FINAL REPORT

REPORT ON THE RISK ASSESSMENT OF THE I-196 INTERSTATE SECTION LOCATED OVER THE FORMER DOMTAR MINE, GRAND RAPIDS, MI

SUBMITTED BY:

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TO:

MICHIGAN DEPARTMENT OF TRANSPORTATION
CONSTRUCTION AND TECHNOLOGY DIVISION
TESTING AND RESEARCH SECTION
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TESTING AND RESEARCH SECTION
CONSTRUCTION AND TECHNOLOGY DIVISION
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1.0 PURPOSE OF THE REPORT

The purpose of this report is to provide an assessment, based on available information, on the risk the former Domtar gypsum mine poses to the stability of I-196. This report includes an interim report prepared by Mr. Jack Parker of Jack Parker & Associates, which is provided in Appendix A. The assessment was based on the following information: (1) survey elevations of I-196, (2) existing documents from the Grand Rapids Gypsum Company, which in 1983 became the Domtar Mine, (3) I-196 construction documents, (4) recently conducted deflectometer and GPR data, (5) discussions with individuals that were involved with the mine and/or construction of I-196 and (6) a report produced by Williams and Works of Grand Rapids, Michigan titled: Kent County Geologic Stability Study for the John Ball Zoological Garden Expansion West of I-196 in September 2002. This report has been updated to include additional information and to make some grammatical corrections. The report is provided in Appendix B, C and D of this report.

2.0 PROBLEM STATEMENT

Gypsum mining started in Grand Rapids, MI in the 1840's along the Grand River and continued until 2000 when the Domtar Mine was closed down due to declining gypsum prices. The Domtar Mine is located on the west side of Grand Rapids in the south half of section 27 (T7N, R12W) and the north half of Section 34 (T7N, R12W). Surface quarrying of gypsum started at this mine in 1848 and after a number of acquisitions formed into the Grand Rapids Gypsum Company in 1860. The mine at that time was known as the Grand Rapids Gypsum Mine. Underground mining started in the 1860's and continued to 1975 when the mine closed due to poor economic conditions. In 1983 the mine was purchased by Domtar, Inc. and reopened with gypsum production starting in 1984. In 1996 Georgia-Pacific purchased the Domtar Mine properties in Grand Rapids and continued to operate the mine until 2000 when the mine was once again closed. Since 2000, the mine has been abandoned and plant processing facilities demolished and the site reclaimed. Equipment in the underground mine was removed including dewatering pumps and the two remaining mine entrances backfilled in with overburden materials. Observations of water in the main mine entry in 2003 indicate that the ground water level has been mostly reestablished and that the mine workings are now completely flooded.

In the early 1960's Michigan Department of Transportation (MDOT) purchased surface right-of-way from the Grand Rapids Gypsum Company for the construction of Interstate I-196 (CS 41029). I-196, which was completed in 1963, crosses the northeast portion of the mine for a length of approximately 2,100 feet from station 442 to 463. Existing mine maps show that the mining below the interstate occurred in the #2 gypsum seam at a depth of approximately 100 feet below the interstate and that no #4 or #5 gypsum seams were mined. The #2 gypsum seam thickness is approximately 12 feet. A map of the underground mine workings below I-196 are shown in Figure 1.

A significant concern for Interstate I-196 is the long-term stability of the surface above the mine from subsidence and sinkhole formation. In addition, the roof and floor rock of the mine contains shale, which loses strength when saturated. Extensive sinkholes as well as subsidence

has occurred over the west and southern portions of the Domtar Mine (west of the interstate) due to roof and pillar collapse as well as some larger scale roof collapse that has occurred in the Georgia-Pacific Butterworth Mine adjacent and to the west of the Domtar Mine.

3.0 SUMMARY OF ASSESSMENT

To date, no distresses have been observed on I-196 nor has any settlement been measured although many of the underground workings below the I-196 have collapsed and that the workings are now filled with water. While sinkholes and subsidence have occurred to the west of I-196, the primary factors that resulted in this surface disturbance do not exist within the I-196 right-of-way. These factors are the mining of the #4 and #5 gypsum seam mining and a lack of roof rock support over the mine workings that stop the collapse mechanism which results in sinkhole formation. It is believed, though, that in the future I-196 may experience some subsidence. However, the estimation of timing and amount of subsidence will require additional investigation. Consequently, it is recommended that continual observation of the area to the west of I-196 be conducted and that periodic monitoring of I-196 both for distresses and elevations changes be conducted.

4.0 EXISTING DOMTAR MINE FILES

Most of the information collected on the Domtar Mine came from files at the former Domtar Mine office. The office buildings were purchased by Dykema Excavators, Inc. and later sold to Kent County. Unfortunately, after the mine was closed in 2000 the mine's files were placed into a dumpster although some (not all) of the files were salvaged before being removed from the site. It should also be noted that when the Grand Rapids Gypsum Company closed in the mid-1970 most of the files are believed to also been discarded with the exception of land related files, such as leases and property issues. The majority of the information collected from the Domtar files was from the period 1983 through 2000. This information was reported in the Kent County Geologic Stability Study for the John Ball Zoological Garden Expansion West of I-196, produced for Kent County in September 2002 by Williams and Works, Inc. of Grand Rapids. It is my understanding that the mine files will remain in the former Domtar office (now owned by Kent County) for the foreseeable future. Access to these files can be obtained either through Kent County or for a limit time through Dykema Excavators, Inc.

For this assessment two additional inspections of the Domtar mine files were conducted to locate information concerning the construction of the interstate over the mine. In particular, we were interested in when the portion of the mine under the interstate had been mined. Only one file was found with information on the mining of the northeast corner of the mine under the interstate. This file contained four maps with one of the maps indicating that the area below the interstate had been mined about 1945. A portion of this map was digitally scanned and is shown in Figure 2.

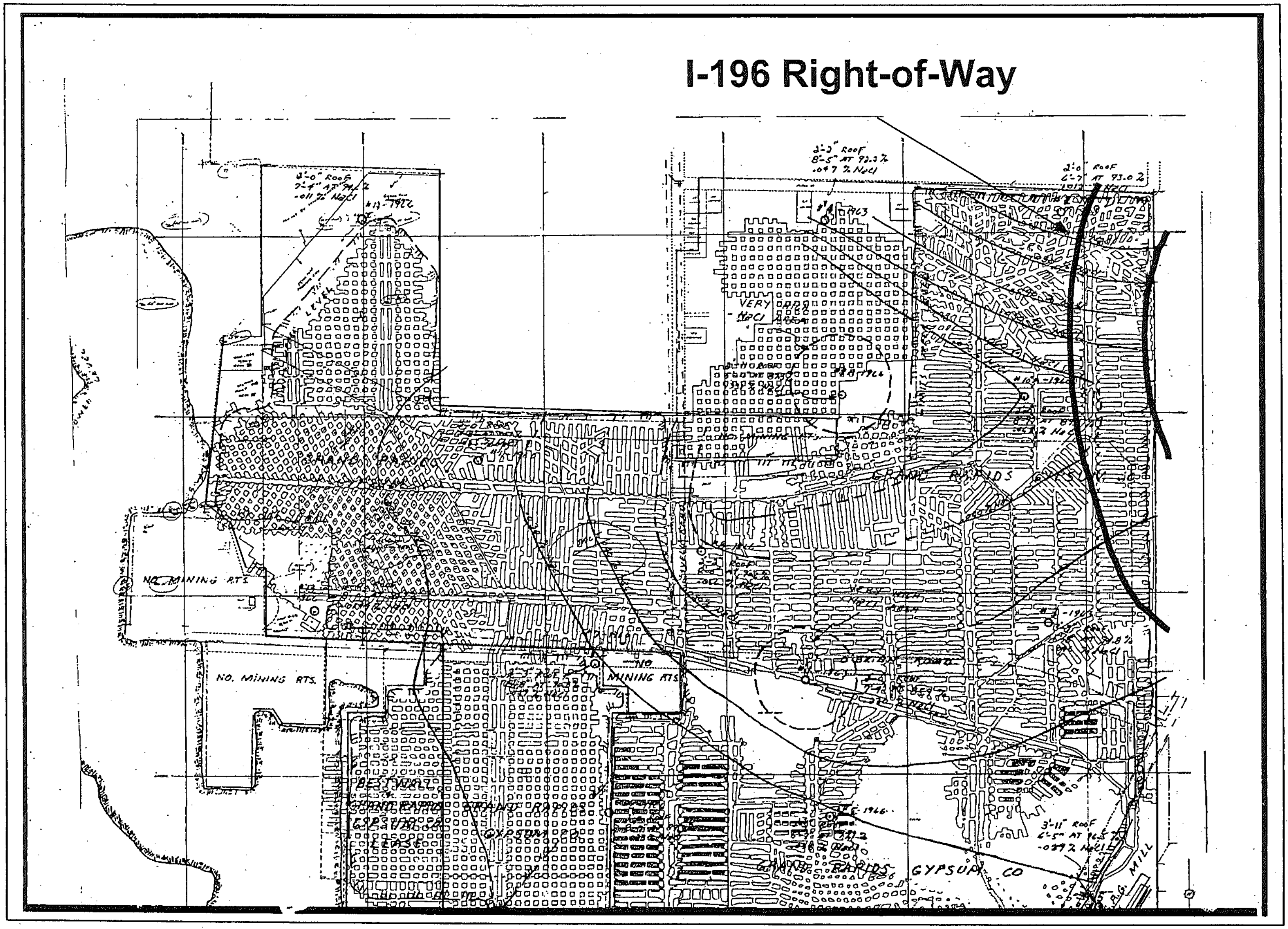


Figure 1. Underground mine workings of the Grand Rapids Gypsum Mine (Domtar Mine) for the #2 gypsum seam.

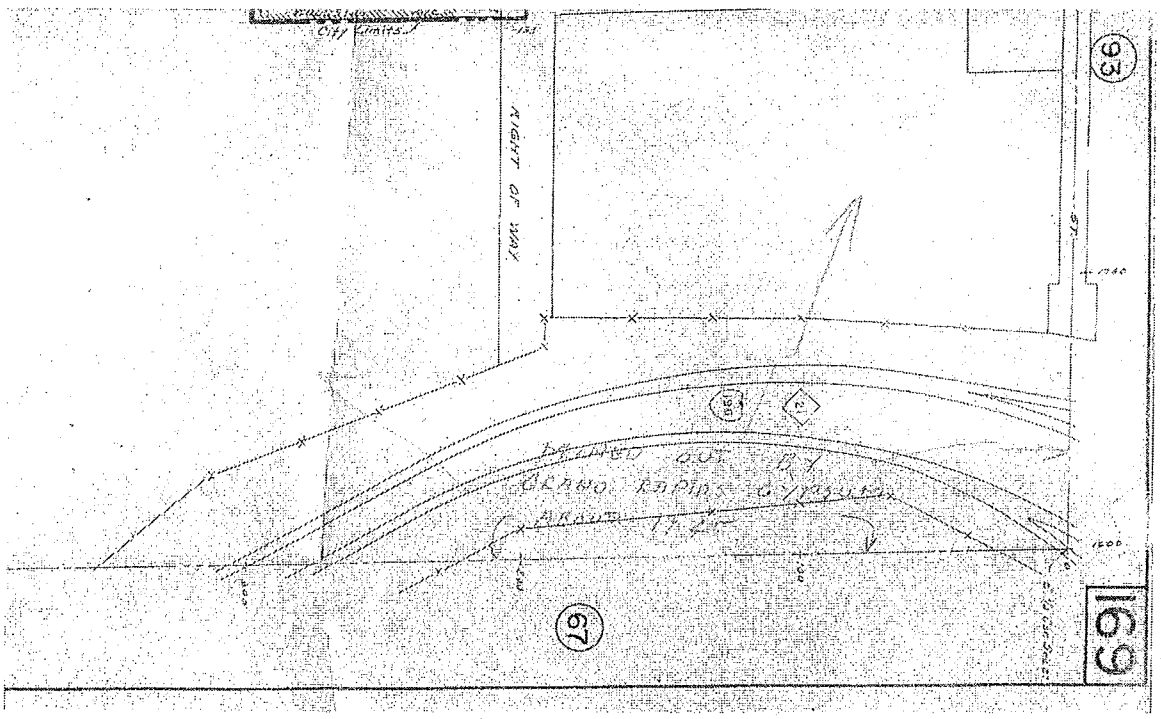


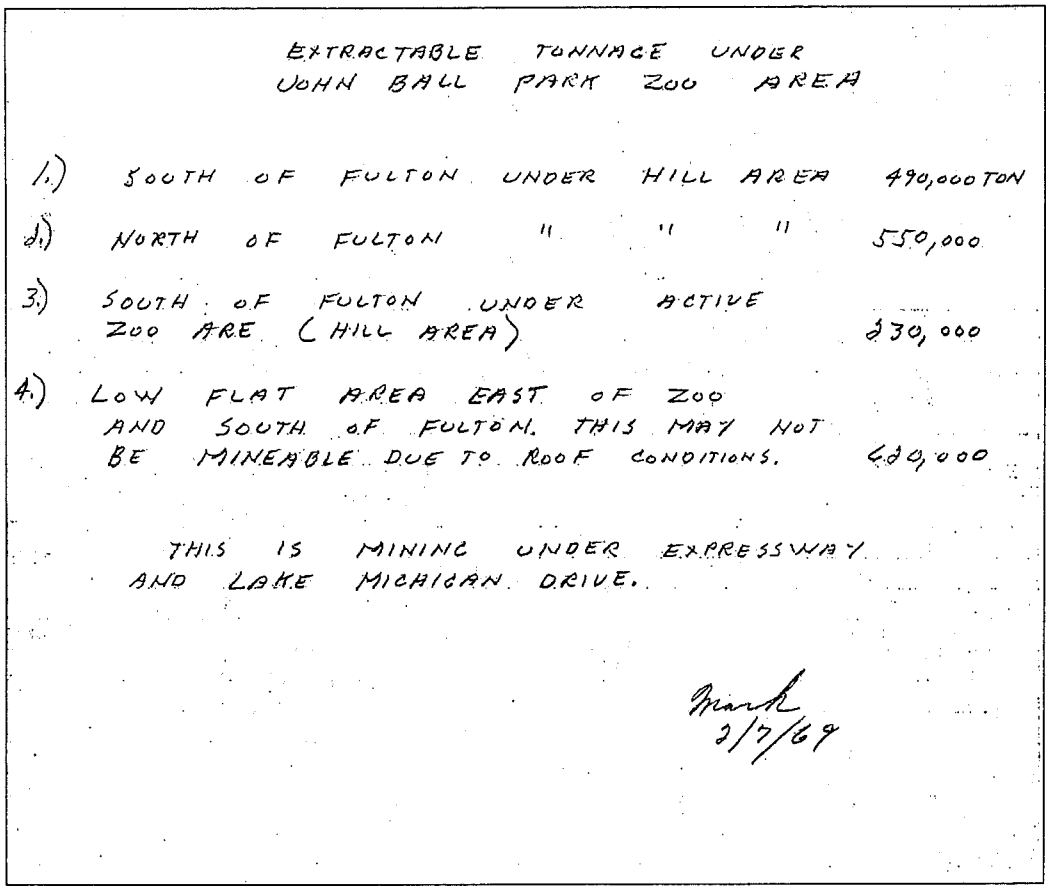
Figure 2. Old map showing the portion of I-196 and where the #2 had been mined and hand written note indicating that it was mined in about 1945.

Also included in this file was a hand written note dated February 7, 1969, shown in Figure 3 that provided the extractable gypsum tonnage for the areas beyond the Domtar Mine to the north and east. It is relatively clear that the tonnage is from the #2 seam since there are areas on the maps where it is noted that the tonnage is only available "if the roof rock is present" indicating that it must be the #2 seam as opposed to the #4 or #5 seams. What is interesting concerning this memo is that the "additional" mining would have mined under all of John Ball Zoo and Park as well as under all of the Lake Michigan/I-196 exchange down to the Butterworth Bridge. If this reserve estimate is representative of the "potential" future mine plans for the Domtar Mine it suggests two possible mining conditions:

(1) The Grand Rapids Gypsum Company believed they could safely mine the #2 seam under the interstate and Zoo/Park without causing subsidence, even though some locations were designated for mining if roof conditions permitted.

(2) That in 1969 (five years after construction of the interstate) that they could *access* the area to the north and east of the mine for future mining. That is, the area must still have been open and accessible in 1969.

It is possible, however, that this estimate may have been put together in an attempt to sell the mine since the mine closed in the mid-1970.



EXTRACTABLE TONNAGE UNDER
JOHN BALL PARK ZOO AREA

1.) SOUTH OF FULTON UNDER HILL AREA 490,000 TON

2.) NORTH OF FULTON " " " 550,000

3.) SOUTH OF FULTON UNDER ACTIVE ZOO ARE (HILL AREA) 230,000

4.) LOW FLAT AREA EAST OF ZOO AND SOUTH OF FULTON. THIS MAY NOT BE MINEABLE DUE TO ROOF CONDITIONS. 420,000

THIS IS MINING UNDER EXPRESSWAY AND LAKE MICHIGAN DRIVE.

Frank
2/7/69

Figure 3. 1969 note on extractable gypsum tonnage beyond the north and east limits of the Domtar Mine.

5.0 I-196 CONSTRUCTION INFORMATION

The I-196 "as-built" construction drawings were inspected from station 420 to 480. The mine is located beneath the interstate from station 442 to 463 at a depth between 90 and 115 feet. The #2 seam room height in this portion of the mine is about 12 feet with the mining room height approximately 8 feet resulting in an overburden depth to room height ratio of about 11 to 14. It should also be noted that the soil boring information provided in the construction plans were not drilled deep enough to intersect the #2 seam.

There is no information on the construction drawings that any special precautions were made to accommodate the underground mines. However, Tom Hynes (MDOT) noted that according to the construction drawings asphalt was constructed over the section of interstate of the mine – in fact this section of interstate was constructed with concrete. It would appear, at least in the design phase, that there was some concern about subsidence of the interstate and MDOT must have believed that asphalt would be an easier pavement to fix in the event of subsidence.

The centerline elevations were taken from the "as-built" construction plans for comparisons to elevations from existing maps and other survey information, which will be discussed later in the report.

6.0 MDOT FILE CORRESPONDENCE

A search of the MDOT files for correspondence concerning the construction of I-196 over the Grand Rapids Gypsum (GRG) mine was made by MDOT. Unfortunately, there was relatively limited information concerning the GRG Mine and the issue of mine subsidence. Correspondence that was reviewed and pertinent to this assessment is provided in Appendix F in chronological order. Important points concerning this correspondence are given below:

a) Discussions between MDOT and the Grand Rapids Gypsum (GRG) Mine concerning building the interstate over the mine started in July 1961. The problems of cave-ins and the stability of the land over the mine were discussed in a joint meeting between MDOT and GRG with the realization that future collapses were possible.

b) MDOT land acquisition of the GRG land started in January 1962 with an initial offer of $28,000 to GRG.

c) GRG refused the offer in a February 13, 1962 memo stating:

> *"Much of the land is over old areas mined by us many years ago. We consider it hazardous for highway use because of the danger of sudden subsidence. Department engineers have seemed unimpressed by our warnings. Of course, through instruments of conveyance or otherwise, our company must have indemnity against damages for injury to persons and property of others."*

An additional issue raised by GRG was that they wanted the right to mine the lower #4 and #5 seams under the land MDOT wanted for the interstate.

d) A second meeting between MDOT and GRG was held in March 7, 1962. The purpose of this meeting was to obtain information concerning mining operations and their influence on proposed expressway design and construction in the area. A following March 8, 1962 MDOT memo discussing this meeting states:

> *"Portions of the pillars were removed in the older north portion, with the result that partial collapse has occurred, causing surface settlements which can be observed.*
>
> *Mr. Fisher was informed that Grand Rapids Gypsum Company would not be expected to be responsible for damage which might be caused*

by or could be traced to collapse of rock formations in present mined-out areas.[1]"

e) MDOT memos dated March 6 and 7, 1962 indicate that MDOT will assume responsibility for subsidence of the #2 mining but not the #4 and #5 seam if they are mined in the future. It is further noted in a March 8, 1962 memo in addressing the question: "*Can the Department assume responsibility for damage caused by subsidence due to construction?*" The response is as follows:

> *"Again economics is the predominant criteria that must be considered to answer this question. We feel that the State Highway Department must assume responsibility for damage caused by subsidence due to construction or use of the highway. This reasonability, in my opinion, would pertain only to the property acquired in fee as permanent highway right-of-way."*

This memo is annotated with the following statement "*This applies to the present mine not future mining.*" This annotation was made to indicate that the Department would only be responsible for problems associated with the existing #2 mining and not the proposed #4 and #5 gypsum mining that would be conducted below the interstate. This correspondence also seems to indicate (but does not state) the no remediation has taken place or is anticipated such pillar robbing, etc. to reduce the potential for subsidence.

f) MDOT initiated eminent domain proceedings against GRG in 1962.

g) A settlement agreement was signed between MDOT and GRG on August 3, 1962. GRG was paid $69,000 for the property and given rights to mine the #4 and #5 seams below the interstate right-of-way. However, it appears that the issue of liability for subsidence from mining the #2 seam was not addressed in this settlement although the title transfer did state that MDOT would be responsible for potential damage due to subsidence from the #2 seam mining.

h) A reference is made in the settlement agreement (Exhibit A) to a report by S.M. Dix and Associates, Inc. concerning the grading and construction of the New York Central Railroad. This report covered a number of issues in an attempt to seek a settlement between MDOT and GRG. A section of the Dix report concerning liability for GRG for subsidence from the #2 seam states:

> *"The area being taken for the Highway passes over mined out areas which could collapse at some time in the future causing a possible drop in the Highway roadbed. Potential liability by the company after the taking introduced a legal question beyond the scope of this analysis.*

[1] It is not clear by this statement whether they were referring to the area directly under the proposed interstate or just general areas in the northern portion of the mine in which sinkholes have been observed at locations where pillars had been removed. However, the mine maps do not show any pillar removal below the interstate. Mr. Fisher was the president of GRG.

Conferences established that this problem was not a major barrier to the ultimate solution and settlement."

Based on this correspondence it is obvious that all parties were aware that subsidence could occur but that this issue was not significant enough to delay the construction of the interstate. We must assume that the Department believed that subsidence when and if it were to occur could be dealt with in the future but more than likely would not be a significant problem.

7.0 MDOT Falling Weight Deflectometer and GPR Data

Falling Weight Deflectometer (FWD) data was collected on September 10, 2002 and covered a length of 5800 feet along the west bound lane and 6900 feet along the east bound lane of I-196. The data is provided in Appendix F. A general observation of the FWD data is that it appears to be variable over the mine area in both the west and east bound lanes while less variable south of the mining area past Butterworth Road. However, the data taken south of the mining area was at greater distances and so some of the variability might have not been recorded. In general, though, the average value of the subgrade resilient modulus over the mining area is not significantly different from data not over the mine or is there any indication that voids have developed below the interstate.

Dr. Chuck Young of the MTU Geophysics Department inspected the ground penetrating radar data and did not observe any features in the data that might indicate subgrade failure or sinkhole formations.

8.0 Individuals Associated with the Mine or Construction of I-196

We contacted a number of people connected with the GRG or Domtar mine or the design and construction of I-196. These people include the following individuals:

a) Charles Johnson – former mining engineer and superintendent of the Domtar Mine from 1983 to 1996. While Mr. Johnson was associated with the mine he never investigated the northeast corner of the mine where the #2 seam was mined. He believed that when GRG closed down this portion of the mine and allowed it to flood after Domtar reopened the mine. He was not aware of any problems associated with the interstate in regards to subsidence.

b) Gerald McCarthy – MDOT Chief of Design at the time of construction. He was not aware whether GRG conducted any operations to limit or eliminate the potential for subsidence of the interstate. He recommended that I contact Kenneth Allemier who worked on this project.

c) Kenneth Allemeir – Mr. Allemier was also not aware whether the mining company or MDOT conducted any work to limit or eliminate the potential for subsidence of the interstate. He suggested that I contact Mr. Robert Hagenboon. I attempted to contact Mr. Hagenboom but was not successful.

The above individuals were not aware if any remediation activities such as removal of support pillars had occurred or if materials had been backfilled into the mine were conducted to minimize or eliminate the problem of subsidence associated with the #2 seam mines under the interstate.

9.0 INTERIM REPORT CONCLUSIONS AND RECOMMENDATIONS DECEMBER 2002

Based on the above information Mr. Jack Parker prepared an interim report, which was submitted to MDOT in December 2002 and is provided in Appendix A. The conclusions and recommendations from this report are listed below.

Tentative Conclusions

a) Our tentative conclusions are that the mine openings must someday close and allow the surface to subside, including parts of the freeway - but that some of the subsidence has already occurred, unnoticed.

b) Some could have occurred in the years between mining (pre-1945) and construction (1964) - around 20 years, but we do not know. Not yet.

c) We have procured some topographic maps, dated 1984 and 1997, and a very cursory comparison suggests that parts of the freeway, at the Fulton interchange, subsided a couple of feet during that interval, and the only indication we have heard of is that one concrete slab in that area "seems to be tilted . . ." To the west of the freeway the maps appear to show as much as 6 ft of subsidence in places during that 13-year period. A map of compared contours, Figure 8, appears in Appendix A.

d) The mining layout in that area, the northeast corner of the mine, is unusual. To us it looks as if it was done with coal-mining equipment, using a coal-mining layout, with rather random formation of pillars followed by slicing up those pillars with diagonal tunnels ... It looks like - and probably was - the "last hurrah" for this part of the mine, gobbling up as much as possible as quickly as possible, to move into better ground further west. We think that this area would have started to fail not long after mining.

e) The geology here is also noteworthy. An exploration hole (1963-2) was drilled from surface about 150 feet west of the freeway (see map) and went through 100 feet of sand and gravel but only 7 feet of rock before entering seam #2 - so apparently there was an extremely thin roof beam above the rooms and pillars and a heavy dead load on that beam - two sufficient reasons for hasty mining and departure. That viewpoint is supported by a note on another old map, on a tract just east of the freeway, listing tons of gypsum reserves "If roof rock is present".

f) One more comment: the northeast corner is the lowest part of the mine, thus the first to get flooded.

g) Now we need to know if the tentative conclusions are correct, how much of the area under the ROW has indeed subsided, and by how much.

Recommendations

a) That MDOT survey elevations along the freeway from Butterworth to Fulton to see how

much change there has been since construction, and since the 1997 survey, and survey some E-W profiles if the changes are significant.

b) That we procure several sets of topographic maps of different ages, all on the same scale, and superimpose them to arrive at contours of subsidence for the various time intervals, and contours of total subsidence, then relate them to the rooms and pillars on the mine maps.

   We would need new, clear copies of the Abrams 1984/Domtar map, the Kent County REGIS 1997 map, USGS 1967 maps - and any others we can find. Perhaps we can get help from Uncle Sam and his satellites. If the maps were digitized the subsidence contours could be generated by computer.

c) If some doubts remain concerning the presence of voids beneath the ROW, we should have a local contractor drill half a dozen exploration holes down through the mining horizon.

d) If subsidence contour maps suggest that subsidence is continuing at significant rates, and that the surface has a long way to go, and that pillars are small in such areas - we may have to consider introducing some kind of inert mineral backfill, maybe sand, maybe flyash, into those parts of the mine - but we doubt it. Given a fair cushion of unconsolidated sand and gravel above the mine it seems that the concrete roadway can "float" around and subside without much distress - just as houses on slabs survive better in earthquake zones than do those on deep and rigid foundations.

   A possible exception to that rule may apply at the boundary of the mine, where there could be, underground, perhaps 10 feet of closure in rooms immediately adjacent to a solid abutment with zero closure - maybe a difference abrupt enough to disrupt the surface.

10.0 CORRESPONDENCE RECEIVED AFTER DECEMBER, 2003

In late December 2002 we received correspondence from Dave Phillips at the Grand Rapids MDOT office that included a seismic survey over the centerline of the interstate conducted in 1962 prior to construction of the interstate by Mr. Douglas N. Hart of the MDOT. A copy of this report is provided in Appendix G. The seismic survey shows that the roof rock over the mine averages about 35 feet - varying from 50 feet to no roof rock. The two closest mine exploration boreholes #2 and #3 (Williams & Works Report, 2002) drilled in 1963 indicates the elevation of the top of the #2 gypsum seam is at 580 feet. The Hart Report, however, indicates that the bottom of the #2 gypsum seam is at 585, which appears to be in error based on additional mine elevation data reviewed. Assuming that the top of the #2 seam is at 580, Figure 4 is a cross-section along the interstate route, while Figure 5 is cross-section showing the roof rock thickness along the interstate route. It can be seen in Figures 4 and 5 that at station 454 the seismic survey shows no roof rock but that along the remaining route the roof rock varies from 25 to 50 feet. Mr. Hart also refers to this roof rock as "hard shale" based on seismic velocity of the shale with an average velocity of 11,900 feet/second (ft/s). In addition, the seismic refraction survey indicated stiff clay to firm shale bedrock above the "hard Shale" layer with an average velocity of 8,500 ft/s. According to Bell (1993), the compressional wave velocities of some common earth materials are as follows:

Sands and Gravels:	1,000 to 5,900 ft/s
Clay wet:	4,900 to 6,600 ft/s
Clay (sandy):	6,500 to 7,900 ft/s
Shale:	6,900 to 14,400 ft/s

Based on Bell's velocities it is possible that that the layer above the "hard Shale" is likely shale as opposed to stiff clay. This would significantly increase the roof rock thickness above the #2 gypsum seam, which is indicated in Figures 4 and 5 as a "possible of possible bedrock or firm stratum."

Mr. Hart was also able to inspect the mine accompanied by the mine superintendent of the Grand Rapids Gypsum Company Mine. According to Mr. Hart's the portion of the underground working between 460 and 462 was free of caving and water. However, attempts to examine the mine workings from station 444 to 459 were unsuccessful due to caved mine roof and water. Further investigation of the mine section below the proposed highway was therefore not conducted. Mr. Hart also noted in this report concerning the relationship to underground caving and evidence of surface disturbance the following statement:

> *"Interpretation of our findings show that the mined area beneath the roadway has caved in the past and is actively caving at present. While none of these caving within the proposed right of way is evident at the surface, there are many exhibits of cone shaped subsidence resulting from collapse of old mine workings."*

Mr. Hart's conclusion concerning construction of the interstate was as follows:

> *"In conclusion, the writer believes that the mine roof conditions under much of the proposed I-96 roadway lying over the mined area are unstable. This is not to imply that the mine under the proposed roadway is on the verge of collapse. It is to indicate, however, that progressive deterioration of the mine roof is underway at this location. The material above the hard shale bedrock at Station 454, survey centerline, should be investigated in detail. This should be done by a deep core boring, as this location could easily become a focal point of possible future mine rock collapse."*

I (Vitton) was also able to contacted Mr. Hart, who lives in Whitmore Lake, Michigan, to discuss his 1962 report. He was aware that the interstate had been constructed over the mine but was not aware of any attempts to stabilize the mine prior to construction. I did mention to Mr. Hart that the area under the interstate had been mined around 1945 but he seemed to think that it had been mined much before that time maybe at the turn of the century. He also indicated that the mine superintendent was very concerned about the construction of the interstate over this portion of the mine. Concerning the date of mining below the interstate Grimsley (1904) provides a map (Plate 17) that indicates that at the turn of the century the extent of mine workings at the Grand Rapids Gypsum Mine was confined to the northeast quarter of Section 35. This plate is shown in Figure 6. The mining below the interstate, which is to the north of Section 35 in Section 27, would have had to occur much later (based on the extent of mining around 1900) would more likely have been mined in the 1930 or 1940's.

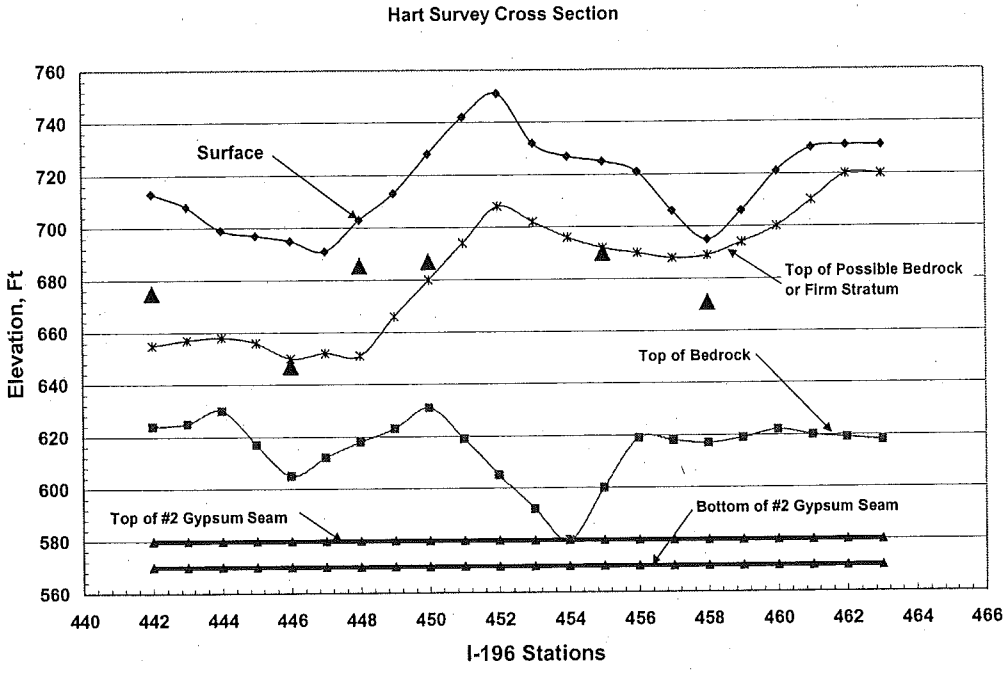


Figure 4. Geologic cross-section along I-196 route based on Hart's seismic refraction study. The triangles indicate the depth where the flight auger hit refusal during the borehole exploration (Hart, 1962) conducted during the seismic refraction study.

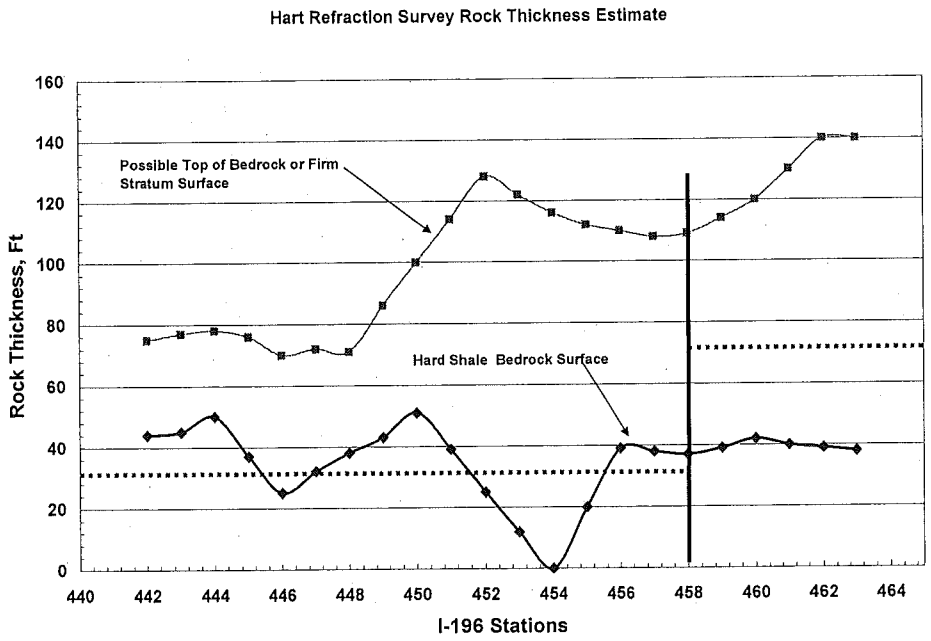


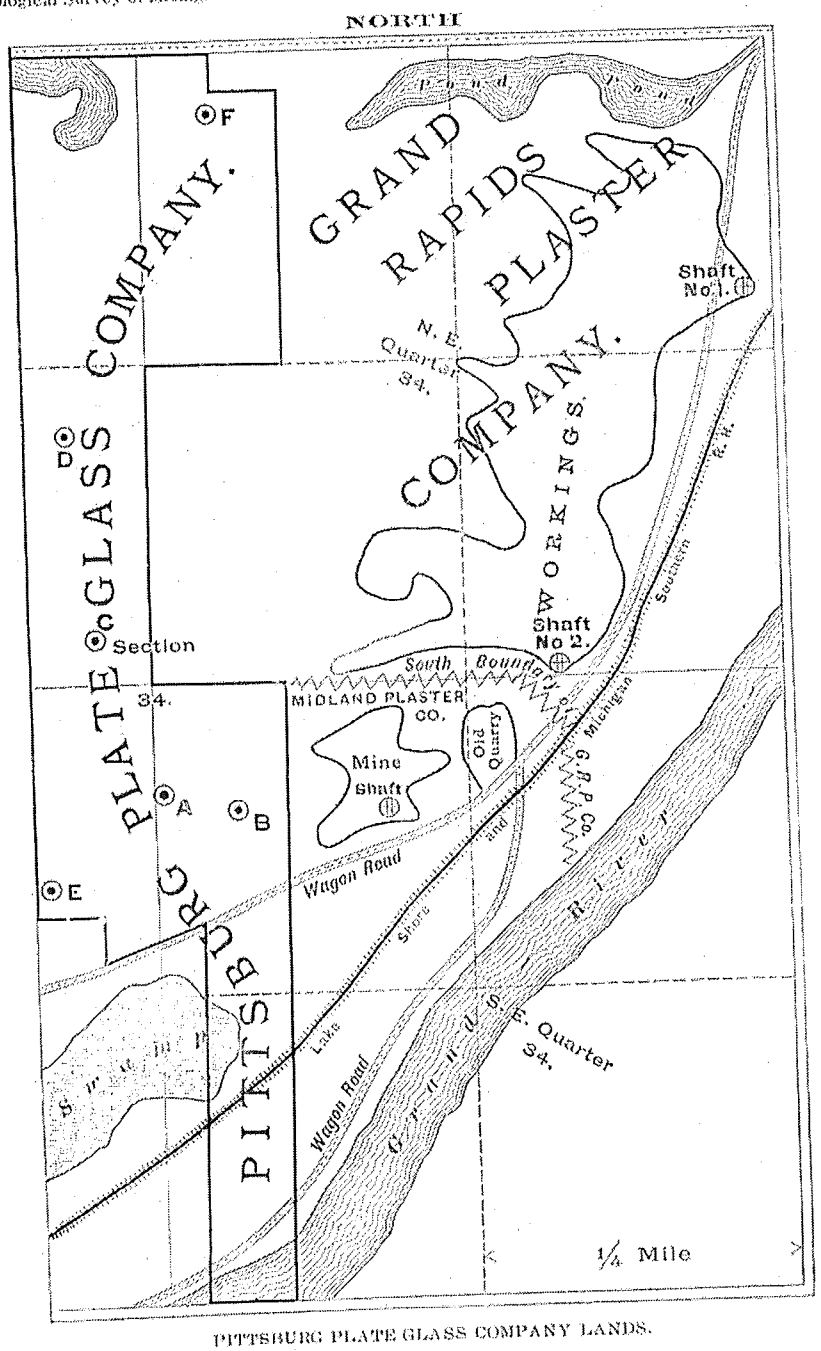
Figure 5. Rock thickness estimate above the #2 gypsum seam based on Hart's seismic refraction study.

11. MDOT SURVEY ELEVATIONS

Prior to completing this report we requested that MDOT survey elevations along I-196 from Butterworth to Fulton to see if any elevations changes have occurred to the interstate since construction. The MDOT survey was conducted in February 2003. The concrete pavement had been surfaced-ground some years before so locations of stations were difficult to determine. Therefore, the survey was started at Station 460+35 at the bullnose of the Lake Michigan on-ramp onto the westbound lane. Unfortunately, this location was directly over the mining area. Due to time constraints the elevation survey was not referenced to a known datum but was done later in the spring. The MDOT elevation data is provided in Appendix H.

The corrected MDOT 2003 elevations data were compared to the 1963 "as-built" elevations as shown in Table 1. A datum correction factor of 0.43 was subtracted from the 1963 data to make it comparable to the 2003 data. From this data it appears that the eastbound lane subsided by about two feet while the westbound lane has risen by about one foot.

Since virtually no distress has been observed on the interstate, it is difficult to imagine that this level of subsidence has taken place. While the elevation data does suggest, as noted in the Interim Report, that some settlement has taken place it is possible that there may be a problem with the datum used in the 1964 survey or that the elevations may be from different locations on the interstate itself. The 1963 elevations provided on the1963 "as-built" construction drawings are for the centerlines of the east and westbound lanes. However, the 2003 elevation data was taken at the edge of the outside lane known as the "edge-of-metal" (EOM). Since this section of interstate is on a curve section and super-elevated, there is a difference in elevation between the centerline and the EOM. Tom Hynes of MDOT calculated the elevation difference between the centerline and EOM and then adjusted the 2003 data accordingly. This corrected elevation data is provided in Table 3. The data, once corrected for super-elevation, shows that there has been virtually no settlement of the interstate in either the east or westbound lanes.



PITTSBURG PLATE GLASS COMPANY LANDS.

Figure 6. Grand Rapids Plaster Company mine boundary from Grimsley (1904) Michigan Geologic Survey Paper that at the turn of the century mining was confined to the northeast quarter of Section 34. The north border of the map is roughly the location of O'Brien Street, while the road identified as "Wagon Road" and located near the mine shaft is now Butterworth Road.

Table 1. Comparison of MDOT Elevations to I-196 As-Built Elevations. Note that a positive difference means the 2003 elevations are higher than the 1964 elevations, while a negative means the 2003 surface is lower than the 1964.

Grand Rapips I-196 MDOT Survey Elevations
WB - West Bound Lane
EW - East Bound Lane

I-196 Westbound Station	MDOT As-Built 1964 WB	Corrected As-Built 1964 WB[1]	MDOT 2003 WB Elevations	West Bound Difference 2003 & 1964	Underground Mine Location	I-196 Eastbound Station	MDOT As-Built 1964 EB	Corrected As-Built 1964 EB[1]	MDOT 2003 EB Elevations	East Bound Difference 2003 & 1964
437	658.60	658.17				437	658.60	658.17		
438	661.14	660.71	659.48	-1.2		438	661.14	660.71	660.86	0.1
439	663.68	663.25	662.44	-0.8		439	663.68	663.25	663.05	-0.2
440	666.22	665.79	665.12	-0.7		440	666.22	665.79	665.38	-0.4
441	668.76	668.33	667.67	-0.7		441	668.76	668.33	667.79	-0.5
442	671.30	670.87	670.18	-0.7		442	671.30	670.87	670.3	-0.6
443	673.84	673.41	672.75	-0.7		443	673.84	673.41	672.78	-0.6
444	676.38	675.95	675.34	-0.6		444	676.38	675.95	675.14	-0.8
445	678.92	678.49	678.20	-0.3		445	678.92	678.49	677.27	-1.2
446	681.46	681.03	681.18	0.1		446	681.46	681.03	679.32	-1.7
447	684.00	683.57	684.06	0.5		447	684.00	683.57	681.61	-2.0
448	686.54	686.11	686.84	0.7		448	686.50	686.07	684.06	-2.0
449	688.94	688.51	689.28	0.8		449	688.85	688.42	686.46	-2.0
450	691.04	690.61	691.41	0.8		450	691.04	690.61	688.64	-2.0
451	692.86	692.43	693.15	0.7		451	693.09	692.66	690.71	-2.0
452	694.00	693.57	694.64	1.1		452	694.58	694.15	692.63	-1.5
453	695.63	695.20	695.91	0.7		453	696.71	696.28	694.31	-2.0
454	696.59	696.16	696.86	0.7		454	698.29	697.86	695.88	-2.0
455	697.25	696.82	697.57	0.8		455	699.72	699.29	697.31	-2.0
456	697.63	697.20	697.95	0.8		456	700.99	700.56	698.51	-2.1
457	697.72	697.29	698.05	0.8		457	702.12	701.69	699.55	-2.1
458	697.52	697.09	697.86	0.8		458	703.07	702.64	700.48	-2.2
459	697.04	696.61	697.40	0.8						
460	696.26	695.83	696.62	0.8						
461	695.20	694.77								
462	693.85	693.42								
463	692.21	691.78								
464	690.29	689.86								

[1]The MDOT 2003 elevations are based on a NAVD88 datum.
To correct the 1964 elevations to the NAVD88 datum approximately 0.43 feet was subtracted from the 1964 elevations.

Table 2. I-196 Eastbound corrected elevations.

I-196 Eastbound

(Eastbound 2003 data has been shifted 100 feet from a starting station of 437 to a starting station of 438)

Features	Curves	I-196 Station	1963 Plan Grade Elevation MSL (ft)	1963 Point of Rotation Grade	1963 Super-elevation	Calculated 1963 Outside EOM Elev	Surveyed 2003 Outside EOM Elev	Difference 2003 - 1963	Mine Location
	3 degree L	420	616.10	615.99	-0.06	617.43			
	3 degree L	421	618.19	618.08	-0.06	619.52			
	3 degree L	422	620.66	620.55	-0.06	621.99			
	3 degree L	423	623.04	622.93	-0.06	624.37			
	3 degree L	424	625.58	625.47	-0.06	626.91			
	3 degree L	425	628.12	628.01	-0.06	629.45			
	3 degree L	426	630.66	630.55	-0.06	631.99			
	3 degree L	427	633.20	633.09	-0.06	634.53			
Station 428+45	3 degree L	428	635.74	635.63	-0.06	637.07			
Former NYC RR Bridge	3 degree L	429	638.28	638.17	-0.06	639.61			
Station 430+28	3 degree L	430	640.82	640.71	-0.06	642.15			
	3 degree L	431	643.36	643.25	-0.06	644.69			
	3 degree L	432	645.90	645.79	-0.06	647.23			
	3 degree L	433	648.44	648.33	-0.06	649.77			
Station 434+05	3 degree L	434	650.98	650.87	-0.06	652.31			
Butterworth Bridge	3 degree L	435	653.52	653.41	-0.06	654.85			
Station 436+36	Transition	436	656.06	655.95	-0.0566	657.31			
	Transition	437	658.60	658.49	-0.0445	659.56			
	Transition	438	661.14	661.03	-0.0225	661.57	661.73	-0.16	
	Transition	439	663.68	663.57	-0.0073	663.75	663.92	-0.17	
	Transition	440	666.22	666.11	-0.0002	666.11	666.25	-0.14	
	Tangent	441	668.76	668.65	0	668.65	668.67	-0.02	
	Tangent	442	671.30	671.19	0	671.19	671.18	0.01	
	Transition	443	673.84	673.73	0.0006	673.72	673.65	0.07	
	Transition	444	676.38	676.27	0.0084	676.07	676.01	0.06	
	Transition	445	678.92	678.81	0.0259	678.19	678.15	0.04	
	Transition	446	681.46	681.35	0.0464	680.24	680.20	0.04	
	Transition	447	684.00	683.89	0.0577	682.51	682.49	0.02	
	3.5 Deg R	448	686.50	686.39	0.06	684.95	684.94	0.01	
	3.5 Deg R	449	688.85	688.74	0.06	687.30	687.33	-0.03	
	3.5 Deg R	450	691.04	690.93	0.06	689.49	689.52	-0.03	
	3.5 Deg R	451	693.09	692.98	0.06	691.54	691.59	-0.05	
	3.5 Deg R	452	694.98	694.87	0.06	693.43	693.51	-0.08	
	3.5 Deg R	453	696.71	696.60	0.06	695.16	695.18	-0.02	
	3.5 Deg R	454	698.29	698.18	0.06	696.74	696.76	-0.02	
	3.5 Deg R	455	699.72	699.61	0.06	698.17	698.19	-0.02	
	3.5 Deg R	456	700.99	700.88	0.06	699.44	699.38	0.06	
	3.5 Deg R	457	702.12	702.01	0.06	700.57	700.42	0.15	
	3.5 Deg R	458	703.07	702.96	0.06	701.52	701.36	0.16	
	3.5 Deg R	459	703.88	703.77	0.06	702.33			
	3.5 Deg R	460	704.53	704.42	0.06	702.98			
	3.5 Deg R	461	705.03	704.92	0.06	703.48			
	3.5 Deg R	462	705.38	705.27	0.06	703.83			
	3.5 Deg R	463	705.57	705.46	0.06	704.02			
	3.5 Deg R	464	705.62	705.51	0.06	704.07			
	3.5 Deg R	465	705.50	705.39	0.06	703.95			
	3.5 Deg R	466	705.25	705.14	0.06	703.70			
	3.5 Deg R	467	704.81	704.70	0.06	703.26			
	Transition	468	704.28	704.17	0.0576	702.79			
Station 469+75	Transition	469	703.74	703.63	0.0461	702.52			
Lake Michigan Dr Bridge	Transition	470	703.20	703.09	0.0255	702.48			
Station 471+84	Transition	471	702.66	702.55	0.0082	702.35			
	Transition	472	702.12	702.01	0.0005	702.00			
	Tangent	473	701.58	701.47	0	701.47			
	Tangent	474	701.04	700.93	0	700.93			
	Tangent	475	700.50	700.39	0	700.39			
	Tangent	476	699.96	699.85	0	699.85			
	Tangent	477	699.29	699.18	0	699.18			
	Tangent	478	698.42	698.31	0	698.31			
	Tangent	479	697.35	697.24	0	697.24			
	Tangent	480	696.06	695.95	0	695.95			

Table 3. I-196 Eastbound corrected elevations.

I-196 Westbound

Features	Curves	I-196 Station	1963 Plan Grade Elevation MSL (ft)	1963 Point of Rotation Grade	1963 Super-elevation	Calculated 1963 Outside EOM Elev	Surveyed 2003 Outside EOM Elev	Difference 2003 - 1963	Mine Location
	3 Degree L	420	616.10	615.99	0.06	614.55			
	3 Degree L	421	618.19	618.08	0.06	616.64			
	3 Degree L	422	620.66	620.55	0.06	619.11			
	3 Degree L	423	623.04	622.93	0.06	621.49			
	3 Degree L	424	625.58	625.47	0.06	624.03			
	3 Degree L	425	628.12	628.01	0.06	626.57			
	3 Degree L	426	630.66	630.55	0.06	629.11			
	3 Degree L	427	633.20	633.09	0.06	631.65			
Station 428+45	3 Degree L	428	635.74	635.63	0.06	634.19			
Former NYC RR Bridge	3 Degree L	429	638.28	638.17	0.06	636.73			
Station 430+28	3 Degree L	430	640.82	640.71	0.06	639.27			
	3 Degree L	431	643.36	643.25	0.06	641.81			
	3 Degree L	432	645.90	645.79	0.06	644.35			
	3 Degree L	433	648.44	648.33	0.06	646.89			
Station 434+05	3 Degree L	434	650.98	650.87	0.06	649.43			
Butterworth Rd. Bridge	3 Degree L	435	653.52	653.41	0.06	651.97			
Station 436+36	Transition	436	656.06	655.95	0.0566	654.59			
	Transition	437	658.60	658.49	0.0437	657.44			
	Transition	438	661.14	661.03	0.0225	660.49	660.35	0.14	
	Transition	439	663.68	663.57	0.0061	663.42	663.31	0.11	
	Transition	440	666.22	666.11	0.0002	666.11	666.00	0.11	
	Tangent	441	668.76	668.65	0	668.65	668.54	0.11	
	Tangent	442	671.30	671.19	0	671.19	671.06	0.13	
	Tangent	443	673.84	673.73	0	673.73	673.63	0.10	
	Transition	444	676.38	676.27	-0.0026	676.33	676.22	0.11	
	Transition	445	678.92	678.81	-0.0144	679.16	679.07	0.09	
	Transition	446	681.46	681.35	-0.0353	682.20	682.06	0.14	
	Transition	447	684.00	683.89	-0.0523	685.15	684.94	0.21	
	Transition	448	686.54	686.43	-0.0596	687.86	687.72	0.14	
	3 Degree R	449	688.94	688.83	-0.06	690.27	690.15	0.12	
	3 Degree R	450	691.04	690.93	-0.06	692.37	692.29	0.08	
	3 Degree R	451	692.86	692.75	-0.06	694.19	694.03	0.16	
	3 Degree R	452	694.29	694.18	-0.06	695.62	695.52	0.10	
	3 Degree R	453	695.63	695.52	-0.06	696.96	696.78	0.18	
	3 Degree R	454	696.59	696.48	-0.06	697.92	697.73	0.19	
	3 Degree R	455	697.25	697.14	-0.06	698.58	698.45	0.13	
	3 Degree R	456	697.63	697.52	-0.06	698.96	698.82	0.14	
	3 Degree R	457	697.72	697.61	-0.06	699.05	698.93	0.12	
	3 Degree R	458	697.52	697.41	-0.06	698.85	698.74	0.11	
	3 Degree R	459	697.04	696.93	-0.06	698.37	698.27	0.10	
	3 Degree R	460	696.26	696.15	-0.06	697.59	697.50	0.09	
	3 Degree R	461	695.20	695.09	-0.06	696.53			
	3 Degree R	462	693.85	693.74	-0.06	695.18			
	3 Degree R	463	692.21	692.10	-0.06	693.54			
	3 Degree R	464	690.29	690.18	-0.06	691.62			
	3 Degree R	465	688.07	687.96	-0.06	689.40			
	3 Degree R	466	685.71	685.60	-0.06	687.04			
	3 Degree R	467	683.35	683.24	-0.06	684.68			
	3 Degree R	468	681.20	681.09	-0.06	682.53			
	4 Degree R	469	679.48	679.37	-0.06	680.81			
	4 Degree R	470	678.18	678.07	-0.06	679.51			
	4 Degree R	471	677.31	677.20	-0.06	678.64			
	4 Degree R	472	676.86	676.75	-0.06	678.19			
	4 Degree R	473	676.84	676.73	-0.06	678.17			
	Transition	474	677.24	677.13	-0.0555	678.46			
	Transition	475	678.07	677.96	-0.0415	678.96			
	Transition	476	679.11	679.00	-0.02	679.48			
	Transition	477	680.15	680.04	-0.0042	680.14			
	Transition	478	681.19	681.08	0	681.08			
	Tangent	479	682.23	682.12	0	682.12			
	Tangent	480	683.27	683.16	0	683.16			

12.0 SUBSIDENCE AND SINKHOLE ASSESSMENT

To date, no distresses have been observed on I-196 that can be related to the former Domtar Mine. In addition, the 2003 survey data indicates that no settlement has taken place since construction in 1963. It is clear from mine records and correspondence that the mining below the interstate had been conducted prior to 1945 and possibly a number of years before 1945. Therefore, the mine workings are at least 60 years old and possibly older – a fairly long time in light of mine stability discussed in the Hart Report. The two issues that need to be evaluated are the potential for (1) sinkhole formations, where the collapse of the mine reaches to the surface and (2) where the collapse structures do not reach the surface but there is a general settling of the surface as the mine collapses over time. These two general issues are further discussed below.

Sinkhole Formation:

A review of subsidence literature for shallow abandoned mines indicates the following general observations for determining if sinkholes will develop from underground workings:

1. The main collapse mechanisms for underground mines are as follows: (1) collapse of the roof span, (2) collapse of the support pillars, or (3) the support pillar either punches into the floor or roof if either layer becomes weaker due to flooding of the mine or other possible factors, e.g., swelling. In general, roof collapse is the most common form of mine collapse and the one observed in the Domtar Mine that leads to sinkhole formation.

2. According to Piggott and Eynon (1976),

   "*if there is at least one competent bed of strata between the mine workings and the surface which has a thickness of at least 1.75 times the appropriate span, the collapse process will be arrested by the competent strata.*"

   The "appropriate span" below the interstate is about 20 feet for the majority of the interstate with the exception of the northern 400 feet of the interstate (stations 458 to 462), which has very irregular span dimensions with some spans up to 40 feet. This would require a roof rock thickness of 35 to about 70 feet to stop or arrest the collapse process. However, it should be noted that for a mining room height of 9 to 10 feet or even possibly 11 feet a room width (or span) of 20 feet would be typical, i.e., a width to height ratio of 2:1, while a room span of 40 feet with a ratio of 4:1 would be highly susceptible to collapse. Figure 5 shows a dashed line indicating a 35 foot level from stations 442 to 458 and a 70 foot height from stations 458 to 463. It can be seen from Figure 5 that only a portion of the interstate is within the "hard shale" layer above the #2 seam. However, as noted in the 1962 Hart report only the underground workings below stations 460 and 462 were found to be free of caving conditions and water, while stations 444 to 459 had sufficient caving and water to make it difficult to investigate. Concerning these conditions Hart made the following three observations: (1) that even though there was caving below the interstate right-of-way there was no observable ground subsidence along the proposed right-of-way; (2) in other parts of the mine, not within the proposed right-of-way, the mine roof had completely collapsed and that large amounts of yellow

sand and cobble gravel were found to be filling the workings. In addition, he observed many funnel-shaped depressions, some 40 to 50 feet in diameter and as deep as 25 feet directly above the collapse areas; and (3) that he also observed mine floor heave and pillar collapse due to swelling of the soft shale beds. It is interesting to note that he did not observe any soil materials infilling the mining workings below the proposed right-of-way. This would suggest that while the mine roof had collapsed, possibly due to the swelling and pillar collapse, no "soil" was infilling the mine has he observed in the other parts of the mine indicating that possibly the roof collapse had been stopped by competent roof strata such as a overlying gypsum seam noted in many of the exploration logs. This further suggests that the layer above the "hard shale" may be a stratum that is competent enough to stop the collapse process leading to sinkholes. The Hart report also conducted continuous flight auger and wash borings at a number of locations along the proposed right-of-way to a depth of 30 to 50 feet. In most borings the auger hit refusal on a dark gray clay or shale as it was described in the boring logs. The location of this stratum is identified in Figure 4 by the triangle symbols. It can be seem that the elevation of these locations correlate well with the stratum identified as a hard clay or shale bedrock above the "hard shale" and having a seismic velocity of 8,500 ft/s. Further evidence of this layer being a firm stratum comes from the action of glacial erosion, which has eliminated much of the #2 seam in the Grand Rapids area. This glacial action has somehow prevented the #2 seam from being eroded at the Domtar Mine due possibly to the bedrock above the #2 seam. Whether this stratum is in fact bedrock or the product of glacial deposition, it appears to be competent enough along with the "hard shale" layer to retard the collapse of the underground mine workings, which was observed by Hart in 1962, some forty years ago.

3. A second observation made by Piggott and Eynon (1976) is that collapses are generally found to only reach to a height of 3 to 5 times the mining room height and only in exceptional cases has it been observed to reach a height of 10 times the mining room height. Whittaker and Reddish (1989), in studying sinkhole formations in Britian and the United States from shallow underground mines, suggest a range of 3 to 7.5 times the mining room height. Since the seam thickness of the #2 seam averaged twelve feet, with one foot of gypsum left for support of the roof and one foot for the floor, the mining height averaged is about10 feet. Therefore, a roof rock thickness of 30 to 75 feet would be sufficient to prevent collapse structures from reaching the surface. Again, assuming that the stratum above the "hard shale" is competent then sinkholes would be unlikely to develop, since the roof rock below the interstate would be between 75 and 140 feet thick.

Given the points above coupled with the length of time since mining and the construction of the interstate, it is unlikely that sinkholes will affect the interstate. However, additional observations of the site to the west of the interstate should be further evaluated to better understand the mechanisms that are causing the formation of sinkholes in regard to the underground workings of the Domtar Mine and its related geology. As suggested in the Williams and Works (2003) report, the two main causes of sinkholes at the Domtar Mine are (1) the mining of the #4 seam and especially the bi-level mining of the #4 and #5 seams appear to be causing significant surface disturbance and (2) the lack of roof rock over the #2 seam. The sinkholes that have formed north of O'Brien Street are likely due to the lack of roof rock, which allows a roof

collapse to work its way through the soil to the surface since the soil does not have the bulking capacity that rock has to volumetrically expand thus arresting the collapse process. Fortunately, both these issues do not appear to be a factor with the interstate.

General Subsidence

It is possible that over time subsidence or settlement to the interstate may occur, since the area below the interstate has been mined. However, based on the elevation survey of the interstate very little to no subsidence has occurred, although it is possible that some settlement may have occurred between the time of mining and construction of the interstate. It is more likely that most if not all of the caving, which was observed by Hart (1962), has been stopped by the overlying rock structure. Overtime, however, the pillars may also collapse or punch into the floor or roof resulting in general settlement of the interstate. The possible mechanisms for this subsidence are discussed in the Parker Interim Report provided in Appendix A. Consequently, it will be important to periodically monitor the elevation of the interstate. In addition, it will also be important to monitor and evaluate the general subsidence to the west of the interstate, which is experiencing subsidence. Knowing the mechanism and rate of settlement to the west of the interstate will provide a means to economically design solutions to any potential surface subsidence if any does develop. As already noted, the interstate, unlike the area to the west of the interstate, has not experience subsidence to date.

An additional possibility concerning subsidence is that the Grand Rapids Gypsum Company may have removed or "robbed" the pillars below the interstate prior to construction, thus allowing the ground to settle and eliminating the risk of future subsidence. However, there are no records to support this likelihood. It would seem, given the concern which the mining company as well as the Highway Department staff had concerning subsidence (as indicated in the correspondence), that robbing the pillars would have been a prudent step to take. An additional observation is that in the negotiations for the interstate right-of-way from the Grand Rapids Gypsum Company, the company retained rights to the #4 and #5 seam below the interstate. It would appear that if the mining company planned to mine these seams in the future eliminating the problem of the subsidence from the #2 seam would have been an important consideration given the critical nature of the interstate. It would have been difficult, though, to "rob" the pillars in 1962 since this area of the mine had been mined pre-1945 and the condition of the mine after twenty years or so may not have allowed safe pillar extraction. Also, mining operations in 1962 were on the west side of the mine and therefore the main haulage ways to the northeast section of the mine may not have been maintained and in a stable enough condition to haul the gypsum out of the mine. On the other hand, the mine correspondence, which indicated that the area below the interstate had been mined prior to 1945, also indicated that the company was interested in mining the #2 gypsum seam to the north, under the Lake Michigan Drive NW interchange, and to the east under the John Ball Zoo. For mining to be conducted the mine would have had to maintain the main haulage to the northeast section of the mine. Unfortunately, the evidence is contradictory as to whether or not pillar extraction had been conducted. Obviously, if pillar extraction had been conducted the risk of sinkhole development or subsidence to I-196 would not be a concern today.

13. CONCLUSIONS

Our conclusions regarding this assessment are provided below.

a) The Grand Rapids Gypsum Company (GRG) mined the area below the interstate prior to 1945 and possibly earlier.

b) The problem of future ground subsidence below the interstate was discussed jointly by MDOT and GRG. It appears from the correspondence that MDOT was willing to accept responsibility if any subsidence were to occur in the future and that no provision such as pillar robbing or mine room filling were attempted.

c) There is no indication that any distress has occurred to the interstate to date.

d) Based on the MDOT elevation survey, there has been no settlement of the interstate since construction in 1963.

e) The mining layout in that area, the northeast corner of the mine, is unusual. To us it looks as if it was done with coal-mining equipment, using a coal-mining layout, with rather random formation of pillars followed by slicing up those pillars with diagonal tunnels ... It looks like - and probably was - the "last hurrah" for this part of the mine, gobbling up as much as possible as quickly as possible, to move into better ground further west. We think that this area would have started to fail not long after mining, although Mr. Hart was able to access this area.

f) A MDOT seismic survey conducted in 1962 indicates, though, that the roof rock varies from 0 to 50 feet, with an average of about 35 feet. An underground inspection noted that the north end of the mine (Station 460 to 462) was accessible while the area below station 444 to 459 was not accessible and that significant cave-in had occurred. Also, the seismic survey indicated that no roof rock was present at Station 454. However, reviewing the seismic velocities provided in the Hart report it appears that this layer may be competent shale that is assisting the support of the mine structure.

g) The northeast corner is the lowest part of the mine, thus the first to get flooded. Since the mine was closed and pumping stopped, the mine has filled with water.

h) Our conclusions are that the mine openings must someday close and allow the surface to subside, including parts of the freeway - but that some of the subsidence has already occurred, unnoticed. Some could have occurred in the years between mining (pre-1945) and construction (1964) - around 20 years, but we do not know. Not yet.

14.0 RECOMMENDATIONS

It is our opinion that the gypsum mines below I-196 will some day completely collapse resulting in some subsidence to the interstate. The amount of subsidence however is not known and consequently we are unable to complete the risk analysis. To complete this risk analysis we recommend the following actions be conducted:

a) That surface above the Domtar Mine and west of I-196 be monitored for sinkholes and general subsidence. This will allow a better understanding of the mine collapse mechanism related to the geology and mine structure.

b) That we procure several sets of topographic maps of different ages, all on the same scale, for the entire CRG (Domtar) Mine and superimpose them to arrive at contours of subsidence for the various time intervals, and contours of total subsidence, then relate them to the rooms and pillars on the mine maps. This will also require that datum's used for the maps are determined.

   We would need new, clear copies of the Abrams 1984/Domtar map, the Kent County REGIS 1997 map, USGS 1967 maps - and any others we can find. Perhaps we can get help from Uncle Sam and his satellites. If the maps were digitized the subsidence contours could be generated by computer.

(c) If subsidence contour maps suggest that subsidence is continuing at significant rates to the west of the interstate, and that the surface has a long way to go, and that pillars are small in such areas - we may have to consider introducing some kind of inert mineral backfill, maybe sand, maybe flyash, into those parts of the mine - but we doubt it. Given a fair cushion of unconsolidated sand and gravel above the mine it seems that the concrete roadway can "float" around and subside without much distress - just as houses on slabs survive better in earthquake zones than do those on deep and rigid foundations. A possible exception to that rule may apply at the boundary of the mine, where there could be, underground, perhaps 10 feet of closure in rooms immediately adjacent to a solid abutment with zero closure - maybe a difference abrupt enough to disrupt the surface.

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