevent lateral torsional buckling of the roof beams. In addition, a pressure relief system was not specified.

As the beams buckled, the end reactions on the beam pocket bearing plates increased when the load from one beam shed to adjacent beams. The flanges on the end channels were bent on at least one end of five of the six roof beams, indicating the beam ends were attempting to rotate prior to the final failure. Bending of the flanges applied point loading to the bearing plates. The buckling also likely caused an inward frictional drag force on the bearing plates, which was then transferred via the studs to the underlying unreinforced grout layer. Most of the beam pockets were found to be delaminated. The internal cracking from delamination reduced the shear resistance of the pocket by decreasing the length of the shear resistance path. In addition, as a result of a construction defect, the shear stirrups in the wall were placed too far away from the bearing plates, since the as-constructed thickness of the grout was much greater (11 inches instead of 1.5 inches) than shown on the engineering drawings. The delamination and the lack of shear stirrups within the shear plane of the pockets allowed at least two of the pockets, E2 and E3, to fail in shear and the bearing plate on W5 tilted down. When the east side pockets failed, the reinforced concrete slab could not support itself and the roof slab collapsed.

The investigators did not find any evidence or reports of previous structural inspection of any of the three silos. Even following an overpressure event in 2011 that caused the roof on Silo 11 to bulge up, and despite the significant damage, no structural inspection was conducted of the roof beams and pockets. An inspection at that time would have uncovered the problems with the buckled beams, puddle weld failures, and delamination in the beam pockets, which then would have caused concern regarding the integrity of adjacent Silos 10 and 12, and could have identified the deficiencies that led to the roof failure of Silo 12.

Training and Experience

Pierre Mezidor had 19 years of mining experience, all at this mine. A representative of MSHA's Educational Field Services staff conducted an in-depth review of the mine operator's training records. The training records for Mezidor were reviewed and found to be in compliance with MSHA training requirements.

ROOT CAUSE ANALYSIS

Investigators conducted a root cause analysis and the following root cause was identified.

Root Cause: Management failed to correct defects on Silo 12 where the victim was working.   Specifically, the operator failed to determine the cause of a partial roof failure the previous year on an adjacent silo. Silos 10, 11, and 12 had not been built to specifications; maintained appropriately; and the operator added additional strain on the silo by allowing the silo to operate with an internal rathole and by subjecting the silo to overpressures during its life of operation. In addition, a modification had been made to one of the roof beams on Silo #12 that significantly weakened the roof.

Corrective Action: Silos 10, 11 and 12 at this mine have been under a Section 103(k) order since August 18, 2012, and have been the subject of an ongoing investigation. The operator must take the actions necessary to repair these three silos, and with the knowledge learned from this investigation prevent future unsafe conditions in the remaining silos at the mine. MSHA will require the operator to take appropriate actions to address the root cause of this accident to ensure that miners can safely work on or near Silos 10, 11, and 12.

CONCLUSION

The accident occurred due to management's failure to correct defects on the silo where the victim was working. The roof decking on Silo 12 was inadequately attached to the roof beams, causing the beams to become unstable and buckle; the grout under the beam ends was too thick and some of the grout in the beam pockets had cracked and delaminated; and the shear stirrups were placed too far below the beam ends to prevent the grout pockets from failing in shear. Also, in 2004 a roof beam was cut when a penetration was made into the roof to install an automatic level detecting device. This cut significantly reduced the load carrying capacity of the beam. These defects led to the collapse of the silo roof slab that was supporting the victim. In addition, adjacent Silo 11 experienced a partial roof failure in 2011 that caused the roof to bulge and caused significant cracking in the reinforced concrete. Management did not adequately investigate the causes and conditions surrounding the Silo11 partial roof failure and therefore did not identify similar conditions existing under the roof of Silo 12.

Management also allowed the silos to operate with defective aeration systems and the presence of a large rathole (partly caused by those defective systems). When the cement would bridge over the rathole and then collapse during discharge, this would create significant suction loading and detrimental vibrations on the roof slab, beams, grout in the beam pockets, and welds. In addition, other equipment including high level indicators and an automatic level detection device were inoperable, making manual measurement necessary and the over pressure events more likely. The over pressurization in the silo resulted in upward pressures on the silo roof slab and its support system (puddle welds and beams), and damage to those components.

When combined, these equipment-related defects and structural deficiencies contributed to the collapse of the roof slab.

ENFORCEMENT ACTION

Issued to Tarmac America, LLC

Order No. 8720505 – issued on August 17, 2012, under provisions of Section 103(j) of the Mine Act. This Order was modified later that same day to Section 103(k) of the Mine Act. Nine additional modifications were made to this Order during the recovery operations after the accident. After the recovery of Mezidor on September 4, 2012, several additional modifications to this Order were made to allow continued investigations of the remaining silos. The conditions that contributed to the accident may still exist on the adjacent silos; therefore, the Order continues to remain in effect as of the issuance of this report.

Citation No. 8724257 -- issued under the provisions of Section 104(a) of the Mine Act for a violation of 30 CFR 56.14100(b):

> *A fatal accident occurred at this mine on August 17, 2012. The victim was on top of Silo #12 getting a depth measurement of the cement in the silo when the roof on the silo collapsed. Following the accident, investigators determined that the hopper aeration piping system was inoperable and that the hopper air blaster was using ambient air rather than thermally dried air to agitate the powder at the bottom of the silo. The moisture caused erratic flow of material and the stored cement hardened, forming a rathole inside the silo. The cement would bridge over the rathole and then collapse during discharge, creating significant suction loading and detrimental vibrations on the roof slab, beams, pockets, and welds. These conditions contributed to the eventual collapse of the silo. Defects on the hopper aeration piping system , the hopper air blaster, and the presence of a rathole were not corrected in a timely manner to prevent the creation of a hazard to persons working on the roof of Silo #12.*

Citation No. 8724258 -- issued under the provisions of Section 104(a) of the Mine Act for a violation of 30 CFR 56.14100(c):

> *A fatal accident occurred at this mine on August 17, 2012. The victim was on top of Silo #12 getting a depth measurement of the cement in the silo when the roof on the silo collapsed. Following the accident, investigators determined that the roof decking on Silo 12 was inadequately attached to the roof beams, causing the beams to become unstable and buckle; the grout under the beam ends was too thick and some of the grout pockets had cracked and delaminated; and the shear stirrups were placed too far below the beam ends to prevent the grout pockets from failing in shear. Additionally, during a previous construction project, the top flange of one of the 30-inch center roof beams was accidently cut, considerably reducing the strength of this beam; and this significant damage was not repaired. These defects made continued operation of the silo hazardous to persons but the silo was not taken out of service and continued to operate. These defects caused the eventual collapse of Silo #12.*

Approved: Doniece Schlick Date: 10/24/13

Doniece Schlick
Acting Southeast District Manager

APPENDICES

A. Persons Participating in the Investigation
B. Victim Data Sheet
C. Technical Discussion
D. Photos
E. Figures

APPENDIX A

Persons Participating in the Investigation

<u>Tarmac America, LLC Pennsuco Cement Plant</u>

<u>Salary</u>

Kevin Baird	VP Cement & Agg Operations
Marco Burgoa	Technical Services Manager – Cmt
Tomas Burgos	Production Supervisor
Guillermo Haberer	Director Alternative Fuels
Jeffrey Harris	Asst Cement Production Manager
Rafael Holguin	Cement Mechanical Maint. Mgr.
Rafael Martinez	Cement Instrument Electrician
Basil Powell	Production Supervisor
Samuel Ricketts	Process Engineer
Humberto Rodiguez	Production Supervisor
Mario Rodriguez	Maintenance Supervisor
Cesar Soriano	Production Supervisor
Carlos Gonzales	Projects Manager
Natalia Davalos	Process Engineer

<u>Hourly</u>

Paul Crupper	Cement Repairman
Hector DeArmas	Cement Weighmaster
Jorge Diaz	Cement Shift Repairman
Rudy Fernandez	Cement Utility Person
Sergio Garcia	Cement Weighmaster
Dax Hallock	Cement Shift Repairman
Moliere Joseph	Cement Equipment Operator
Anthony Laberdesque	Process Control Operator
Cesar Lopez	Cement Utility Person
Reynerio Martinez	Cement Repairman
Ricardo Martinez	Cement Utility Person
Jose Morales	Cement Shift Repairman
Paul Mosely	Cement Instrument Electrician
Alejandro Ortiz	Cement Shift Repairman
Jorge Padron	Cement Shift Repairman
Ernesto Perez	Cement Shift Repairman
Richard Rhyne	Process Control Operator
Antonia Riu	Cement Repairman

Lazaro Sainz	Cement Repairman
Hector Sanchez	Cement Instrument Electrician
Leonel Vega	Forklift Operator & Utility

G&R Minerals

Jim Love	Vice-President of Operations
Tim Kressley	Director of Operations South Florida

Ogletree, Deakins, Nash, Smoak & Stewart, P.C

William K. Doran	Attorney
Michael T. Heenan	Attorney

Miami-Dade Medical Examiner Department

Dr. Emma Lew	Medical Examiner

Miami-Dade Police Department *

Michael Bracci	Sergeant
Jessica Alvarez	Detective
Michael Scott	Detective

Miami-Dade Fire Rescue Department *

Jeff Strickland	Captain
Andrew Hook	Battalion Chief

Mine Safety and Health Administration

Scott K. Johnson	Supervisory Mine Safety and Health Inspector
Jose J. Figueroa	Supervisor Special Investigator
Terence M. Taylor	Senior Civil Engineer
Sonia Conway	Mine Safety and Health Inspector
Thomas G. Galbreath	Mine Inspector Safety and Health Inspector
Donnie R. Lewis	Mine Safety and Health Inspector
Robert R. Peters	Mine Safety and Health Inspector
David E. Rosenau	Mine Safety and Health Inspector
Richard E. Woodall	Mine Safety and Health Inspector

*Participated in daily stakeholder meetings. Numerous other Miami-Dade police and fire personnel were involved in the rescue and recovery efforts.

APPENDIX B

Victim Data Sheet

Accident Investigation Data - Victim Information

Event Number: 0 9 1 6 9 4 3

U.S. Department of Labor
Mine Safety and Health Administration

Victim Information: 1

1. Name of Injured/Ill Employee:	2. Sex	3. Victim's Age	4. Degree of Injury:
Pierre Mezidor	*M*	*58*	*01 Fatal*

5. Date(MM/DD/YY) and Time(24 Hr.) Of Death:	6. Date and Time Started:
a. Date: 07/17/2012 b.Time: 8:11	*a. Date: 07/17/2012 b.Time: 8:11*

7. Regular Job Title:	8. Work Activity when Injured:	9. Was this work activity part of regular job?
199 Cement Equipment Operator	*036 measuring silo content level*	Yes X No

10. Experience

	Years	Weeks	Days
a. This Work Activity:	*10*	*0*	*0*
b. Regular Job Title:	*10*	*0*	*0*
c. This Mine:	*19*	*8*	*0*
d. Total Mining:	*19*	*8*	*0*

11. What Directly Inflicted Injury or Illness?	12. Nature of Injury or Illness:
120 working surface (top of silo) collapsed	*370 Victim fell into cement filled silo*

13. Training Deficiencies:

Hazard: New/Newly-Employed Experienced Miner: Annual: Task:

14. Company of Employment: (If different from production operator) Independent Contractor ID: (if applicable)

Operator

15. On-site Emergency Medical Treatment:

Not Applicable: X First-Aid: CPR: EMT: Medical Professional: None:

16. Part 50 Document Control Number: (form 7000-1) 17. Union Affiliation of Victim:

Victim Information:

APPENDIX C

TECHNICAL DISCUSSION

Beam Pockets

The channel extensions that were bolted to the ends of each of the roof beams rested on bearing plates that were cast into the silo wall within the confines of a metal beam pocket box (figure 1). As per the design drawings, the channels were not welded to the bearing plates so that lateral movement of the beams would be permitted. The sheet metal boxes were 8 inches deep, 16 inches wide and 23 inches high. There was no plate on the bottom side of the box. Within the box, there was a bearing plate that was dimensioned 8 inches wide by 12 inches long. The bearing plates for Beams 1 and 6 were ¾ inches thick and the plates for Beams 2-5 were 1 inch thick. Four bent studs were welded to the underside of each plate. These studs were L-shaped and had a 3/8 inch diameter and were 5 inches long. Specifically, the stud was straight down for a distance of 3½ inches and to the right for a distance of 1½ inches.

The bearing plates rested on high strength grout and the L studs were embedded within the grout. The design drawings indicated that the contractor could choose from four different brands of grout: Sonnogrout, Sealtight V-3, Crystex, or Euco NS grout. The properties of the grouts varied depending on whether they were considered fluid, flowable, or plastic. The 28-day compressive strengths varied from 6,200 psi for Sonnogrout 10K moderate flow to as high as 11,088 psi for Sealtight V-3 plastic. The grout layer thickness was shown on the drawings to be 1½ inches thick (plus or minus). Post failure compressive testing and petrographic analyses coordinated by Carrasquillo Associates revealed that of the five samples taken, four had an average compressive strength of 9,120 psi, while one sample taken from W5 had a strength of only 5,390 psi. The petrographer did find that two different types of grout were used in pocket E3. The low strength sample from W5 did not meet the expected minimum strength of the four brands permitted by the designer; however that pocket had internal delamination and was spalled.

At a distance of two inches below each of the beam pockets, the designer specified that size No. 3 shear stirrups should be installed on 4-inch centers (figure 2). The stirrups were to be Grade 40 steel. Typically five stirrups would be placed below a pocket.

Mill Feed Pipes

F3, F4, and F6 mills feed Silos 10, 11, and 12. Each mill had its own 12-inch diameter piping system to feed whichever silo was desired (photo 3). Typically, only one mill would feed a silo at a time, although it was possible to feed a silo with more than one pipe. If more than one pipe was used at a time, it was possible to overpressure a silo, as the dust collection system would likely not be able to vent the excess pressures fast enough as the silo filled. One such overpressure event occurred within Silo 11 in 2011, that caused the roof to bulge up, the reinforced concrete to significantly crack, and the bent over reinforcing bars at the perimeter of the slab to pop out (photo 4). Persons interviewed stated, that after that event the fill height on Silo 11 was restricted to no closer than 40 feet, as dust was coming out of the roof if the level got too close to the roof. In addition, when the silos fill, the internal pressure could cause a net positive pressure on the roof when the silo was getting full even with the dust collector operating and only one mill feeding.

Alberto Hernandez, Maintenance Supervisor, indicated that the Silo 12 measuring cap had blown off the year prior to the collapse, which was how they knew that the baghouse on Silo 12 was clogged. Persons interviewed also indicated they were aware of the cap blowing off.

An undated report prepared by the operator indicated that all the SK valves on the silo feed pipes had been disconnected from their electric motors and were operated manually with a sledge hammer. The report indicated that this method was inadequate because it damaged the valves and did not ensure the valve was fully closed. An improperly seating valve disc would let material flow through the side which would wear out the disc. Further, a leaking valve would allow pressurized air flow to a silo that was not intended to be fed at the time. The report stated that the F6 valves were in pristine condition, the F3 valves were in fair condition and the F4 valves were in poor condition and needed to be replaced. Scale had built up on the inside of some of the pipes feeding Silo 12 (photo 5). Scale would create resistance in the line that the FK pumps would need to overcome to pneumatically convey the materials and it could affect the proper seating of the valves.

Dust Collector/Bag House

Each of the silos was equipped with a Mikropul dust collector mounted on the roof. The three dust collectors were also referred to as bag houses. Their purpose was to allow the air used to convey the powder into the silo to escape the silo without allowing the product to leave the containment. Without a way for the air to escape, the storage silo would become pressurized, which could then damage the silo and not allow any material to move in. Dust collectors operate using a blower fan to draw air from inside the silo through a collection of filter bags, then the fan discharges the clean air back to the atmosphere. The dust particles are captured by the bags. Company records indicated there were 121 bags per dust collector. These filters became coated by these particles and could clog. To prevent this, an air pulse was systematically shot into the bag to make it puff out, which then caused the dust to fall off the bag back into the silo. The airflow then returned to normal. The design drawings indicated the dust filter was specified at 7644 CFM[4] at 200ºF. The fan was a New York Blower Size 294LS. It was to be sized for 7644 ACFM at 7 inches SPWG[5] at 200ºF. This equates to a vacuum suction pressure (i.e. downward pressure on the slab) equal to 35 psf.

During interviews, several persons indicated the dust collectors could be operated remotely by the control room operator. They stated it was common for the silo to operate with the dust collector running even when no cement powder was being pumped into the silo. The switch on the dust collector was held in the constant run mode. This was accomplished by jamming the switch with a nut or other means to operate in a constant run mode. A pebble was found resting on the switch box of neighboring Silo 11 and a nut was found jamming the switch of the bag house located on the roof of Silo 8 (photo 6). The control room operator indicated the fan symbol on the control board was illuminated prior to the accident, which meant the dust collector was running. In addition, Jose Morales, Production Shift Mechanic, who was the last worker atop Silo 12 prior to the accident, indicated that the dust collector was running when he was there measuring the silo depth approximately an hour before the collapse.

Typically, the quantity of air removed by a suction fan was, by design, greater than the quantity of air entering the silo. This was to allow the silo to have a slightly lower air pressure inside compared to outside. This slightly negative pressure prevented any dust from escaping through cracks or bad seals in the silo.

Approximately 12 months prior to the collapse, the roof on the bag house for Silo 12 had to be replaced, as rainwater was leaking onto the filters and causing them to clog. According to Hernandez, the silo measuring cap had been blowing off as a result of the baghouse filter clogging, which was when they discovered that the

[4] ACFM = Actual Cubic Feet per Minute
[5] SPWG = Static Pressure Water Gauge

bag house roof had been leaking. When the filters clogged, the dust collection suction was reduced. This could lead to a positive pressure on the silo roof when cement was being blown into the silo. In addition, as the silo level got near the top, the internal air pressure also increases.

Several persons interviewed, indicated that maintenance had been conducted on the Silo 12 dust collector weeks before the accident and that suction had improved. According to Hernandez, when he looked at the filter bags after the accident, they did not appear to have been clogged (photo 7).

Roof Ports and Openings

The measuring port on Silo 12 was not shown on the original engineering drawings (figure 3). It was added at a later date (photo 8). The port also served as a pressure relief valve. If the internal pressure exceeded the force required to lift the lid off the measuring port, then the lid would blow off. While the lid on the measuring port for Silo 12 was not recovered, the lid from Silo 11 was weighed and found to be 60 pounds. The lids were similar designs. The silo lid was 12 inches high, had a 12-inch outside diameter and a 3/8-inch wall thickness. One circular port recovered that was believed to be the port for measuring the cement depth had an inside diameter of 7.75 inches (photo 9). Based on that inside diameter, the pressure required to lift the 60 pound lid off the port would have been approximately 183 psf (or 1.44 psi[6]). Persons interviewed stated this port was not for the radio transmitter level indicator because it would have had six attachment bolts. In May, 2013, Borton Contractors and Engineers (Borton), measured the inside diameter or the ports on neighboring Silo 10 and 11, and reported an inside diameter measurement of 7.5 inches.

There were two, 6-inch-diameter ports originally constructed for the high level detectors. These ports were installed adjacent to the inspection hatch and both ports were found within the concrete slab remnant containing the inspection hatch. Persons interviewed stated these indicators were not functioning.

The original design provided an observation port be installed near the center of the silo. The port was not recovered from Silo 12. Borton measured similar ports and lids on Silos 10 and 11 and found that they weighed 26 pounds and their ports had an 8-inch inside diameter. The outside diameter of the observation port was not measured; however, from scaling of a photo showing both the lid of the

[6] psi = pounds per square inch

measuring port and the lid of the observation port, the observation port appeared to be 80% smaller in outside diameter, which meant the observation port was a much tighter fit. Based on that inside diameter, and assuming the cap was not snug enough to bind, the pressure required to lift the 26 pound lid off the port would have been approximately 74 psf (or 0.52 psi).

An 18-inch radio transmitter level indicator was found in the evidence lay down area for Silo 12 (photo 10). Persons interviewed stated the device did not work well and had not been operable. This device was added sometime around 2004. It is believed that the penetration of the roof to install this device likely resulted in the cutting of the top flange of Beam 3.

There was a collector box frame measuring 3 foot-6 inches by 2 foot, located at the center of the silo roof. The pipes conveying product from both the F3 and F4 mills discharged into this box. Also, each silo had a 3-foot by 2 foot-6 inch inspection hatch, located near the center of the roof. Around 2006, the original inspection hatches on each of the three silos had been converted to serve as the intake for the pipe discharging from the F6 mill. The 12-inch diameter piping heading to these three silos from the F6 mill was installed by Coalburn Construction.

Net Uplift Pressure on the Silo Roof

Silos 10, 11, and 12 all had fill restrictions to within 10 feet of the silo roof. Persons interviewed stated that filling these silos too close to the roof would cause positive upward pressure on the roof. When the pressure was large enough, it would cause cement powder to leak out of cracks or around ports at the silo roof. The lid on the measuring port also served as a pressure relief mechanism. Based on the weight of a typical cap for these three silos and the inside diameter of the portal, the uplift pressure to lift the lid was 183 psf. The average pressure from the self-weight of the roof slab, including the concrete above the decking and in each of the corrugations, was approximately 76 psf downward. The difference between the uplift pressure and the self-weight was 107 psf of net upward pressure. This pressure was resisted by the puddle welds attaching the slab decking to the roof beams and by the segments of the vertical bars from the silo walls that were bent horizontally into the slab around the perimeter of the structure.

The observation port also could serve as a pressure relief and it would take less pressure to lift off the lid, since it weighed 26 pounds. However, this port was a much tighter fit than the measuring port, so it would have been more likely to bind, particularly when scale built up at the port. If this port had been able to provide adequate relief, then the measuring port would likely not blow off and the slab would not feel net uplift pressure, since the average slab dead load of 76 psf would exceed the uplift load of 74 psf.

Silo Feed, Flow, and Discharge

F3, F4, and F6 mills fed Silos 10, 11, and 12. Three pipes ran to each of the three silos on common pipe racks, so that each mill had the option of discharging into any one of the silos. F4 was the oldest mill, followed by F3, and then F6, which was added around 2006. The access hatches on Silos 10, 11, and 12 were modified to accept the feed pipe from F6 mill. The cement temperature leaving the mills varied from 165° to 185° F and the mills produced cement at the following rates: F3 mill at 90 tons/hour, F4 mill at 140 tons/hour, and F6 mill at 103 tons/hour. The FK pumps were used to pneumatically convey the product to the silos. The pressures indicated in the control room were 32 psi on the non-drive side of F3 (drive side was short circuited), 18 psi on the drive side of F4, and 22 psi on the drive side of F6. Hernandez indicated the FK pumps had a maximum pressure of 32 psi and could put 16 psi in the silo feed lines.

Persons interviewed stated the level indicators on Silos 10, 11, and 12 had not been functional for several years. Therefore, to inventory the silo levels manual measurements were taken. Specifically, a cloth tape with a weight attached to the end was lowered into the silo until resistance was felt on the end of the tape. The resistance indicated the weight had landed on the surface of the cement powder. The tape was then read to determine the depth of the stored cement powder below the silo roof.

The silo load-out from Silos 10, 11, and 12 was controlled from a room positioned in Silo Cluster 1- 9. Air slide chutes conveyed the material from the hopper outlets of each of the three silos to the Load-out No. 3 scale. The hoppers of each of the three silos were originally equipped with piping to inject air through ports of the sides of the inclined hopper plates. These air systems were to create air slides, but persons interviewed indicated they had not worked for a long time. Their purpose was to assist with material flow inside the hopper. In addition, at the hopper outlet, there was an air blaster system to shoot air into the outlet (photo 11). The blaster used ambient air from outside of Silo 11, which could contain humidity. Humid air and condensation could cause the cement particles to begin to hydrate (i.e. stick together). The original drawings showed a thermal dryer on the air supply; however, it was likely removed at some time, as it was not found in its specified location. The lid on the outside air intake filter next to Silo 11 was partially off, which would have further allowed moisture to get into the intake air system for the three silos. The injection of moist air, rather than dry air, into the cement powder in the silo hoppers may have caused caking of the material, which led to clogs at the outlet of the hopper and a rathole in the stored powder. Other means used to break up clogs and encourage flow included beating on the hopper shell with sledge hammers and using jam rods at the hopper outlet, the side access door, and/or the silo withdraw air slide chutes.

The silo was designed with a funnel flow hopper. However, over time, cement powder built up inside and formed a rathole or donut, which decreased the live storage capacity of the silo (figure 4, photos 12-13). When stored cement powder bridges over a rathole or donut and then suddenly collapses into the flow channel, it can cause large suction loads on the silo roof, depending on the amount of collapsing stored material above the flow restriction. Collapsing material caused a piston effect where high overpressures could occur in the lower part of the silo and suction could occur in the upper part. Flow-induced silo vibrations could cause significant dynamic loads. Several workers reported feeling vibrations on the roof of Silo 12.

<u>Silo Levels July and August, 2012</u>

Silo 12 was filled between July 1 and July 23, 2012, with the later date being the last time material was pumped into the Silo 12 before the accident. Therefore, the material sat and compacted for 25 days. After the silo had been filled, trucks were loaded out as follows: August 1st – 1 truck (25 tons); August 14th – 1 truck (26 tons); August 15th - 9 trucks (232 tons); August 16th - 86 trucks, (2,245 tons); and August 17th – 12 trucks (304 tons). A total of 2,832 tons of material was removed compared to the total storage capacity of 16,147 tons when considered full.

On July 23, 2012, the silo was nearly full with a measured depth from the cement powder surface to the roof of only 9 feet. The level was maintained up until August 15, 2012, when the level dropped only 2 feet to 11 feet below the roof. On August 16, 2012, just one day before the accident when 2,142 tons was pulled from the silo, the level remained at 11 feet and that measurement was taken at 9:30 pm by Dax Hallock, Shift Mechanic. Apparently this is when a vast majority of an underlying void was created within the stored cement, since the depth of the material was unaffected by the significant tonnage that was removed by that time. Then between 9:30 p.m. and midnight an addition 103 tons was removed. Jose Morales measured the silo level around 12:30 a.m. .on August 17, 2012 and it had dropped to 148 feet below the roof. Therefore, sometime in that four hour interval an internal bridge of material collapsed.

A measurement of 148 feet would correspond with a depth where the measuring tape was 15 feet below the interface of the silo wall and conical hopper bottom. The hopper is 33 feet high, so the ball on the tape measure would have been resting 18 feet above the outlet of the hopper. Since 103 tons should have only corresponded with a drop of 1 foot in the level of the material (i.e. 11 feet down to 12 feet), it appeared the unpredicted reading of 148 feet below the roof surface indicated the tape ball had found its way down a flow channel, which suggested the underlying void had now reached the top surface of the stored material. Six hours later at 6:45 am, Morales again measured the material level and found it was still 148 feet below the surface, even though an additional 304 tons was loaded out of the silo in the time interval since his last measurement. This appeared to indicate a new lower bridge of arched material had formed within the hopper.

Based on silo depth measurements between July 6 and July 7, 2012, when the level rose 46 feet, the physical inventory on Silo 12 increased by 4,986 tons, even though an additional 1,171 tons was sold. This implies that overall 6,157 tons was pumped into the silo by F6 mill, which was pumping into Silo 12 on those days. F6 mill generated product at approximately 103 tons per hour, which over a 24 hour time frame was only 2,472 tons. This large disparity between how the measurements changed compared to the amount of cement that could actually be placed in the silo, suggested there was a significant hardened non-flowing material that formed a rathole or donut and therefore it did not take as much new material to fill the hole and caused the silo level to rise 46 feet in such a short period of time.

Likewise, on July 16 and 17, 2012, the inventory rose 16 feet, the inventory gained 1,723 tons and there were 3,008 tons sold. Therefore, this implied that 4,731 tons was added to the silo, but F6 mill could only generate 2,472 tons in 24 hours. This again suggested there were considerable high peaks of hardened material around the inside perimeter of the silo and/or a significant void had formed within the cement powder above the hopper.

On the morning of the accident, Silo 12 would not flow so the load out operator switched to pulling material from Silo 11. At that time, based on control room data, it appeared F6 mill was actively feeding Silo 11. Several miners attempted to use an air blaster and beat on the hopper of Silo 12 with a sledge hammer, but it would not start flowing despite being nearly 80% full. A void had formed and the material was bridged over the flow channel (photo 14). Persons interviewed stated the air blaster was used on Silo 12 from approximately 4:00 a.m. to 7:30 a.m. The air blaster was switched over to Silo 11 so it was not on under Silo 12, as it could only work on one silo at a time. When the collapse occurred, no persons were under Silo 12.

On the morning of the accident, the air slide leaving Silo 12 to the loadout was empty. However, after the collapse and during the recovery operations, material was found at the bottom of the hopper, so either that material was there immediately after the collapse or that material had made its way to the discharge opening as part of the disturbance during the recovery operations.

Roof Loads

Aside from supporting their self-weight, the roof beams supported the roof slab and decking, the piping system, the dust collector, the fan for the dust collector, the hoist system, the mechanical control center (MCC) room, instrumentation, and any additional personnel or equipment that is brought onto the roof (photo 15). The dust collector and flange were weighed after the collapse. Some pieces of concrete were still attached to the flange. Their combined weight was 10,480 pounds. The dust collector fan with motor and pedestal weighed 1,250 pounds. The majority of the weight associated with the MCC room was transmitted to the outside walls by two bearing beams that spanned across the arc of the silo roof associated with the MCC room. In addition to the weight of the piping system, there was scale build up found within the pipes. This scale was much denser than the loose powder flowing within and therefore added some weight to the roof.

Other loads on the roof included negative pressure from the dust collector suction (35 psf), positive uplift pressure (183 psf) from the silo pneumatic feed system (when the dust collector clogged, was turned off, or was unable to vent the injected pressures fast enough), and negative pressure associated with erratic flow (collapsing bridges). In addition, the erratic flow caused silo roof vibration when the roof rebounded after the suction.

The silo roof was also subjected to periodic wind loading that caused an upward pressure on the slab and additional weight associated with hardened cement dust that would stick to the roof of the silo. While most of the slab was broken into small pieces by the collapse, the amount of built up material found on the slab remnants did not appear to be significant.

Condition of the Beam Pockets Post Failure

Using a personnel platform suspended from a crane, each of the roof pockets were examined after the collapse to determine: the condition of the bearing plates, the distance to the stirrups, the thickness of the grout layer, the existence of any delamination cracks (i.e. internal cracks/splitting within the curvature of the wall or grout), the existence of spalling, and other visible cracks through the wall (Table 1), (photos 16-25). As a result of the failure, two of the pockets, including both the metal beam box and bearing plates, were completely broken off the wall. These were pockets East 4 and East 5. Delamination was checked by sounding the vertical face of the grout. The grout thicknesses were found to vary from 7.5 to 11 inches, which was well in excess of the 1.5 inches (plus or minus) specified on the design drawings. The following table summarizes the post failure condition of the pockets.

Table 1: Roof Beam Pocket Inspection

Beam Pocket	Condition of Bearing Plate	Delamination Detected	Grout Layer Thickness (distance from base plate to top of shear stirrups)	Stirrups	Failure of Pocket
East 1	still in place	yes at near surface	10 inches	could not determine	no
East 2	plate tilted, grout sheared (G&R Mineral Services removed the hanging plate during recovery to mitigate a potential falling object hazard)	part of grout face broke off to allow plate to tilt down so delamination likely existed. Also large honeycombed area below the pocket	10 inches	5 stirrups visible	yes
East 3	no plate grout sheared	yes, delaminated in pocket with numerous cracks	11 inches	1 stirrup visible	yes
East 4	no pocket or plate	pocket and grout were pulled off by the collapse sequence so could not determine	could not be measured as pocket was pulled off by the collapse	5 stirrups visible	yes
East 5	no pocket or plate	pocket and grout were pulled off by the collapse sequence so could not determine	could not be measured as pocket was pulled off by the collapse	5 stirrups visible	yes
East 6	still in place	no	10 inches	could not determine	no
West 1	still in place	no, except for material at location of a bent jacking rod	10 inches	could not determine	no
West 2	still in place	no, except near a spalled area	10 inches	could not determine	no
West 3	still in place	yes	8 inches	could not determine	no
West 4	still in place	yes	9 inches	could not determine	no
West 5	plate tilted	yes with some spalling	7.5 inches	2 stirrups visible	yes
West 6	still in place	yes at near surface	11 inches	could not determine	no

The delamination on the beam pockets likely occurred from the repetitive loadings applied by the roof beams. This could have been a result of the vibration from erratic flow in the silo, where large suction loads could occur when the cement product bridged and arched, and then collapsed during emptying. In addition, flexing of the roof beams and buckling caused rotation and lateral frictional drag on the bearing plate, which transmitted the lateral loading through the anchor L-shaped studs to the unreinforced, thick layer of grout. Thermal expansion and contraction of the roof beams also likely added to lateral loading on the bearing plate studs. In addition to the lateral loading, the fluctuating loading on the bearing plates were subjecting the grout pockets to varying bearing stresses. The grout likely delaminated at the vertical plane of one or both of the L-stud pairs.

On the outside walls, there were diagonal cracks at the corners of the beam pockets and relatively horizontal cracks running between the corners of each of the adjacent pockets. These cracks were also evident on neighboring Silos 10 and 11 where the roof was still intact (photo 26). These cracks were likely caused by stress on the outside layer of vertical bars related to vertical deflection of the roof slab and subsequent catenary action from lack of beam support. The cracks also may have been related to temperature and shrinkage cracking.

Two of the 12 bearing plates were not recovered. They were either from East 3, East 4 or East 5, as only one of the three was found within the debris. A large piece of grout was found attached to two front anchor studs on one of the bearing plates recovered inside the silo. The grout piece was fragmented into three pieces with the largest being 11 inches high. The other two pieces of grout were 8.5 inches high and 2 inches high (photo 27).

Concrete Cracking

By reviewing the maintenance records and interviewing employees, it did not appear that the operator was aware of any significant cracking on the roof slab of Silo 12. There was a worn elastic membrane coating on the surface of the roof, which had been placed to prevent water ingress. The coating likely masked some of the slab cracks. A crack was noted in 2011 by Thomas Burgos, Production Supervisor, and that crack was repaired on August 19, 2011, by the maintenance department. Sergio Garcia, Loadout Operator, reported that rain water was getting into Silo 12 roof around the port and there were other cracks that had been sealed. He indicated that suction from the dust collector had been pulling the water in through the cracks. When water reached the stored cement powder, it would start the hydration process and cause caking.

Aside from cracking up near the roof beam pockets, overall, there were not many cracks on Silos 10, 11, and 12. There were a few horizontal cracks, but no obvious vertical cracks over the remainder of the height. The cracks around the beam pockets were likely the result of tension in the outer walls near the beam pockets, as the vertical bars attempted to carry part of the silo roof weight in catenary action after the roof beams deflected and buckled (photo 26). The cracks also may have been related to temperature and shrinkage cracking.

In a concentric discharge silo, such as these three silos, cracking related to asymmetric flow can occur if the flow channel tilts toward and intercepts the wall on one side of the silo. Ratholes can cause the powder to flow asymmetrically toward one wall. However, in Silo 12 there did not appear to be any flexural cracking associated with asymmetric flow.

Roof Beams and Lateral Torsional Buckling Failure

Based on the unique features of the beams, the investigation team was able to identify which beams would have been considered Beams 1 through 6. Beams 3 and 4 were mirror images of each other and were laid out backwards in the evidence lay down area. By comparing the fillet weld remnants that attached the dust collector to the top flange of the beams, it was possible to later determine the correct orientation of the two middle beams. Beam 3 had been damaged by a torch cutting the top flange. Specifically, nearly one half of the flange had been burned through when an opening was added to the roof of the silo (photo 28). This was likely for the installation of the radio transmitter level indicator. Apparently, when the roof slab and decking were cut open, the hole aligned with the location of the roof beam, so the installer cut part of the roof beam. When the flange was cut to the intersection with the web the individual appeared to have moved the port a few inches over and then re-cut the flange. The radius of the arc cut the second time did not interfere with the web of the beam. This second cut was a 9 inch wide by 3.5 inch deep arc in the flange. Cutting significantly weakened the stability of the top flange of the beam; therefore, the overall carrying capacity of the beam was diminished.

Since cross bracing was not a part of the roof beam support system, the designer specified that the decking should be welded to the top flange of each beam on a spacing frequency of one weld per every 12 inches of beam length. This meant

Beams 1 and 6 should have had 37 welds each, Beams 2 and 5 should have had 48 welds each, and Beams 2 and 3 should have had 54 welds. These welds were arc spot welds, also known as puddle welds. The drawings did not specify a minimum size (diameter) for the welds, nor was there a welding electrode specified. The drawings did generally indicate that the welding electrodes were specified as E70XX, which had a minimum tensile strength of 70 ksi. A micro-hardness test of two of the welds after the collapse indicated they had a tensile strength in excess of 70 ksi. The decking welds were to provide support and stability to the top flange of the roof beams and thereby prevent a lateral torsional buckling failure.

All six beams were recovered after the accident (photo 29). Beam 6 was recovered in one piece, but four other beams had to be cut into two pieces for removal due to capacity limitations on the crane and other obstructions within the silo during recovery. Beam 4 had to be cut into three segments for removal. None of the bolts failed on any of the extension channel-to-roof beam end connections of the six beams.

Each of the beam segments removed from the accident were inspected to determine the number of residual puddle welds that were to provide lateral support to the top flange of each beam prior to connection failure. Post collapse the welds were inventoried and a weld was not considered to have provided any lateral restraint if the contact failure surface was smooth, which indicated the weld material had not gotten hot enough to melt the base metal with the metal of the welding electrode. For example, a smooth flange with only discoloration of the beam where the weld was originally made was not considered an effective weld and therefore did not provide lateral support to the top flange of the beam (photo 30).

There were five possible types of failures of the puddle weld connections between the decking and the beams: the decking failed around the weld due to the large size of the weld; corrosion of the decking around the weld led to decking failure rather than the weld; the weld pulled off the beam flange due to lack of fusion to the base metal of the beam; the weld was small and it failed; and the welder failed to completely burn through the bottom plate of the decking so the deposited weld metal never reached the underlying beam (photos 31-34). Fatigue damage may have also played a role. Some of the weld failure surfaces were smooth. This either indicated that fatigue was present or that the connection failed some time ago and repetitive vibration during discharge and fluctuating internal pressures inside the silo led to the failed surfaces rubbing against each other over time, which created the smooth surface on the weld (photo 35).

The post collapse inventory of semi-competent welds included only 4 welds on Beam 1, 9 welds on Beam 2, 42 welds on Beam 3, 9 welds on Beam 4, 17 welds on Beam 5, and only 8 welds on Beam 6 (Table 2). Therefore, Beams 1, 2, and 4 only had 11, 19, and 17 percent, respectively, of semi-competent welds to provide lateral torsional stability. All of the beams recovered from the collapse appeared to have buckled sideways, which was indicative of a lateral torsional buckling failure (photo 29). In addition, the flanges on the end channels were bent on at least one end of 5 of the 6 roof beams, which indicated the beam ends were attempting to rotate prior the final failure (photo 36). It was not clear what degree of rotation occurred prior to the day of collapse, but evidence from Silos 10 and 11 indicated the channel flanges would deflect and roll due to lateral torsional buckling, even though the slab had not failed.

Table 2: Examination of Roof Beams and Remnant Arc Spot Welds

Beam	Approximate Number of Welds Required Based on 12" Spacing	Number of Significant Welds with Residual Material	Percentage of Significant Welds Compared to Required Welds	Hardened Concrete on Top Flange near Buckle indicating Prior Buckling	Condition of Beam
1	37	4	11%	yes	Buckled at approximately 33% distance from east end
2	48	9	19%	yes	Buckled at distance approximately 40% of span length from east end
3	54	42	78%	yes	Twisted at the location of the cut top flange
4	54	9	17%	yes	Buckled near midspan
5	48	17	35%	no	Buckled near midspan
6	37	8	22%	yes	Buckled near midspan

Of the six beams recovered from the debris, five of the beams had areas of hardened concrete adhering to their top flange in the vicinity of the primary buckle location. These beams were numbers 1, 2, 3, 4, and 6. The presence of hardened concrete suggests some separation of the beam from the decking prior to the day of the collapse. All six beams were buckled or twisted to differing degrees.

Testing and Metallurgical Evaluation of Corrugated Decking and Puddle Welds

A 2 foot by 3 foot section of galvanized decking was tested and evaluated by the West Penn Testing Group, located in New Kensington, Pennsylvania. Four specimens were cut from the decking (two from the top sheet and two from the bottom sheet) to measure the yield and ultimate tensile strengths of the steel and its modulus of elasticity (Table 3). In addition, a metallurgical evaluation was conducted on the two arc spot welds that were located on this piece of decking to determine their strength and likely cause of failure. The two welds were cut to prepare cross sections for hardness testing and for microscopic examination. The evaluation concluded that the welds failed from a single shear overload event with the direction of loading being transverse to the axis of the roof beam. The weld failures resulted from extensive porosity and lack of fusion defects that reduced the load carrying capacity of the weld cross sections (photo 37). Poor weld workmanship, improper weld parameters, and excessive gaps between the decking and the top surface of the roof beam were believed responsible for the lack of fusion and porosity defects. Based on the amount of corrosion oxidation on the surface of the welds, it was concluded that both welds failed early in life - long before the day of the roof collapse. In addition, there was no evidence found of weld fatigue or tensile overload.

Table 3: Tensile Testing Results of Metal Decking Sheets

Sample ID	Top Plate 1	Bottom Plate 1	Top Plate 2	Bottom Plate 2
Ultimate Tensile Strength (psi)	56,000	52,300	54,500	51,700
0.2% Yield Strength (psi)	49,300	44,500	49,100	43,800
% Elongation (2 in)	22.2	29.9	27.5	26.6
Modulus of Elasticity (ksi[7])	22,259	26,459	21,517	22,983

[7] ksi= kips per square inch, where 1 kip = 1,000 pounds

The metallurgist approximated the percentage of fused weld metal between the weld and the top surface of the beam. This was accomplished by measuring the percentage of deformed weld substrate adjacent to the fractures and along the length of the cross sections. One weld was estimated to be 24 percent fused and the other 61 percent. The strength of the weld metal was determined using Vicker 500gr micro-hardness testing (Table 4). The Vicker values were then converted to equivalent ultimate tensile strengths. The higher hardness found near the fracture surface of weld M2 was attributed to a finer weld metal grain size that resulted in a more rapid cooling rate at the beam/weld interface.

Table 4: Weld Ultimate Tensile Strength - Based on Vickers Micro-Hardness

Location of Test on Cross Section	Weld M1	Weld M2
Top	101 ksi	98 ksi
Middle	100 ksi	101 ksi
Bottom – Near Fracture	86 ksi	115 ksi

Signs of Failure on Adjacent Silos 10 and 11

Following the roof collapse on Silo 12, CA/WDP Consultants conducted an inspection of the roof structure supporting Silos 10 and 11 and found signs of incipient failure. To inspect the roof beams and end bearings, the metal boxes encompassing the beam pockets were cut open for access. The grout below the beams was sounded for delamination. In addition, impact echo and ground penetrating radar were used to assess the integrity of the concrete surrounding the pocket. Generally, like Silo 12, they found the silos had a considerable amount of grout layer beneath the beam bearing plates. Similar to Silo 12, they found horizontal and diagonal cracks on the exterior silo walls at the beam pockets.

On Silo 10, both of the 30-inch deep middle beams (nos. 3 and 4) were rotated (photo 38). At Beam 3, there was an 8 to 9 inch high gap between the beam and the roof slab at the east side (photo 39). The grout at East 3 pocket was crumbled and there was no bearing plate detected, although it may have previously fallen into the silo. Beam 4 had a clockwise rotation at the east pocket and the right lower flange of the beam end channel was deflected upward as a result of the rotation (photo 40). The grout under East 4 pocket was delaminated under the bearing plate. No deficiencies were found with Beams 1, 2, 5, and 6 or the pockets associated with each of these beams.

On Silo 11, deficiencies were noted on Beams 2, 3 and 4. Specifically, a gap existed between the beams and the roof slab. Aside from a 1-inch gap between the roof slab and Beam 2, the East 2 pocket was showing signs of delamination (photo 41). The flange on the beam end channel was bent. Beam 3 was rotated to the south and the beam was slightly bowed (photos 42-43). The East 3 pocket was delaminating and the flange on the beam end channel was bent. West 3 pocket was likewise delaminated and the flange on the beam end channel was bent. Although Beam 4 had a gap between the beam and the roof slab, there were no deficiencies detected at the beam pockets at either end (photo 44). Beams 1, 5 and 6 were found to be in adequate condition, as well as all of their associated beam pockets with the exception of West 6, where there was no bearing plate visible. However, the sounding results may have indicated the plate was present below the surface of the grout.

Construction Deficiencies with Silo 12 Roof

Beams 2 and 5 were installed backwards. Beam 2 was fabricated with skewed stiffeners for the W12x26 cross beam that spanned between Beams 1 and 2. The cross beam was for support of the hoist on the southeast side of the silo. However, this beam was actually installed at the location of Beam 5. In contrast, Beam 5 was not fabricated with stiffeners. However, in the recovery, this beam was found with add-on angle plate stiffeners that were obviously not installed by the fabricator. These stiffeners were added near the position of the overhead hoist system. The stiffeners were welded to the web of the beam. The angles at the end of the cross beam were bolted to the web of original Beam 5 (which was actually installed at the location of Beam 2). The bolt holes in the beam were oversized and cut by a torch. By examining the fracture surface on the 5 inch angles at the end of the cross beam attached to Beam 1, it was apparent that this fracture surface matched the fracture surface on the 5 inch remnant metal angle pieces still bolted to Beam 2 (which originally was supposed to be Beam 5).

The grout thickness below the beam bearing plates was shown on the drawings to be 1-1/2 inches thick plus or minus. Instead, at some beam pocket locations the thickness was on the order of 11 inches. This added thickness increased the distance between the beam bearing plate and the underlying shear stirrups, which therefore reduced the resistance to a shear failure through the grout layer. In addition, when grout thicknesses exceed 4 inches, aggregate should have been used with the grout to extend it and to help dissipate hydration heat and therefore cracking.

As indicated above, when the silo was constructed, the metal decking formwork for the concrete roof slab was not welded to the top flange of the beam as specified by the designer. Specifically, the design specified welds on 12-inch centers, but the number of semi-competent welds found indicated that only a fraction of those required were actually substantially made. Beams 1, 2, and 4 only had 11, 19, and 17 percent, respectively, of the number of substantial required welds. Without the required number of competent welds installed, the resistance to uplift pressure in the silo and the lateral torsional stability of the beams was compromised. Based on the post collapse condition of the beams, it appears the beams failed due to lateral torsional buckling.

Analyses

The roof beams were originally designed assuming continuous lateral support would be provided along their length. This continuous support was to be provided by welding the corrugated metal decking to the top flange of each of the six beams. The design drawings specified puddle welds every 12 inches on center along the beam. The original design used an allowable beam stress of 60 percent of the yield strength of the steel, which corresponded to an allowable bending stress of 22 ksi[8].

According to the original design calculations, the roof beams were designed to support the roof slab and an applied live loading of 50 psf. There was no additional allowance for the 35 psf suction loading due to the dust collector, so the suction pressure would have been, by default, a portion of the 50 psf live loading.

Following the collapse, the beams were evaluated for lateral torsional buckling using the Load Resistance Factor Design (LRFD) code of the American Institute of Steel Construction. It was determined that if the beams had continuous lateral support they were adequate to carry the specified original design loads (self-weight plus 50 psf live load). However, since many of the puddle welds were ineffective and others had failed prematurely, the beams were also evaluated as if there was no lateral support to the top flange. In all six cases, the beams were inadequate and would be expected to fail in lateral torsional buckling. This is consistent with the condition of some of the beams on neighboring Silos 10 and 11. An additional evaluation was made of Beam 3, assuming reduced section and plastic moduli at the location of the cut. Even assuming full lateral support, since

[8] 0.6 x 36 ksi = 21.6 ksi or approximately 22 ksi

this beam had the most significant welds, the capacity of the cut beam was below the required design strength.

Aside from the beams being susceptible to lateral torsional buckling from downward loads, the beams were also susceptible to lateral torsional buckling from uplift pressures on the underside of the slab. In cases where the puddle welds held in tension, the bottom flange had to resist compression. Since there was nothing bracing the bottom flange over such a long span from wall to wall, the bottom flange would be susceptible to rotating and buckling sideways.

The grout pockets were also evaluated. The shear strength of the grout varied depending on which of the four products had been used. Using the range of compressive strengths (and associated empirical shear strengths) and the physical evidence, the potential failure planes were evaluated. It was found that if the pockets were delaminated in the vicinity of the anchor studs (as was detected after the collapse) the pockets would fail in shear. This was likely exacerbated by the transfer of loads from one beam to the next, when an adjacent beam would buckle. The load transfer would ultimately have to be resisted by the beam end channel reactions at the pockets.

Measurements were taken of each of the puddle welds on top of the six roof beams. Only the welds that were considered to have fused with the base metal of the beam flange were considered to provide competent support. Using either the measured diameter or the approximate comparable diameter if it was square in shape, the capacity of the connection was determined, which was governed by the lesser of the weld strength or the decking plates around the weld. These tensile capacities were then compared to the force of the tributary slab uplift pressure (average of 107 psf) on the welds, assuming the measuring port was the first available means of pressure relief. It was found that the tensile capacity of these connections was in many cases exceeded.

The shear capacity of the puddle welds was also evaluated. The flutes in the decking were oriented perpendicular to the span of the beam and the flute corrugations were embossed to transmit shear. Since there was no intention of the beam and slab acting as a composite member, there were no shear studs welded through the decking to the top flange of the beam. However, in the absence of studs, the puddle welds were able to transmit some shear from the roof beams to the corrugations in the decking and then ultimately to the underside of the slab at the top of the flutes. Therefore, even though the welds were not intended to resist shear, they likely did have to serve that purpose. The shear was highest at the ends of the beam and lowest toward the middle. The loads acting on the slab likely generated enough shear along some of the beams to fail the as-built puddle welded connections in longitudinal direction of the beam span. The welds along the east half of Beams 2 and 4, as well as the east half of Beams 1 and 5, likely failed in longitudinal shear.

As the metallurgical evaluation revealed, some welds also failed from shear in the transverse direction. This could have occurred when welds were trying to restrain the top flange from buckling or when the decking was initially supporting the wet concrete during construction. Then, without some of the puddle welds helping to resist uplift events, the remaining welds were subjected to even more tension. Five out of the six beams likely did not have adequate welds to resist a net uplift pressure of 107 psf. Therefore, a majority of the welds likely failed sometime prior to the day of the collapse and therefore were not available to prevent a lateral torsional buckling failure of the beams.

The capacity of the reinforced concrete slab was evaluated both considering the original span distances between the roof beams and then considering that a roof beam had lost contact with the bottom of the beam as a result of buckling and/or bearing plate displacement associated with grout failure. The distance between the top and bottom steel reinforcing bars was measured at a few undamaged locations and found to vary from 3.5 to 4 inches centers. The slab had adequate capacity to span the original beam distances. When the span was doubled to account for lack of support from one of the beams, the slab was still found to have capacity for that condition. Since the decking was embossed, the concrete slab and deck would have behaved compositely in the north-to-south span direction**.** Considering both sheets (the top hat and bottom) in the flexural capacity of the composite deck, the reinforced slab could actually span the entire length of the 31-foot-long sheet, which could occur if three underlying support beams were buckled or had lost contact with the slab.

Appendix D

Photos

Photo 1 – Overview of Silo 12 (left), 11 and 10. Silo cluster 1-9 is on right side of picture.

Photo 2 – Silo 10 (left), 11, and 12 (circa 1996). This was prior to the MCC and F6 mill piping being added.

Photo 3 – Roof of Silo 11 showing dust collector position (arrow) and fan on the west side (left) and the feed pipe rack with F6 piping being the uppermost. The measuring port (right) is circled. Note all piping leading to Silo 12 (lower left) was removed during the recovery.

Photo 4 – Damage to Silo 11 roof when it was over pressured in 2011. The roof bulged and the bent over vertical reinforcing bars popped out of the slab at the perimeter when the roof relaxed.

Photo 5 – Scale built up in pipes coming from the mills (recovered from Silo 12).

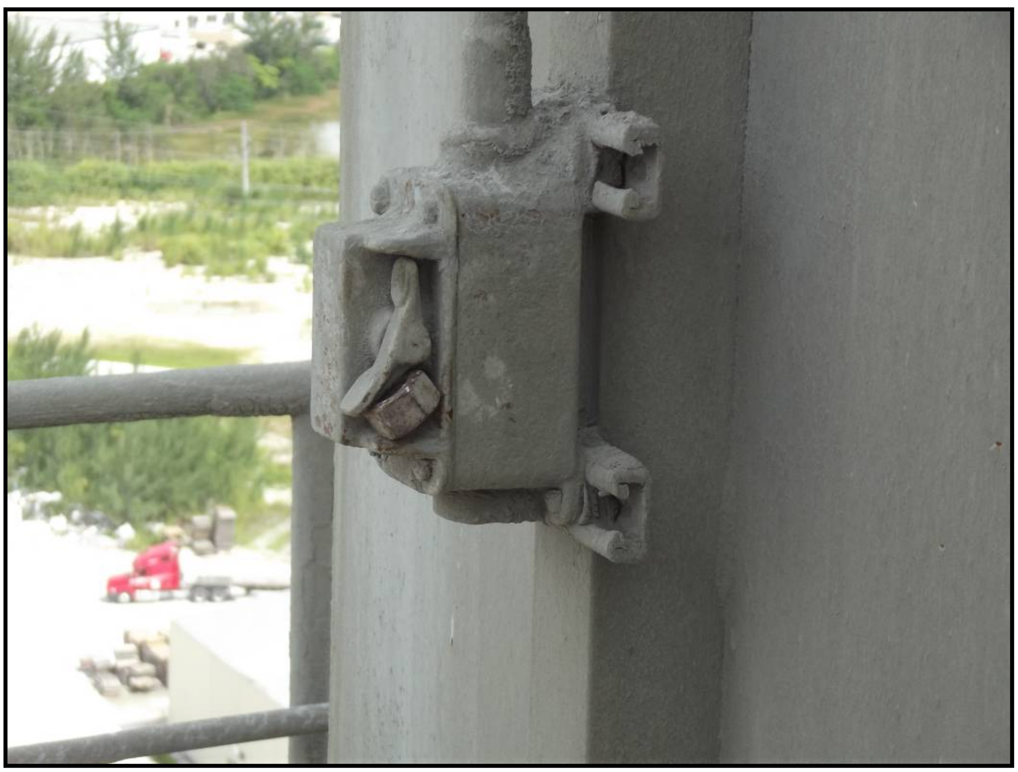

Photo 6 – The dust collectors on the cement product silos were constantly run. The jog switches were kept on using nuts or other means to prevent shut off.

Photo 7 – Air filter bags in the Silo 12 dust collector were partly caked.

Photo 8 – Typical measuring cap for Silos 10, 11, and 12. Cap weighed 60 pounds and also acted as a pressure relief device.

Photo 9 – Measuring port from Silo 12. Inside diameter measured 7-3/4 inches.

Photo 10 – An 18 inch radio transmitter level indicator from the roof of Silo 12. The top flange of Beam 3 was likely cut when this equipment was installed circa 2004.

Photo 11 - Intake ambient air supply for the silo hopper air blaster. Cap (arrow) on intake filter was not attached.

Photo 12 – Stable rathole revealed as Silo 12 was drawn down.
Picture taken on September 11, 2012.

Photo 13 – Stable rathole as Silo 12 was drawn down. Picture taken on September 14, 2012. The flow channel tended toward the east wall.

Photo14 – Bottom of rathole as of October 11, 2012, as the hardened material was removed.

Photo 15 – Overview taken in 2004 looking at the east side of Silo 12 (left), 11, and 10 roofs. Circled area shows two ports on Silo 12. The upper left port was an observation port as per the original drawings and the lower right port was for a radio transmitter level indicator added (circa 2004). Note this photo was taken prior to the addition of F6 mill piping.

Photo 16 – Looking toward north wall. Photo taken 1 day after Silo 12 collapse. Large slab section still attached to the dust collector would have spanned from Beam 3 to the north wall.

Photo 17 – Overview of the six west side beam pockets on Silo 12. Pocket W1 is on the left of the photo and Pocket W6 is on the right.

Photo 18 – East 1 pocket of Silo 12 was intact, but near surface delamination detected in 10 inch-thick grout layer.

Photo 19 – At East 2 pocket of Silo 12, the grout sheared below the front half of the bearing plate and it tilted downward. Note honeycombed concrete void below the exposed shear stirrups.

Photo 20 – Grout delaminated and sheared off at Silo 12 East 3 pocket. Multiple cracks present in 11 inch-thick grout layer.

Photo 21 – Silo 12 East 4 pocket completely torn from silo wall above the location of the shear stirrups (arrows)

Photo 22 – Silo 12 East 5 pocket completely torn from silo wall above the location of the shear stirrups (arrows)

Photo 23 – Silo 12 East 6 pocket intact and no delamination detected in 10 inch-thick grout layer.

Photo 24 – Silo 12 West 3 pocket hidden delamination detected in 8.5 inch-thick grout layer.

Photo 25 – Silo 12 West 5 pocket bearing plate tilted down and delamination detected in 9 inch layer of grout.


Photo 26 - Cracking at the beam pockets on the east side of Silo 11. This cracking was typical on all three silos.

Photo 27 – Chunk of grout and bearing plate that sheared off. This plate was from either East 3, East 4, or East 5 pocket.

Photo 28 – Cut top flange of roof Beam 3 of Silo 12. Hardened concrete on flange and in the (circled) cut line indicate the beam had been buckled for some time prior to the day of collapse. Cut was likely made when the radio transmitter level indicator was installed circa 2004.

Photo 29 – Layout of Silo 12 roof beams. Beam 1 (only partly visible) is against left wall. Left to right is Beam 2 (2 sections), 4 (3 sections), 3 (2 sections), 5 (2 sections), and 6 (intact).

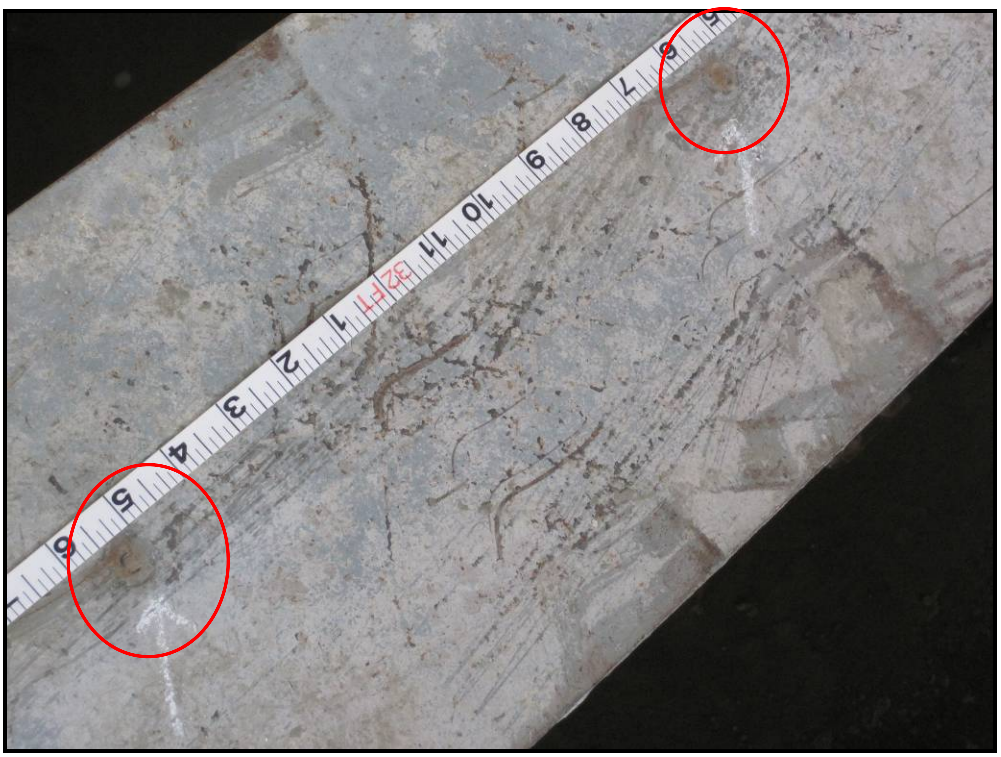

Photo 30 - Two faint markings where puddle welds did not adequately bond to the top flange of Beam 2 approximately 32 feet from the west end of the beam.

Photo 31 – Example of two puddle welds (circled) on the underside of the deck. The old residual hardened concrete next to the right weld indicates the weld had failed well before the collapse.

Photo 32 – Example of a decking failure around the weld. The decking was significantly corroded around the weld suggesting the failure had occurred prior to the day of the collapse. The decking metal will fail first when the weld is larger and stronger then the decking.

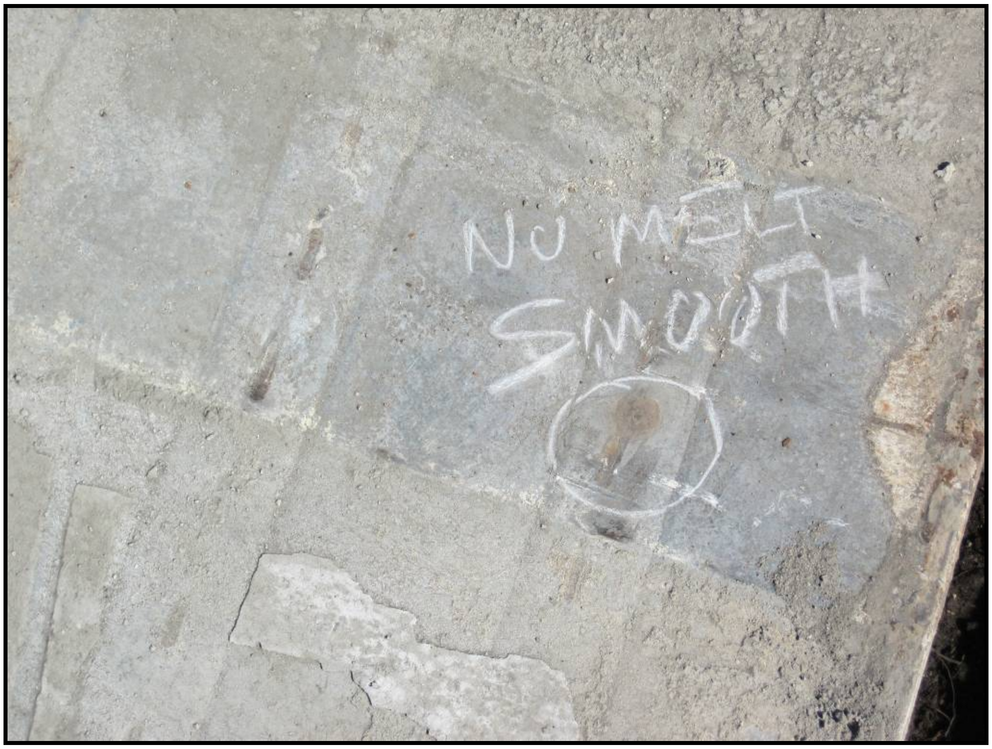

Photo 33 – Location where puddle weld did not penetrate the bottom plate of the roof deck.


Photo 34 – Puddle weld failure on Beam 6 with a dished top surface. Weld was corroded, indicating that it had likely failed long before the day of the collapse.

Photo 35 – Puddle weld with rubbed smooth failure surface on the top flange of Beam 5.

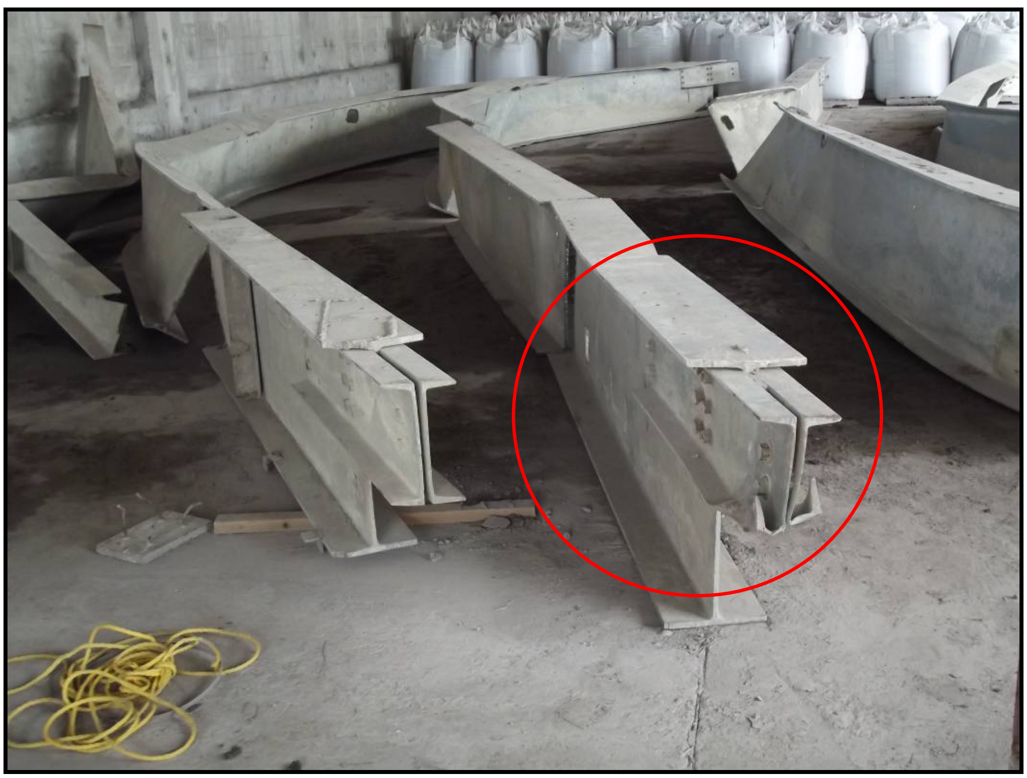

Photo 36 – Buckled webs on Beam 4’s east side back-to-back end bearing channels.

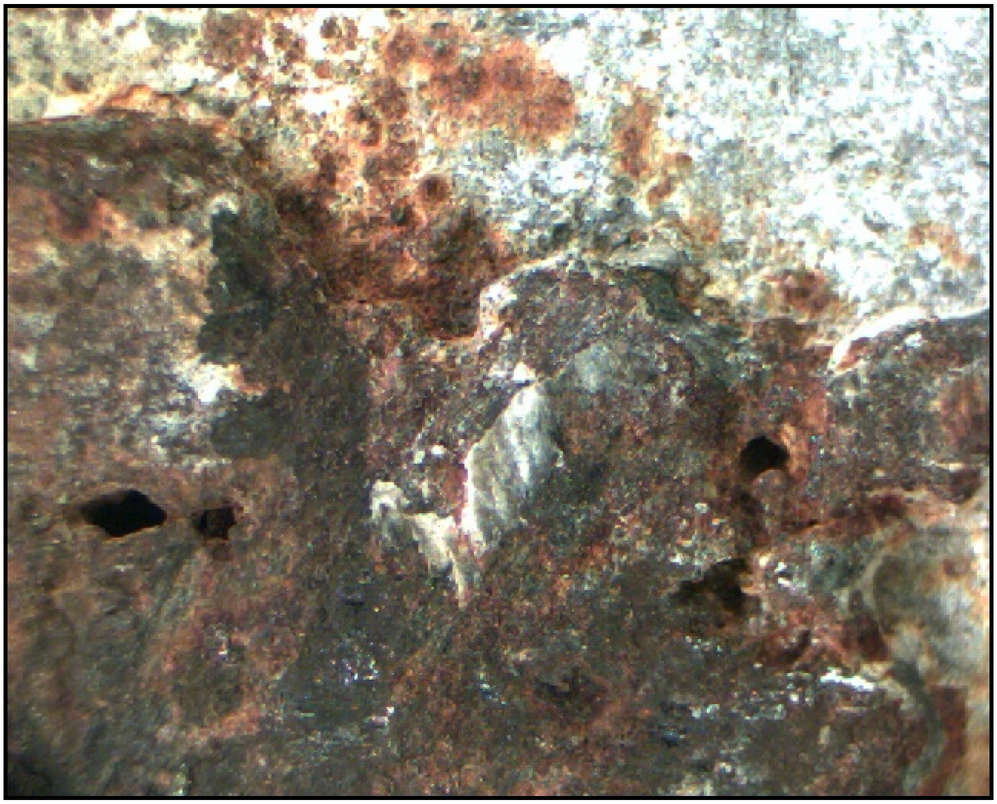

Photo 37 – Porosity and old corrosion on the failure surface of puddle weld M1. The weld was still attached to the underside of the metal decking.

Photo 38 – Silo 10 beam pockets E3 (left) and E4 (right). Neither Beam 3 nor 4 was in contact with the roof. Beam 4 is also significantly rotated.

Photo 39 - View looking in East 3 pocket of Silo 10 at separation between Beam 3 and the underside of the roof slab.

Photo 40 – At East 4 pocket of Silo 10, Beam 4 is rotated and separated from the roof slab by approximately 5 inches.

Photo 41 – View in East 2 pocket of Silo 11. Beam 2 has a rotated top flange that is separated from the underside of the roof decking by approximately 1 inch.

Photo 42 – View in East 3 pocket of Silo 11. Beam 3 is rotated south and slightly separated from the underside of the roof slab.


Photo 43 – Rotation of the end channels and roof Beam 3 along with cracking of the grout pad at the West 3 pocket of Silo 11


Photo 44 – Looking in East 4 pocket of Silo 11. Beam 4 is rotated to the left out beyond the end channel. A small gap existed between the top flange and the underside of the roof slab.

Appendix E

Figures

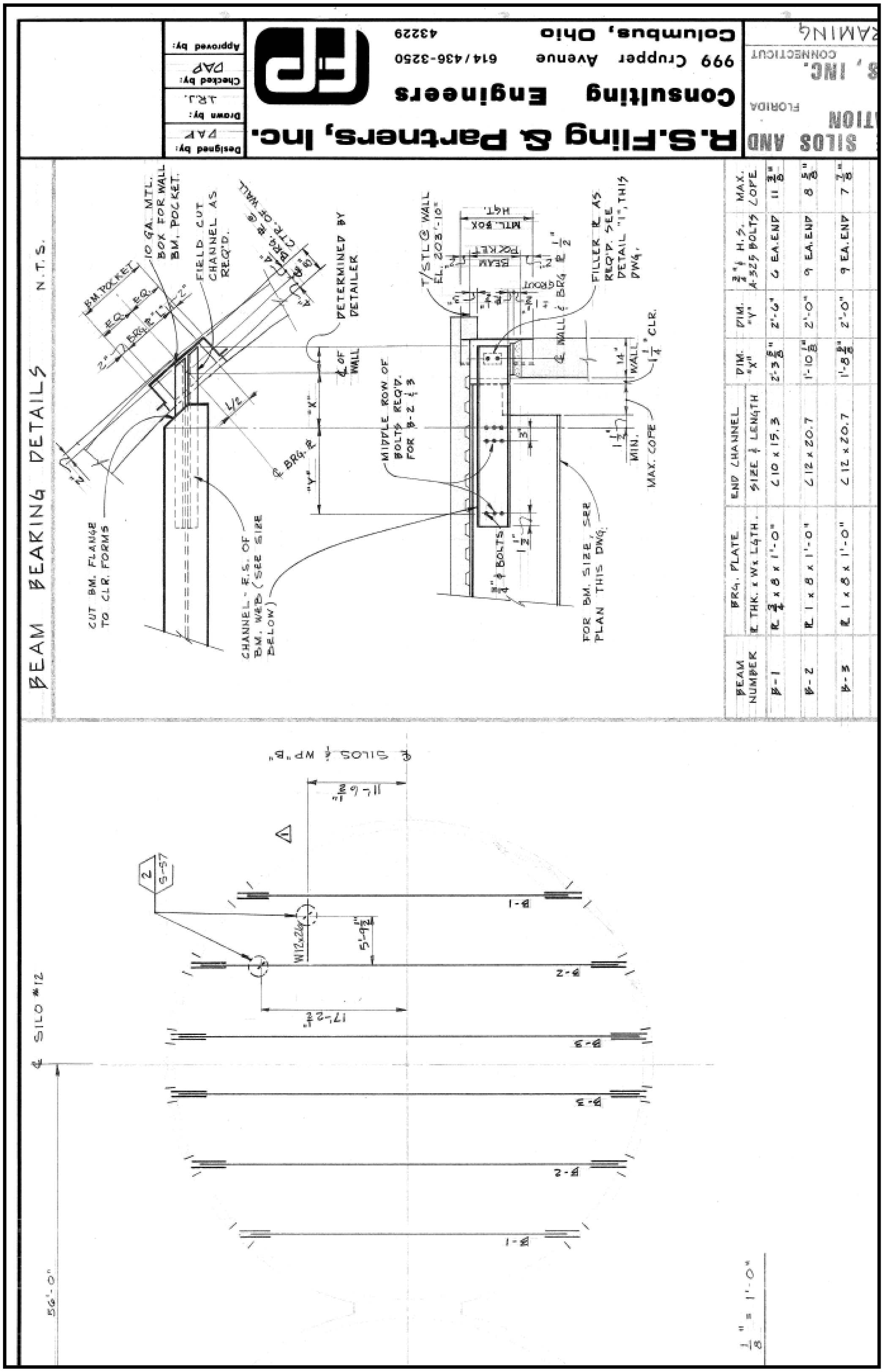

Figure 1 – Original engineering drawing by R.S. Fling showing the roof beam layout and beam pocket details.

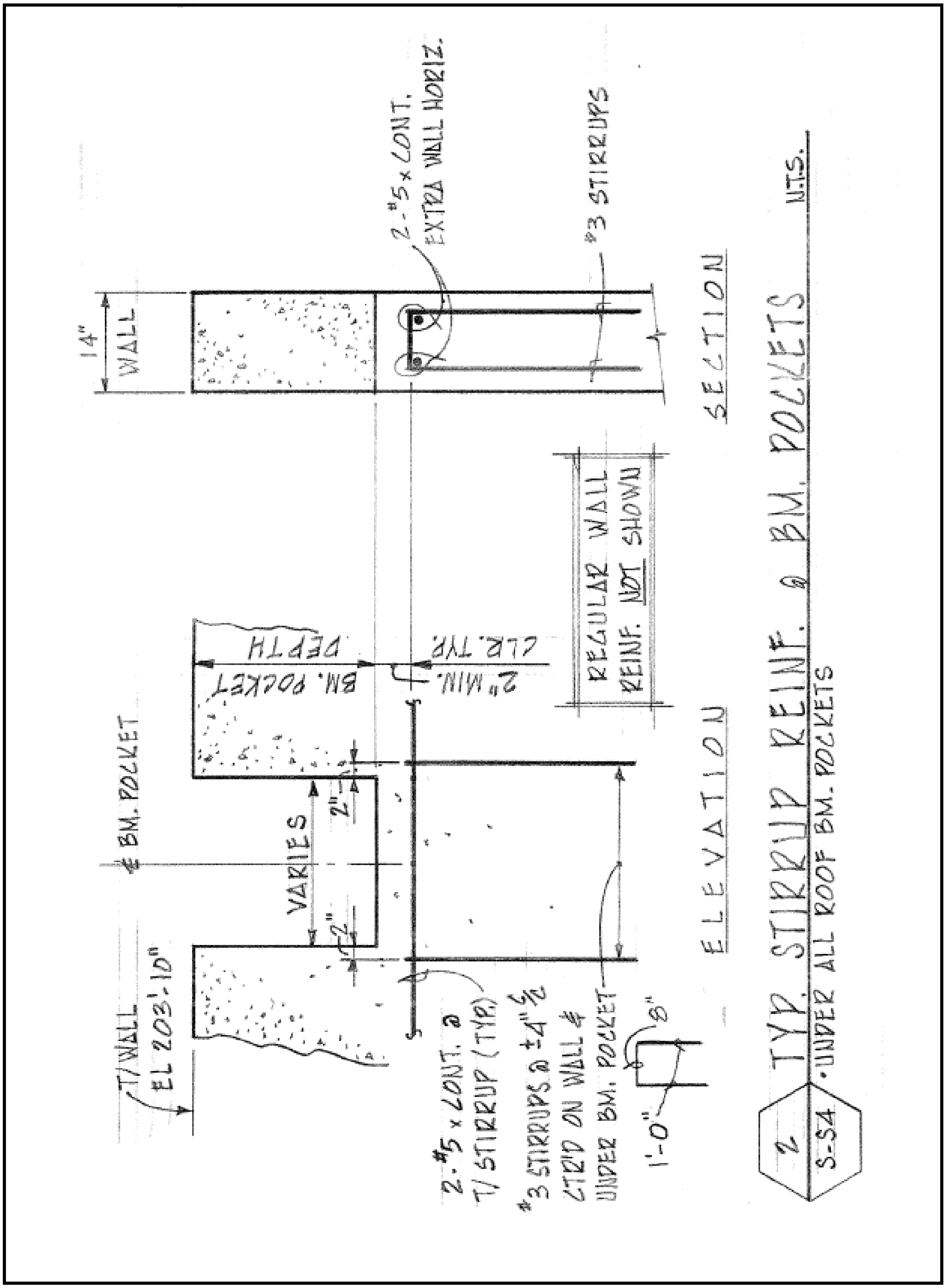

Figure 2 – Original engineering drawing by R.S. Fling showing beam pocket shear reinforcing.

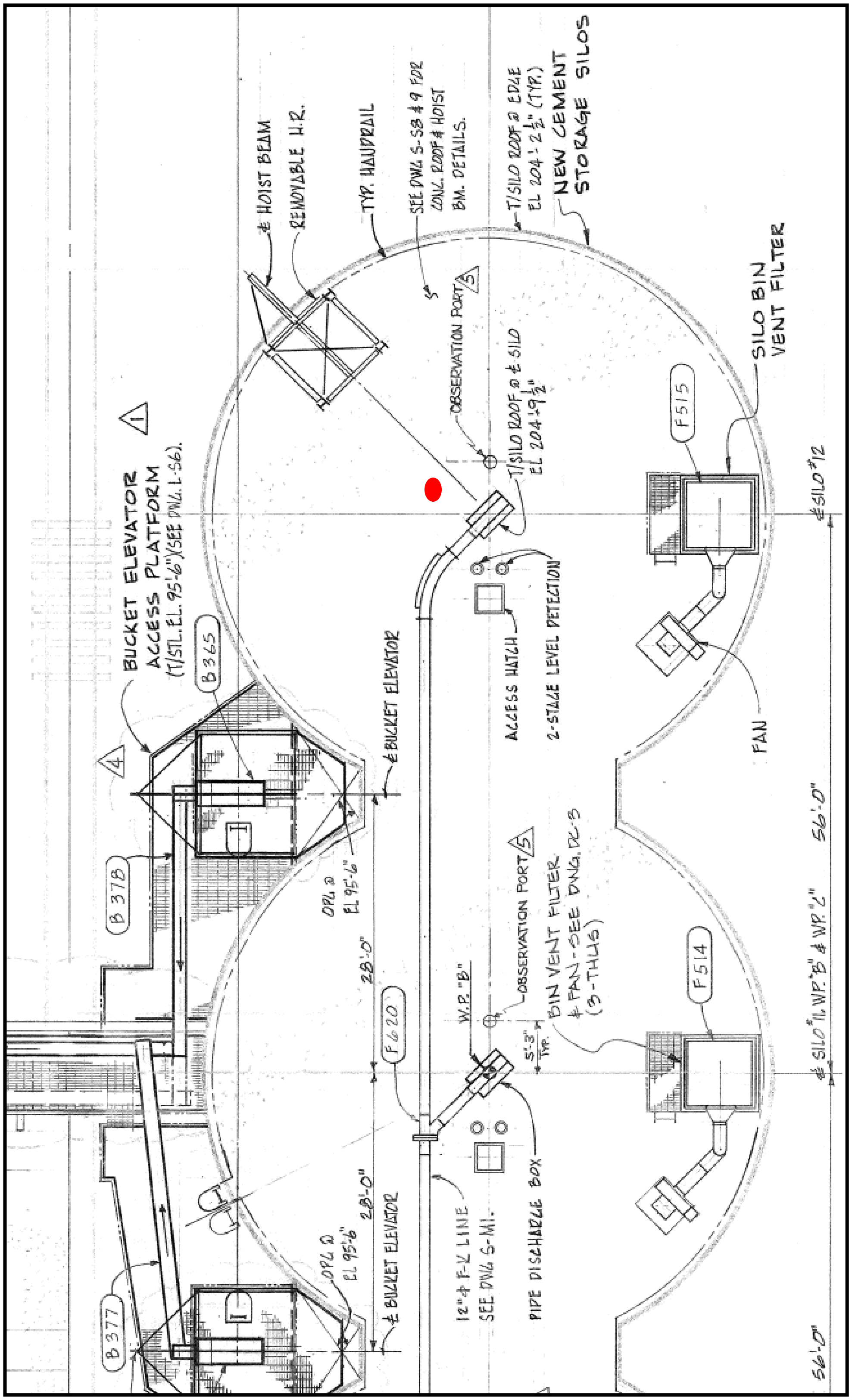

Figure 3 – R. S. Fling drawing with layout of roof ports on Silos 11 and 12. Solid circle is the location of added penetration on Silo 12 (circa 2004) for the radio transmitter level indicator.

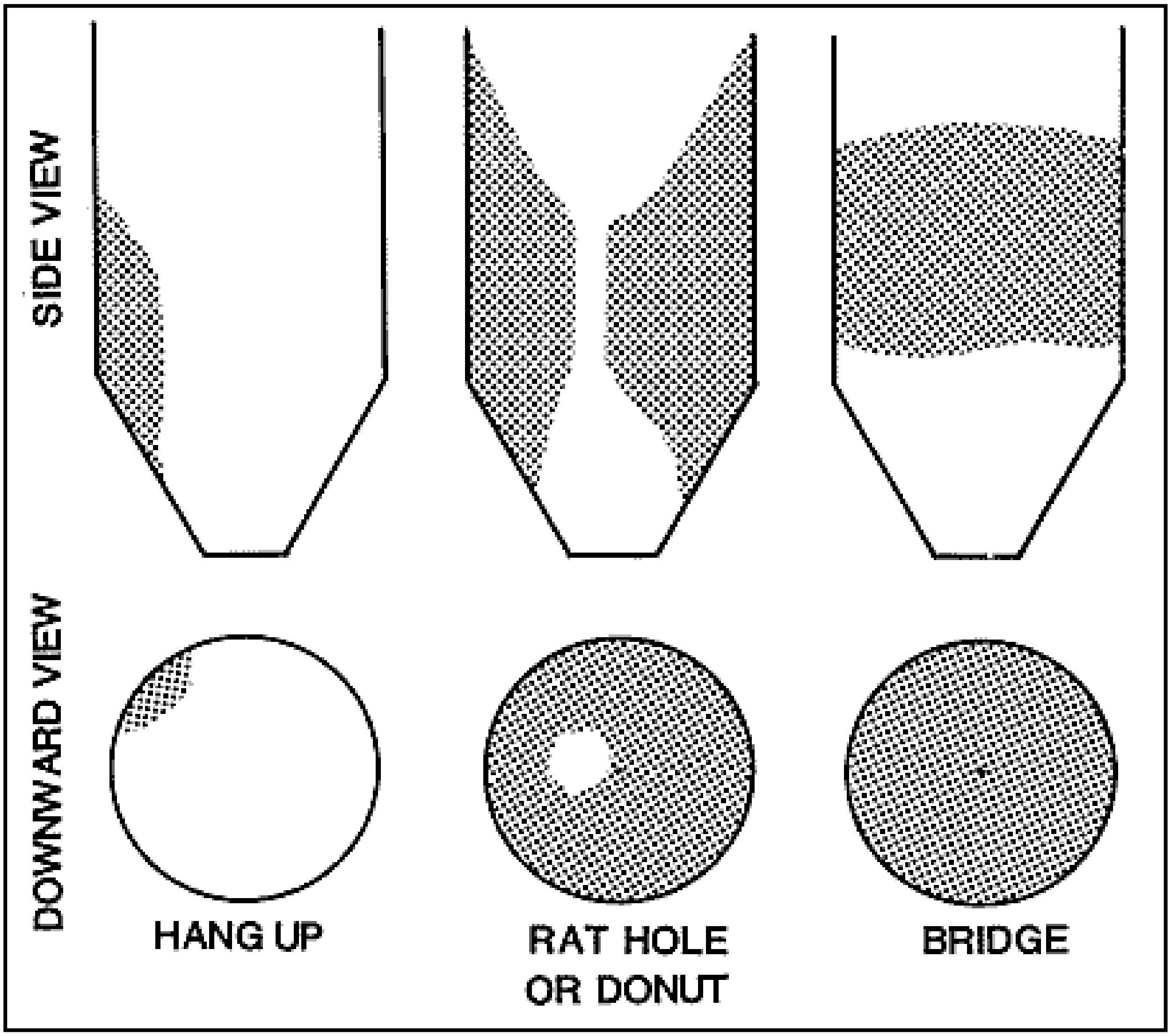

Figure 4 - Illustration of types of material flow irregularities.
Source: Canadian Grain Commission Website.