Structural Performance and Collapse Sequence

Didion Corn Mill Facility – Cambria, Wisconsin
Grain Dust Explosions – Event of May 31, 2017
CSB Investigation 2017-07-I-WI

Prepared for the **U.S. Chemical Safety Board**
1700 Pennsylvania Avenue, NW, Suite 910
Washington, DC 20006

Prepared by ***Atlas Engineering, Inc.***
551A Pylon Drive, Raleigh, NC 27606
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Executive Summary

Background and Scope of Report

The Didion Milling (Didion) facility in Cambria, Wisconsin mills corn and produces corn-based food products. A series of grain-dust explosions devastated the facility on May 31, 2017. Five mill workers were killed, and the blasts destroyed or severely damaged eight major mill buildings.

The U.S. Chemical Safety Board (CSB) began an on-site investigation soon after the event. Our firm assisted the CSB with site access and safety protocols during CSB's fieldwork. We later prepared a review of the facility's methods of construction and its compliance with industry standards and building codes.

This report describes the mill buildings' structural response to the blast loads, and how their design and construction affected that response. We have also outlined a probable sequence of structural damage and collapses that occurred on the day of the event. The CSB requested we focus on the construction and blast response at Mills A, B, C, D, F, and the Boiler Building.

Post-blast aerial image of Didion Mill. (photo by CSB)

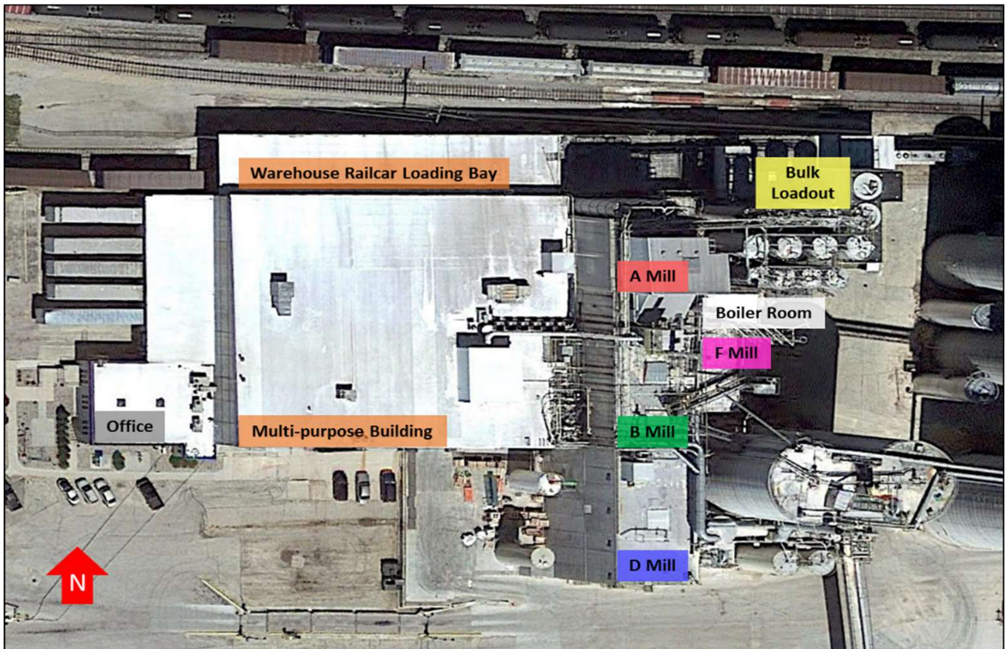
Findings

The Didion Mill buildings were especially vulnerable to severe damage and collapse during blast loads. Their vulnerability was due to a heavy reliance on concrete pre-cast and tilt-up design, poorly conceived layout of the buildings, weak structural connections, problems with construction quality, and lack of blast vents.

The blasts completely destabilized Mills C and F, the Multi-Purpose Building, Office, Rail Car Loading Bay, and Boiler Building – all of them pre-cast or tilt-up structures – in a failure mode known as disproportionate collapse.

Based on witness accounts and the post-blast conditions observed at Mills A, B, C, D, and F, the sequence of structural failures most likely includes an initial powerful blast at the lower level of B-Mill, a delay during the collapse of adjacent buildings, and then subsequent blasts, including one that damaged the B-Mill's fourth level.

Pre-Blast: Building Types and Configuration



Pre-blast layout of mill buildings.
(photo/diagram by CSB)

Mill building construction is outlined as follows –

Mill Building*	Year constructed	Dimensions (ft)			Structural Type
		N-S	E-W	Height	
A-Mill	mid-1990's	39	43	78	Slip-formed, cast-in-place concrete
Boiler	mid-1990's	46	41	17	Pre-cast concrete
Multi-Purpose	1999 - 2001	140	175	37	Pre-cast & tilt-up concrete
Office	1999 - 2001	44	60	17	Pre-cast concrete
B-Mill	2002	90	43	77	Cast-in-place concrete columns & floors; tilt-up concrete wall panels
F-Mill	2005	49	22	75	Pre-cast & tilt-up concrete
C-Mill	2006	68	45	34	Pre-cast & tilt-up concrete
D-Mill	2011	74	43	75	Cast-in-place concrete column & floors; tilt-up concrete wall panels
	**Buildings shown in red: Fully collapsed on May 31, 2017* **Buildings shown in blue: Severely damaged on May 31, 2017*				

Pre-Blast: Building Types and Configuration (cont.)

The following sections describe the major mill buildings as they existed at the time of the 2017 blast event. All the buildings were of concrete construction.

A-Mill was a five-story cast-in-place concrete building. Its columns, walls, and floors were cast monolithically; the building's structural connections were continuous, with closely spaced reinforcement bars crossing each connection.

B-Mill was a four-story concrete building with a hybrid structural system. The building's four columns and elevated floors and roof slab were of cast-in-place concrete, while the exterior wall panels were of pre-cast, tilt-up construction. The wall panels were attached to the cast-in-place floor and roof slabs with reinforcement dowels that were epoxy-grouted into holes drilled into the panels. There were two levels of wall panels, the lower tier spanning from levels 1B to 3B, and the upper tier enclosing level 4B.

C-Mill was a two-story structure built inside the Multipurpose Building, with partition walls and a mezzanine floor level constructed of pre-cast and tilt-up panels. C-Mill was constructed under the roof of the Multi-Purpose Building, and shared a wall with B-Mill.

D-Mill was a three-story concrete building that was built as an extension off the south wall of B-Mill. D-Mill had a hybrid structural system. There was one column, two floors, and a roof slab of cast-in-place concrete, while interior walls and the exterior wall panels were of pre-cast, tilt-up construction. The wall panels were attached to the cast-in-place floors and roof slab with reinforcement dowels that were epoxy-grouted into holes drilled into the panels. There were two levels of exterior wall panels, with the lower tier spanning from levels 1D to 3D, and the upper tier enclosing level 4D.

F-Mill was a concrete building of pre-cast and tilt-up construction, erected between B-Mill and the Boiler building. F-Mill's floors and roof were supported on B-Mill's east wall panels, and on top of the Boiler Building's west wall. F-Mill was the same height as B-Mill, but had three floor levels instead of four.

The **Boiler Building** was a single-story structure of pre-cast concrete construction, with load-bearing wall panels and pre-cast concrete roof panels.

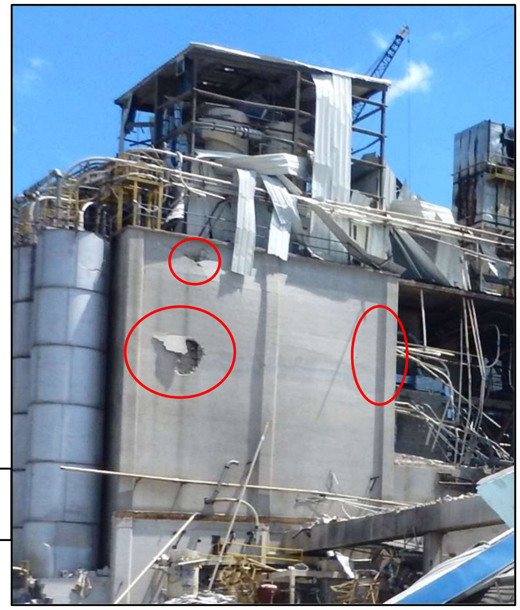
The **Multipurpose Building** was a tall single-story structure of pre-cast and tilt-up construction. There were three girder lines spanning east-west. Precast roof panels spanned north-south, supported by the girders and by load-bearing tilt-up wall panels along the north and south sides of the building.

Post-Blast Condition of Mill Buildings

A series of grain-dust explosions on May 31, 2017 collapsed or severely damaged nearly every building at the site. The post-blast condition of seven major mill buildings is summarized below -

A-Mill remained standing and largely intact. There were isolated areas of severe damage at the west exterior wall, at levels 4A and 5A, where the cast-in-place concrete wall fractured and bulged outward between pilaster columns.

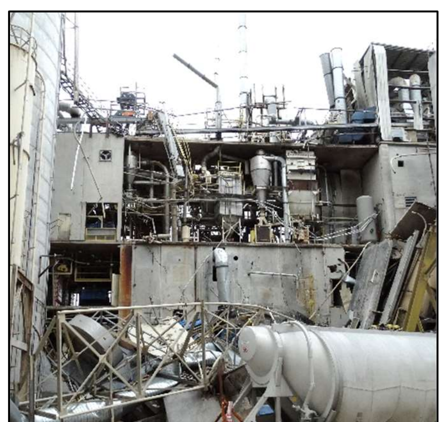
At level 4A, the wall tore loose from its monolithic connection with the floor slab. The damage appears consistent with a powerful interior blast at levels 4A and 5A.



West side of A-Mill. Circles show holes and bulges at the west wall. (photo by CSB)

B-Mill - Interior blasts at B-Mill left its cast-in-place columns and floor slabs standing but damaged or destroyed almost all its exterior tilt-up wall panels. Most of the lower-tier panels at levels 1B-3B were buttressed by adjacent buildings (Multi-Purpose, C-Mill, and F-Mill). These panels bulged outward or fractured at their connections to the building but remained roughly in place. The lower-tier 1B-3B wall panels that were not buttressed or braced by adjacent buildings were blown clear of the building.

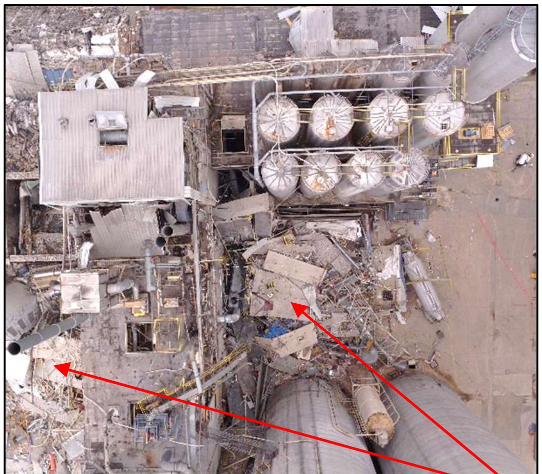
West side of B-Mill.
(photo by Atlas)



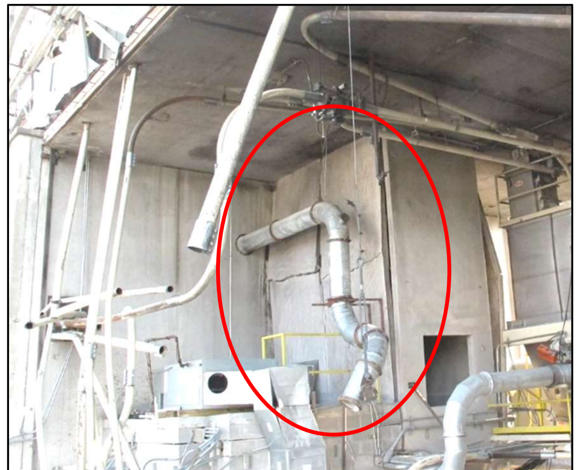
East side of B-Mill.
(photo by Atlas)

Post-Blast Condition of Mill Buildings (cont.)

B-Mill (cont.) - All the upper-tier wall panels at 4B broke free and landed on top of the collapsed debris of the adjacent Multi-Purpose Building, C-Mill, and F-Mill. At the northern end of level 4B, the airshaft that it shared with levels 1B-3B (and possibly with A-Mill's airshaft) was fractured and bulged outward, damage consistent with high blast pressure inside the airshaft.



Overview of B-Mill. Arrows show wall panels from 4B atop C-Mill (left) and F-Mill debris (right). (photo by CSB).



North end of 4B, west side. Circle shows fractured walls of airshaft. (photo by CSB)

C-Mill's tilt-up walls and precast mezzanine floor level were built inside the Multi-Purpose Building. C-Mill and the Multi-Purpose Building collapsed entirely. The C-Mill debris landed largely within its original footprint.

D-Mill remained standing but its lower-tier tilt-up wall panels were damaged, with panels at the west and south sides breaking partially free from the building and bulging outward. Two panels at the west side fractured, broke free and fell away from the building.

In contrast, the upper tier of wall panels at D-Mill appeared undamaged.

D-Mill, view looking northeast. Partial failure at lower tier wall panels; upper tier appeared undamaged. (photo by Atlas)

Post-Blast Condition of Mill Buildings (cont.)

F-Mill collapsed entirely. Most of its debris landed inside its original footprint. Most of the **Boiler Building** collapsed. Part of its debris field fell to the east of its original footprint.

F-Mill debris, under wall panel from 4B (photo by CSB)

Boiler Building debris. (photo by Atlas)

The **Multi-Purpose Building's** tilt-up exterior wall panels and precast roof panels collapsed, along with three girders and one column. The roof panels fell within the building's footprint, while the exterior walls toppled over outwards.

Collapse of Multi-Purpose Building, looking east. (photo by CSB)

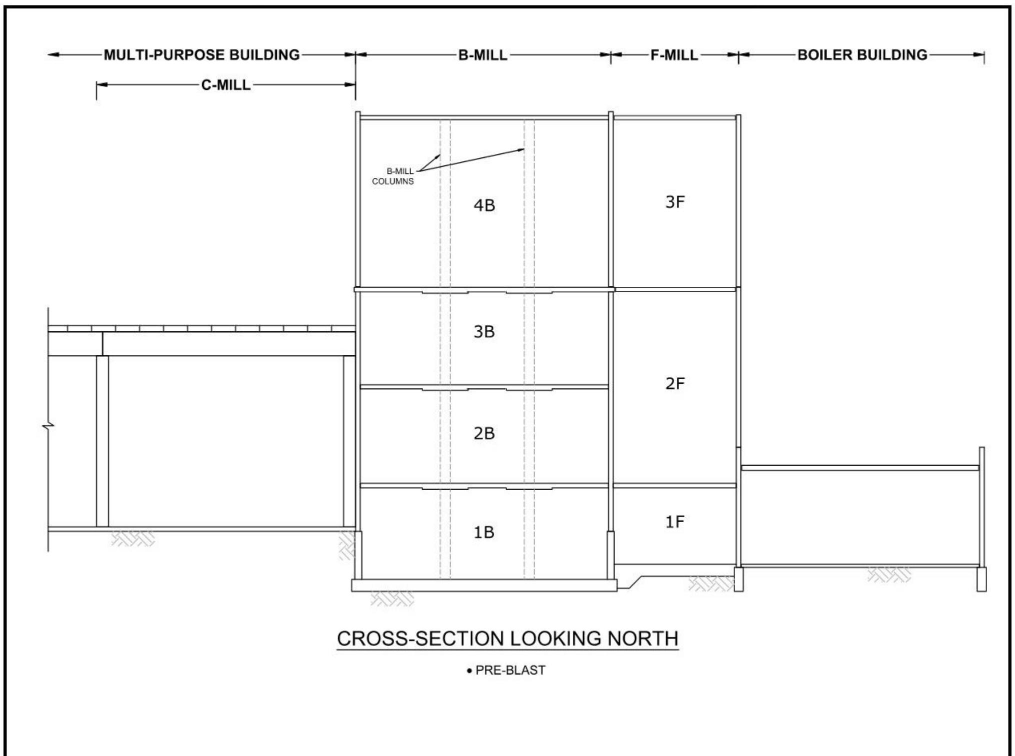
Probable Collapse Sequence

We have compiled the probable damage and collapse sequence for mill buildings A, B, C, D, F, the Boiler Building, and the Multi-Purpose Building.

This sequence of events is based on witness accounts of the blasts as outlined in the CSB investigation; the layout and structural interconnections between the buildings; connection types and how they failed; and on the at-rest position of the structural debris.

Pre-Blast

The following diagram is a cross-section view, looking north, across a portion of the facility that includes C-Mill, B-Mill, F-Mill, the Boiler Building, and a part of the Multi-Purpose Building. This view shows how these buildings were structurally interconnected.



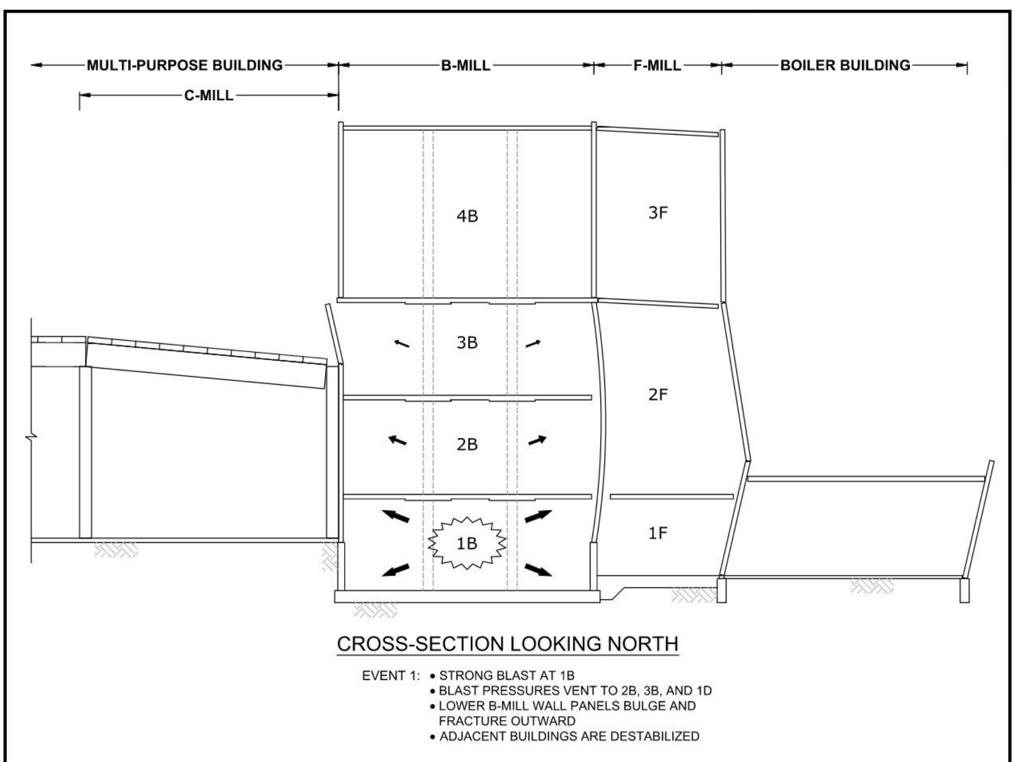
PRE-BLAST

Probable Collapse Sequence (cont.)

Event 1

Fire and deflagration broke out inside process equipment. Burning product and hot gases erupted into B-Mill at level 1B, when an inlet filter was blown off a product transport pipe, causing process materials and fugitive dust, already present at 1B, to loft and ignite. The blast generated a flame front and high interior pressure, which –

- Vented into the B-Mill airshaft, A-Mill, and D-Mill's lower stories. D-Mill's lower-tier wall panels partially detached and bulged outward; B-Mill's lower-tier wall panels bulged outward, shifting and destabilizing the adjacent tilt-up structures -
    - C-Mill's 2C floor level and interior wall panels displaced west and fell off their bearings, initiating the collapse of C-Mill; a roof girder at Multi-Purpose fell off its column, dropping all its tributary roof panels
    - At F-Mill, the 2F floor slab shifted east several inches, pushing F-Mill's eastern wall off its bearing at the west wall of the Boiler Building, initiating the collapse of F-Mill and the Boiler Building
- The lower-tier wall panels at 1B-3B that were not blocked by C-Mill or F-Mill blew completely off the building; this vented the remaining interior pressure at B-Mill and D-Mill



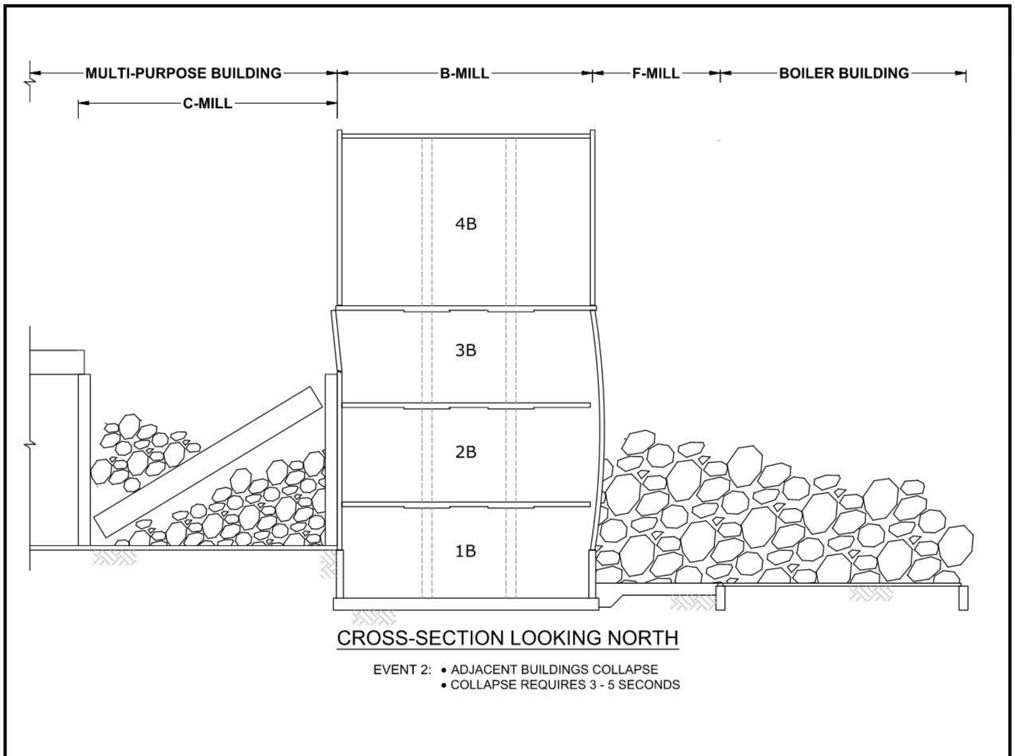
EVENT 1

Probable Collapse Sequence (cont.)

Event 2

C-Mill, parts of the Multi-Purpose Building, F-Mill, and the Boiler Building collapsed.

- It took three to five seconds for connections and members to break apart and for the broken pieces to fall to the ground.
- With the collapse of F-Mill, the eastern 4B wall panels were no longer braced by F-Mill's upper stories



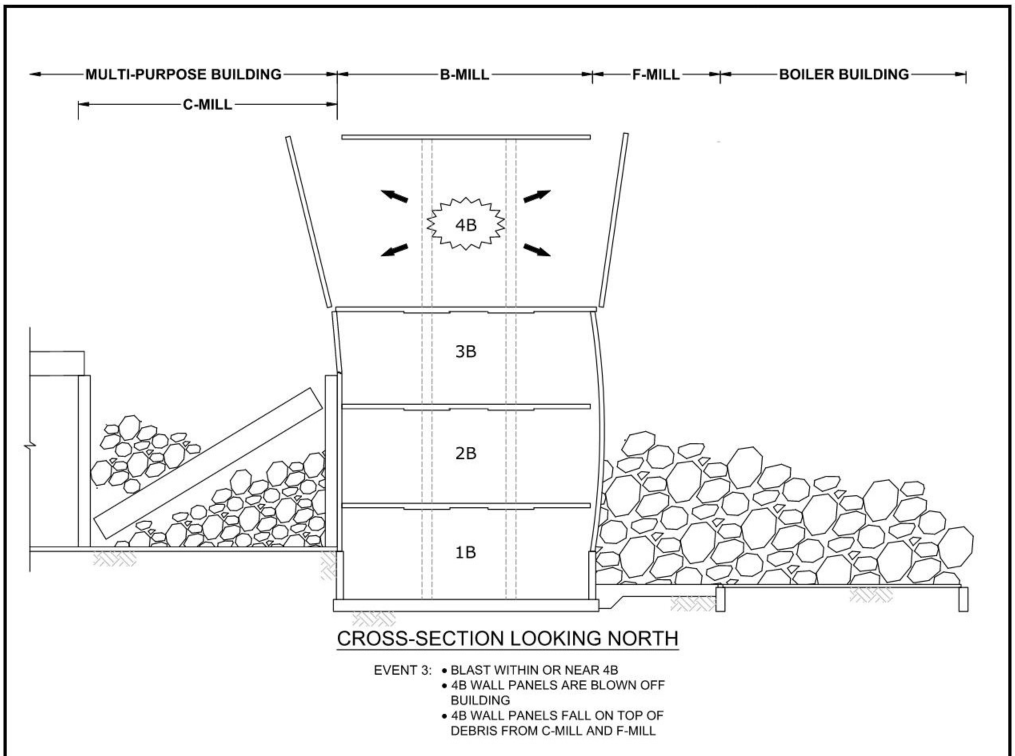
EVENT 2

Probable Collapse Sequence (cont.)

Event 3

Sometime after the collapse of C-Mill, the Multi-Purpose Building, and F-Mill, a secondary blast pressurized the 4B interior. The blast pressure inside 4B–

- Blew all the 4B wall panels off the building; the panels readily detached at a relatively low interior pressure, due to weak and missing wall panel connections
- The prompt loss of 4B's wall panels effectively vented the interior pressure, minimizing damage at the upper level of D-Mill
- The 4B wall panels fell on top of the C-Mill and F-Mill debris piles on either side, largely intact; little damage was seen along their connection lines, indicating poor connection performance



EVENT 3

Probable Collapse Sequence (cont.)

Event 3 – Possible Source of Secondary Blast
There were signs that fire and blast pressure emanated from the 4B level airshaft, at the building's north end. The airshaft walls were broken outward and there were scorch marks at the north end of the 4B level.

Nearby, there was clear evidence that a powerful blast occurred at 4/5A, at a location just north and at the same elevation as the damaged 4B airshaft. The west wall of A-Mill was blown through at 4/5A, and nearby parts of the wall ripped free of A-Mill's floor slabs and bowed outward, as shown in the photos below.

Severe damage at A-Mill west wall (circle) is at same elevation as fractured airshaft at 4B (arrow). (photo by Atlas)

NW corner of 4B, showing fractured airshaft walls (circle at right). Note bulged and cracked wall at A-Mill, just a few feet away (circle at left). (photo by CSB)

A-Mill was built of cast-in-place concrete, with monolithic, continuous connections between walls, columns, and floor slabs. The wall panels had short spans and continuous support along all four sides. Fracturing and breaching the west wall of A-Mill would require higher blast pressure, than blowing off the large, poorly-connected tilt-up wall panels at B-Mill. Based on their relative strength, it appears likely that a powerful blast inside 4/5A sent fire and high pressures into the B-Mill airshaft, and then into the 4B interior, blowing off its wall panels and venting the blast pressure.

The damage and collapse sequence described above appears consistent with what is known about the incident and the post-blast behavior at the Mills A, B, C, D, F, the Boiler Building, and the portion of the Multi-Purpose Building near C-Mill.

This sequence is not comprehensive, as other blast events apparently occurred at other locations, including the northwest quadrant of the Multi-Purpose Building, the Bulk Load-Out area, and the dry-grit filter just east of D-Mill. Based on CSB's findings, it appears that burning grain and deflagrations traveled within process equipment to several parts of the facility and initiated blast events at several locations.

Structural Performance by Construction Type

Among mills A, B, C, D, F, the Boiler Building, and the Multi-Purpose Building, there is a clear correlation between construction type and structural performance during the 2017 grain blast events –

> A-Mill, the only mill building at the site of completely **cast-in-place construction**, sustained the least damage. Even though severely damaged with a part of its western wall blown out, A-Mill remained stable and relatively safe to enter. The blast damage at levels 4A and 5A did not lead to failures at other parts of the structure.
>
> B-Mill and D-Mill were of **hybrid construction**, with cast-in-place columns and floor slabs, and tilt-up concrete panels for exterior walls. At these two buildings, the cast-in-place components survived relatively intact, while most of the tilt-up wall panels were either heavily damaged or had blown off the buildings entirely.
>
> The construction of C-Mill, F-Mill, the Boiler Building, and the Multi-Purpose Building included load-bearing **pre-cast and tilt-up** wall panels, and **pre-cast** floor and roof panels. These buildings collapsed completely. Blast loads broke apart weak structural connections and the heavy, destabilized components drove progressive, total collapse. This is a typical destruction sequence for pre-cast and tilt up structures, where damage is often disproportionate to the triggering event.

Commentary on Design and Construction

Mills B, C, D, F, and the Boiler and Multipurpose Buildings were especially vulnerable to severe damage and collapse due to their design and how they were constructed.

The buildings included no blast vents. None of the building designs included features to contain, withstand, or vent explosions from combustible grain dust as outlined by NPFA standards 61, 68, or 69, industry standards that were well-established at the time the buildings were designed and built.

Adjacent structures shared walls and foundations, with floors and roofs of newer buildings bolted or pinned to the walls of older ones. This layout and interconnection of buildings was a major factor in their pattern of progressive collapse during the blast events.

Poor quality control during construction was also a factor. Based on information provided by Didion's Construction Manager in a 2017 interview, construction of the buildings proceeded without regular inspection or testing programs. Concrete was rarely tested, welds were not inspected, and no proof-testing was conducted to confirm the capacity of anchor bolts, epoxy-adhered dowels, or bolted connections.

Post-blast evidence shows that floor and roof panels were weakly connected or entirely unconnected to their support bearings. Photos also show that many wall panel connections came apart readily at loads far below their rated capacity. At several locations, connections shown in the drawings were omitted in the actual construction. Details about these conditions are provided in Appendix A.2.

In summary, the building layout, structural design, lack of blast vents, and shortcomings in construction quality all combined to make these buildings especially prone to severe damage and progressive collapse during the 2017 blast event.

The facts and opinions included in this report are based on our observations at the site in June – July 2017, and on information provided to us. If any new information comes to light, please forward it to our office for our additional consideration.

Report Prepared by: Tom Caldwell, PE, Senior Partner, Atlas Engineering, Inc.

Appendix

A.1 Sources

A.2 Performance of Structural Connections at Mill Buildings

Appendix A.1: Sources

We relied on the following sources in preparing this report -

1. Atlas Engineering's observations, notes, and photographs from post-blast fieldwork with CSB team at Didion Mill site, June-July 2017

2. U.S. Chemical Safety Board (CSB), materials and photos from the Didion Mills investigation No. 2017-07-I-WI

3. "Didion Milling Explosion Assessment", by ABS Group, Final Report R0, dated September 19, 2018

4. Mill Building construction drawings provided by CSB –

    a. "Mill Equipment Layout", (5) sheets of composite floor plans for **Mills A, B, C, D, F, and Boiler Building**; by Didion, dated Oct. 7, 2013

    b. "Processing Area", (6) sheets labeled S-PC3 through S-PC8 showing structural sections and floor reinforcement plans for **B-Mill**; by J.R. King Engineering, dated Mar. 9, 2001 with revisions through Jan. 17, 2002

    c. **"C-Mill"**, (3) sheets labeled DWG #100040-1, -2, and -2 (sic) showing wall layout dimensions, some equipment, and an elevation view; by Didion, dated Oct. 11, 2010

    d. "Process Building Addition", (22) sheets of construction drawings for **D-Mill**, Project #11001P; by Jerome R. King, PE, dated May 1, 2011 with revisions through July 12, 2011

    e. "Bran Processing Expansion", (13) sheets of construction drawings for **F-Mill**; by Jerome R. King, Structural Engineer, plot date Dec, 21, 2004

    f. "Warehouse Expansion", (3) sheets labeled S-1 through S-3 showing overall layout dimensions for the **Multi-Purpose Building**; by J.R. King Engineering, sheets dated June 28, Sept. 18, and Nov. 13, 1998, with revisions through Nov. 17, 1998

    g. "Boiler Walls, Floor, Roof; Boiler Foundation; Tilt-Up Wall Construction", (3) sheets of construction drawings for the **Boiler Building** labeled S-1 through S-3; by J.R. King Engineering, dated Aug. 4 and August 14, 1994 with revisions through Aug. 20, 1994

5. Hilti, Inc., "2011 Hilti North American Product Technical Guide", HVA Adhesive Anchoring System specifications

Appendix A.1: Sources (cont.)

6. CSB / Atlas phone interview of Didion Construction Manager, June 23, 2017

7. "Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities", NFPA 61, editions 1995, 1999, 2002, and 2008

8. "Standard on Explosion Protection by Deflagration Venting", NFPA 68, editions 1994, 1998, 2002, and 2007

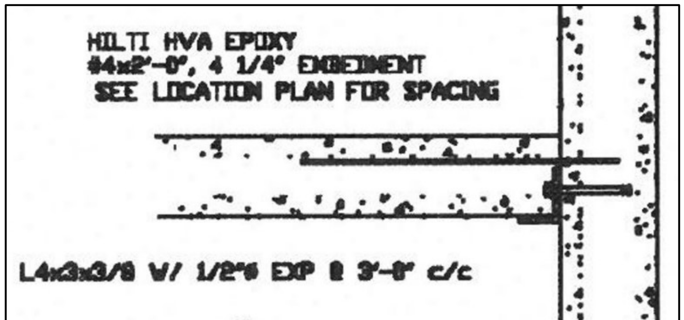
9. "Standard on Explosion Prevention Systems", NFPA 69, editions 1992, 1997, 2002, and 2008

Appendix A.2: Performance of Mill Building Structural Connections

The structural connections at the mill buildings and how these connections failed had a great effect on the performance of the buildings under blast loads, the level of destruction at the site, and the progressive nature of the collapses. The following sections describe several types of structural connections used at the mill buildings and how they failed. Information about structural connections was limited, as it was based on incomplete construction plans and on what could be seen by studying post-blast images.

Wall panel connections at B-Mill: Where the panels were mounted outboard of the slab, 24” long, 1/2” diameter steel reinforcing bar dowels were set into 4-1/4” holes drilled into the panels.

The dowels were adhered in the drill holes with an epoxy product made by the Hilti company. The long end of each bar was embedded into the outer edge of the cast-in-place concrete floor and roof slabs. The spacing of the bars varied from 12” to 36”.



B-Mill floor slab/ /wall panel connection (detail, B-Mill plans)

Specifications from Hilti show that the epoxy connections at B-Mill, if properly made, would carry over 12,000 lbs of tension before failing. At this load the 1/2" bars would yield (permanently stretch), and the concrete around the hole would spall and show substantial damage. To stress the dowels to this level at a typical B-Mill panel would require an internal blast pressure of 2 to 3 psi.

Where panels separated from the buildings, post-blast photos show the dowels still embedded in the floor and roof slabs. This means the connections failed at the epoxy connections at the wall panels.

Undamaged, clean dowels at 4B east roof edge. Adjacent slab edge - missing dowels (photo by CSB)

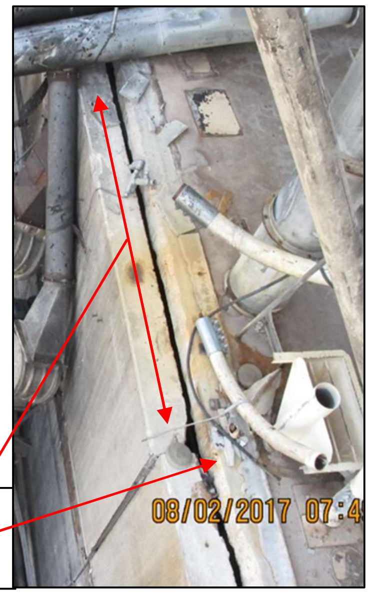
In post-blast photos, the exposed dowels show no signs of yielding. The exposed bars are relatively clean of epoxy residue or concrete debris. Photos show no pattern of concrete damage at the panels along the lines of the dowel holes, either at the panels that fell off 4B, or at the 1B-3B panels that bulged outward from the building.

Appendix A.2 (cont.)

These observations indicate that the epoxy connections failed well below their specified capacity. The most common cause for substandard connection performance in epoxy connections is poor workmanship. Successful epoxy connections require careful cleaning, measuring, mixing, and curing at the right temperature. In-field tensile proof-testing of epoxy connections is essential for reliable load capacity. Based on a 2017 interview with Didion's Construction Manager, no regular testing program was in place during the construction of the mill buildings.

The available plans for B-Mill did not show how the bottom and top edges of the wall panels connect to the building slabs, where the panels are mounted just inboard of the slab edge. Post-blast photos at B-Mill show a few vertical dowels and damaged concrete where bottom-edge connections apparently existed, but these signs were far apart; it appears that each panel had at best one or two bottom-edge connections.

Photos show that top-edge connections existed along the east 1B-3B panels. These consisted of 1/2" bars spaced about 24" on-center. However, photos show no signs of top-edge connections at three 1B-3B panels along the west side of the mill, where the top part of the panel fractured outward, exposing the panel's top edge. These observations indicate that connections installed along the top and bottom edges of the 1B-3B panels were widely spaced at some locations and entirely missing at others.



Top edge of 1B-3B panels at west side, showing lack of any connections to 4B slab (photo by CSB)

In summary, post-blast conditions show that the wall panels at B-Mill were not well attached to the building. Panel connections appeared badly made, and many connections were missing altogether.

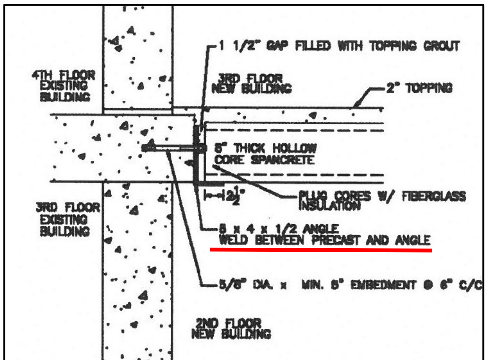
Wall panel connections at D-Mill: The available plans for D-mill were more detailed and show more robust wall panel connections than the plans for B-Mill. The horizontal rebar dowels that connected the wall panels to the cast-in-place floor slabs were larger, more closely spaced, and embedded deeper in the wall panels. The panels are attached at their top and bottom edges with rebar or welded stud connections at 24 inches on-center.

Post-blast photos show that about half of the D-Mill's lower-tier panels bulged outward or broke free. At most of these, the mid-panel row of connections failed, while the top and bottom panel connections held. In contrast, the upper tier of wall panels showed no signs of deformation or movement. Blast pressures at the upper stories of D-Mill were apparently moderate, as relatively weak metal door panels and other coverings along the exterior walls survived with little damage.

Appendix A.2 (cont.)

Connections at F-Mill: The available plans for F-Mill show that most of the weight of this 75' tall concrete building was supported by B-Mill's east wall, and the Boiler Building's west wall; these two buildings pre-dated F-Mill.

The plans show F-Mill's floors as 8" thick hollow-core planks, spanning east-west, with 2-1/2" wide bearings at shelf angles bolted to wall panels. The connection details call for a "weld between precast and angle", but no weld size, length, or spacing is specified, and no weldable embed plate is shown or called out for the pre-cast concrete floor plank.



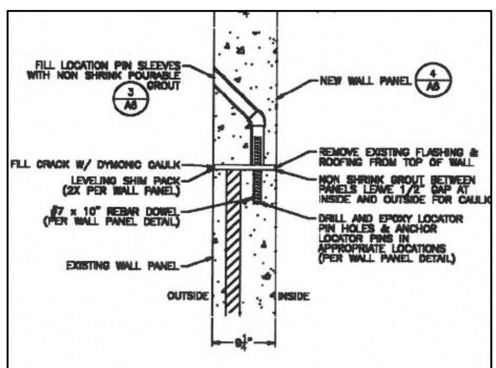
F-Mill detail; Floor supported by its connection to B-Mill; weld spec is incomplete

Post-blast photo shows shelf angle intact at B-Mill floor slab; no signs of broken welds. (photo by CSB)

This is significant, because without effective and properly-sized welds, the floor panels would be liable to fall off their bearings under blast loading. Post-blast photos show the complete collapse of F-Mill. The steel shelf angles that supported F-Mill's floors were left intact along B-Mill's 1B-3B east panels. The shelf angles show no sign of damage – if the connections had included any welds at all, they were too small to damage the shelf angles when the pre-cast planks fell away.

Where F-Mill's wall panels were stacked atop each other, or on top of the Boiler Building's west wall panels, the plans called for an unusual and difficult-to-construct dowel connection.

The design requires installation of drilled and epoxied dowels in the lower panel that must line up precisely with PVC sleeves cast into the upper wall panel. Even if successfully installed, no more than two connections are called for per panel width.

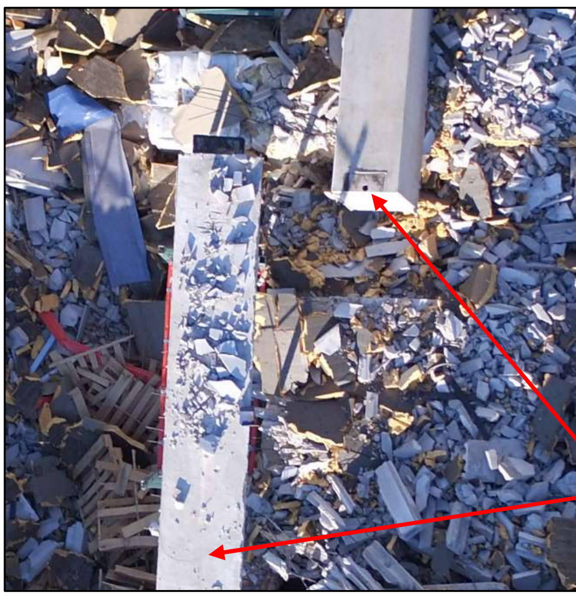


F-Mill, connection at stacked panels.

Appendix A.2 (cont.)

Connections at Boiler Building: Plans show this simple single-story building consisted of pre-cast insulated wall panels and 10" hollow-core roof planks. Connection details include a shelf-angle bearing and a top-of-panel bearing, both with specified welds at embed plates. Most of the Boiler Building collapsed; it was likely taken down when debris from the much taller F-Mill fell in on it.

Connections at the Multi-Purpose Building and C-Mill: The available plans for these buildings show their basic layout but no details. Information on their connections is based on post-blast photos of their debris piles. The Multi-Purpose Building consisted of tilt-up exterior wall panels and pre-cast hollow-core roof planks that spanned north-south. The roof planks were supported by the north and south wall panels, and by three girder lines that spanned east-west. The girders and the columns that supported them were pre-cast.



Post-blast photos show that the column-to-girder connection consisted of a vertical dowel bar cast into the column, that engaged a receiver hole in the girder. Normally, the receiver hole would be grouted to complete the connection, but photos show the connections to be ungrouted and incomplete.

The Multi-Purpose Building's hollow-core roof planks rested on the girders, but had no actual connection to them.

<u>Multi-Purpose girders</u>
Ungrouted bearing hole at a fallen girder.
At an erect girder, no sign of structural attachments for roof panels.
Roof panels simply rested atop the girders.
(photo by CSB)

C-Mill included tilt-up interior wall panels and a mezzanine floor level, all constructed within the Multi-Purpose Building and under its roof. We found no information available about structural connections at C-Mill.

In summary, post-blast observations clearly show poor performance of structural connections at many locations and missing connections at others. Some connections were omitted by design, as at the roof panels of the Multi-Purpose Building. Connection details were incomplete or lacking for Mills C, F, and B, in the plan sets we reviewed. Post-blast photos provide ample evidence of poor construction workmanship.

The lack of testing and inspections meant that substandard connections became part of the structural fabric of the mill buildings. Inadequate, poorly-made, and missing structural connections played a major part in the severe and progressive damage experienced at the Didion Mill site.

.end of appendix.