Journal of the National Academy of Forensic Engineers®

http://www.nafe.org
ISSN: 2379-3252

Vol. XXVI No. 2 December 2009

Forensic Engineering Examination of 11 Foot Diameter Sanitary Sewer

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Abstract

A 11 foot diameter sanitary sewer settled and collapsed leaving 7 homes damaged on the South side of 15 mile road in Sterling Heights, (North Detroit) Michigan. The sewer was 60 feet below the ground surface, and had settled and lost overburden material for several years prior to the major 2004 collapse. The main depression was 130 feet wide and 245 feet long with a depth of 30 feet. The sudden collapse of the surface portion was over 10,000 tons and dropped approximately 30 feet. The resulting initial collapse vibration exceeded the re-construction vibration and was the cause of ongoing visible damage to the 7 homes along the South side of the roadway.

Keywords

Infiltration, Loss of Support, Sewer Collapse, Vibration settlement, Construction vibration, Workmanship, Construction damage, Psychological Damage, Pollution of Ground Water, Public Agency Neglect, Historic Water Table.

Scope

Determine if the damage to the 7 home was a result of the sewer collapse or poor workmanship by the building contractor of the homes.

Facts

Figure 1

Over 150 homes in Fontana Villas, were built starting in 1999. The collapse occurred in late 2004. The collapse occurred under 15 Mile Road, which ran East to West along the Northerly border of Fontana Villas, the location of the 7 homes investigated were along the bottom of this photograph. The aerial view, see figure 1, of the sinkhole created by the collapsed 11 foot diameter sewer failure identifies close proximity to the 7 homes that were investigated. An earlier failure in this same pipeline occurred in 1978, approximately 900 feet to the East of the 2004 failure. Many conclusions and recommendations from the 1978 failure were ignored and were thereby, contributory to this 2004 failure.

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Facts and Procedure

The repair of the sewer, road, utilities and landscaping had all been completed prior to the author's involvement in this project. Extensive detailed records from the various agencies and contractors were available and used as a basis of engineering judgements concerning the sewer collapse and subsequent re-construction.

1. *Review of engineering and construction documentation for the project, including history of this specific portion of the sewer collection system.*
   Extensive records of the 1978 failure suggested monitoring was recommended with detail records of the repair to this earlier failure in 1978. Inspections, suggested during the failure in 1978, were not followed and thereby were contributory to the current failure. Infiltration of massive amounts, approximately 7,000 cubic yards, of ground material was the most likely failure mechanism. As the ground infiltrated into the sewer the support of this massive sewer started to sag and crack, thereby allowing a faster infiltration of material into the sewer. Original engineering studies confirmed this material included significant amounts of silt and fine granular materials. These materials, as stated in the furnished 1978 Executive Summary, could have infiltrated into the sewer with a small water head above the crack. The head calculated for piping was 1.7 to 4.6 feet. The water head from the suspicious value of 31 feet below the surface still produced a head of approximately 25 feet. The invert of the sewer was approximately 60 feet below the surface, that still allowed a head of 25 feet or more to allow piping into the sewer before failure. As the support for the sewer failed the sewer settled and opened the cracks wider and wider, thereby increasing piping into the sewer. The concrete sewer filled half full of sewerage would weigh approximately 12,000 pounds per lineal foot or 850 pounds per square foot below the sewer.

2. *Interview and inspect the 7 residences for damage and consistencies for the home damage.*
   While the damage was not catastrophic, homes settled in the portion nearest to the collapse from 2 inches to nearly 4 inches. This settlement in conjunction with homes that were structurally well built did suffer many more minor damage profiles. It was common for basement walls to crack and leak ground water, another indication the water table was not 31 feet below the surface. Doors sticking or windows losing their thermopane properties and not working properly as before the collapse were common. Drywall cracks and other cosmetic damage was consistent and seen in all the residences investigated. The video documentation noted in the various engineering materials were never produced for our use in comparison. As the vibration from the construction continued, the interior and cosmetic damage became more noticeable to the residents. The stress on all the homes structural components, as they were realigning their internal stresses, were exacerbated by the construction vibration that was constant for several months. While the vibrations were not sufficient to cause further foundation settlement they did cause the interior cosmetic damage to be very noticeable to the residents. Residents complained of items vibrating off shelves and the vibration even caused cooking pans to dance off the burners unless held in place. This vibration and loud noise was at a

minimum, detrimental to the psychological health of the residents that had no options but to stay in their damaged homes. Even the local Property Appraiser reduced the appraised value of their homes to the land value with little or no value for the home. This made it impossible to sell their home and move, but the mortgage still had to be paid to maintain their credit.

3. *Obtain permit plans and information from the construction of the homes.*
   Permit plans were obtained from the City of Sterling Heights and confirmed the brick ledge elevations when the homes were being built. This allowed for comparison of the settlement of the homes from the time they were built to the time of this authors inspection. Results confirmed the homes settled from 2 inches to nearly 4 inches down to the North or toward the sewer failure. The homes showed little or no settlement at the front, however, many settlement issues were noted in the sidewalks and streets on the side away from the sewer collapse.

   a. *The homes were only a few years old were built as a subdivision with hundreds of homes.*
      The homes in Fontana Villas were built starting in 1999 and included over 150 homes. One home included in this investigation, built in 2003, was not due for its 1 year warranty inspection and repair as agreed during the sale of the home. All the remaining 6 homes were past their 1 year warranty inspection and repair period, and had been successfully repaired to the owner's satisfaction.

   b. *Correlate the home 'brick ledge' elevations with the re-construction settlement records, confirmed no settlement of the foundation during re-construction.*
      A requirement by the Sterling Heights Building Department was to have the 'brick ledge' elevation shown on the Building Department records was critical in evaluating why these homes were experiencing cracks and cosmetic damage after the sewer collapse. These 'As Built' elevations allowed this engineer to determine the homes had settled from 2 to 4 inches since the homes had been built. The oldest home was only 5 years old at the time of the sewer collapse.

4. *10,000 tons of cavity existed when the ground surface collapsed.*
   A 7,000 cubic yard hole was left after the sewer collapsed. This confirmed at least 10,000 tons of fill material had fallen approximately 30 feet during this collapse. The description of a loud 'thud' was evidence the collapse was sudden and mostly in one quick action. This falling of 10,000 tons of fill 30 feet would cause a shock to the fill under the homes and was more than the re-construction vibrations produced by re-construction activities. However, the construction vibrations would continue to cause the homes to re-distribute the stresses and show the identified cracks and cosmetic damage described by each of the homeowners.

   a. *This amount of overburden disappearance was not noted by the infrastructure downstream.*
      No information was collected to indicate the downstream infrastructures had noted the fill material being identified or a problem. This confirms this was occurring over years, at least 3 or more.

i. *Therefore the infiltration into the sewer was gradual and over several years.*

The infiltration into the sewer was slow and took several years to move the fill into the sewer from under and around the sewer line. The 60 foot depth of the sewer allowed the fill around the sewer to 'bridge' over until the cavity around the sewer was large enough, and no longer able to bridge over the cavity, the surface collapsed into the hole visible in Figure 1 and caused the cross section damage seen in Figure 2.

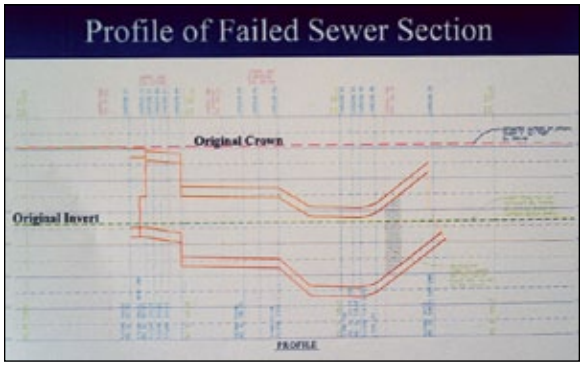

Figure 2

ii. *When the 11 foot diameter sewer started to settle, the fill material would have found its way into the sewer and proceeded downstream over several years.*

The initial infiltration was silt thru the fine cracks in the structure of the sewer. The sewer was 18 inch thick concrete walls with an 11 foot diameter hole for the sewerage to pass. As the infiltration caused a loss of support for this structure, the structure started to sag, and crack further, thereby allowing a faster piping into the sewer line. The final documentation of the location of the sewer structure confirmed the sewer had settled 10 feet vertically for a length of approximately 75 feet with lesser settlements for a distance of over 200 feet.

iii. *Wall thickness of 11.5 inches or 62% of required thickness, near station 69+29.*

The substandard thickness of the sewer concrete occurred at station 69+29 and was very near the failure, shown in Figure 2 as the cross hatched area toward the right. This area had been previously repaired by reinforcing rather than re-mining. Station 69+29 was identified to be a control joint. This was likely the first area which began to fail in the 2004 collapse.

iv. *The 10,000 tons of material would have half filled the sewer for over 4,000 lineal feet.*

The 10,000 tons of material that had disappeared before the collapse, would have filled the 11 foot diameter pipe for a distance of over 4,000 lineal feet. No such fill material was noted in the pipe that remained downstream and no cleaning of the downstream pipe was noted. It was therefore the conclusion of this author that the piping had occurred over a period of several years.

5. *Engineering documentation noted the 'historic ground water level' to be 31 feet below the surface. No supporting documentation was furnished and was refused when requested.*

The documentation noted and was assumed to have been 31 feet below the surface (See Figure 3). Since this was noted as "historic" I looked for the supporting documentation for that determination. No supporting documentation was included in the material furnished. The DWSD was contacted by

the clients Attorney and requested the supporting documentation for this "historic" determination, no such evidence was ever produced to support that the water table was 31 feet below the surface as a 'historic ground water level'.

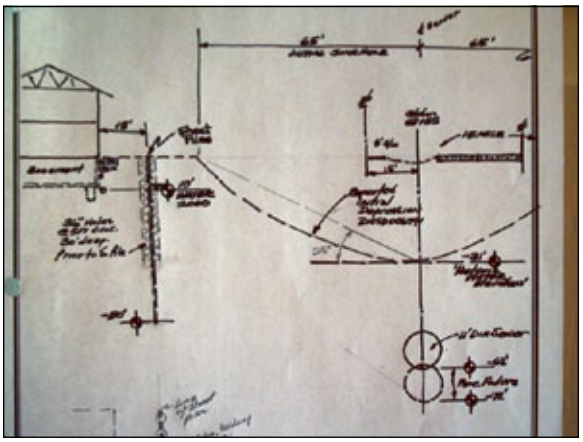

Figure 3

Without supporting documentation for this 'historic water level' an investigation ensued to determine what evidence was available to establish the water level when the subdivision was planned and built. The original water levels from the initial borings in 1968 and again in 1999 when the homes were started in the Fontana Villas Subdivision were 10 to 13 feet below the surface. If the re-construction area near the worst of the break indicated a 'historic water level' of approximately 31 feet, this author opined it would take at least a couple years to leave evidence that the water level was at the stated levels. This would strongly suggest the infiltration started about 2001 and accelerated until the catastrophic collapse in August of 2004. Survey and boring information recorded when the sewer was last inspected in 1994 did not indicate a serious settlement, cracking or infiltration.

a. *Analysis of the borings before the subdivision was built confirmed the ground water level was approximately 10 to 11 feet below the surface in 1968.*
   The original borings used during a sale of this parcel in 1968 indicated the water table was between 10 and 11 feet below the surface. This was again confirmed in 1999 with borings near the entrance to Fontana Villas. Therefore the infiltration leading to the 2004 collapse started and was well advanced in 2001, enough to leave evidence of a stable water table 31 feet below the surface near the collapse. As the infiltration started thru the small cracks and piped silt into the sewer, the sewer lost support and sagged, further opening the cracks and allowing an acceleration of the piping into the sewer until the catastrophic collapse in August of 2004.

b. *If the ground water table near the sewer was evidenced to be in the range of 31 feet, it would confirm the water infiltration into the sewer for several years prior to this major collapse.*
   Assuming the 31 foot historic water level was correct, and using 2 years to leave evidence of this 'historic' level, the piping into the sewer was accelerating in 2001, heading toward the collapse of 2004. The concrete sewer pipe was 18 inch thick concrete with a flow of approximately half full; that would yield approximately 850 pounds per square foot bearing to support the sewer pipe. When the sewer started to lose support, the pipe would sag and cause further cracks and increase the flow until the catastrophic collapse in August of 2004.

6. *Protection of homes was a primary concern of the Re-Construction activities; however, very little help was afforded to the residents most affected by these activities.*
   The re-construction crews were very anxious and efficient in planning and executing the steps necessary to assure the homes were protected; however they did not help the homeowners in many simple steps that would have been useful to help their psychological reactions to unusual circumstances that necessarily followed with the re-construction.

   a. *Constant noise from the reconstruction effort, each machine had its own unique noise that was intermittent, variable, and impossible to ignore:*
      Multiple sizes of generators, lights, cranes, sheet pile driving operations, caisson drilling machines, test drilling, pumps, water well drill machines, drilling and pressure grouting operations, bulldozers, front end loaders, backhoes, trucks and a wide variety of very loud, exhaust producing machines were constantly working very near homes #1 thru #7, during the first several months of the reconstruction.

      The residents, without construction experience, did not know what sounds and dangers were coming next and certainly not how to cope with the unknown dangers. Often the fear of the unknown is more detrimental than the real consequences of certain irritants.

   b. *Loud intermittent noised from equipment like steel pile driving; that the residents had no idea of when or how loud the sounds would be that entered their home. No instruction or suggestion for how to deal with loud noise or even when it was scheduled caused additional trauma to the residents that lived near the worksite.*
      A baby 10 days old when this started had minimal protection from the loud, intermittent noises produced. Elderly residents likewise had very little reaction time, and no help on how to protect themselves or their homes from the loud construction noises. No suggestions or help from Detroit Water and Sewer on how to mitigate the noise entering the residence. Sound curtains or ear protection instruction would have been a large help.

   c. *Very bright lights were used 24 hours a day to light the worksite, this produced an atmosphere that deprived the residents of sleep and again each light group had a generator to provide power to assure the lights worked.*
      The bright lights lit the residences like noon, this continued the first several months of the re-construction. Many people that lived in the homes could not sleep because of the continual lights. Blackout and sound curtains would have

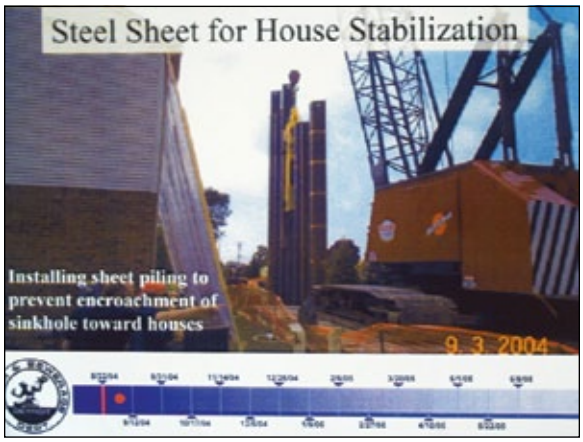

Figure 4

helped the residents, especially with being able to sleep. The light generators, while loud, were at least continuous and residents could get used to the noise.

d. *Vibration was a very troublesome consequence of the construction. No monitoring that identified the extent of the vibrations were preserved for a later evaluation.*
The residents were assured that the vibrations were being monitored and were safe; however, DWSD made the erroneous assumption that vibrations less than 2 inches per second were safe. That level of vibrations, from blasting studies, has been widely accepted to "prevent structural damage" they did not account for the damage to the homes and residents caused by lower vibrations. Psychological damage begins at 0.50 inches per second or lower. Cosmetic damage will be evident at 0.75 inches per second. The recordings were usually not started until approximately 1.5 inches per second and often higher. Vibrations, caused pans on the stove to dance off unless held, items on shelves would be vibrated off and often break, even a large TV with part of its cabinet broke and caused damage to objects nearby. The homes, under changing stresses from the initial collapse of the sinkhole, continued to relieve and redistribute the stresses throughout the structure. Vibration from the construction activities exacerbated cosmetic and psychological damage to the residents. That is the reason the drywall cracks and basement cracks as well as other window, door and structure problems kept getting worse. One major concern of the residents was, is my home safe, is it going to fall and injure my family? This was a typical concern of the residents, I assured them the damage would be cosmetic and very unlikely to cause a major collapse of their home.

7. *Noise, vibration, bright lights, equipment hazards, smell, detours for access were constant annoyances for the residents along the South Border of 15 Mile Road.*
The daily trauma to the residents was intermittent and caused major distress to their living in the home. Hazards of having a 100 ton crane within 20 feet of their home (See Figure 4), making a very loud noise and steel piling being swung near their homes was a major cause of stress for the residents. Vibration was intermittent, depending on the specific construction items that were being performed. In addition to the vibration, the smell of construction especially the raw sewerage was overpowering at times. The constant equipment in their neighborhood and changing access detours were an additional irritant for the residents.

a. *As the surface hole expanded toward the homes, in the first few days after the collapse, concern was expressed for the safety of the homes nearest the sinkhole.*
During the initial phase of identifying the danger to the residents, all seven homes were evacuated and moved into a motel for several days. After several days they were moved back into their home and assured that everything was safe and they would restore their homes and lives back to their pre-collapse condition.

i. *Sheet piles were installed within 15 feet of some homes.*
Upon returning home, the neighborhood was drastically changed, construction equipment, noise, vibration and lights were a overwhelming influence on their quiet lifestyle. Several residents had to endure a 100 ton crane handling and driving steel piling within 15 feet of their home. See Figure 4 and note the home on the left, with a splash curtain to help keep the equipment grease from splashing onto their homes and windows. Nothing was provided to prevent the loud noise, vibration, lights and concern for the residents safety. No indication was provided to assure the residents of their safety or when their disrupted lives would be restored to their pre-collapse condition.

ii. *Elevation monitoring was performed to assure residents their homes were stable.*
The re-construction crews monitored the elevation change on the rear 2 corners of their home to verify the homes were not settling due to the very loud re-construction noises encountered by the residents. The homes did not settle more due to the sheet piling installation, because the initial shock of 10,000 tons of overburden falling 30 feet exceeded the vibration produced by the re-construction vibration.

iii. *De-Watering holes and grout injection were installed to reduce the amount of water flow toward the collapsed sewer.*
De-watering holes and injection of grout produced more loud noises, lights and vibration to the consternation of the residents. The re-construction crews determined it would not be good for the ground water to flow toward the newly formed hole created from the failed sewer main. This makes one wonder; if the water table was at its historic low of 31 feet below the surface, why was ground water flowing toward the hole?

b. *Vibration from the construction activities was a constantly changing condition due to the activities being performed.*
Vibration was changing daily depending on the work being performed, sometimes the cooking pans would 'dance' off the stove unless held in place, or small items on shelves would vibrate and fall to the floor, even a large TV and part of its cabinet fell during one episode of vibration. The re-construction crews insisted no harm would come to them or their property due to the re-building process. Their homes would be repaired to better than their pre-collapse condition; however later they discovered that Detroit Water and Sewer would deny all damage to their homes.

i. *Vibration was thought to be safe, to the residents, below 2 inches per second.*
Structural damage can be expected to homes when the vibration exceeded 2 inches per second from construction blasting; however no provision was described that explained what effects constant vibration would have on the residents. Through research, that was not challenged, the psychological effects to the residents start at 0.5 inches per second, with cosmetic damage

closely followed starting at 0.75 inches per second. The constant loud noise and intermittent vibration caused unidentified, mental trauma to the residents.

ii. *No information was provided to the residents on the level of vibration and its likely effects.* The residents were told that the vibration levels were monitored and they should have no concern for their property or personal damage due to the monitored vibration. Only later when the vibration records were reviewed was it learned that the monitors were set to only come on and record with a level above 1.5 inches per second and often the monitors were turned off when the level exceeded 2.5 inches per second. These levels were definitely into the range of damage to the homes as well as the residents.

c. *Sound levels were for the most part ignored and little help was afforded to the residents to cope.* Sound levels were very loud and intermittent 24 hours a day, this combination made it impossible for the residents to get a restful nights sleep, especially during the early re-construction efforts. Sound level readings were recorded but no information about how to cope was afforded to the residents. Sound levels above 130 decibels were recorded with no warning to the residents. No help was provided for the residents, dealing with this new intrusion into their lives. The very loud sound of a top fuel dragster leaving the line is in the range of 125 decibels. Sound curtains or hearing protection could have been recommended for the reducing some of the problems faced by the residents. Impulse noise is a very short duration noise such as; a steel hammer striking a steel plate. This was the often a description offered by the residents. This short impulse noise is usually not caught on the equipment that was used to monitor noise at this re-construction site.

d. *Bright lights were a constant irritation to the residents.*
The bright lights to light the worksite 24 hours a day, 7 days a week made the entire living portion of the homes like noon. This constant light left the residents without restful sleep and added to their already hectic lives.

e. *Equipment hazards were a concern for many residents.*
Strange equipment and noises caused the residents to fear going into the rear yard. This in conjunction with many workers that were strange to the neighborhood and caused another level of stress to an already stressful situation. Residents had never been up close to this wide variety of machines and tasks and feared the unknown.

f. *Detours for access to and from their neighborhood were a constant annoyance for nearly a year.* The main entrance to Fontana Villas was closed with the sinkhole and would not be accessible for over 9-1/2 months. The equipment, often parked in the Fontana Villas roadways caused the residents to make different paths to the rear entrance for going about their daily living activities.

g. *Smells from the broken sewer main, that contained raw sewerage was a health as well as psychological worry for the residents.*
The raw sewerage smell and contamination lasted for several months and was a concern for the residents. They had little information from DWSD on how to cope or what the dangers might have been.

h. *Homes continued to show new signs of distress and deterioration.*
Most homes continued to relieve the pent up stresses caused by the first collapse of the sinkhole, damage continued until this author investigated the homes. While the vibration stresses were below the initial vibration stress, the homes continued to realign themselves and left telltale signs such as; drywall cracks, windows not working, doors not operation properly, thermopane windows and doors losing their seals, basement cracks opening and leaking, driveways and sidewalks showing signs of settlement were all conditions noted after the initial sinkhole collapse.

i. *Homes will be restored to their original condition or better.*
This was the most egregious misleading promise made by DWSD. The homeowners expected their property to be restored to its pre-collapse condition; however, they had to hire a legal team and investigate their claim to get DWSD to seriously consider their loss. Even with the property appraiser de-valuing their property to the value of the land, DSWD still maintained the position that no harm had been foisted upon the homeowners. Fortunately the court proceedings restored some of the money losses to the homeowners. They still have to deal with the medical and physical conditions such as missing trees and future health problems. DWSD never delivered as promised.

Analysis

The residents were living a quiet American Life, when suddenly, without choice, their lives were thrown into turmoil for nearly a year. The physical stress of not understanding what effects the collapse and re-construction would have on their financial and home safety weighted heavily on their minds. The psychological stress of dealing with the smells, noise, lights and possible toxic exposure had an additional emotional effect on each of the residents.

Detroit Water and Sewer Department failed to perform simple helpful guidance steps for the affected residents. Things as simple as advising on how to cope with the wide range of construction and safety issues would have been very helpful. Even 3 years later the cooperation from DWSD was very difficult and almost non-existent. For instance many subcontractors were afraid to work for the residents on simple functions, such as establishing a simple survey elevation of the homes to determine if and when the homes settled. This investigating engineer had to engage 5 surveyors to finally get one that would perform the simple task of establishing the elevation of the monitor marks for the settlement during the pile driving operations. The local surveyors would say ‘no problem’ on the phone, but when the materials arrived in their office, they suddenly could not perform the work for weeks, and sometimes

months. Ironically the survey that was performed proved that the homes did NOT settle further after the re-construction efforts and marks on the houses were in place.

The residents would have been more cooperative and probably not have engaged legal help if the DWSD had simply helped the people understand and cope with the unique and unfamiliar problems encountered by the residents after the collapse, that was not their fault. As clearly demonstrated during this investigation the fault was squarely on DWSD for not following the advice from the 1978 collapse analyses 900 feet East in the same sewer line. A 5 year inspection recommended by that failure and investigation would have prevented this collapse and saved millions of dollars and untold stress to the residents.