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ʊ Paper presented at the NAFE seminar held in January 2024 in Daytona Beach.
‡ Paper presented at the NAFE seminar held in January 2023 in San Antonio.
§ Paper presented at the NAFE seminar held in January 2022 in Tucson.

Forensic Engineering Analysis of a Residential Fire Caused by an Open Neutral

By Steve Pietropaolo, PE, DFE (NAFE 769S) and Yoandi Interian, PE, DFE (NAFE 1260M)

Abstract

An open neutral or floating neutral is a condition that occurs when the electrical current passing through the neutral conductor in a multiwire circuit is not balanced. This condition can occur when there is a break in the neutral wire, resulting in a loss of continuity in the neutral. As a result, an imbalance in electrical voltage is created in the electrical system. This paper will discuss the forensic engineering analysis of a residential fire caused by an open neutral. It will discuss in detail how a large tree fell on power lines near the house, fractured a nearby residential utility pole, caused a failure of the neutral service splice, and resulted in the separation of the neutral portion of the service line. It will further discuss how the open neutral resulted in a power strip overheating and caused the fire.

Keywords

Forensic engineering, open neutral, floating neutral, electrical fire, utility pole, neutral service splice, relocatable power strip (RPT), power strip

Introduction and Background

A structural fire broke out in a single-family residential house in Westchester County, New York, resulting in significant damage to the house. The house was a two-story wood-framed structure, approximately 1,800 square feet in size and 103 years old (**Figure 1**).

Based on a review of available documents, on the day of the fire, the following sequence of events was established:

Figure 1
Front view of the subject two-story single-family residential house. Photo taken by utility company on the night of the fire.

- Before 2:24 p.m.: A tree falls across the street from the subject house.
- 2:24 p.m.: The electrical utility company was notified by the local police department of fallen tree and downed wires.
- 2:25 p.m.: The utility company sends a technician to the scene.
- 2:58 p.m.: A technician from the utility company arrives at the scene and reports a broken utility pole in front of the subject house, but no downed wires were reported.
- 4:38 p.m.: The utility company was notified by the local fire department of a structural fire at the subject house and requested the utility company shut off all utilities to the house.

Upon arrival, the utility company found no evidence of any downed wires. The utility pole directly in front of the house had fractured as a result of the nearby fallen tree and strained the service lines extending to the house. The

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utility hypothesized that the neutral wire had pulled out of the connector near the weather head.

At the time of the fire, no one was present inside the house, and no injuries were reported. However, the house sustained severe structural damage as a result of the fire. Following the reported fire, the authors were engaged to evaluate the circumstances that led up to the structural fire, identify the cause of the fire, and determine whether the utility contributed to the cause of the fire. Various discovery documents were reviewed, and a site inspection of the scene was conducted. A lab examination of the evidence collected from the scene was also performed.

Scene Examination Post-Fire

A joint-scene examination of the property was conducted several days after the fire. **Figure 2** provides an aerial view of the house and the surrounding property.

A triplex service drop from utility pole #1 (located directly in front of the house) extended toward the service entrance of the house near the northwest corner of the house. Note: A service drop is a set of electrical cables that connect a utility company's power to a customer's building. The term "triplex" refers to the three wires in the cable that are twisted together in a set.

A service mast and weather head were mounted on the northwest corner of the house. The service mast (a rigid metal conduit extending vertically from the electrical meter box up toward the roof line) and weather head (a protective fitting placed at the top of the service mast) protect the electrical system and ensure a safe entry point for the utility power. The triplex service drop cable contained two aluminum insulated conductors and one bare conductor. The two insulated conductors serve as the "hot" legs of the service, while the bare conductor serves as the "neutral" leg of the service. The bare neutral conductor also served as the messenger wire and will be referred to as the "messenger neutral conductor." Note: A "messenger wire" is a wire that is run along with a cable to provide mechanical support for the cable.

The two insulated conductors were connected to the two insulated service entrance conductors with a utility connector and were intact at the time of the fire (**Figure 3**). The neutral service entrance conductor was also connected to the end of the neutral messenger conductor and was intact (**Figure 3**). Note: A neutral service entrance conductor is an electrical conductor that forms part of the service entrance wiring to a building. The role of the neutral service conductor is to provide a return path for electric current back to the utility's distribution system.

The opposite end of the messenger neutral conductor was found lying on the roof in front of the weather head. The messenger neutral conductor contained two splice connectors (**Figure 4**). A section of the messenger

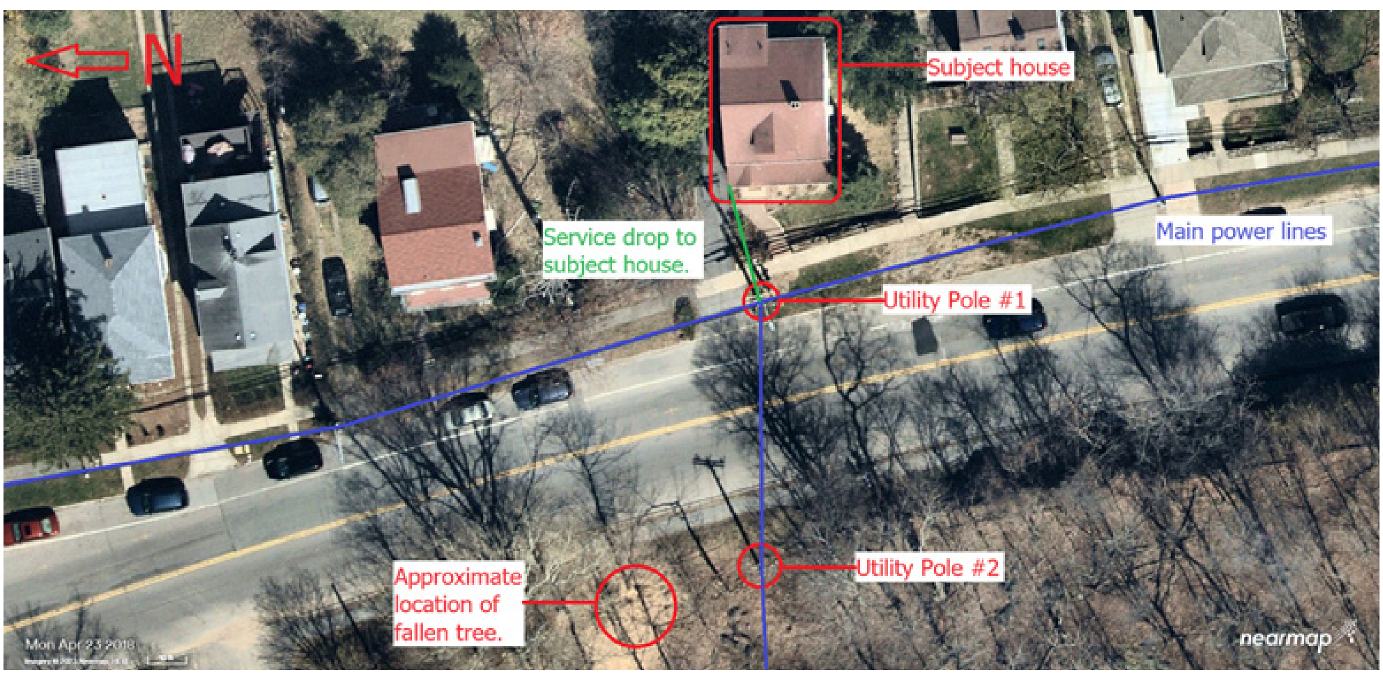

Figure 2
Aerial view of the subject property and surrounding area obtained from Nearmap.com (dated April 23, 2018).

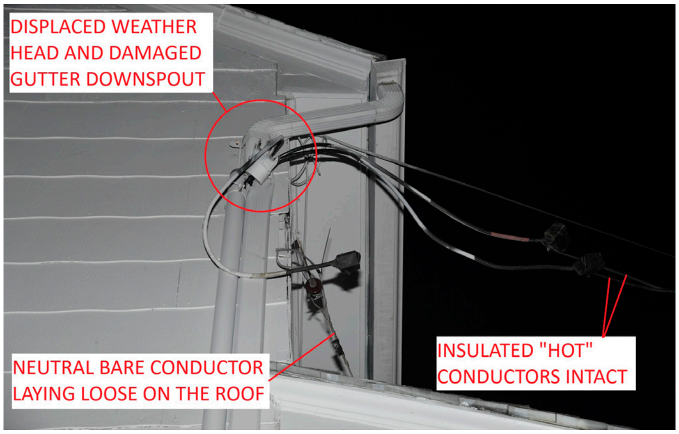

Figure 3
View of the service drop connection at the service entrance to the house — night of the fire (looking south).

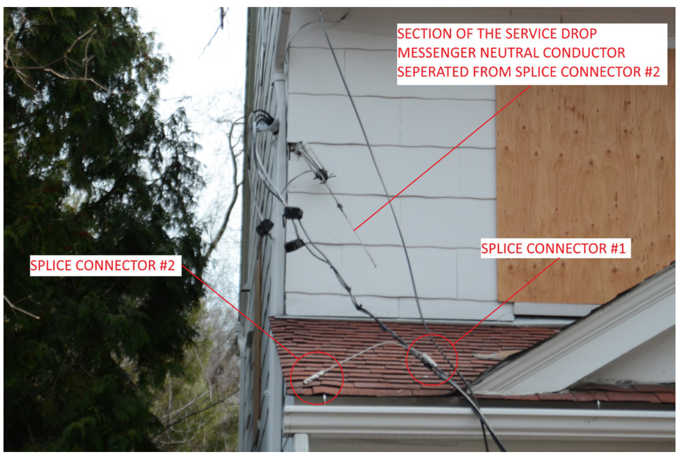

Figure 4
View of the service drop connection at the service entrance to the house (looking east).

neutral conductor had separated from the splice connector closest to the weather head. A service insulator bail was attached to an eyelet that was firmly attached to the building structure. Note: A service insulator bail is a component used in electrical service installations to hold and support the overhead service drop. The insulator bail provides a non-conductive support for the power lines and ensures the proper distance between the electrical conductors and other parts of the structure.

A section of the messenger neutral conductor wire was still connected to the insulator bail, as shown in **Figure 5**. Displacement of the weather head mast was visible as evidenced by the recent crushed gutter downspout near the subject vertical service entrance mast. There was no evidence of any lightning strike (e.g., scorch marks on the exterior).

Figure 5
View of the insulator bail firmly attached to the building structure.

Figure 6
View of the utility pole #1 leaning away from the house.

Utility pole #1 (located directly in front of the house on the east side of the street) had fractured at the base and was leaning toward the street (**Figures 6** and **7**). The utility pole was found leaning on the main power lines running in the north-south direction along the street. No guyed wires were found attached to utility pole #1. Directly across the street (on the west side of the street) was another utility pole (utility pole #2). Power lines crossed the subject street from utility pole #1 to utility pole #2 to feed a nearby school.

The subject tree that fell was located approximately 30 feet north of utility pole #2. The tree fell onto the primary feeder lines, crossing between utility pole #1 and utility pole #2. Utility pole #1 was pulled in a southwest direction and fractured the utility pole at the base.

Figure 7
Utility pole #1 fractured at the base (night of the fire).

The house was serviced by a 200A service. A service panel was in the basement and contained 38 breakers. A 20A breaker servicing the living room of the subject house was found in the "tripped" position.

The triplex service drop conductors and connectors were disconnected from the service entrance and taken as evidence. Additionally, the subject tripped breaker and various wiring and electrical appliances from within the subject house were removed and taken as evidence for further examination.

Fire Origin

The local fire department determined that the fire originated in the living room near the TV entertainment center. The cause of the fire was determined to be accidental and electrical in nature. The author further evaluated the fire scene using the scientific method as detailed in the 2017 edition of the National Fire Protection Association *Guide for Fire and Explosion Investigations* (NFPA 921-2024)[1]. Note: NFPA 921-2017 was the version of the guide in place at time of the site visit. Combining witness statements, physical evidence (i.e., degree of damage, fire patterns, fire dynamics), and conducting an arc survey (mapping) of the area of origin, the source of the fire was confirmed to have originated in the living room in the vicinity of the entertainment equipment. Further analysis determined that the cause of the fire was due to a failure of a relocatable power tap (RPT) — a.k.a., a power strip — located in the living room.

Laboratory Examination of Evidence

The following items, amongst other components, were present in the area of fire origin: Soundbar, phone charger, Bluray DVD player, Sony charging station, Play Station (PS4), Nintendo Switch, Roku, Verizon Modem and Wi-Fi router, LG television, and two unknown RPT devices. One of the RPT devices was significantly more damaged than the other. All of the electronic devices were plugged into the various RPT devices, which were plugged into a duplex receptacle (outlet) located on the living room wall to the right of the entertainment center. A 20A Murray model circuit breaker was protecting the living room circuit. That circuit breaker was found to be in the "tripped" position after the fire. The circuit breaker was tested in the laboratory and found to be functional. None of the devices (except for the lesser-damaged RPT) was found to exhibit signs of electrical activity or failure. Once the 20A circuit breaker tripped, the entire entertainment area was not energized. Therefore, these devices would not have caused the fire.

Failure Mode of Power Strips

RPTs are equipped with voltage suppression devices called metal-oxide-varistors (MOVs) that "clamp" or restrict transient (or voltage) fluctuations in an electrical circuit. These devices can fail catastrophically if exposed to higher-than-normal voltage. The authors have personally performed laboratory testing in the past on MOV devices subjected to higher voltages (up to 220V), proving these effects. Based on previous testing performed along with historical research, MOVs can overheat and cause fires[2].

Standard for Safety Surge Protective Devices (UL 1449) sets requirements for surge protective devices (SPDs), also known as surge protectors or surge suppressors[3]. The standard specifies these devices' testing and performance criteria to ensure they effectively protect against transient voltage surges and spikes. The standard covers various aspects, such as surge current ratings, response times, endurance, and safety considerations, to ensure the reliability and effectiveness of surge protection devices. For end products to comply with the UL 1449 standard, some level of protection must be afforded to the MOV to prevent failure from an abnormal over-voltage/limited current condition. Traditionally, various methods for thermally protecting MOVs have been provided to meet the requirements of UL 1449[4].

X-rays performed on the lesser-damaged RPT confirmed the failure of at least one MOV device due to overvoltage. The more-damaged RPT was destroyed, with only the metal electrical busses remaining or recovered during the fire scene overhaul and evidence collection. The fact that this RPT was more severely damaged is evidence that it was exposed to fire effects for a longer period of time.

All experts involved in the forensic investigation agreed that the fire was caused by an MOV failure within the damaged RPT device. The more-damaged subject RPT was never excavated from the solidified debris and never evaluated to determine if the MOVs within the device were thermally protected to meet the requirements of the UL1449 standard.

Open or Floating Neutral

Per Section 9.5.2 of NFPA 921-2017, "[a]n electrical installation with an open neutral conductor will not have a fixed 120V between each hot leg and the neutral. There will still be 240V between the two legs, but instead of the voltages of the two legs being fixed at 120V to neutral each, they may vary to some other values that add up to 240V (**Figure 8**). All 120V circuits connected to the open neutral conductor will be affected. The actual voltages in the legs will depend on the loads on the two legs at any particular time. For example, the voltages might be 60 and 180 as in Figure 9.5.2. The higher voltage can overheat or burn out some equipment, and the lower voltage can damage some electronic equipment. Occupants may have seen incandescent lights that were too bright or too dim or appliances that overheated or malfunctioned in some way. A floating neutral condition is not dependent on proper grounding of the service. Removing the grounding electrode connection does not cause an open neutral[1]".

In a multiwire circuit, such as the case at this property, the neutral conductor carries the load imbalance. **Figure 9**, showing a three-wire circuit, has been supplied to assist in the explanation of an open neutral. As shown in Figure 1 of **Figure 9**, the neutral conductor is designed to carry the imbalance of the two loads. In this example, there is one load requiring 0.5A on one phase, while the load on the second phase is drawing 2.5A. The difference of the two currents, 2A, will flow back to the transformer and into the service supply. When the loads are balanced (a very unusual condition), the current on the neutral is 0A. When the neutral conductor is "open," the voltage becomes unstable, and no current flows through the "open" messenger neutral conductor. Note: An "open" neutral condition refers to an interruption in its continuity (i.e., broken, disconnected).

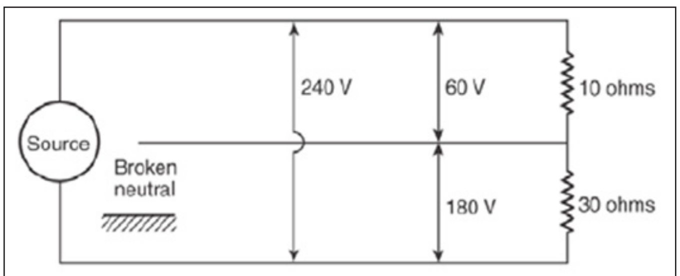

FIGURE 9.5.2 An Example of the Relation of Voltages in 120/240 V with an Open Neutral.

Figure 8
Figure 9.5.2 from NFPA 921-2017.

The flow of current is the same for both loads, only flows on the live conductors, and the neutral returns no unbalanced load to the service. When this occurs, the voltage drop across a load can be calculated using equation 1 (Ohm's Law) — where I is the electrical current (which is the same in an open neutral condition), and R is the resistance of the loads[5].

(Eq. 1) $V = I \times R$

A higher-wattage device will have a lower resistance than a lower-wattage device. In an open neutral condition, the smaller wattage device will see the larger voltage drop. In Figure 4 of **Figure 9**, the 60W bulb will be very bright because its voltage drop is five times greater than the voltage drop across the 300W bulb.

A neutral conductor provides a return path for electric current to the utility company's electrical system[5]. When the messenger neutral conductor wire became separated — and because the loads in the home were not balanced — it caused an imbalance in the electrical voltage to the RPT and the various components connected thereto.

"An open or floating neutral poses a significant risk to electrical equipment and can result in equipment failure or fire[6]." Typically, the failure mode of the MOV devices occurs when they are exposed to overvoltage (greater than 120V). This overvoltage can cause excessive heat and failure of an MOV device, causing a fire before an overcurrent protection device, like the circuit breaker, trips or opens, as was confirmed at this location based on the evidence.

Note that when a power strip fails, the heating effects and the resulting fire exposure to the first fuels can occur immediately thereafter, followed by ignition to the secondary and tertiary fuel loads. "First fuels" refer to the materials that initially catch fire and begin the burning process (e.g., paper products, cooking oils, clothing, wood, etc.). "Secondary fuels" refer to materials that catch fire after the "first fuels" have ignited and help spread the fire (e.g., furniture, drywall and plaster, insulation materials, appliances, etc.). "Tertiary fuels" refers to materials that ignite after the fire has grown and spread (e.g., wooden beams

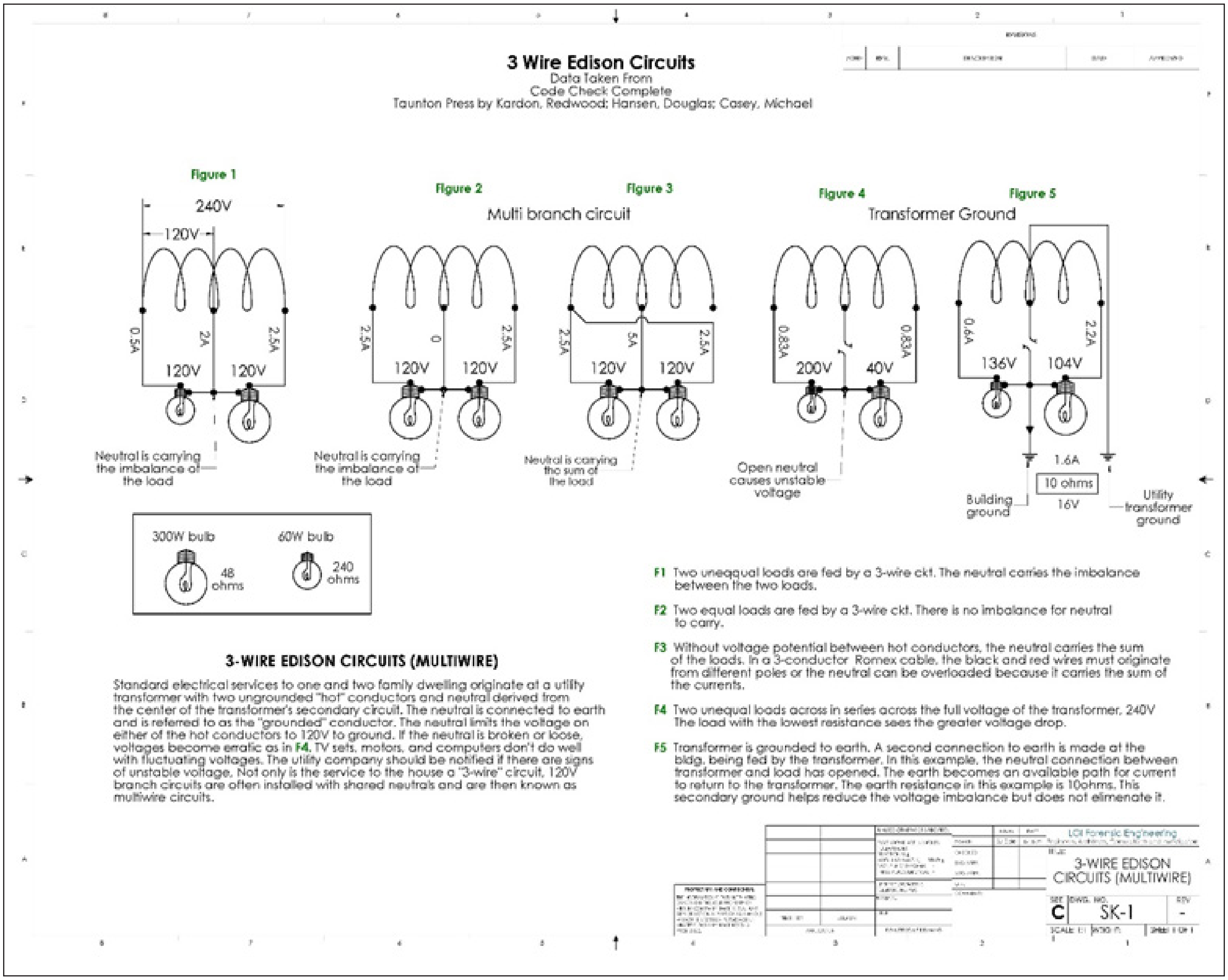

Figure 9
A sketch showing a three-wire Edison circuit (multiwire).

and framing, roof materials, flooring, etc.). There was no one at home when the fire started.

Subject Neutral Service Splice

The messenger neutral conductor was examined at the scene and in the lab. The bare conductor contained two compression-type splices approximately 2 feet from each other (**Figure 10**)[7]. A compression splice is designed to connect two ends of a conductor.

A destructive examination of both the intact and separated splices was performed during a lab examination. Splice connector #1 was intact, and both conductors were still attached. Before destructive examination, the section of the messenger neutral conductor with the purple taped end extended toward utility pole #1. The section of the messenger neutral conductor between splice connectors

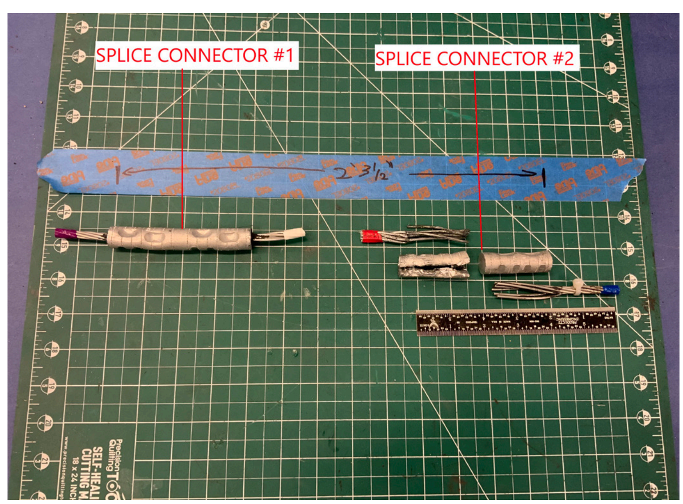

Figure 10
Splice connector #1 and #2 examined during a destructive lab examination.

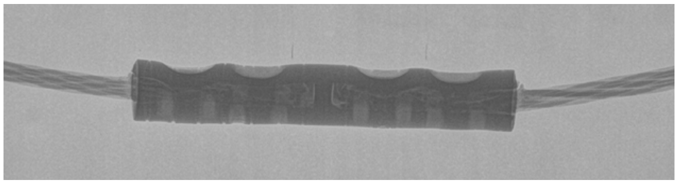

Figure 11
X-ray of splice connector #1 showing proper embedment of the conductors.

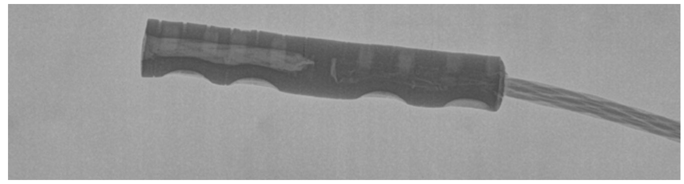

Figure 12
X-ray of splice connector #2 showing proper adequate embedment of "house"-side conductor.

#1 and #2 are identified by the white and red taped ends. The red taped end of the messenger neutral conductor was intentionally pulled from splice connector #2 during the examination. The conductor connected to the "house" side of splice connector #2 (shown taped in blue) had separated because of the tree fall, resulting in the "open" neutral condition. X-ray examination showed that the crimp was within manufacturer guidelines/specifications (**Figures 11** and **12**).

Crimp splices are used to connect two ends of a conductor. The compression sleeve/splice is designed to service drop or short-span overhead distribution lines. These splices are designed for a holding strength of 700 pounds.

The plaintiff's initial theory put liability on the utility company for not properly de-energizing the service to the home and properly pulling the meter after the tree fell. Through the course of the investigation, the plaintiff's theory shifted to a "defective" splice with no analysis or testing to support their theory. The authors had planned on further testing of the compression splice; however, the case settled — and no further testing was performed.

Utility Pole #1

Utility pole #1 was installed sometime in 2001. At the time of installation, the utility pole was approximately 45 feet long and buried approximately 8 feet in the ground. This placed the top of the pole at approximately 37 feet above the ground. The primary power lines were located approximately 35 feet above the ground, and the service drop to the subject house was located approximately 25 feet above the ground.

The utility company classified utility pole #1 as a "class 1" pole with a specified wood species of Southern pine. The subject utility pole was last inspected and treated in 2013 by the utility, and no issues were noted at the time. During the scene examination, no wood rot or insect damage around the base of the utility pole was discovered.

The strength of a utility pole is determined by the fiber strength of the wood species from which the pole is produced. The *National Electrical Safety Code* (NESC-1997) references ANSI O5.1-1992 for determining the permitted stress level of natural wood poles based on fiber strength[8,9]. Note: Although NESC-1997 is not the current version, it was in place at time of the utility pole installation.

The fiber strength provided by ANSI O5.1-1992 represents the Modulus of Rupture (MOR) for that wood species. The MOR represents the maximum load-carrying capacity of a member in bending, and it is an accepted criterion of strength[10]. For Southern pine and Douglas fir wood poles, the fiber strength is given as 8,000 psi. A similar value for the fiber strength of Southern pine is also referenced by the North American Wood Pole Council[11].

It is worth noting that the *National Design Specification Supplement for Wood Construction* (NDS) also provides tabulated design reference values for use in the design of wood structures. However, the values provided in the NDS have been developed using American Society for Testing and Materials (ASTM) standard D2555, *Standard Practice for Establishing Clear Wood Strength Values*, and Standard D245, *Standard Practice for Establishing Structural Grades and Allowable Properties for Visually Graded Lumber*. When comparing average strength values (i.e., MOR values) of a specific wood species to the design reference values given by the NDS, the design reference values often have a built-in safety factor for material strength, thus the discrepancy in strength values. Nevertheless, when designing utility poles, the material's properties should be obtained from ANSI O5.1 as required by the NESC-1997.

Based on the length and class type of the pole, ANSI O5.1-1992 also provides the minimum required circumference at 6 feet from the butt and the minimum circumference at the top of the pole. For a Southern pine pole approximately 45 feet in length, the minimum circumference at 6 feet from the butt is equal to 43 inches, and the minimum circumference at the top of the pole is 27 inches.

Force Exerted on the Neutral Service Splice

The subject tree near utility pole #2 fell toward the south and onto the power lines going east-west between utility pole #1 and utility pole #2. The force of the tree caused utility pole #1 to fracture and be pulled toward the west. As a consequence, the service drop conductors between the subject house and utility pole #1 were placed under tension.

Figure 13 is a free-body diagram of utility pole #1 showing the various forces acting on the utility pole following the tree fall and immediately after the utility pole fractured. The utility pole represents a cantilevered beam with a circular cross-section. At the top of the member, the forces acting on the pole are represented by F_p, the force exerted by the primary power lines crossing the street between utility pole #1 and pole #2, and by F_s, the force resisted by the service drop conductors extending toward the subject house. The distance from the ground to the primary power lines is represented by d_p, and the distance from the ground to the service drop is represented by d_s.

Before the failure of the pole, the utility pole was in a state of static equilibrium with no net forces acting on the utility pole. During a state of static equilibrium, the sum of moments about any point on the pole would be equal to zero. Following the failure of the utility pole, in order to maintain static equilibrium, the sum of moments acting on the pole would have to be maintained at zero. Taking the sum of moments about point A, equation 2 is derived.

(Eq. 2) $\sum M_A = (F_p \times d_p) - (F_s \times d_s) = 0$

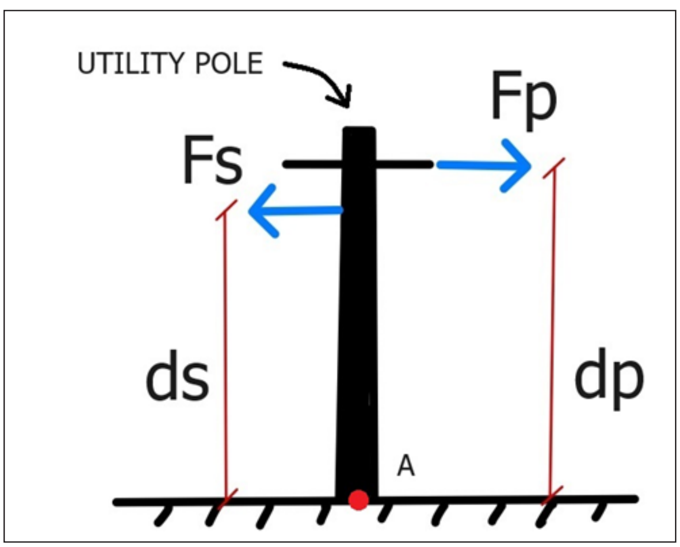

Figure 13
Free-body diagram showing the forces acting on utility pole #1 at the time of the tree fall.

Following the tree fall, the subject pole fractured at the base because of a net bending moment imposed on the subject pole greater than the resisting moment of the subject utility pole. The resisting moment is the amount of force a pole can withstand at the point of maximum stress before it breaks[10].

The resisting moment for the subject utility pole can be obtained by solving for M_{max} in equation 3, where σ represents the fiber strength of the wood species, and S is the section modulus of the cross section of the subject member. The section modulus of the cross section can be calculated by using equation 4 and 5, where d represents the diameter of the circular cross section and C, represents the circumference of the pole at ground-line.

$$\text{(Eq. 3) } \sigma = \frac{M_{max}}{S}$$

$$\text{(Eq. 4) } S = \frac{\pi * d^3}{32}$$

$$\text{(Eq. 5) } d = \frac{C}{\pi}$$

The minimum circumference provided by ANSI O5.1-1992 for a wood pole is based on a classification point located 6 feet from the butt. The setting depth of utility pole #1 provided by the utility company was approximately 8 feet. A pole is a tapered cylinder; therefore, the circumference of the utility pole at the ground line, C, was derived from equation 6 to account for the additional two feet of depth. C_b is the pole circumference at 6 feet from the butt, C_t is the circumference of the pole at the top, D_p is the distance from butt of pole to top of pole, D_g is the distance from the pole butt to the ground-line, and D_b is the distance from pole butt to classification point given by ANSI O5.1-1992.

$$\text{(Eq. 6) } C = \frac{(D_p - D_g) * (C_b - C_t)}{(D_p - D_b)} + C_t$$

$C = 42.1"$

$C_b = 43"$

$C_t = 27"$

$D_p = 45'$

$D_g = 8'$

$D_b = 6'$

Using equation 3 and solving for M_{max}, we can derive at equation 7:

$$\text{(Eq. 7) } M_{max} = \frac{\sigma * \pi}{32} * \left(\frac{c}{\pi}\right)^3$$

$$M_{max} = \frac{8000psi * \pi}{32} * \left(\frac{42.1''}{\pi}\right)^3$$

$$= 1{,}890{,}107 \; lb \text{ - } in$$

$$= 157{,}508 \; lb \text{ - } ft$$

The calculated maximum allowable bending moment of utility pole #1 represents the maximum bending moment that can be resisted by the pole before catastrophic failure. The subject force exerted by the falling tree on the primary lines between utility pole #1 and pole #2 created a net bending moment on the subject utility pole that equaled or exceeded the resisting moment of the pole. The net bending moment exerted at the base of the cantilever utility pole can be calculated using equation 8.

$$\text{(Eq. 8) } M = M_{max} = (F_p * d_p)$$

As a result of the failure of the utility pole (i.e., $M \geq M_{max}$), the service drop conductors were placed in tension in an attempt for the system to maintain static equilibrium. We can derive equation 9 from equations 2 and 8 using this relationship.

$$\text{(Eq. 9) } M_{max} = (F_p * d_p) = (F_s * d_s)$$

Solving for F_s, we can derive at equation 10.

$$\text{(Eq. 10) } F_s = {M_{max}}/{d_s}$$

$$= {157{,}508 \; lb - ft}/{25 \; ft}$$

$$= 6{,}300 \; lb$$

Based on the above calculations, a force of approximately 6,300 pounds was exerted on the service drop conductors as it resisted the net bending moment exerted on utility pole #1 by the fallen tree.

Based on the manufacturer's information for the subject splice on the neutral wire closest to the house, the subject splice had a holding strength of approximately 700 pounds. Under the force of the fallen tree, the subject splice was subjected to a force much greater than 700 pounds and thus resulted in the failure of the neutral splice connector closest to the house.

The eyelet and insulator bail at the point of attachment were discovered to be undamaged following the tree fall. Additionally, no portion of the bare neutral conductor between the point of attachment and utility pole #1 was discovered to have failed. It is the authors' opinion that, based on the inherit sag in the service drop conductors as well as the relatively low holding strength of the splice connector, the force exerted on the service drop was immediately relieved by the failure of the splice connector.

Based on the location of utility pole #1, the pole was a dead-end pole for the power lines extending toward the west. Rule 264 of NESC-1997 provides that the use of "guys, braces, or other suitable construction" shall be provided to provide additional strength when the loads on the structure are greater than can be supported by the structure alone[8]. NESC-1997 further provides that "such measures shall also be used where necessary to limit the increase of sags and provide sufficient strength for those supports on which the loads are sufficiently unbalanced, for example, at corners, angles, dead-ends, large differences in span lengths"[8]. However, at the time of the joint-scene examination, utility pole #1 did not contain any guyed wires or braces. The use of guyed wires at this location would have been expected to have provided additional lateral support to utility pole #1 and significantly decreased the forces exerted on the service drop conductors.

Conclusion

The authors concluded that the fire was caused by an open neutral event that caused the failure of RPT devices, resulting in overheating. The open neutral event was created because a large tree caused catastrophic damage to a utility pole, exposing the home's service line neutral to excessively large forces. These excessively large forces acted upon a properly installed splice on the neutral, causing it to separate. The utility service provider properly spliced the service neutral in accordance with the manufacturer's specifications and industry standards. The utility pole was not installed with guy wires at the time of the tree fall. Guy wires would have reduced the forces exerted on the compression splices as a result of the tree fall.

Acknowledgements

Special thanks to the laboratory staff at LGI Forensic Engineering, P.C.

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Beyond the Building Code: A Forensic Approach to Construction Defect Evaluation Utilizing the Construction Variance Evaluation Methodology

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Abstract

The applicable building code provides prescriptive specifications that allow construction of the built environment without the need for design professionals to dictate every aspect of every project; however, the building code does not consider all available materials, designs, and/or methods of construction — nor does it consider possible alternatives or construction variances. Since there is more than one way to accomplish a goal, a forensic investigation should consider the intent and purpose of a prescriptive specification (i.e., the desired performance) in order to determine whether an as-built construction variance is capable of accomplishing the same without adversely affecting a structure. This paper will explore the installation of cement plaster veneer and manufactured window assemblies to demonstrate how construction variances can still meet the intent and purpose of applicable prescriptive specifications. As a result, a true forensic approach to construction defect evaluation should not blindly follow prescriptive specifications. Instead, it should employ engineering analysis and a practical method such as the construction variance evaluation methodology (CVEM) to consider the performance aspects of construction variances before concluding that such variances are construction defects.

Keywords

Alternative, analysis, building code, construction, defect, deficiency, evaluation, forensic engineering, intent, investigation, methodology, performance, prescriptive, purpose, specification, variances

Introduction

A true forensic approach to construction defect evaluation should consider the intent and purpose of a prescriptive specification in order to determine whether an as-built construction variance is capable of accomplishing the same without adversely affecting a structure. The applicable building code provides prescriptive specifications to aid the construction of the built environment without the need for design professionals to dictate every aspect of every project; however, the building code does not consider all available materials, designs, and/or methods of construction. These limitations are addressed in Chapter 1 of the International Building Code (IBC) and the International Residential Code (IRC).

According to the Introduction in the Preface of the 2021 IBC[1]:

> *The International Building Code® (IBC®) establishes minimum requirements for building systems using prescriptive and performance-related provisions.*

Similarly, according to the Introduction in the Preface of the 2021 IRC[2]:

> *The International Residential Code® (IRC®) establishes minimum requirements for one- and two-family dwellings and townhouses using prescriptive provisions.*

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The aforementioned ideology is also presented in similar verbiage in all preceding versions of the IBC and IRC.

According to the Merriam-Webster Dictionary, the word "prescriptive" is an adjective that means acquired by, founded on, or determined by prescription or by long-standing custom. Therefore, the building codes can be regarded as adopted manuals of prescribed construction specifications that have a history of successful performance (i.e., based on long-standing custom). Consequently, alternative materials, designs, and construction techniques may be used in practice that can accomplish the general intent and purpose of the building codes without meeting their exact prescriptive specifications.

According to Section 101.3 of the 2021 IBC[1]:

> ***101.3 Purpose.*** *The purpose of this code is to establish the minimum requirements to provide a reasonable level of safety, health and general welfare through structural strength, means of egress, stability, sanitation, light and ventilation, energy conservation, and for providing a reasonable level of life safety and property protection from the hazards of fire, explosion or dangerous conditions, and to provide a reasonable level of safety to fire fighters and emergency responders during emergency operations.*

Similarly, according to Section R101.3 of the 2021 IRC[2]:

> ***101.3 Purpose.*** *The purpose of this code is to establish the minimum requirements to provide a reasonable level of safety, health and general welfare through affordability, structural strength, means of egress, stability, sanitation, light and ventilation, energy conservation and safety to life and property from and other hazards and to provide a reasonable level of safety to fire fighters and emergency responders during emergency operations.*

According to Section 104.11 of the 2021 IBC (similar verbiage is also presented in all preceding versions of the IBC)[1]:

> ***104.11 Alternative materials, design and methods of construction and equipment.*** *The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed alternative meets all of the following:*
>
> *1. The alternative material, design or method of construction is satisfactory and complies with the intent of the provisions of this code,*
>
> *2. The material, method or work offered is, for the purpose intended, not less than the equivalent of that prescribed in this code as it pertains to the following:*
>
> *2.1. Quality*
> *2.2. Strength*
> *2.3. Effectiveness*
> *2.4. Fire resistance*
> *2.5. Durability*
> *2.6. Safety*

Similarly, according to Section R104.11 of the 2021 IRC[2] (similar verbiage is also presented in all preceding versions of the IRC):

> ***R104.11 Alternative materials, design and methods of construction and equipment.*** *The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code. The building official shall have the authority to approve an alternative material, design or method of construction upon application of the owner or the owner's authorized agent. The building official shall first find that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, not less than the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety…*

Based upon the preceding, the building codes acknowledge their prescriptive limitations, and, as such, they permit the use of alternative materials, designs, and construction techniques when an alternative is deemed to be "satisfactory" and "complies with the intent" of the provisions of the codes, and the alternative can also provide a "reasonable level" of safety, health, and general welfare.

The building codes are intended to cover conventional and common construction practices by employing recipe-style measures like a cookbook (i.e., using prescribed amounts of prescribed ingredients and baking them in a prescribed manner for a prescribed amount of time will yield a standard food product). Continuing with the cookbook analogy, a construction variance from a prescriptive specification may be akin to baking a chocolate chip cookie with marginally less sugar, a substitution of whole wheat flour in lieu of white flour, or excluding a portion of one chocolate chip. In the end, the baker still achieves the desired result of a chocolate chip cookie that still has all the essential ingredients, qualities, and functions of a standard chocolate chip cookie. On the contrary, a more-significant construction variance may be akin to baking a chocolate chip cookie with a substantial reduction in the amount of sugar or the omission of chocolate chips, which would yield a product that does not conform to a standard chocolate chip cookie.

The prescriptive provisions of the building codes provide a means to the end, assuring a minimum level of performance, and the prescriptions, themselves, are not the end, nor are they the only means to the end. As a result, the building codes affirm that materials, designs, and methods of construction may deviate from the prescriptive specifications of the building codes under certain circumstances when an alternative is "satisfactory" and can accomplish the general intent and purpose of the building codes. Regardless of the building official's involvement during the original construction of a project, the building codes contemplate the use of alternative materials, designs, and construction methods. Therefore, the same potential alternatives should be contemplated during the post-construction forensic investigation of code variances.

Post-construction forensic evaluations that are based solely upon an exacting compliance with prescriptive building code specifications can be viewed as being myopic if such evaluations do not consider the capacity of a product, element, component, or system to perform its intended function in its as-built state. As affirmed by the building codes, alternative materials, designs, and construction methods may be used in practice to accomplish the general intent and purpose of the building codes without meeting their exact prescriptive specifications. As a result, meeting prescriptive code specifications after the fact is mostly academic. Since it is the intent of the building codes to prescribe specifications that yield a standard level of acceptable performance, the actual performance of the construction variance should generally govern its evaluation.

Construction Variance Evaluation Methodology

Over the years and through the forensic investigation of thousands of structures, the authors developed the Construction Variance Evaluation Methodology (CVEM), which is illustrated in **Figure 1**, as a practical and objective method for the forensic evaluation of construction variances to determine whether or not a variance is "satisfactory" and "complies with the intent" of the provisions of the codes.

As illustrated in **Figure 1**, the CVEM is not solely based upon compliance with prescriptive specifications or failure/damage; rather, it adopts the ideology of a respected engineering pioneer, T.Y. Lin, who stated "…engineers who, rather than blindly following the codes of practice, seek to apply the laws of nature," and it implements engineering judgement to determine whether a component or system that exhibits a construction variance is capable of performing its intended function in conjunction with the manifestation of distress (or the likelihood for the manifestation of distress in the future)[3]. When evaluating a construction variance with respect to the potential for distress to manifest in the future, one should consider the passage of time as well as any expected future catalyst (e.g., wind event, rainfall event, etc.) to determine the future ability of a component or system to perform its intended function. Through extensive forensic investigative experience, the CVEM, by applying the laws of nature and utilizing engineering judgement, has been well established as a practical and objective method for evaluating construction variances. The CVEM also provides an alternative to blindly following codes of practice — a method that may be perceived as a myopic approach used to achieve a predetermined outcome.

In a peer reviewed paper titled "Misapplication of Pressure Vessel Codes in Forensic Applications," which was published in the *Journal of the National Academy of Forensic Engineers* (December 2020), Bart Kemper, P.E. stated the following regarding code compliance[4]:

> *…Directly analyzing a structure with respect to a code assesses "code compliance" …being "out of code compliance" does not necessarily indicate failure nor predict the failure mode.*

In addition, in a paper titled "An Expert Guide to Identifying Construction Defects," which was published in the *International Institute of Building Enclosure Consultants Interface* (July 2016), Derek Hodgin, P.E. stated the following regarding as-built conditions[5]:

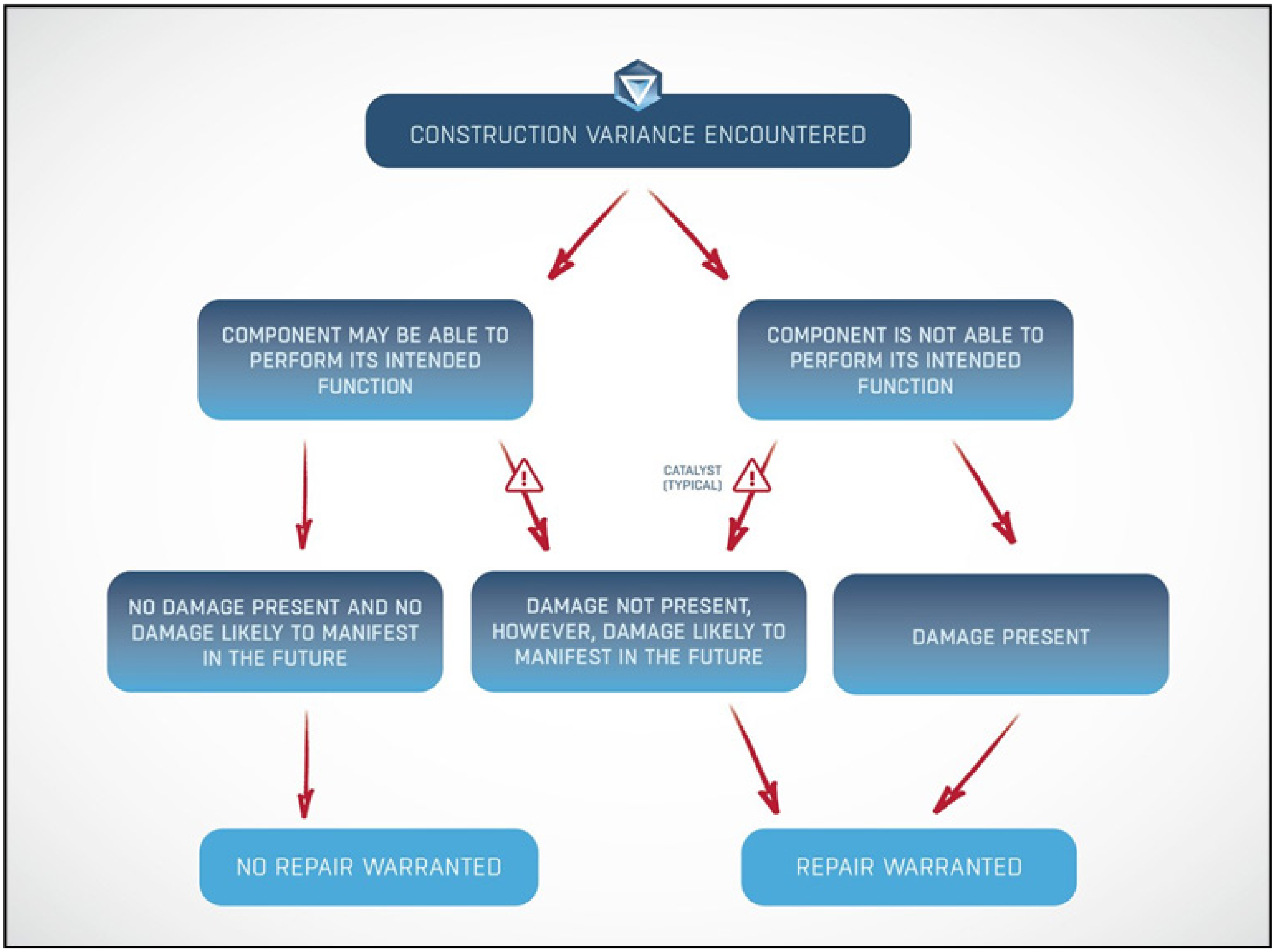


Figure 1
Construction Variance Evaluation Methodology (CVEM).

> *…The analysis of an as-built condition should be based on function, not technical deviations from specific requirements with no margin for error.*

The aforementioned ideologies expressed by Kemper and Hodgin support the forensic evaluation illustrated by the CVEM.

As examples of the application of the CVEM, this paper will explore the installation of cement plaster veneer and manufactured window assemblies to demonstrate how construction variances may or may not meet the general intent and purpose of building code and/or code-referenced standard specifications when the exact prescriptive specifications are not met.

A "deficiency" is a condition absent of something necessary for completeness or perfection, and a "defect" is a condition of an imperfection or abnormality that impairs quality, function, or utility; however, the two terms are often used synonymously. For the purpose of this paper, the authors do not make any intentional distinction between the use of "deficiency" and "defect."

Strength of Lath Attachment for Cement Plaster (Stucco) Veneer

With respect to residential structures governed by the IRC, the attachment of metal lath for cement plaster (stucco) veneer is addressed in Section R703.7.1 of the 2021 IRC as well as Section 7.10.2.2 of ASTM C 1063[2,6]:

> ***R703.7.1 Lath.*** *Lath and lath attachments shall be of corrosion-resistant materials in accordance with ASTM C1063. Expanded metal, welded wire, or woven wire lath shall be attached to wood framing members or furring... The lath shall be*

attached with 1½-inch-long (38 mm), 11-gage nails having a $^{7}/_{16}$-inch (11.1 mm) head, or $^{7}/_{8}$-inch-long (22.2 mm), 16-gage staples, spaced not more than 7 inches (178 mm) on center along framing members or furring and not more than 24 inches (610 mm) on center between framing members or furring, or as otherwise approved. Additional fastening between wood framing members shall not be prohibited...

ASTM C 1063-18b (version referenced in Chapter 44 of the 2021 IRC) *7.10.2.2 Diamond-mesh expanded metal lath, flat-rib expanded metal lath, and wire lath shall be attached to… vertical wood framing members with 6d common nails… or 1-in. (25 mm) wire staples driven flush with the plaster base. Staples shall engage not less than three strands of diamond mesh and flat rib expanded metal lath or not less than two strands of wire lath and penetrate the wood framing not less than ¾ in. (19 mm). When metal lath is installed over sheathing, use fasteners that will penetrate the framing members not less than ¾ in. (19 mm).*

Similar verbiage is also presented in all preceding versions of the IRC and ASTM C 1063.

It should be noted that Section 7.10.2.2 of ASTM C 1063-18b conflicts with Section R703.7.1 of the 2021 IRC with respect to lath fasteners[2,6]. Section 7.10.2.2 of ASTM C 1063-18b specifies that lath fasteners shall penetrate wood framing members not less than ¾ of an inch; however, Section R703.7.1 of the 2021 IRC only prescribes for fasteners to align with wood framing members (or furring), but it does not specify a minimum penetration depth into the wood framing members[2,6]. In fact, the 2021 IRC prescribes the use of $^{7}/_{8}$-inch-long staples to attach the lath, which is not consistent with the penetration depth suggested by Section 7.10.2.2 of ASTM C 1063-18b when lath is applied over exterior sheathing materials[6]. According to Section R102.4.1 of the 2021 IRC, where conflicts occur between the provisions of the IRC and referenced standards, the provisions of the IRC shall apply[2]. As a result, it is debatable whether or not the specifications of ASTM C 1063-18b even apply to metal lath fasteners because the IRC provides its own specifications for lath attachment that take precedence over those provided elsewhere.

The installation of metal lath utilizing fasteners that align with wood framing members (wall studs) is illustrated in **Figure 2**.

In some parts of the United States, it is a common construction practice to attach the metal lath directly to wood structural sheathing panels, such as plywood or oriented strand board (OSB), with staples spaced at approximately 6 inches on center each way without any regard for the alignment of fasteners with underlying wood framing members (wall studs) as illustrated in **Figure 3**. Without any analysis, the aforementioned practice is often asserted to be a construction deficiency by some simply because the placement of fasteners does not strictly comply with the exact prescriptive specifications of the IRC; however, it should be noted that Section R703.7.1 of the 2021 IRC also provides an option to attach the metal lath "as otherwise approved"[2].

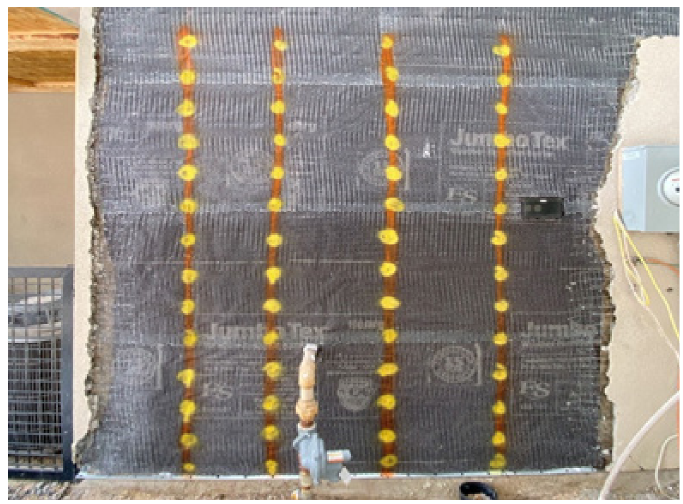


Figure 2
Installation of lath fasteners (yellow dots) aligned with underlying framing members (vertical red lines).

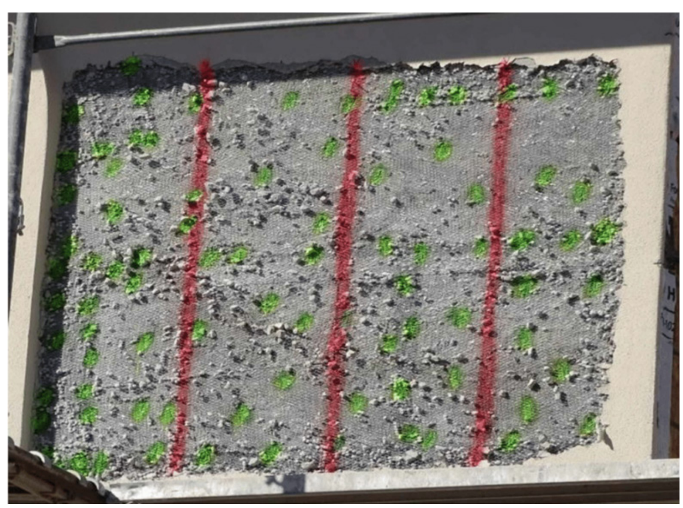


Figure 3
Installation of lath fasteners (green dots) without regard to alignment with underlying framing members (vertical red lines).

In consideration of metal lath installed over an exterior wall sheathed with $^7/_{16}$-inch-thick OSB panels, a staple fastener $^7/_8$ of an inch in length would penetrate the full depth of the sheathing panel regardless of whether or not the staples were aligned with framing members. According to the International Staple, Nail and Tool Association (ISANTA), the withdrawal capacity of a staple fastener in a wood substrate is a function of the staple leg diameter, the staple leg penetration depth, and the specific gravity of the wood substrate[7]. According to the National Design Specification (NDS) for Wood Construction, the specific gravity of Spruce-Pine-Fir is 0.42 (a common lumber species for wall studs in the authors' part of the country)[8]. According to the NDS, the specific gravity of OSB sheathing is generally 0.50[8]. Assuming the same staple gauge (leg diameter) for both substrates, an approximate 45 percent increase in the specified quantity of staples would be required to penetrate $^7/_{16}$ of an inch into OSB sheathing with a specific gravity of 0.50 in order to yield an equivalent withdrawal capacity as the minimum quantity of staples specified in Section 7.10.2.2 of ASTM C 1063-18b (¾ of an inch of penetration into a wall stud with a specific gravity of 0.42)[6].

Assuming the presence of additional fasteners to transfer forces from the OSB sheathing to the wall studs, an equivalent withdrawal capacity that meets the intent of ASTM C 1063 can be achieved by utilizing an approximate 45 percent increase in the minimum quantity of specified fasteners when installed through $^7/_{16}$-inch-thick OSB sheathing by itself. In addition, the installation of $^7/_8$-inch-long staples at a spacing of approximately 6 inches on center each way would provide in excess of three times the total quantity of staples specified by Section 7.10.2.2 of ASTM C 1063-18b when exterior wall studs are spaced at 16 inches on center[6]. As a result, metal lath installed with staple fasteners spaced at approximately 6 inches on center each way would actually exhibit a higher withdrawal capacity than metal lath installed in strict compliance with ASTM C 1063-18b[6]. Although the installation of metal lath with staples spaced at 6 inches on center each way requires the use of more fasteners, it should be noted that Section R703.7.1 of the 2021 IRC explicitly states that additional fastening between wood framing members shall not be prohibited[2].

In a white paper titled "Questioning the Stucco Lath Fastening Requirements of ASTM C1063," which was published in the *Journal of Architectural Engineering* (March 2010), Brett D. Newkirk, P.E. of Alta Engineering Company reached a similar conclusion regarding the attachment of cement plaster veneer to an underlying wood substrate[9]:

> *The stucco clinging to the OSB sheathed walls of most residential and low rise commercial buildings is probably not going to fail due to non-ASTM compliant fastening. In fact, the analysis shows that when consideration is given to the greater frequency of fasteners naturally occurring through implementation of the hand rule, the attachment to the sheathing alone is superior to the attachment to the framing members alone. The rationale for the current ASTM C1063 requirement appears to be an antiquated stipulation that does not acknowledge the significant holding capacity of the structural sheathing used in many buildings today.*

When staples in metal lath are not aligned with framing members, some investigators may assert that the as-built condition is a construction deficiency without any further analysis simply because the observed condition does not meet the exact prescriptive specifications of the building codes; however, as affirmed by the building codes, alternative materials, designs, and construction methods may be used in practice to accomplish the general intent and purpose of the building codes without meeting their exact prescriptive specifications. Accordingly, the CVEM serves as a practical and objective method for the forensic evaluation of construction variances to determine whether or not a variance is "satisfactory" and "complies with the intent" of the provisions of the codes.

In implementing the CVEM, one should first determine the intent of the applicable building code specifications to determine whether or not the construction variance in question is capable of performing its intended function in its as-built state. The intent of specifications associated with the attachment of metal lath in cement plaster veneer is to ensure that the cement plaster veneer is adequately attached to the structure for safety and durability. As previously discussed, it is possible to attach metal lath to a wood structural sheathing panel in a manner that provides an equivalent (or greater) withdrawal capacity than the prescriptive specifications of 2021 IRC without meeting the exact prescriptive specifications of the 2021 IRC (i.e., without aligning the fasteners with framing members).

In the event that metal lath for cement plaster veneer is attached to the substrate in a manner that does not meet the exact prescriptive specifications of the building codes, the as-built condition should be further evaluated to determine whether the as-built condition is capable of performing the intended function. If the metal lath is attached to the substrate in a manner to provide a withdrawal capacity equivalent to (or better than) the withdrawal capacity provided by the prescriptive specifications of the IRC — and there are no salient signs of excessive cracking, out-of-plane cracking, and/or detachment from the substrate (with no reason to suspect that such distress may manifest in the future) — the investigator would be justified in concluding that the as-built attachment of the cement plaster veneer is "satisfactory" and "complies with the intent" of the provisions of the IRC. Therefore, the construction variance is not a construction deficiency. On the contrary, if the metal lath is attached to the substrate in a manner that yields associated distress in the veneer (or such distress is likely to manifest in the future under typical usage conditions), the investigator would be justified in concluding that the as-built attachment of the cement plaster veneer is not capable of performing its intended function; therefore, the construction variance is a construction deficiency.

Installation of Flanged Windows to Prevent Moisture Intrusion

With respect to residential structures governed by the IRC, the installation of window assemblies is addressed in Section R609.1 of the 2021 IRC[2]:

> ***R609.1 General.*** *This section prescribes performance and construction requirements for exterior windows and doors installed in walls. Windows and doors shall be installed in accordance with the fenestration manufacturer's written installation instructions. Window and door openings shall be flashed in accordance with Section R703.4. Written installation instructions shall be provided by the fenestration manufacturer for each window or door.*

Similar verbiage is also presented in all preceding versions of the IRC.

Section R609.1 of the 2021 IRC specifies that window assemblies shall be installed in accordance with the manufacturer's written installation instructions[2]. As a result, compliance with the manufacturer's written instructions for the installation of window assemblies and associated flashing components is apparently mandatory to achieve compliance with the 2021 IRC.

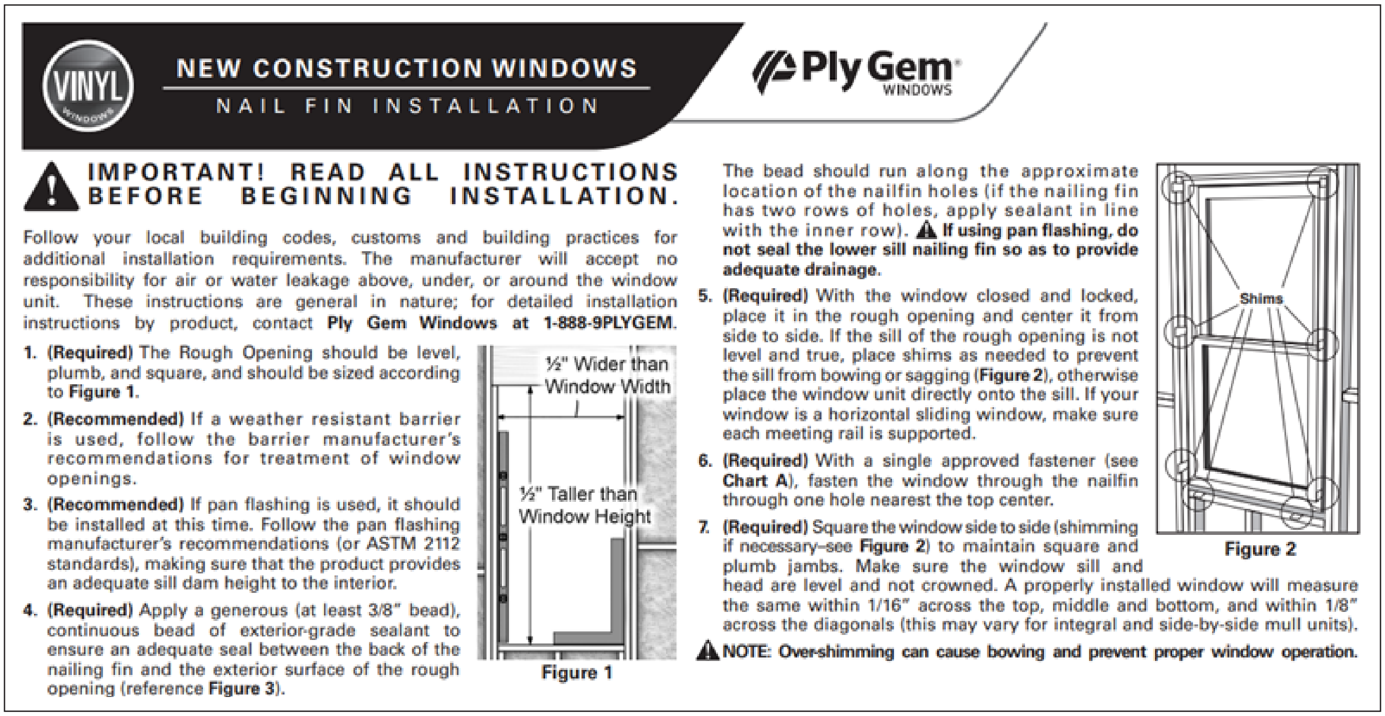
Based upon the authors' experience, written instructions for the installation of flanged window assemblies vary by manufacturer. While some window manufacturers may specify a fastener schedule relative to the prefabricated fastener holes in the mounting flanges (i.e., fasteners at every prefabricated fastener hole or fasteners at every other prefabricated fastener hole), some manufacturers specify a fastener schedule based upon a measured spacing (i.e., fasteners at 12 inches on center), which may result in some prefabricated fastener holes in the mounting flanges not being filled.

In addition, some manufacturers specify the application of sealant behind the mounting flanges of the window assembly, while others do not include any such specifications. As a result, an accurate evaluation of window installation cannot typically be performed without consulting the applicable manufacturer's written installation instructions.

The written installation instructions for vinyl window assemblies manufactured by Ply Gem®, a portion of which are provided in **Figure 4**, specify the application of sealant behind the mounting flanges to seal the window assembly to the substrate; however, the written installation instructions for vinyl window assemblies manufactured by Jeld-Wen®, a portion of which are provided in **Figure 5**, do not specify the application of sealant behind the mounting flanges[10,11].

The differences in window installation instructions, with respect to the inclusion/omission of sealant behind the mounting flanges, demonstrates an inconsistency amongst window manufacturers regarding the potential benefit of sealant applied behind the mounting flanges. Due to the fact that the 2021 IRC specifies that window assemblies shall be installed in accordance with the manufacturer's written installation instructions, the 2021 IRC consents to the installation of window assemblies in both manners. According to Section R601.1 of the 2021 IRC, the installation of vinyl window assemblies by Ply Gem® is apparently code-compliant with the application of sealant behind the mounting flanges; however, the installation of vinyl window assemblies by Jeld-Wen® is apparently code-compliant without the application of sealant behind the mounting flanges[2,10,11]. Although the two aforementioned vinyl window assemblies are similar in nature, the determination of whether or not a specific assembly complies with the exact prescriptive specifications of the IRC hinges upon the published manufacturer installation instructions available and provided at the time of construction.

When sealant is not specified to be installed behind the mounting flanges of window assemblies, self-adhering flashing membranes are typically specified to be installed over the mounting flanges of the windows to provide a weather-tight seal between the window and the underlying substrate. Regardless of a manufacturer's specification to include/omit sealant behind the mounting flanges, the authors have found that properly applied self-adhering



VINYL WINDOWS

NEW CONSTRUCTION WINDOWS
NAIL FIN INSTALLATION

Ply Gem WINDOWS

IMPORTANT! READ ALL INSTRUCTIONS BEFORE BEGINNING INSTALLATION.

Follow your local building codes, customs and building practices for additional installation requirements. The manufacturer will accept no responsibility for air or water leakage above, under, or around the window unit. These instructions are general in nature; for detailed installation instructions by product, contact **Ply Gem Windows at 1-888-9PLYGEM.**

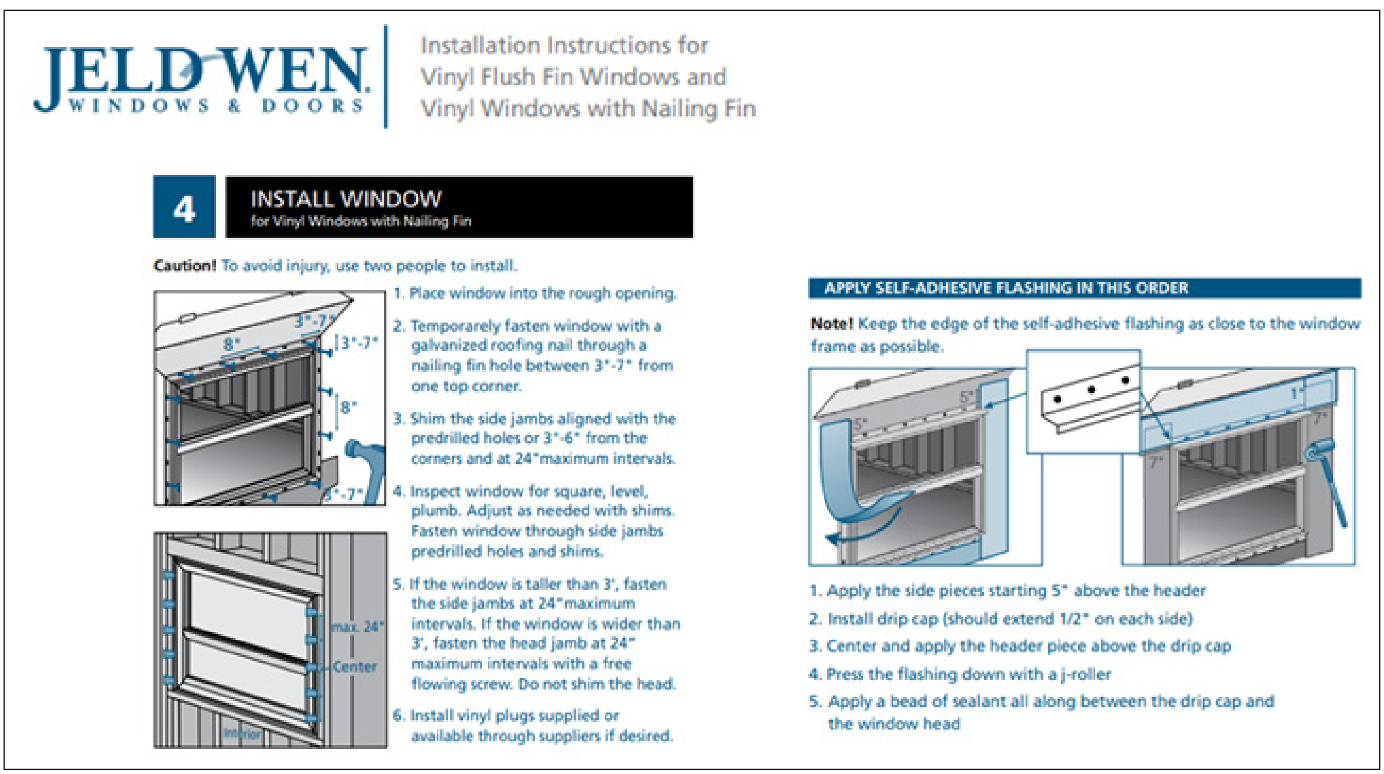
1. **(Required)** The Rough Opening should be level, plumb, and square, and should be sized according to **Figure 1.**
2. **(Recommended)** If a weather resistant barrier is used, follow the barrier manufacturer's recommendations for treatment of window openings.
3. **(Recommended)** If pan flashing is used, it should be installed at this time. Follow the pan flashing manufacturer's recommendations (or ASTM 2112 standards), making sure that the product provides an adequate sill dam height to the interior.
4. **(Required)** Apply a generous (at least 3/8" bead), continuous bead of exterior-grade sealant to ensure an adequate seal between the back of the nailing fin and the exterior surface of the rough opening (reference **Figure 3**).

The bead should run along the approximate location of the nailfin holes (if the nailing fin has two rows of holes, apply sealant in line with the inner row). **If using pan flashing, do not seal the lower sill nailing fin so as to provide adequate drainage.**

5. **(Required)** With the window closed and locked, place it in the rough opening and center it from side to side. If the sill of the rough opening is not level and true, place shims as needed to prevent the sill from bowing or sagging (**Figure 2**), otherwise place the window unit directly onto the sill. If your window is a horizontal sliding window, make sure each meeting rail is supported.
6. **(Required)** With a single approved fastener (see **Chart A**), fasten the window through the nailfin through one hole nearest the top center.
7. **(Required)** Square the window side to side (shimming if necessary–see **Figure 2**) to maintain square and plumb jambs. Make sure the window sill and head are level and not crowned. A properly installed window will measure the same within 1/16" across the top, middle and bottom, and within 1/8" across the diagonals (this may vary for integral and side-by-side mull units).

NOTE: Over-shimming can cause bowing and prevent proper window operation.

Figure 4
Window installation instructions by Ply Gem®[9].



JELD-WEN WINDOWS & DOORS

Installation Instructions for Vinyl Flush Fin Windows and Vinyl Windows with Nailing Fin

4 INSTALL WINDOW
for Vinyl Windows with Nailing Fin

Caution! To avoid injury, use two people to install.

1. Place window into the rough opening.
2. Temporarely fasten window with a galvanized roofing nail through a nailing fin hole between 3"-7" from one top corner.
3. Shim the side jambs aligned with the predrilled holes or 3"-6" from the corners and at 24" maximum intervals.
4. Inspect window for square, level, plumb. Adjust as needed with shims. Fasten window through side jambs predrilled holes and shims.
5. If the window is taller than 3', fasten the side jambs at 24" maximum intervals. If the window is wider than 3', fasten the head jamb at 24" maximum intervals with a free flowing screw. Do not shim the head.
6. Install vinyl plugs supplied or available through suppliers if desired.

APPLY SELF-ADHESIVE FLASHING IN THIS ORDER

Note! Keep the edge of the self-adhesive flashing as close to the window frame as possible.

1. Apply the side pieces starting 5" above the header
2. Install drip cap (should extend 1/2" on each side)
3. Center and apply the header piece above the drip cap
4. Press the flashing down with a j-roller
5. Apply a bead of sealant all along between the drip cap and the window head

Figure 5
Window installation instructions by Jeld-Wen®[10].

flashing membranes over the mounting flanges would negate the need for sealant behind the mounting flanges.

When window assemblies are installed without an application of sealant behind the mounting flanges, some investigators may assert that the as-built condition is a construction deficiency without any further analysis; however, as affirmed by the building codes, alternative materials, designs, and construction methods may be used in practice to accomplish the general intent and purpose of the building codes without meeting their exact prescriptive specifications. Accordingly, the CVEM serves as a practical and objective method for the forensic evaluation of construction variances to determine whether or not a variance is "satisfactory" and "complies with the intent" of the provisions of the codes.

In implementing the CVEM, one should first determine the intent of the applicable building code specifications to determine whether or not the construction variance in question is capable of performing its intended function in its as-built state. The intent of specifications associated with the installation of window assemblies is to ensure that the assemblies are adequately attached to the structure for safety, durability, and weather-resistance. As previously discussed, the 2021 IRC does not explicitly state whether or not sealant must be applied behind the mounting flanges of window assemblies, and it consents to the installation of window assemblies with and without the application of sealant behind the mounting flanges, depending upon the manufacturer of the window assembly.

In the event that a flanged window assembly by any manufacturer is installed into a rough opening without an application of sealant behind the mounting flanges, the as-built condition should be further evaluated to determine whether the as-built condition is capable of performing the intended function. If the installation of the non-sealed window assembly includes other measures, such as self-adhering flashing membranes, to prevent the passage of air and/or water behind the flanges — and there are no salient signs of water intrusion adjacent to the window assembly (with no reason to suspect that water intrusion may manifest in the future) — the investigator would be justified in concluding that the as-built installation of the window assembly is "satisfactory" and "complies with the intent" of the provisions of the IRC. Therefore, the construction variance is not a construction deficiency. On the contrary, if the installation of the non-sealed window assembly does not include other measures to prevent the passage of water behind the flanges — and signs of water intrusion are extant and adjacent to the window opening — the investigator would be justified in concluding that the as-built installation of the window assembly is not capable of performing its intended function; therefore, the construction variance is a construction deficiency.

Clearance Below Cement Plaster Veneer for Drainage Provisions

With respect to residential structures governed by the IRC, required clearances between cement plaster (stucco) veneer and underlying horizontal surfaces are addressed in Section R703.7.2.1 of the 2021 IRC[2]:

> ***R703.7.2.1 Weep screeds.*** *A minimum 0.019-inch (0.5 mm) (No. 26 galvanized sheet gage), corrosion-resistant weep screed or plastic weep screed, with a minimum vertical attachment flange of 3½ inches (89 mm), shall be provided at or below the foundation plate line on exterior stud walls in accordance with ASTM C926. The weep screed shall be placed not less than 4 inches (102 mm) above the earth or 2 inches (51 mm) above paved areas and shall be of a type that will allow trapped water to drain to the exterior of the building…*

Similar verbiage is also presented in all preceding versions of the IRC.

Section R703.7.2.1 of the 2021 IRC specifies that weep screeds along the bottom edges of cement plaster (stucco) veneer shall be placed not less than 4 inches above the earth or 2 inches above paved areas[2]. The 2021 IRC does not explicitly include any specifications for a minimum clearance between cement plaster veneer and an underlying horizontal foundation surface (e.g., porch, patio), but it is often asserted in forensic investigations that such surfaces should be considered "paved surfaces," thus requiring not less than 2 inches of clearance between the horizontal foundation surface and the veneer.

It should be noted that cement plaster (stucco) veneer and adhered masonry veneer are similar cladding systems as both systems maintain the same requirements for underlying moisture management systems, and both systems require base coats of cement plaster installed with the same plaster accessories (e.g., lath, edge casing accessories, corner accessories, weep screeds, etc.), where applicable. In fact, both cladding systems can be installed identically until the application of the surface finish. While cement plaster (stucco) veneer is completed with an application of a finish/color coat over the cement plaster base, adhered masonry veneer is finished with an application of brick, stone, or tile adhered to the cement plaster base. The only material difference between cement plaster (stucco) veneer and adhered masonry veneer is the finished surface.

With respect to residential structures governed by the IRC, required clearances between adhered masonry veneer and underlying horizontal surfaces are addressed in Section R703.12.1 of the 2021 IRC[2]:

> ***R703.12.1 Clearances.*** *On exterior stud walls, adhered masonry veneer shall be installed:*
>
> *Minimum of 4 inches (102 mm) above the earth;*
>
> *Minimum of 2 inches (51 mm) above paved areas; or*
>
> *Minimum of ½ inch (12.7 mm) above exterior walking surfaces that are supported by the same foundation that supports the exterior wall.*

Section R703.12.1 of the 2021 IRC specifies that adhered masonry veneer shall be installed a minimum of 4 inches above the earth and a minimum of 2 inches above paved areas — similar to the aforementioned prescriptive specifications for cement plaster (stucco) veneer. However, unlike the prescriptive specifications for cement plaster (stucco) veneer, Section R703.12.1 of the 2021 IRC also explicitly specifies that adhered masonry veneer shall be installed a minimum of ½ of an inch above exterior walking surfaces that are supported by the same foundation as the exterior wall (e.g., porch, patio) as illustrated in **Figure 6**[2].

Due to the fact that the 2021 IRC permits the installation of adhered masonry veneer within a distance of ½

Figure 6
Adhered masonry veneer installed with not less than ½ of an inch of clearance to the foundation.

of an inch above a monolithic porch/patio surface, the IRC apparently acknowledges the fact that ½ of an inch of clearance at such locations is sufficient to provide adequate drainage for a cladding system comprised of cement plaster (adhered masonry veneer and/or stucco).

When cement plaster (stucco) veneer is installed with a clearance of less than 2 inches to an underlying porch/patio surface, some investigators may assert that the as-built condition is a construction deficiency without any further analysis simply because the observed condition does not meet the exact prescriptive specifications of the building codes. However, as affirmed by the building codes, alternative materials, designs, and construction methods may be used in practice to accomplish the general intent and purpose of the building codes without meeting their exact prescriptive specifications. Accordingly, the CVEM serves as a practical and objective method for the forensic evaluation of construction variances to determine whether or not a variance is "satisfactory" and "complies with the intent" of the provisions of the codes.

In implementing the CVEM, one should first determine the intent of the applicable building code specifications to determine whether or not the construction variance in question is capable of performing its intended function in its as-built state. The intent of specifications associated with clearances between cement plaster (stucco) veneer and underlying horizontal surfaces is to ensure that the moisture management system can evacuate water at the base of the wall and protect the veneer/wall assembly from contact by surficial water and/or ground movement. As previously discussed, the 2021 IRC permits the installation of a similar cladding system (adhered masonry veneer) within a distance of ½ of an inch above a monolithic porch/patio surface, which indicates that ½ of an inch at such locations is sufficient to provide adequate drainage for a cladding system comprised of a cement plaster base.

In the event that cement plaster (stucco) veneer is installed with a clearance of less than 2 inches to an underlying monolithic foundation surface (e.g., porch, patio), the as-built condition should be further evaluated to determine whether the as-built condition is capable of performing the intended function. If the cement plaster (stucco) veneer is installed with sufficient clearance to provide adequate drainage for the moisture management system and protect the veneer/wall assembly from contact by surficial water and/or ground movement (½ of an inch is considered sufficient for similar cladding systems) — and the veneer does not exhibit any salient signs of excessive cracking and/or staining associated with an accumulation of water behind the veneer (with no reason to suspect that such distress may manifest in the future) — the investigator would be justified in concluding that the as-built clearance of the cement plaster veneer is "satisfactory" and "complies with the intent" of the provisions of the IRC. Therefore, the construction variance is not a construction deficiency. On the contrary, if the cement plaster (stucco) veneer is installed with less than ½ of an inch of clearance and/or the veneer exhibits signs of distress consistent with an accumulation of water behind the veneer (or such distress is likely to manifest in the future under typical usage conditions), the investigator would be justified in concluding that the as-built clearance of the cement plaster veneer is not capable of performing its intended function. Therefore, the construction variance is a construction deficiency. Other factors such as roof cover, weather exposure, and grading/drainage conditions may also be considered in the evaluation of this construction variance as well.

Summary

As demonstrated through examples associated with the installation of cement plaster veneer and window assemblies, a construction variance is not necessarily a construction defect simply because the as-built condition does not meet the exact prescriptive specifications of the building codes and/or code-referenced standards. As affirmed by the building codes, alternative materials, designs, and construction techniques may deviate from the prescriptive provisions under certain circumstances when an alternative is deemed to be "satisfactory" and "complies with the intent" of the provisions of the codes. Fasteners utilized to attach metal lath to a substrate for the application of cement plaster veneer can achieve an equivalent (or better) withdrawal capacity than the prescriptive specifications of the building codes despite the fact that fasteners may not align with framing members as specified. In addition, the installation of flanged window assemblies installed without an application of sealant behind the mounting flanges can provide adequate water-resistance despite the fact that sealant may be specified in the installation instructions by some manufacturers. Further, a clearance between cement plaster veneer and an underlying foundation surface (e.g., porch, patio) may still provide adequate drainage for the moisture management system and protect the veneer/wall assembly from contact by surficial water and/or ground movement despite the fact that such clearance may not be consistent with the prescriptive specifications of the applicable building codes.

The examples discussed herein are simply a small sample of common construction variances to demonstrate the need for additional evaluation of a construction variance prior to concluding that a construction variance is a construction defect.

Conclusion

Post-construction forensic evaluations that are based solely upon an exacting compliance with prescriptive building code specifications can be viewed as being myopic if such evaluations do not consider the capacity of a product, element, component, or system to perform its intended function in its as-built state. As affirmed by the building codes, alternative materials, designs, and construction methods may be used in practice to accomplish the general intent and purpose of the building codes without meeting their exact prescriptive specifications.

Meeting building code specifications after the fact simply for the sake of complying with building code specifications is mostly academic. Since it is the intent of the building codes to provide specifications that yield a standard level of acceptable performance, the actual performance of the disputed item should generally govern its evaluation. Remediation of a construction variance in which the remediated condition would not yield any salient improvement in performance beyond that which is already provided by the current as-built condition can be considered economic waste.

The CVEM developed by the authors serves as a practical and objective method for the forensic evaluation of construction variances to determine whether or not a variance is "satisfactory" and "complies with the intent" of the provisions of the applicable codes. The CVEM provides a guide through which additional analysis and engineering judgement can be utilized to determine whether a component or system that exhibits a construction variance is capable of performing its intended function as an alternative to blindly following codes of practice.

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Forensic Environmental Assessment and Hydrology in Louisiana's First Oil Field: A 100-Year Recreation of Historical Land Use

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Abstract

Approximately 110 years after the discovery of oil in Louisiana, fourth- and fifth-generation landowners filed a legacy lawsuit to recover damages resulting from alleged environmental contamination of family property from oil exploration, extraction, and storage. As part of the complaint, the descendants claimed that, due to the new technology of the oil industry, their uneducated ancestor could not have had reasonable knowledge and business relationships to fully understand the contracts he signed with oil companies to lease his land for oil exploration. Forensic environmental assessment and hydrology enabled the recreation of the site's historical land use and its potential for environmental impacts. Forensic analyses utilizing records and sources from disciplines typically not consulted in engineering studies provided essential insight into the origins of drainage alterations and contaminant transport across the site, including family records that demonstrated the plaintiffs' ancestors had knowledge of (and contributed to) the site's purported deteriorated conditions.

Keywords

Environmental assessment, hydrology, drainage, land use, Louisiana, oil, forensic engineering

Overview

A lawsuit filed by fourth- and fifth-generation landowners claimed environmental damage of family property resulting from oil exploration, extraction, and storage activities dating back to 1901 in Louisiana's first oil field. As part of the claim, family members alleged that the predecessor oil company took advantage of an uneducated, non-English-speaking farmer to avoid responsibility for environmental damages incurred on his land. Attorneys for the defendant, British Petroleum (BP), approached the author (forensic engineer) regarding the feasibility of reconstructing conditions on the plaintiffs' land before, during, and immediately after oil exploration in context of the larger Jennings Oil Field (site of Louisiana's first successful oil well) from approximately 1900 to the 1930s. Additionally, the defendant's attorneys had specific interest in determining the level of knowledge the original owner and his descendants had regarding early oil industry operations, specific operational activities on their land, and business managerial involvement pertaining to those activities. To address allegations of environmental contamination and lack of landowner knowledge dating back more than 110 years, four key areas of forensic environmental engineering and forensic hydrologic investigations were necessary:

1. Development of the Jennings Oil Field with a focus on Section 47 of Acadia Parish with respect to standard practices impacting the landscape.

2. Construction, use, and operation of earthen storage tanks for oil and produced water.

3. Discharge practices of earthen storage tanks and their effects on drainage and contaminant transport.

4. Knowledge and involvement of plaintiffs' ancestors regarding oil operations on their land.

The forensic engineering (FE) approach utilized ASTM E1527, *Standard Practice for Environmental Site Assessment: Phase I Environmental Site Assessment Process*, to recreate site conditions and personal knowledge dating to the beginning of the 20th century[1]. Since early industrial operations pre-dated governmental reporting requirements typically reviewed as part of the Phase I investigation[2], the list of suggested resources detailed in Section 8.3.4 Standard Historical Sources of ASTM E1527 was instrumental to this FE investigation. That list of sources of

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information regarding the history of property uses, included, but was not limited to, aerial photographs, recorded deeds and leases, court proceedings, United States Geological Survey (USGS) topographic maps, miscellaneous maps, newspaper archives, and local libraries.

Scientific investigations of present-day pollutant concentrations from legacy oil field wastes focus on collection and analysis of water, sediment, flora, and fauna — and on analysis of contaminant transport pathways[3,4,5,6]. While generating considerable data and insight into lingering effects of early oil field operations, such studies do not provide environmental assessments of legacy oil fields when they were in operation.

Site-specific land uses and impacts from oil field operations on natural water bodies that existed more than a century ago require a forensic engineering investigation. A forensic environmental assessment that includes surface water contaminant transport must recreate a landscape and local environment that no longer exist, cannot be sampled, and are beyond the memory of any living person. An equivalent forensic engineering question would be: What was the structural integrity of the steel used in a building constructed 110 years ago that no longer exists? Engineering principles in historic context support the forensic engineer in answering those questions.

Answering historic questions of land use and hydrologic changes — and of specific knowledge by people no longer living — requires a time-series analysis of multiple and varied documents in conjunction with engineering expertise. For land use changes, this is a straight-forward process of comparing maps and aerial photographs to interpret how and why features changed in the time periods between the documents. Interpreting those changes from two-dimensional images to three-dimensional ground conditions requires remote sensing and aerial photography training. Coupling the images with the engineering hydraulics and physics of water, biology of vegetative changes, and construction of oil field infrastructure reveals the history of the land and its drivers for change.

This process is similar when reconstructing a person's knowledge when that person is not available for a deposition. Conducting a reasonably exhaustive search[7] on an individual will produce a multitude of documents, most of which do not specifically answer the question of what a person knew or should have known. Connecting those disparate pieces of information in a time series of documents, however, can reveal when a person gained knowledge of a specific action. For example, the United States federal census includes a question regarding each person's occupation. A time-series analysis of federal census records demonstrates that the original landowner, the uneducated, French-speaking patriarch, self-identified as an "oil king" and the owner of an oil field in 1910[8], whereas his occupation was farming in 1900[9]. Clearly, his situation changed over that decade, supported and confirmed when analyzing contracts and business filings dates pertaining to the oil company he formed after oil was discovered on his property.

To fulfill the scope of charge, this FE investigation consisted of:

1. Literature review of the standard practices of oil extraction/storage and produced salt water disposal from the early 1900s to approximately 1932 and how they were applied to the subject property;

2. Review of lease histories and lawsuits pertaining to the subject property with respect to potentially environmentally damaging practices;

3. Engineering analyses and interpretation of historic maps, aerial photographs, technical reports, and survey data for contemporary land and water alterations resulting from oil extraction and storage on the subject property; and

4. Landowner family history regarding knowledge of oil and gas operations in general and of specific operations on their properties.

Jennings Oil Field and Section 47

September 21, 1901 was the beginning of the oil industry in Louisiana when Scott Heywood brought in a gusher near present-day Evangeline, Louisiana (**Figure 1**) that "spewed sand and oil for seven hours, until a nearby rice field resembled a black lake[10]." Early oilmen understood crop damage from oil extraction was a possibility. Heywood acknowledged that the flowing oil of that first well ruined several acres of the farmer's (Mr. Clement's) rice field, but he had paid Mr. Clement $10 in advance for any damage that might occur as a result of drilling activities[11]. Thus, the owners understood that oil infrastructure would be constructed on their land if drilling were successful. Original landowners of the subject property in Section 47 were Eugene Houssiere and Arthur Latreille, who signed their first oil exploration lease in April 1901 (five months before Heywood brought in the first successful well). The lease allowed for "mining and operating for oil, gas, and laying pipelines, and of building tanks, stations

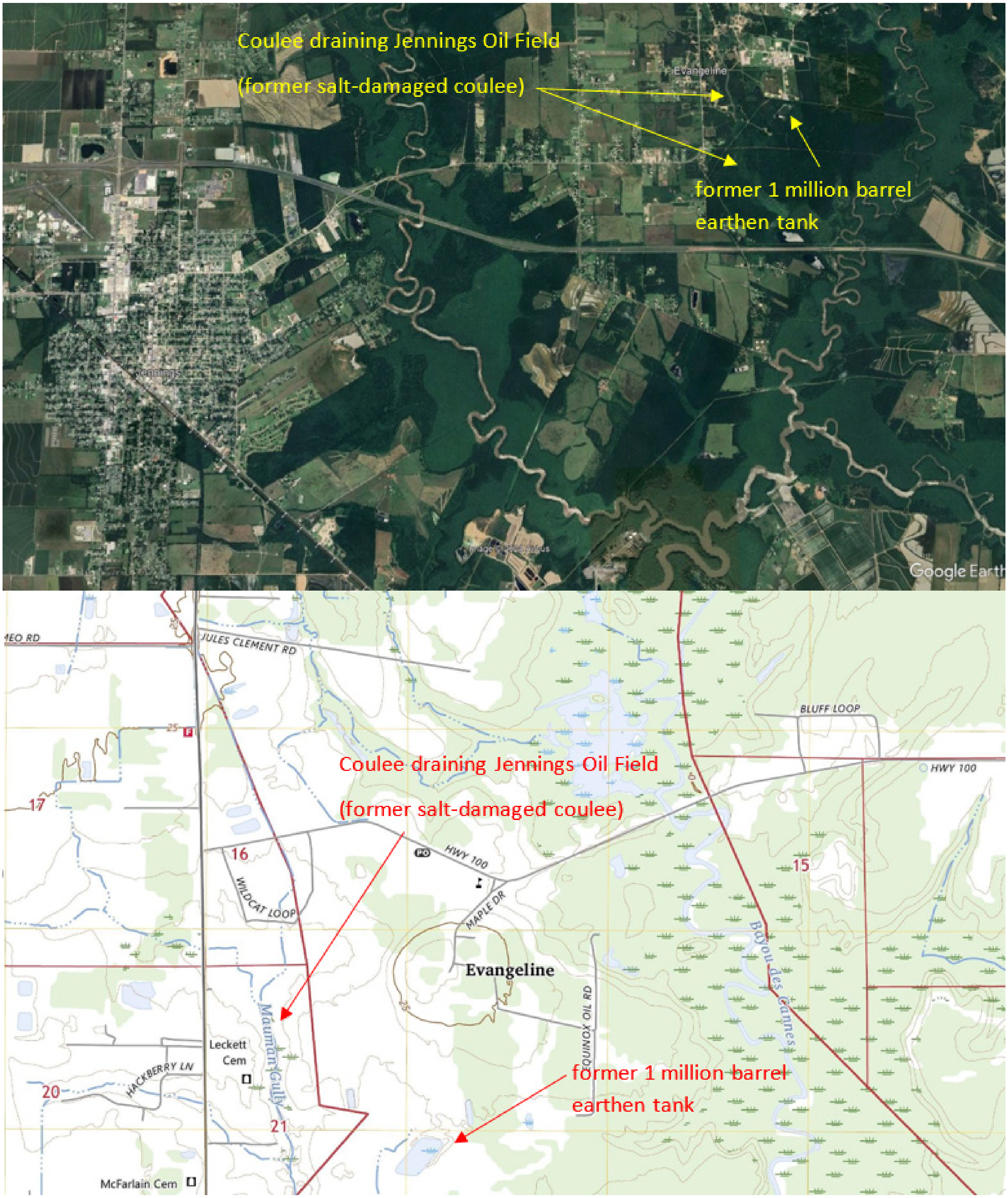


Figure 1

Vicinity images of the Jennings Oil Field and Section 47. Evangeline, Louisiana in Acadia Parish is located 40 miles east of Lake Charles, Louisiana. Prior to oil discovery in the Jennings Field, rice farming was the predominant occupation of its residents. French-speaking, uneducated Cajuns were among its early settlers, adding to the complexity of historical investigations in this region. The 1 million barrel earthen storage tank just south of the subject property is still visible in present-day photographs and maps[16,17].

and structures thereon to take care of said products[12].” On August 4, 1904, Producers Oil Company, part of the Texas Company, brought in the first great Jennings gusher on the Houssiere-Latreille tract. Following that success, Producers Oil put down several wells “in rapid succession[13].” By 1906, the Jennings Oil Field had 92 wells, five of which were in Section 47 on the plaintiffs’ land[13]. By 1910, the field had expanded to 445 wells with 73 on the plaintiffs’ land, 57 of which were producing oil[14]. Over the next 90 years, Houssiere family members executed 30 leases for oil and gas exploration on their property in Section 47[15].

Applying environmental engineering expertise and analyzing suggested informational sources detailed in ASTM E1527 for engineering applicability determined the development of the Jennings Oil Field and Section 47 resulted in the following key points in the forensic environmental assessment:

1. The Jennings Oil Field had an environmentally “messy” history of spilling gushers — something not unique to the Jennings Field. These actions were part of the culture of the boom era and universally practiced by operators in early oil fields before the onset of environmental regulations.

2. Rapid development of the Jennings Oil Field contributed to environmental degradation of the field and its surrounding areas. Constructing oil field infrastructure to store and manage crude oil lagged behind successful drilling operations.

Use of Earthen Storage Tanks

Production in the Jennings Oil Field reached 80,000 barrels daily within a few months of the first successful well. It was a “mad rush to get the oil out first” with the result that earthen tanks built “by the hundreds of thousand barrels each”[11] and above-ground pipelines crisscrossed the field to transport oil from wells to storage tanks to the rail station for shipment to buyers. Building earthen tanks to store oil prior to shipment was an oil field practice that became the norm[11] throughout the field. Even when storage capacity exceeded three million barrels (with oil transported from the field through pipelines and rail cars), storage remained a significant problem[10].

The USGS determined that tankage in the Jennings field at the close of 1904 was about 30,000,000 barrels — the larger portion of which was in earthen reservoirs. Their opinion was that earthen tanks had been “found fairly satisfactory” and much cheaper than steel tanks. The USGS additionally commented that some of the earthen tanks had “nothing done to them beyond excavating to the required depth” while others were lined with timber or were covered with a “light board roof.” Their estimate of an earthen tank’s capacity was 25,000 to 350,000 barrels[13].

The U.S. Bureau of Mines provided guidance in reservoir construction, suggesting that “the outside slope of the embankment... when finished should be thoroughly sprinkled with oil” to prevent bank erosion during heavy rains. They further commented that “it is good practice when the reservoir is in use to oil the slope two or three times a year” to prevent vegetation growth and subsequent death, which (when dry) was a fire hazard[18].

Contemporary newspapers from 1902 to around 1920 reported oilmen “believed” the “immense earthen oil tanks” were the “proper” method for handling the millions of barrels of oil. When tanks were “properly constructed,” the “siepage [sic] is not thought to exceed one-fourth of an inch,” and it was “claimed” that the sediment associated with the crude oil, asphaltum, and paraffin prevented oil from seeping farther into the earth[18]. Scott Heywood’s brother, Alba, testified that Jennings-Heywood Syndicate earthen tanks experienced “only 10 percent” oil losses to seepage, leakage, and evaporation[19].

Seepage losses varied due to construction methods, soil types, and oil characteristics. Wooden-lined tanks built on clay soils tamped by mules or machines had lower loss rates than tanks constructed solely from plowing dirt to the depth of the underlying clay and pushing it to the outside to create impounding levees[20]. Oil seeps were commonly observed through levee walls and on the ground adjacent to the tanks[21,22]. As oil was a valuable commodity, tank owners attempted to recapture as much of the seeped oil as possible by building ditches or moats around the perimeters of their tanks and using pick-up pumps to return oil to the reservoirs (**Figure 2**).

Between the smaller, immediate-need well storage pits and the larger, longer-term collection earthen tanks, the Jennings Oil Field became dotted with open pits resembling oil lakes, visible in aerial photographs as late as the 1950s (**Figure 3**). In **Figure 3** and subsequent figures, the outlined areas mark the boundaries of the plaintiffs’ properties at issue in this case.

Oil was not the only liquid stored in the massive earthen tanks. Produced water was an unwelcomed by-product of oil drilling operations. Heywood called it the “fatal salt

Figure 2
Photograph looking northeast on the Houssiere-Latreille property of earthen and steel oil tanks with pipelines, collection ditches, and pick-up pumps. For scale, a man stands in front of an earthen oil storage tank. Its containment levee is taller than the man. Wooden oil derricks on Houssiere-Latreille property are visible in the background[23]. See **Figure 5** for a plan view of this location on the Hervey map.

water intrusion[11].” As will be discussed in the following section, initially, the salt water drained across the oil field to naturally low areas, collected in the central coulee, and eventually discharged into Bayou Des Cannes, contaminating streams and ruining rice fields.

Oil producers argued “the Record clearly establishes that there is no way to care for the salt water that comes up from the ground with the oil, than to allow it to flow to the Gulf in the natural drain[25].” Further, they stated that “the discharge of salt water is practically a condition upon which the ordinary use and enjoyment of oil lands depends. The discharge of salt water is part and parcel of the process of mining oil... .” This opinion was also shared by the Heywood Oil Company, Bass & Benckenstein, and the Texas Company in their brief to the Louisiana Supreme Court, “[salt] is not a merchantable commodity. It must be gotten rid of. And the natural outlet is toward the sea from whence it came[26].” Thus, early oilmen understood produced water could impact soils and water as it flowed

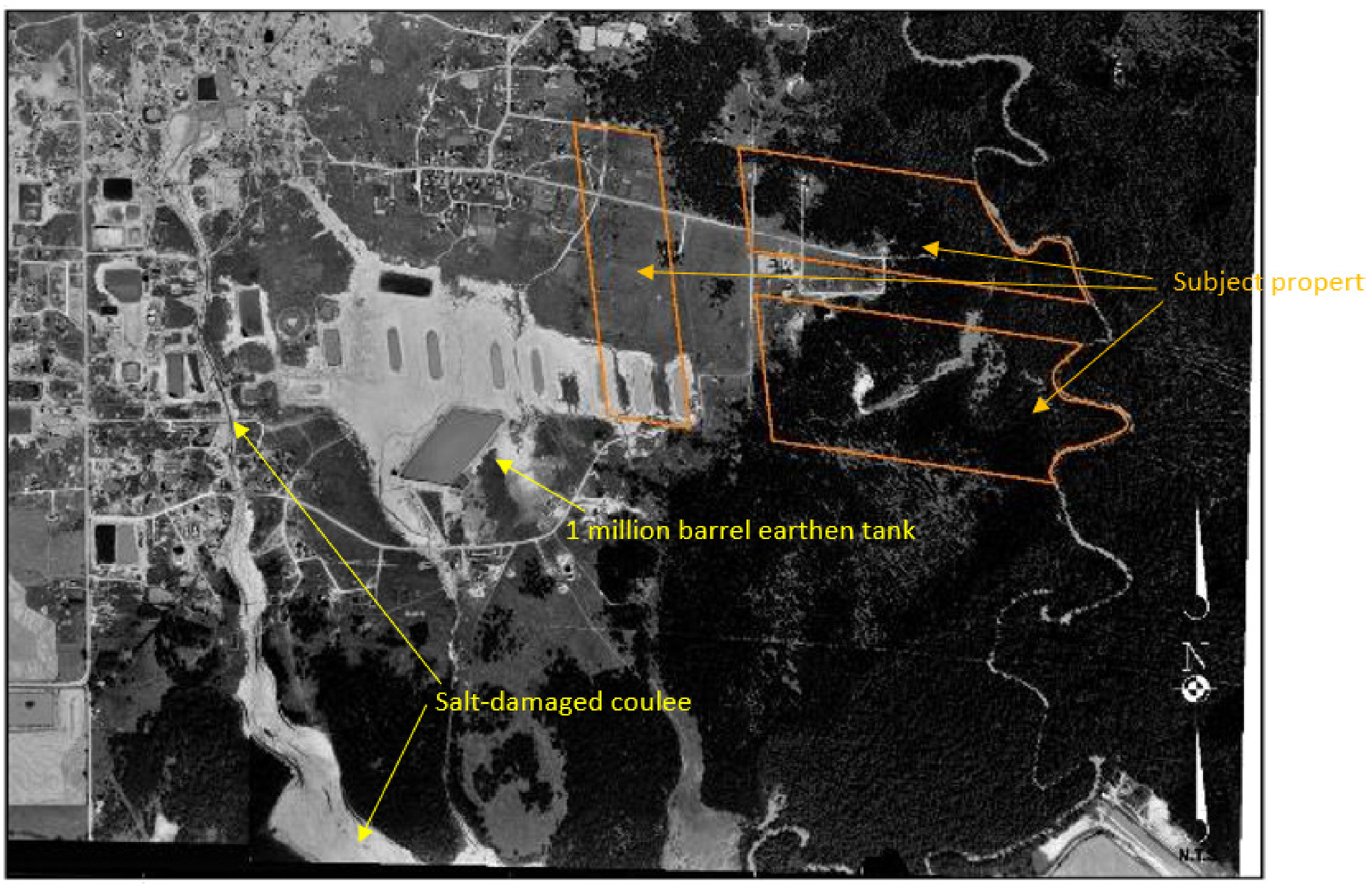


Figure 3
Photograph of the three properties of interest outlined in orange in Section 47 and of Jennings Oil Field in 1953. Massive earthen storage tanks are obvious on the Houssiere-Latreille and surrounding properties. Bayou Des Cannes is on the eastern edge of the subject property. The salt-damaged coulee from the center of Jennings Field is in the southwestern portion of the photograph[24]. The outlines of the three properties of interest will also appear on subsequent images.

downstream, but the best way to remove it from the oil field was to allow it to drain naturally. As will be discussed in the following section, oil field infrastructure altered those natural drainage patterns in the Jennings Oil Field.

Several thousand barrels of produced water accompanied several hundred barrels of oil — a ratio that led to the next big storage problem in the Jennings Oil Field. The problem was so pervasive that state legislators enacted a law requiring oil field operators to store the produced water from March 1 to September 1 (the rice growing season) and release it into natural waterways during fall and winter months. According to Heywood, "when this law went into effect, the old empty earthen tanks became as valuable to store salt water as they had been to store crude petroleum[11]."

By the 1920s, the petroleum industry recognized that large quantities of salt water that accompanied field production were becoming storage and disposal problems. The technical means of minimizing or eliminating the effects of produced water upon the environment were much less obvious, and, for a lengthy period, field operators contended with a shortage of scientific data on which to base disposal efforts. In practice, technical advances for brine disposal and their applications to new and existing fields lagged behind the accelerating pace and geographic range of field exploration and development[27].

Among early professional reports, the U.S. Bureau of Mines published *The Disposal of Oilfield Brines* nearly three decades after the discovery of oil in the Jennings Field. Their work provided a review to date of knowledge on the subject and noted that the "disposal of brines produced with crude oil and natural gas has long been a constant source of trouble to oil and gas operators, as well as to farmers and stock-raisers in the vicinity of producing fields[28]."

In Louisiana, the number of fields increased dramatically, quadrupling total production of oil and gas during the decade. Each field had unique characteristics that affected which methods were appropriate for its production, storage, and disposal. During the 1930s, brine discharge continued to surface impoundments or to water bodies[27]. The initial slow pace of engineering advancement for oil field brine disposal did not indicate the quest for improved methods of disposal had ceased, and, during this period, associated problems became better understood.

A patent filed in 1937 stated, "Another important factor in the operation of such an oil well is the disposal of the salt water recovered with the oil. Several solutions have been tried but in every instance are open to conspicuous objections. … When this refuse salt water can be impounded in storage pits, this practice is frequently followed. However, the maintenance of storage pits is subject to limitations both as to capacity and feasibility of locating them near the head of the well… . In many instances, the salt water is allowed to drain into existing running streams, but, in this case, there is a limit to what can be done without acting contrary to the public interest or infringing upon the rights of neighboring land owners[29]." Until engineers developed a viable solution to produced water disposal, natural drainage outlets would continue, albeit as the least preferred method.

Among the leading entities in advancing oilfield disposal practices, the American Petroleum Institute (API) was the first national trade association for the oil industry[30]. In 1920, API began collecting and publishing oil industry statistics. That effort continues today as a leading and credible source of industry data utilized worldwide. The organization also developed and published industry standards, recommended practices, and policies beginning in 1924[31].

At the annual meeting of the Production Division of the API in 1930, V.L. Martin, Chairman of the Standing Committee on Disposal of Production Wastes, reported "suggested remedies" to production waste disposal. His suggestion as "the most practical [method] of salt water disposal at present seems to be accomplished by dilution." That is, disposal into natural water bodies. He further stated, "While such practice is contrary to law, it is the only method available which will reduce the potential damage to water supplies[32]." In other words, dilution is the solution to pollution, according to the API in 1930.

During the 1931 meeting, V.L. Martin reported an update on the Standing Committee on Disposal of Production Wastes, stating that his committee's accomplishments were "not up to [their] own expectations,[33]" due in large part "to the lack of pertinent data to such work." He stated that, "The committee feels that it cannot recommend any radical changes in methods of disposing of wastes without setting out definitely the objectionable effects resulting from present methods of disposal… . To date, we have been unable to secure any authoritative information as to the effects of production division wastes on live stock, land, vegetation, surface water, etc."

Twelve years into its work supporting the petroleum industry and recommending best practices, standards, and policies, the API continued to lack the necessary data to produce a standard of practice for the disposal of produced water, leaving operators to follow best practices and legal restrictions applicable in their areas of operation. While no longer on the "bleeding edge" of oil field management, operators in the Jennings Oil Field were nonetheless on the "leading edge," operating without industry standards regarding brine disposal but within well-known, acknowledged industry practices.

Applying environmental engineering expertise and analyzing suggested informational sources detailed in ASTM E1527 for engineering applicability determined earthen storage tanks resulted in the following key points in the forensic environmental assessment:

1. Earthen storage tanks were widely used, obvious features in the Jennings Oil Field.

2. It was common knowledge that earthen storage tanks seeped oil. Oil field infrastructure included ditches and pumps specifically to recapture seeped oil.

3. Produced water became an environmental contaminant on land and in water bodies located downstream from the Jennings Oil Field, necessitating its storage during the agricultural growing season.

4. For more than 30 years, surface storage and direct discharge into surface water bodies were well-known, acknowledged, and accepted practices for produced water storage and discharge.

5. Earthen tanks were present at least into the 1950s on the subject land and throughout the Jennings Oil Field — even after improved storage and transportation made them obsolete.

6. The time line of direct disposal of produced water into natural water bodies continued at least into the 1930s — 30 years after the discovery of oil in the Jennings field.

Salt Water Discharge, Hydrology, and Drainage

As a waste by-product, produced water from oil operations freely flowed across the oil field surface, collected in ditches and coulees, and ultimately discharged into Bayou Des Cannes. Within four years of the first successful oil well, environmental damage from salt water discharges was evident in downstream rice fields. On August 21, 1905, William McFarlain filed suit against many of the operators in the Jennings Oil Field for oil and salt water damage to his downstream property[34]. Civil Engineer J. H. Hervey surveyed the Jennings Oil Field in response to the lawsuit filed by McFarlain, stating his map "was intended for a drainage map and tankage map" (**Figure 5**). When questioned about how waste oil drained from the wells, Hervey testified that "it goes thru [sic] the ditches that were made by natural drainage to the natural drainage of the main country[35]."

Researchers have utilized extensive soil, water, flora, and fauna sampling/testing to track past oil field produced water drainage into surface waters and groundwater[3,4,5,6]. Employing forensic environmental assessment and forensic hydrologic engineering through the methodology detailed in ASTM E1527, while not providing constituent concentrations, provides analyses of conditions contemporary to times of oil field operations.

The USGS EarthExplorer website[36] has multiple data sets of historic aerial photographs for use in a time-series analysis. For example, a historic aerial photograph and map time-series analysis shows the evolution of the natural drainage coulee in the center of the Jennings Oil Field to a salt-damaged drain through downstream fields and into Bayou Des Cannes from 1905 to 1953 by interpreting important land characteristics as they change. **Figure 4**, a 1933 aerial photograph, provides additional context to **Figure 5**, the 1905 field map, and to Hervey's salt water drainage description.

In **Figure 4**, two water bodies border Section 47 of the Jenning Oil Field: Bayou Des Cannes to the east and the central drainage coulee to the west. Even though the photograph does not contain topographic data, the "water flows downhill," or down elevation gradient, understanding of hydrology informs the forensic hydrologist that higher elevations are present between those two water bodies. The central coulee is a low elevation linear feature in this landscape — surface water flows into it. The central coulee drains downstream (downhill) to Bayou Des Cannes, an even lower elevation linear feature. Also, natural ditches and bayous typically increase in width as they flow downstream due to additional runoff they receive and transport along their paths to their discharge points in larger water bodies. In between low elevations natural drainage channels higher points of elevation must exist[37].

Vegetation differences evidenced in **Figure 4** also indicate elevation differences, thus, hydrology and drainage directions. Vegetation on land closer to natural water bodies is dense with tree canopies; vegetation farther away (uphill) is dense with prairie grasses (or rice). Upland

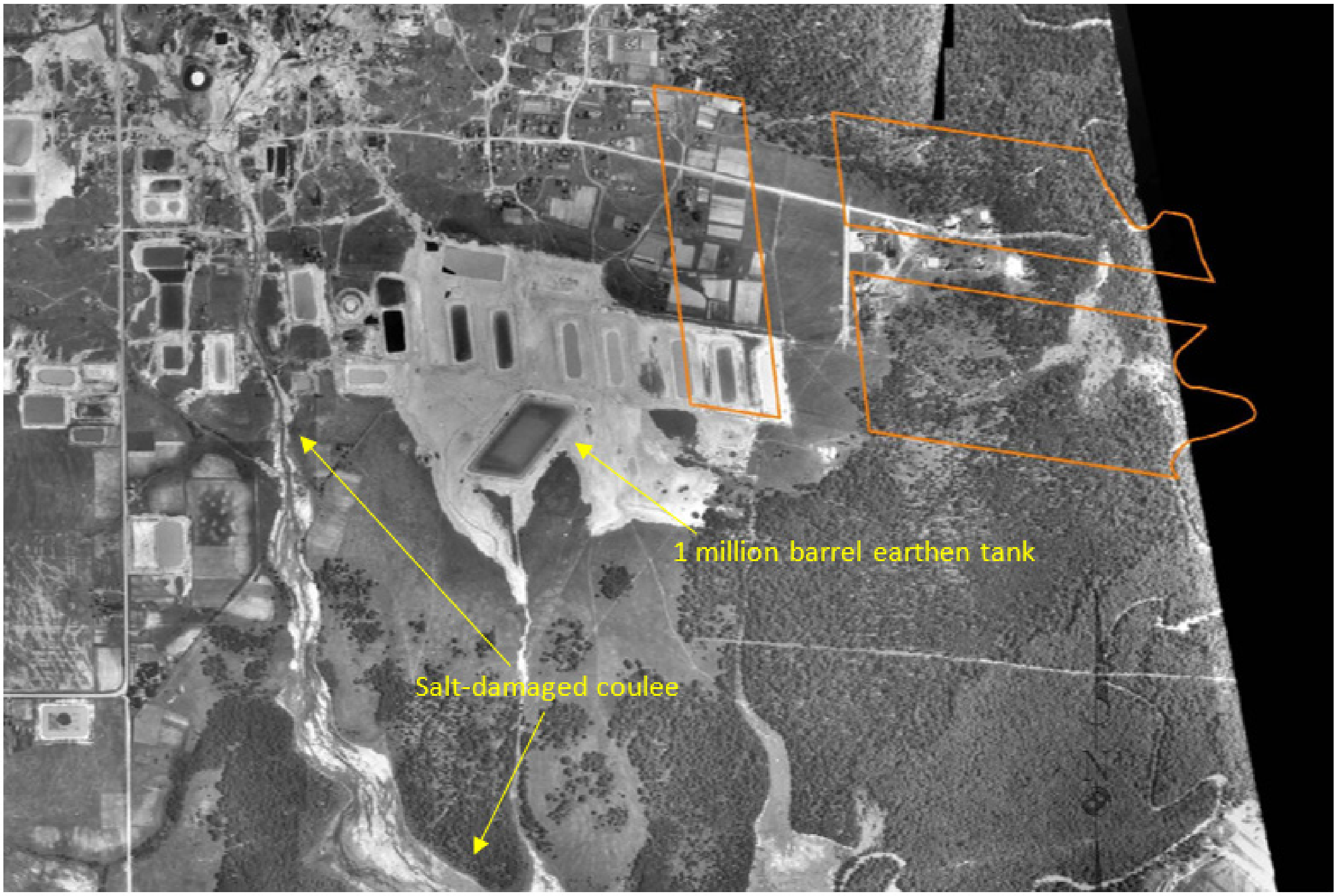
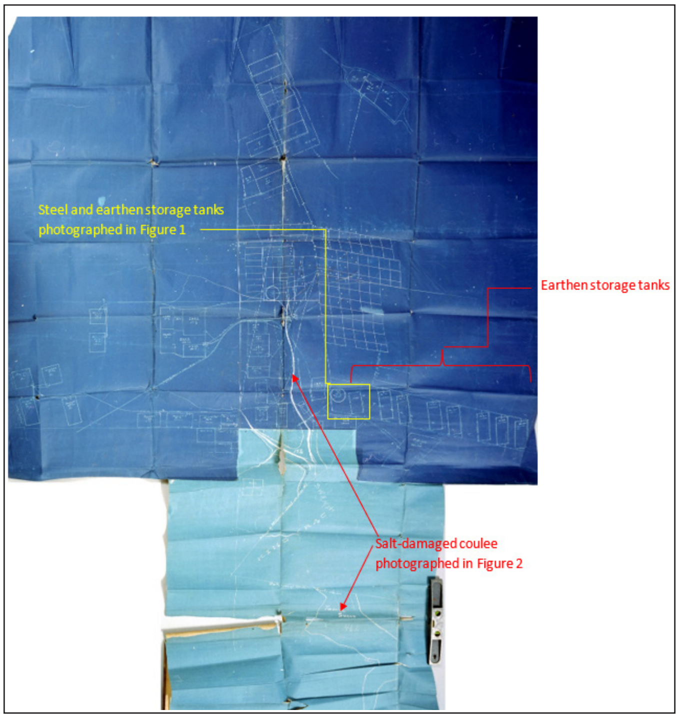


Figure 4

The earliest photograph of the three properties of interest dates to 1933[39]. The light-colored area in the center of the photograph illustrates vegetation removal as part of safe operational practices around open crude oil storage tanks. Light-colored meandering shapes along natural drainage pathways illustrate salt deposits or salt scarring of the land by produced water.



vegetation cannot grow and survive in wetter soils. Wetland vegetation present in low-lying elevations close to water bodies possess evolutionary adaptations that allow it to grow in saturated conditions[38]. The first successful well in Jennings Oil Field was in Mr. Clement's rice field, located in the northwestern corner of **Figure 4**. Although oil operations have disturbed the natural and cultivated vegetation in the vicinity of his former rice field, vegetated land extant is farther from natural water bodies and presents as grass (not tree canopy). Therefore, vegetative patterns also support north-to-south natural drainage through the oil field with west-to-east drainage closer to Bayou Des Cannes. It is

Figure 5

Hervey map detailing the Jennings Oil Field, specifically the drainage and earthen storage tanks on and near plaintiffs' properties. Oil field infrastructure had begun altering the natural drainage pattern by 1907 when Hervey produced this map. Produced water flowed down the center coulee and discharged into the rice field south of the Jennings Oil Field, ruining crops. Ultimately, the salt water entered Bayou Des Cannes, contaminating irrigation water of downstream farmers[23].

important to note that vegetation changes from winter leaf-off or drought killing grasses, for example, could reflect the dates of the photographs versus environmental responses to possible contaminant transport.

Color variations in **Figure 4** also provide information on vegetation and drainage impacts from oil operations. The lightest colors are predominantly locations devoid of vegetation, that contain infrastructure, or are salt scarred. Locations devoid of vegetation are generally by design in **Figure 4** (e.g., the tops of banks of earthen tanks and land between and around earthen tanks). Dying vegetation was a fire hazard in an open field; appropriate maintenance would have been to minimize vegetation near crude oil facilities. The presence of infrastructure generally creates straight lines or geometric patterns (straight lines and right angles are rare in nature). Longer linear features are roads, while smaller square or rectangular-shaped features are typically buildings. However, larger square or rectangular shaped features can be bare fields.

Knowing land uses of the surrounding areas is essential to differentiate geometric shapes of similar sizes when viewing two-dimensional images. Salt scarring is easily confused with a lack of vegetation near oil field infrastructure exposed to produced water. For example, the central area of **Figure 4** is likely a combination of vegetation removal for safety and salt deposits from produced water. The easiest method to distinguish salt scarring from produced water runoff and contaminant transport is to analyze the shapes of the light areas farthest from the earthen tanks. A non-geometric, naturally meandering pattern strongly suggests salt scarring from overland flow of produced water versus vegetation loss by design. The salt water follows the natural (or altered) drainage patterns determined by topography. Produced water has a higher density than fresh water, so it moves as a stratified layer along the bottom of the drainage ditch and under the fresh water precipitation. Also, salt in produced water does not evaporate with the water. Thus, the lightest colors in **Figure 4** present in meandering patterns along drainage paths are more likely to be salt deposits (scarring) than vegetation removal.

The time-series analysis approach requires applying the techniques used to analyze **Figure 4** to subsequent chronological photographs. Comparing the 1933 aerial photograph (**Figure 4**) to the 1940 aerial photograph (**Figure 6**), the 1940 image shows vegetation returning to the western fringes and in the northwestern portion of the wooded area[40]. Land to the south of the salt-scarred coulee is less vegetated than in 1933. The area around the large

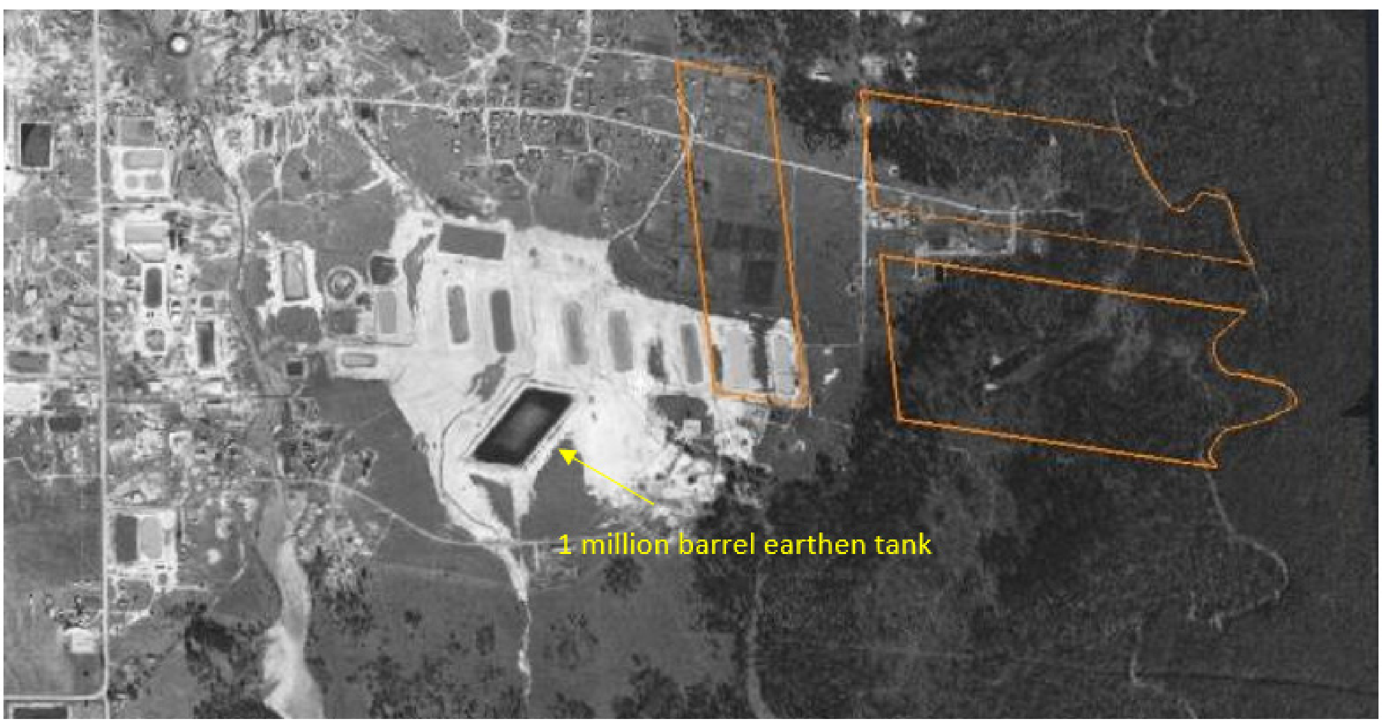
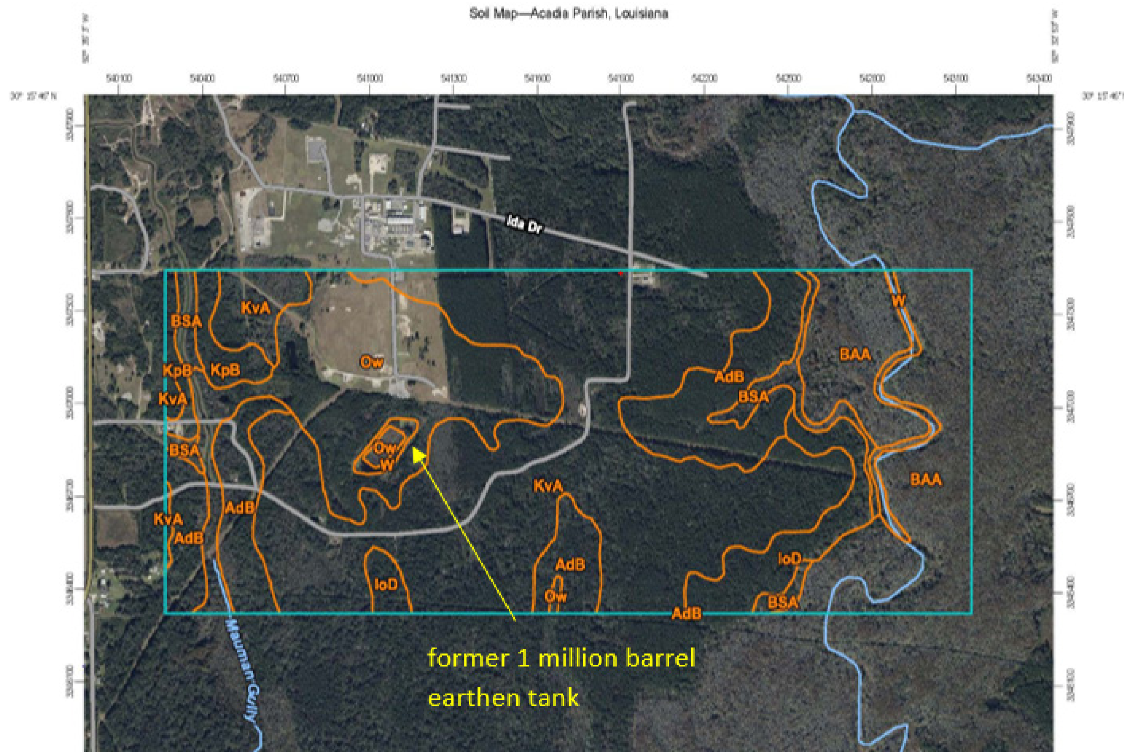


Figure 6

A 1940 aerial photograph of the subject property and surrounding area[40]. Comparing this photograph to the 1933 photograph as part of a time-series analysis illustrates changes on the land surface. When performing the FE analysis, it is important to determine the date of the photographs to account for seasonal changes with respect to water levels and vegetation growth.

earthen tanks appears to be slightly re-vegetated. The tank on the northern edge of the southern portion of the subject property appears to drain to the edge of the sparse vegetation through a small ditch. This tank was likely used to store salt water until it could be discharged during the regulated months between September and March, and the ditch likely directed the discharge to minimize the impact of the overland flow of the salt water. Support for this conclusion comes from undisturbed soil types in the subject area. Silty loam soils on the subject property facilitated drainage toward Bayou Des Cannes while the frequently flooded Basile and Brule soils adjacent to Bayou Des Cannes (**Figure 7**)



Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
AdB	Acadiana silt loam, 1 to 3 percent slopes	104.1	13.1%
BAA	Barbary mucky clay, 0 to 1 percent slopes, frequently flooded	132.1	16.6%
BSA	Basile and Brule, 0 to 3 percent slopes, frequently flooded	22.3	2.8%
IoD	Iota silt loam, 3 to 8 percent slopes	37.4	4.7%
KpB	Kaplan silt loam, 1 to 3 percent slopes	18.3	2.3%
KvA	Kinder-Vidrine complex, 0 to 1 percent slopes	343.2	43.1%
Ow	Oil-waste land	128.0	16.1%
W	Water	10.9	1.4%
Totals for Area of Interest		**796.5**	**100.0%**

Figure 7

Present-day soil survey on the subject properties and surrounding land[41]. For areas unaltered by oil field operations, present-day data informs past hydrology and drainage patterns on the subject land. Interestingly, the 1 million barrel earthen tank just south of the plaintiffs' properties presently map as oil-waste land and water — the remaining tank infrastructure continues to hold water.

encouraged produced water ponding, leading to salt scarring shown in the 1940 photograph (**Figure 6**)[41].

Extending the aerial photograph time-series analysis to more recent decades, available in GoogleEarth, reveals that in the half century since the 1940 photograph, the subject area was no longer an active oil field, and the two large, earthen storage tanks on the subject property were severely degraded (**Figure 8 top**). The eastern tank appears filled in with sediment and its perimeter levees removed, while the western tank retained its shape and ability to hold liquids, although greatly reduced in capacity. More than 100 years after the discovery of oil on the subject property, the area appears environmentally recovered with healthy vegetation covering locations of former earthen tanks (**Figure 8 bottom**). In fact, the entirety of the Jennings Oil Field experienced immense recovery from 1995 to 2009 with the dozens of earthen storage tanks infilled and closed and the main coulee revegetated over its former salt scars.

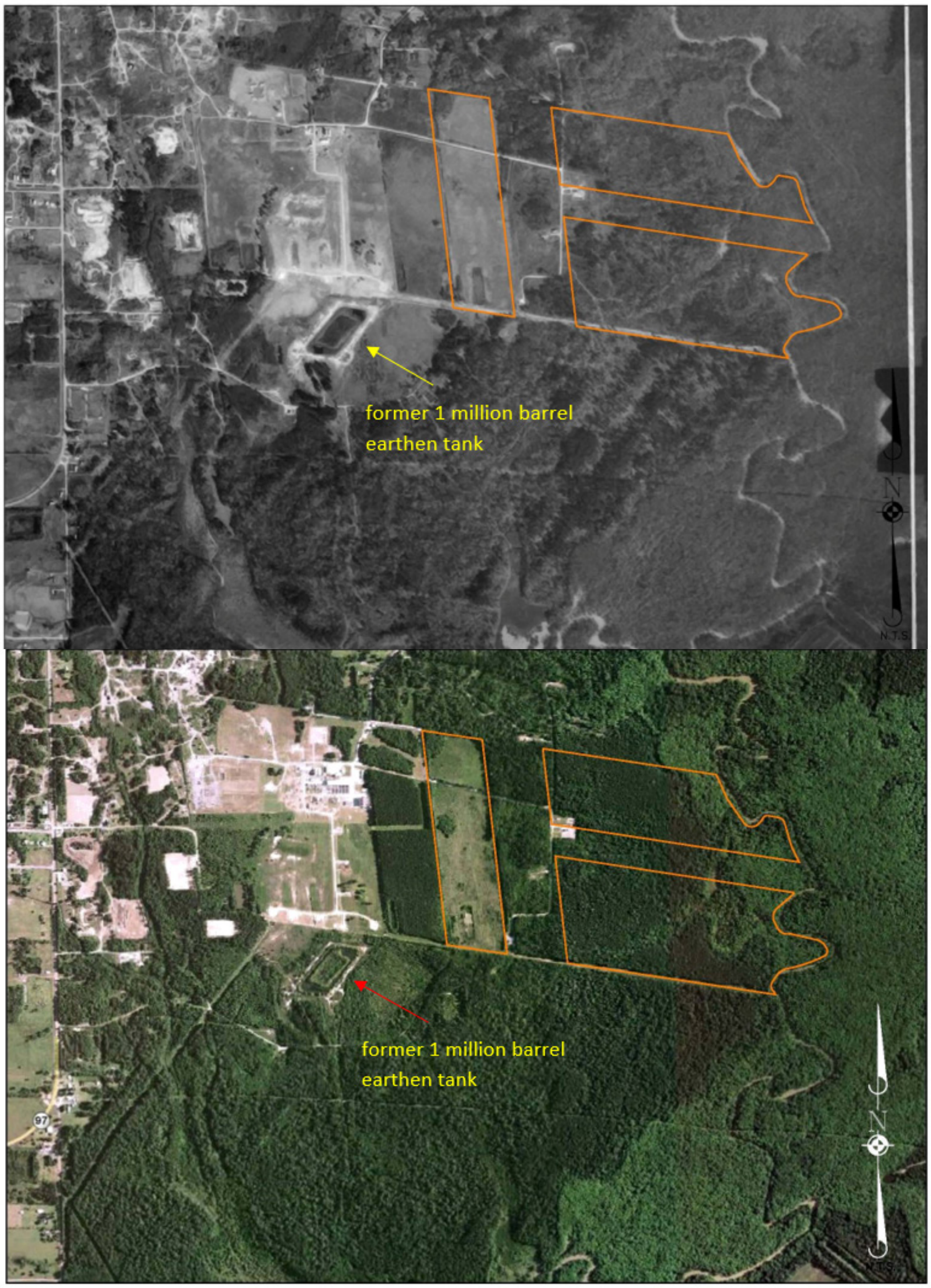


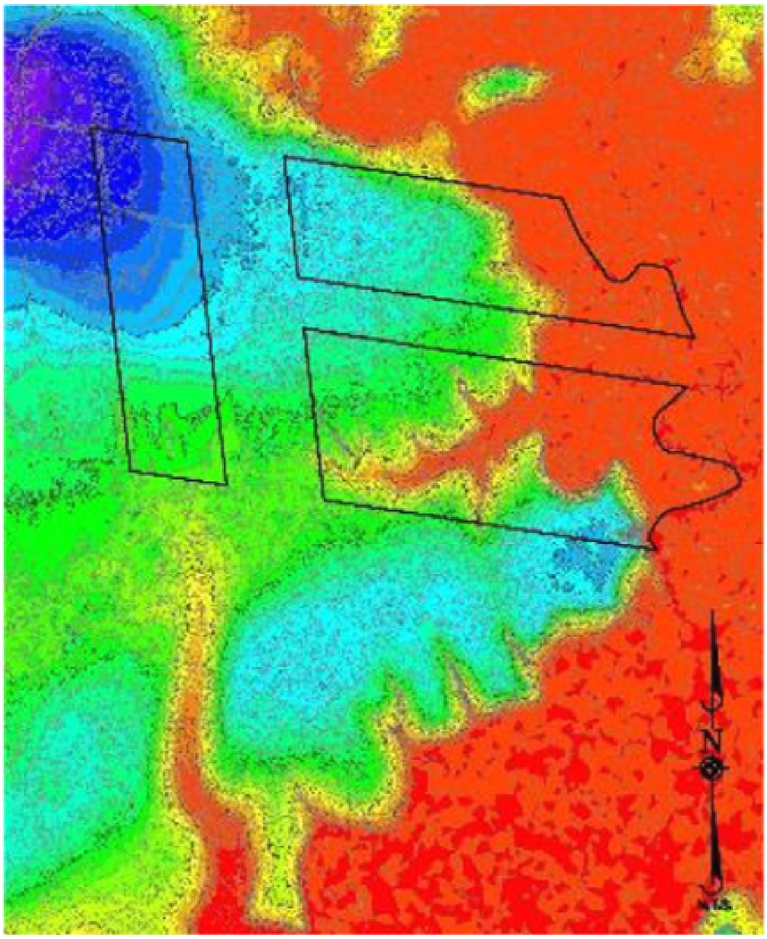
Figure 8

1995 (top)[42] and 2009[43] (bottom) aerial photographs of the subject property and surrounding area. The Jennings Oil Field experienced immense recovery from 1995 to 2009 with the closure of earthen storage tanks and revegetation in previously denuded areas.

Coupled with the historic drainage map and aerial photographs, a present-day topographic map utilizing LiDAR (Light Detection and Ranging) data provides further insight into historic drainage patterns. Small topographic features difficult to discern on hand-drawn maps and large-scale aerial photographs are more evident in the millions of data points collected with LiDAR (**Figure 9**).

Higher elevations are represented by purple and blue, medium elevations are represented by green and yellow, and lower elevations are represented by orange and red. The coulee on the southeastern portion of the subject property is clearly illustrated as a west-to-east “finger” draining between two areas of higher elevation (as discussed previously for the central drainage coulee) into Bayou Des Cannes. This is the area designated as the “salt water discharge impact area” in the plaintiff’s expert report[45]. A similar coulee, shown as a yellow-orange-red finger, drains south (down elevation gradient) from the western portion of the subject property.

Based on the down elevation gradient, the coulee on the southeastern outlined



Minimum Elevation (ft)	Maximum Elevation (ft)
-0.03	0.00
0.00	2.00
2.00	4.00
4.00	6.00
6.00	8.00
8.00	10.00
10.00	12.00
12.00	13.00
13.00	14.00
14.00	15.00
15.00	16.00
16.00	17.00
17.00	18.00
18.00	20.00
20.00	22.00
22.00	24.00
24.00	26.00
26.00	28.00
28.00	30.00
30.00	38.12

Figure 9

LiDAR map of the subject property shows that it is at lower elevations than surrounding property. The three properties of interest are outlined in black. The salt dome on which most of the 1930s drilling took place is located in the northwestern corner of the map (purple and blue round shape). Surface water flowed to and across the subject property from higher, adjacent elevations, transporting oil field wastes to Bayou Des Cannes and other lower lying areas[44].

property is the surface water runoff collection point for only a small portion of the subject property. As illustrated in **Figure 9**, based on elevation gradient, the western part of the subject property drains predominantly to the south, consistent with Hervey's description in the McFarlain case. The northern part of the property drains predominantly to the east into Bayou Des Cannes, again based on elevation gradient. Therefore, the southeastern part of the subject property is, for the most part, the only contributing drainage area to that coulee.

Land south of the subject property (on the northeastern corner of Section 40) is the dominant surface water runoff source for the coulee on the subject property due to its higher elevations. The LiDAR map in **Figure 9** shows a higher elevation in blue in that northeastern corner of Section 40. Based on topographic analysis with the highest elevations delineating the drainage watersheds, approximately half of that area in blue drains north into the coulee on the subject property, and approximately half drains south into Bayou Des Cannes. Thus, the area designated as the "salt water discharge impact area" by plaintiffs' experts predominantly receives surface water runoff, historically including salt water and oil from the oil fields — from the property south of the subject property.

Figure 10 also illustrates altered natural drainage patterns resulting from oil field infrastructure. The gold-outlined drainage subcatchment in the south-central area of the photograph outlines the diverted overland flow path water must take between and around large earthen storage tanks. The green-outlined drainage subcatchment

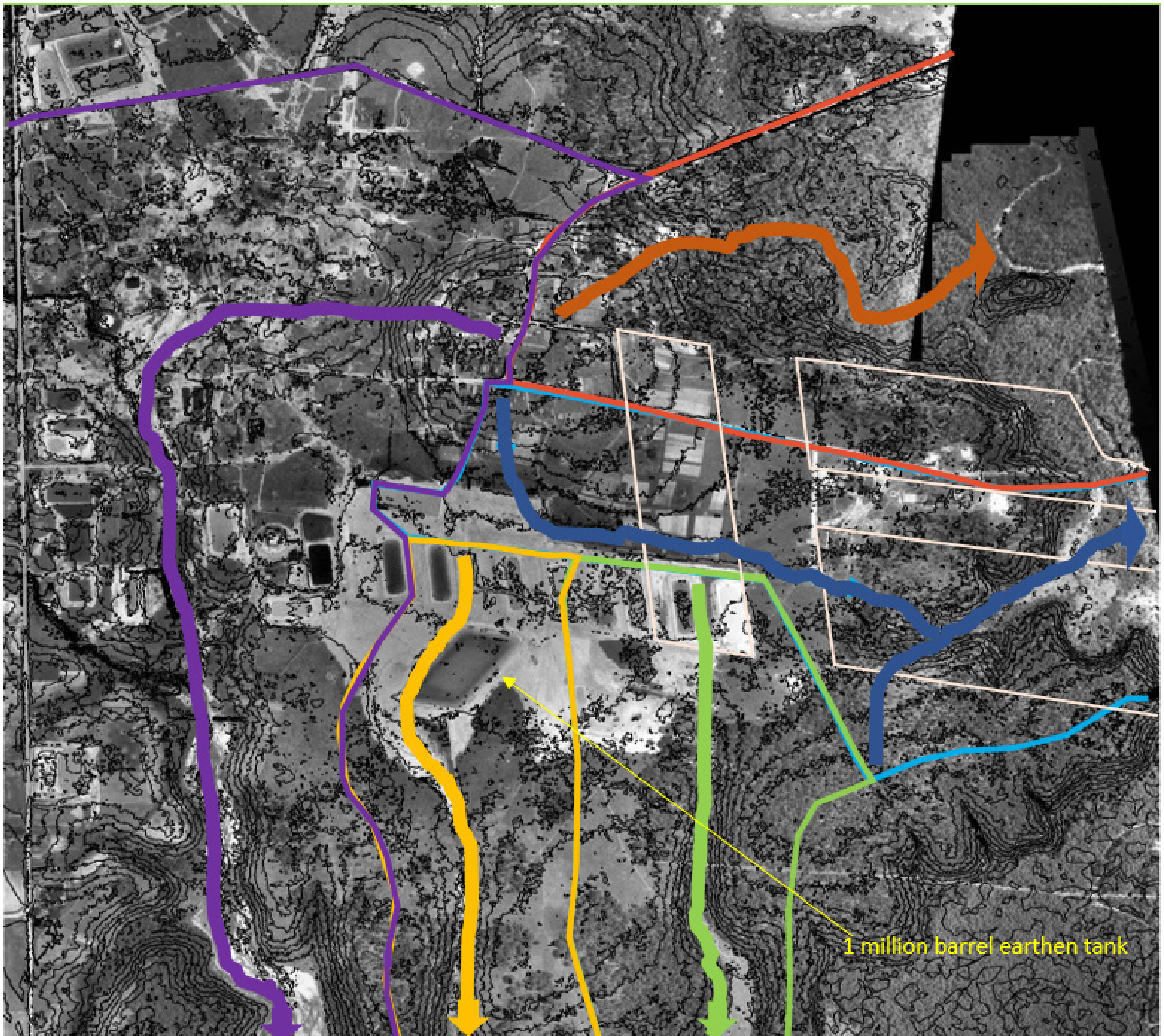


Figure 10
LiDAR elevations[44] overlaid on the 1953 aerial photograph[24] with thick lines and arrows to illustrate overland flow directions. Each color is a separate drainage subcatchment based on higher elevations around its perimeter. Forensic hydrologic analysis refuted plaintiffs' claim of salt water scarring on their property by the defendant's action when combining elevation and property boundary data with a historical aerial photograph.

east of the gold subcatchment also depicts a diverted overland flow path between earthen storage tanks. Prior to tank construction, overland water flow would have followed the natural land contour and flowed from higher elevations to lower elevations. For this area, that dominant flow path is toward the south, eventually discharging into Bayou Des Cannes.

Analysis of historic USGS topographic maps support this interpretation. The 1960 topographic map, closer in time to oil field operations than LiDAR data, illustrates an elongated white area at the same location as the "salt water discharge impact area" (**Figure 11**)[46]. Based on the contour lines, the area that drains through this arm of Bayou Des Cannes is limited to that including and immediately surrounding the southeastern portion of the subject property. The northeastern portion of the property flows to the northeast and east, and the western portion of the subject property shows a predominantly southern flow direction.

Historic aerial photograph and topographic map analyses, two-dimensional representations of actual land

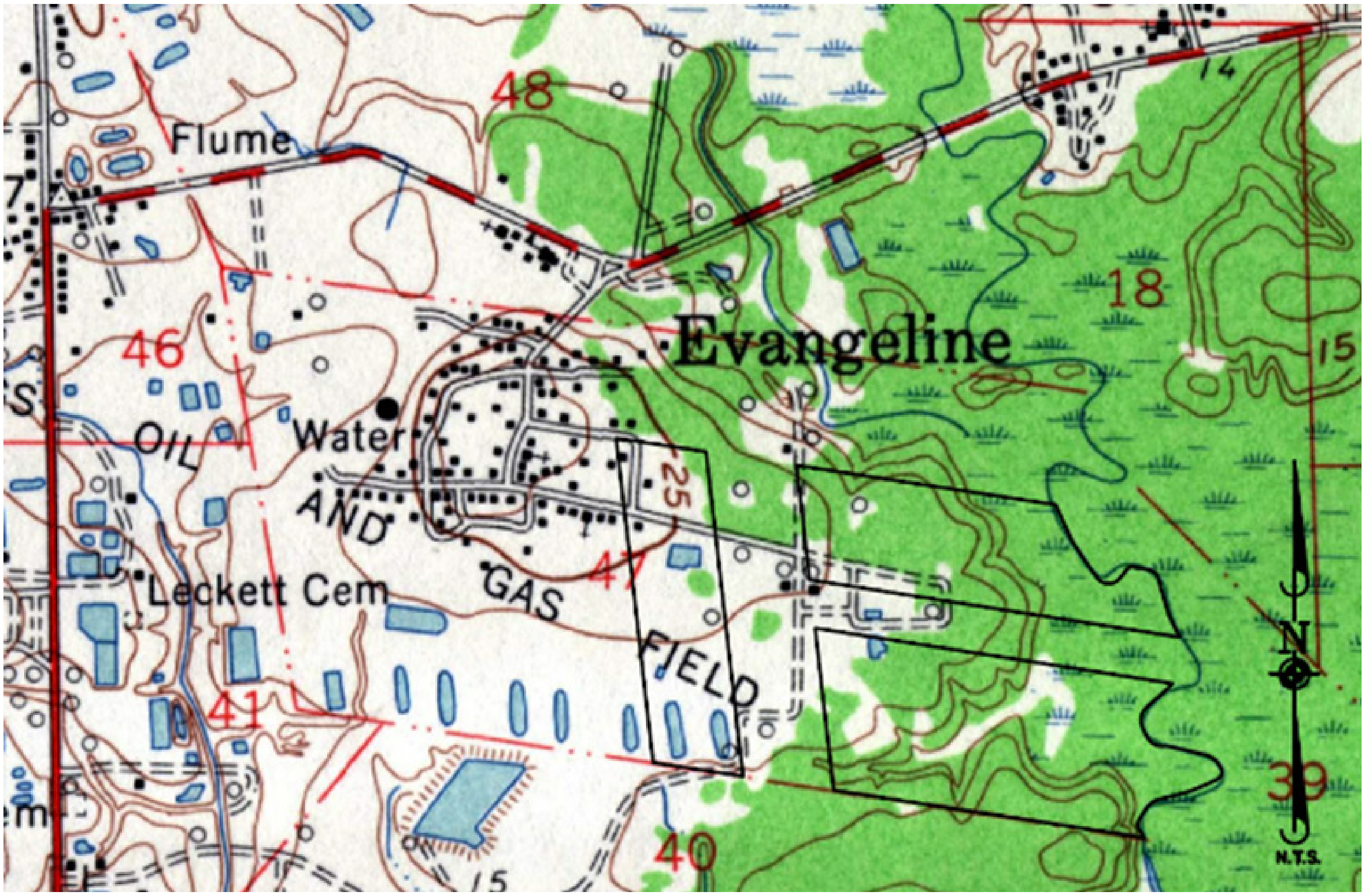


Figure 11

A 1960 U.S. Geological Survey topographic map of the subject property and surrounding area[46]. LiDAR data collected 50 years later exhibit flow patterns and altered drainage paths consistent with oil field operations mapped in 1907.

conditions close in time to oil field operations, are essential tools for forensic hydrology and drainage engineering. Coupled with contextual knowledge of field operations and historic land uses, the forensic engineer can prepare a detailed analysis of how an altered landscape evolved over more than a century.

Applying hydrology and drainage engineering expertise and analyzing suggested informational sources detailed in ASTM E1527 for engineering applicability determined the following key points in the forensic hydrology investigation:

1. Present-day survey data can corroborate testimony provided 110 years earlier regarding drainage patterns and contaminant transport from the oil field to surrounding areas.

2. Time-series analyses of aerial photographs and maps illustrate natural and built environmental changes resulting from upstream oil field stressors. Readily available GoogleEarth can be a good starting point for photographs. For a longer period of record, USGS EarthExplorer has photographs dating back to the 1940s. For historic topographic maps, USGS topoViewer has maps dating from 1880 to 2024.

3. Compiling data from multiple sources (including maps, photographs, testimony, and government reports) provides insight into historic land use and potential pollutant transport that predates environmental reporting requirements.

Family Knowledge of Oilfield Operations

As part of the claim, family members alleged that the predecessor oil company took advantage of an uneducated, non-English-speaking farmer to avoid responsibility for environmental damages incurred on his land. The plaintiffs alleged that for more than 30 years, out-of-state companies constructed and utilized earthen storage tanks for crude oil and produced water with the knowledge that such technology was environmentally detrimental to their ancestors' property. Further, the plaintiffs alleged those predecessor companies contractually obligated their ancestors to their disadvantage due to their lack of business and industry knowledge.

Determining what someone knew (or should have known) 110 years in the past is a difficult task. ASTM E1527 recommends landowner interviews to ascertain their knowledge of environmental liens and spills on their property. Such interviews are not possible with deceased owners, and taking the word of current owners as to what their ancestors knew or did not know can be risky. The forensic environmental assessment approach to this part of ASTM E1527 requires investigating the family through their records, including land transactions, censuses, business archives, newspaper articles, lawsuits, and professional publications.

The first generation owner was Eugene Houssiere. U.S. federal census data in 1900 for Eugene listed him as an unnaturalized farmer who could not speak English[9]. By 1910, Eugene was an "oil king" and the owner of an oil field who spoke only French[8]. By 1920, he reported that he could speak English and that his profession was a "capitalist[47]." Eugene Houssiere testified in the McFarlain case, during which he answered in the affirmative when asked if he were an oil man[48]. Additionally, the plaintiff's attorneys in the McFarlain case described him as "an oil man himself, interested in the oil field and the oil industry[49]."

A second generation owner was Charles Houssiere who was "quite involved in the management of the rapidly growing Houssiere and Latreille concerns" (e.g., Houssiere-Latreille Oil Company and others)[50]. A colleague remarked of Charles that he "had the best brain for figures of any businessman I ever knew. He could add mazes of figures in his head, knew the assessed valuation of every ward and town and their millages. He had his fingers on every deal in the parish, and knew what land, crops, cattle, oil leases and timber were worth." He further stated that "although oil was [his] stock and trade… he could hold his own in any sort of deal." Hildebrand continued, "You never got the best of Charles R. Houssiere in a deal. ... His mind worked like a machine gun in action. He could always out think you." Hildebrand even went so far as to suggest that if Charles had been older — and come into the family oil business earlier — that "he would have seen to it that things were done differently" with respect to the litigation involving the Jennings-Heywood Oil Syndicate[51].

A third generation owner was Charles Houssiere, Jr., who earned a master's degree in chemical engineering from the Massachusetts Institute of Technology and a doctorate degree in petroleum engineering from the University of Texas, Austin, researching oil and gas topics for his master's thesis and dissertation. Charles Houssiere, Jr. worked extensively in the oil business as an academic and as an engineer. He was a member of the Society of Professional Well Logging Analysts and American Institute of Mining Engineers — Society of Petroleum Engineers[52].

Louise Ismerie Houssiere, sister to Charles Houssiere, Jr., was another third-generation owner who worked seven summers (1934-1940) in the office of an independent oil operator (likely Houssiere-Latreille Oil Company). She attended the Massachusetts Institute of Technology and received a master of science degree in geology in June 1941 with a thesis entitled "Studies in Salt Resistant Drilling Muds." She worked as a research chemist and drilling mud engineer in the Baroid Division of the National Lead Company, as the chief micropaleontologist for the Southern Texas Division of Texaco, Inc., and as a subsurface geologist and reservoir engineer with Sohio Petroleum Company[50].

Members of the Houssiere family owned multiple petroleum-related businesses beginning in 1903 with the Houssiere-Latreille Oil Company and continuing through the mid-1950s. The business objects and purposes included leasing land for developing, drilling, buying, and selling natural gas, oil, and petroleum — and for constructing and managing infrastructure conducive to petroleum operations. They signed oil leases on behalf of themselves and the family businesses, set contract terms for royalty payments in crude oil rather than in cash, and included clauses to ensure aggressive drilling on their land, which included potential environmental impacts they could observe on a daily basis[15]. Multiple generations of the Houssiere family had specific knowledge of oil field technology, personally engaged in the business of oil on their property, and aggressively directed drilling on their lands.

Utilizing the techniques and suggested informational sources detailed in ASTM E1527 for a time-series analysis of visibly evolving site conditions and of personal knowledge of oil operations, analyzing family and business histories resulted in the following key points in the forensic environmental assessment:

1. Contemporary testimony regarding site conditions and operations a century ago is obtainable without owner interviews. For this case, litigation photographs, maps, and testimony from the property owner in 1907 depicted or described site conditions just six years after the discovery of oil on the plaintiffs' properties.

2. Source evaluation is essential when presented with conflicting information. Legal documents (including contracts, business filings, and land transactions) are the most credible sources of information. Multiple legal documents created over a 50-year period refuted many plaintiffs' claims.

3. It is possible to interpret what a person in the past knew or should have known. One's education, publications, and occupations evidence a person's technical knowledge. A person's documented living and working environments reveal what one should have known. Walking a property, smelling petroleum, and signing oil exploration leases are examples that a person should have known oil operations were occurring on one's property — even if that condition were not explicitly stated in a written document.

4. Information that a person could be reasonably expected to know is demonstrated through a preponderance of evidence, taken in totality, through deductive or inductive reasoning. For example, directing lease holders to aggressively drill on one's land, receiving crude oil rather than money for royalty payments, and placing newspaper advertisements offering oil field services illustrate one has knowledge, interest, and expertise in crude oil exploration and management.

Conclusion

This FE investigation validated that the modern Phase I Environmental Site Assessment methodology detailed in ASTM E1527 is appropriate for the discovery and interpretation of facts regarding human and physical conditions relative to allegations of environmental contamination, altered drainage, and uninformed landowners that occurred more than 100 years ago. Through documentary research detailed in ASTM E1527, this FE investigation demonstrated that claims the predecessor oil company took advantage of an uneducated, non-English-speaking farmer to avoid environmental responsibility on their leased lands were false.

The original landowner, as well as several of his descendants in multiple generations (including the plaintiffs' generation), possessed technical and business knowledge of oil exploration and storage operations on their land. Impacts of oil exploration, storage, and transportation were open and obvious — from earthen storage tanks of tens of thousands of barrels capacity to pipe-strewn former rice fields to law suits from downstream neighbors. The potential for environmental damage from oil operations was known in the industry and accepted as an inevitable consequence of extracting oil. The plaintiffs' ancestors understood that produced water discharge and crude oil seepage were simply costs of doing business — costs they considered acceptable in pursuit of their own oil business objects and purposes.

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Ethical Responsibility: When the Forensic Engineer is Faced with Notifying Occupants to Vacate

By Gregory L. Boso, PE, DFE (NAFE 748M)

Abstract

Holding the obligation to protect life, safety and welfare paramount required the forensic engineer in this case to notify the homeowner to vacate her new home constructed in an active landslide. The forensic engineering evaluation of a four-year-old home revealed extensive damages caused by active soil mass flow in glacial lake deposit soils and a natural spring that imposed excessive hydrostatic pressure on the front foundation wall. The homeowner remained in the home for nearly four years during the investigations while insurers and their engineers argued over coverage. The structural analysis revealed significant probability of imminent collapse, threatening the safety and welfare of occupants and creating both a compelling necessity and an ethical obligation to notify the homeowner of grave peril to the occupants and their need to vacate and abandon the premises.

Keywords

Safety, unsafe conditions, landslide, construction defect, ethics, obligation, ethical responsibility, tunnel vision, forensic engineering

Introduction and Background

A medical professional invested her life savings into a two-level home she believed was her dream home (see **Figure 1**). As part of the deal, she was offered and accepted the purchase of the new home warranty through the builder in 2010. Soon after occupying the home with her son and daughter, cracks began forming in drywall surfaces, and the lower level (a walk-out basement with a wood-joisted floor system above the crawl space) became unleveled. She contacted the builder in September 2011. In November 2011, she initiated her claim of defects in the construction with the home warranty company, seeking answers into the cause of problems in the home.

Figure 1
Street view of the subject home's south face.

The builder's engineer ("B-E"), who also had provided foundation design guidance early in the project construction, responded after notice was given. B-E concluded there was no differential settlement but that there was differential movement in the foundation. The home warranty company dispatched a forensic civil/structural engineer ("HW-E") to evaluate the structure in December 2011, who concluded the damages were caused by differential foundation settlement and that movement in the brick veneer (along the right side of the structure) was attributable to lack of brick ties. The homeowner retained an engineer ("O-E") in 2012 — who also provided home inspections — to inspect the property. O-E provided two reports, the final (submitted in August 2013) of which concluded that the home suffered from significant movement, and additional movement would threaten the safety of occupants.

However, O-E did not make a determination about

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the habitability or the potential threat to the safety, health, and welfare of occupants or the public. None of the three engineers (B-E, HW-E, or O-E) identified the imminent threat to the occupants through a sudden catastrophic failure, nor was that threat conveyed to the home's occupants.

In 2014, the homeowner's attorney retained a forensic engineer ("A-FE"), the author, to inspect and complete a forensic analysis. That analysis revealed that the home was located in an active landslide that had damaged the home and was threatening the safety of its occupants. Upon identifying the imminent risk, A-FE had an ethical obligation to notify the occupants to vacate.

Codes of Ethics Are Foundations for Engineer's Conduct

The first fundamental canon of the engineering *Code of Ethics* published by the National Society of Professional Engineers ("NSPE") states, "Engineers, in the fulfillment of their professional duties, shall hold paramount the safety, health, and welfare of the public[1]." Other technical societies have similar codes of ethics[2,3]. A library of cases has been developed by NSPE's Board of Ethical Review ("BER"), many providing direct guidance regarding the ethical obligation of engineers to notify their supervisors, clients, other affected parties, and authorities having jurisdiction when conditions manifestly threaten the health, safety, and welfare of the public.

This paramount foundational tenet is similarly embodied within many state laws. Regarding the practice of engineering, for instance, Alabama states: "In order to safeguard health, life, safety, welfare, and property, the practice of engineering in this state is a learned profession to be practiced and regulated as such, and its practitioners in this state shall be held accountable to the state and members of the public by high professional standards in keeping with the ethics and practices of the other learned professions in this state[4]."

Other state laws are similarly written, such as: Minnesota §326.02; Nebraska Rev. Stat. §81.3402; and Oklahoma §59.475.1. New York promulgates, "The practice of the profession of engineering is defined as performing professional service such as consultation, investigation, evaluation, planning, design or supervision of construction or operation in connection with any utilities, structures, buildings, machines, equipment, processes, works, or projects ***wherein the safeguarding of life, health and property is concerned***, when such service or work requires the application of engineering principles and data" at §145-7201[***emphasis added***][5]. The health, safety and welfare of the public, which includes affected parties, is the paramount foundational concern of the forensic engineer when reviewing, analyzing, and reporting conditions manifest in structures, systems, or works.

Earlier Engineering Evaluations

In the subject case, the owner's initial 2011 call to the builder of her home expressed concern over cracks and other damage to the drywall surfaces. The owner's call initiated a series of site visits and investigations. The first investigation was conducted by B-E, who reviewed conditions in October 2011 and issued a written report stating, "structurally it does not appear to be a differential foundation settlement issue." However, in apparent contradiction, B-E concluded the report with, "To repair the settlement in the back corner, I recommend a helical pier be installed under the footing… . " B-E also indicated that nothing should be done to the structure until the following spring to determine if further movement occurred.

In November 2011, following review by B-E, the builder notified the home warranty company ("HWC") of the owner's claim of structural damages (**Figure 2**). The builder included a copy of B-E's report with the warranty claim.

HWC engaged the services of a national forensic engineering firm, who assigned a forensic civil/structural engineer ("HW-E") to review conditions in the structure. HW-E's initial investigation was a "Distress Inventory Report" of the subject home that occurred in December 2011.

The HW-E report included notation of the following, generally: in the front right bedroom, a bowed and inoperable window, cracks present in the bedroom ceiling, and uneven margins for the bedroom closet doors; cracks in the tile floor and raised tiles in the main (right) bathroom; drywall repairs to cracks at the kitchen with the east hallway; in the stairway, drywall cracks in the ceiling and at vertical corners as well as interface between the walls and ceiling; in the basement, wall and ceiling cracks in the hall and left rear bedroom; and, in the garage, separation and cracks at wall and ceiling locations. Exterior observations included: separations between the brick veneer and right (or east) face window frames at their forward (south) sides with the rear (north) sides noticeably bowed; a vertical crack through the brick veneer at the right rear (northeast) corner with up to 1 inch of lateral movement observed; stair step cracks from the head and sill of the north window of the east face; and, at the crawl space access,

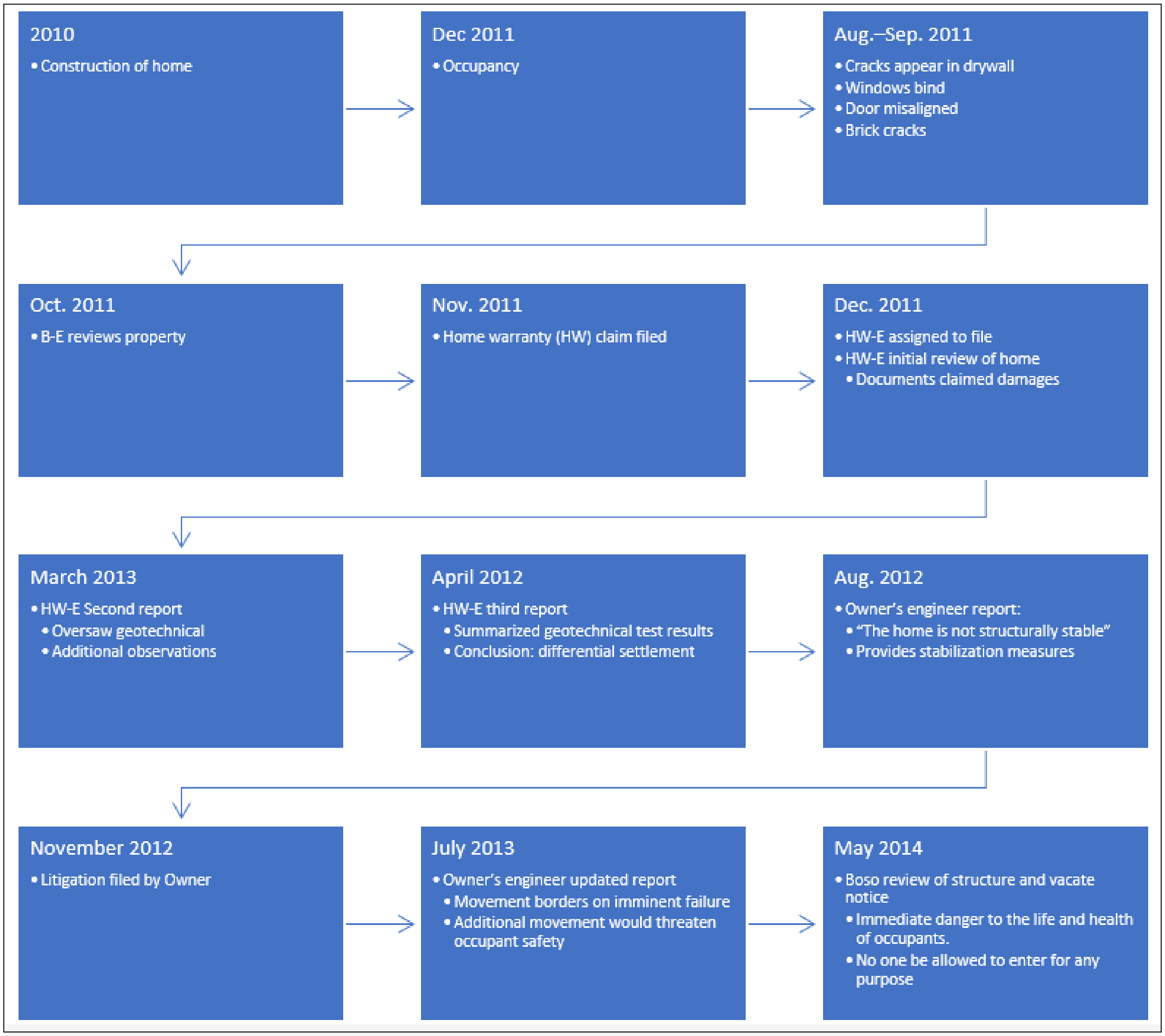

Figure 2
Timeline of events leading to May 2014 determination.

hairline crack above the opening with uneven "reveals" or margins. Within the crawl space, HW-E observed: a stair step crack in the north portion of the east crawl space masonry wall; moisture present in the east and south walls at the southeast corner; and the ground beneath the plastic vapor barrier was very soft and muddy with standing water present. No conclusions or recommendations were presented in the December 2011 report.

HW-E made two subsequent site visits and generated corresponding reports with the last report dated April 2012. The last HW-E report described geotechnical investigations at the right rear corner and concluded that settlement of the structure at that corner, caused by improperly consolidated fill material, was the root cause of problems being experienced. The HW-E's report also concluded that the lack of adequate brick ties between the brick veneer and wood-framed structure contributed to the "brick movement." No investigation of soil conditions at the front or along the sides of the subject home was conducted.

In August 2012, the owner engaged O-E to inspect the property to help understand accumulating damages as well as newly developing damages. O-E observed movement in the front foundation wall sufficient to cause heaving of the crawl space floor at the footing. O-E further stated, "significantly major foundation movement has occurred within the home, concentrating at the right rear areas of the foundation resulting in a one inch horizontal movement within the right side crawl space foundation with additional lateral movement occurring along the rear crawl space foundation wall… This lateral movement is literally pulling the interior of the basement and main floors apart with majors [sic] cracks in the walls and ceilings."

During a return visit one year later, O-E documented an additional ¾ inch of movement at the right-side bedroom window in a year. Movement within the structure was described as "rearward." O-E initially concluded that the structure was, "not structurally stable with ongoing structural movement." O-E went on to say, "Significant repairs and reinforcement along with an interior crawl space foundation drain will be required to stabilize the foundation and interior of the home." O-E's updated 2013 report added, "This home continues to suffer significant and major ongoing movement. Although there did not appear to be any major failure in the structure at this time of the inspection, the home demonstrates significant stress and movement that boarders [sic] on immanent [sic] structural failure." However, O-E did not declare the structure to be unsafe.

Both B-E's and HW-E's report concluded that the structure was being affected by differential settlement at the right rear corner. O-E's 2013 report was the first to express concern about the safety of the structure and its occupants. However, O-E's report suggested a remediation plan without consideration of sequencing of demolition, stabilization of retained soils, or any temporary measures to assure worker safety while accomplishing remediation. Photographs from HW-E's and O-E's reports were used as comparisons for A-FE's investigation to document the movement of the structure and to confirm progression of the structure's movement — and its perilous and compromised state that threatened occupants.

Tunnel Vision

Tunnel vision is the mental constriction of the field of vision during an engineering evaluation. The consequence of this phenomenon is a limiting of the observations and evaluation of the investigator. As a result, the observer focuses and reports on a limited area of observed damage without regard to the whole.

In the matter of the subject property, the first three engineers reviewing the location focused on the conditions at the right rear corner of the premises and what they perceived as differential settlement. B-E began by focusing on the settlement at the right rear corner that needed to be monitored. He stated in his 2011 report, "to repair the settlement in the back corner… ." The HW-E continued that narrow focus, evaluating only the "differential settlement." The first two engineers identified the conditions at the right rear corner "differential settlement" and focused on repairing that corner of the home. None of them appeared to have asked themselves the true forensic question: "What is causing the movement?"

Even the O-E focused on stabilization and repair. In 2012, the O-E stated that, "significantly major foundation movement has occurred within the home…, this lateral movement is literally pulling the interior of the basement and main floors apart with majors [sic] cracks in the walls and ceilings, and [the] home is not structurally stable with ongoing structural movement. Significant repairs and reinforcement, along with an interior crawl space foundation drain will be required to stabilize the foundation and interior of the home."

O-E was the first engineer to make observations beyond the right rear corner. Although O-E acknowledged that the front foundation wall was moving, neither the safety of the building nor the occupants were addressed in O-E's opinions, nor was stating the obvious — that the wall had failed. In his subsequent report of August 2013, O-E opined, "The home continues to suffer significant and major ongoing movement. Although there does not appear to be any major failure in the structure at this time of this inspection, it demonstrates significant stress and movement that boarders [sic] on immanent [sic] structural failure. Time is now critical to the stability of this home and the safety of the owner and occupants."

There was no indication by O-E that the homeowner needed to have urgent concern about the safety and well-being of herself and her family and should leave — or, at the very least, consider leaving the premises. After that non-specific warning, O-E refocused on repairs.

It was a matter of significant forensic concern that none of these engineers seemed to comprehend that the front basement wall had failed. The fact that it had not yet collapsed did not mean that it had not already failed. The very fact that the basement wall supporting the front wall of the house had slid meant that the factor of safety was less than 1.0 from the outset.

B-E and HW-E focused only the right rear corner of the house. O-E recognized the movement of the front basement (crawl space) wall. All three engineers focused on remediation. Tunnel vision prevented all of them from recognizing the imminent threat to the safety of the owner and her family.

Review of the Subject Property

A-FE was retained in May 2014. Initial review found a wood-framed, single-family dwelling constructed on a full basement foundation system. Facing the south with the ground surface downgradient to the rear (north) of the lot, the street providing access to the property was approximately 4 feet above the main floor elevation. A constructed lake was situated along the northern property boundary approximately 25 feet below the street and 60 feet to the rear of the structure.

A sanitary sewer for the development extended across the rear yard — approximately 15 feet from the northwest (rear left) corner of the subject structure. Repair of the sanitary sewer was completed the previous month as a result of a 2-foot ground shift that separated the 8-inch PVC sewer line joint near the left rear corner of the home.

The front and left side yards presented as a "washboard" where the soil surface was folded with 2- to 3-inch wrinkles (**Figure 3**). Repairs to approximately 80 feet of the north side of the concrete paved street had been made, evidenced by the newer concrete appearance. However, the north side of the street, which was previously repaired, had moved to the north by approximately 1½ inches, and soils along the vehicle recovery area of the street cross section beyond the northern curb had settled approximately 12 inches at several locations on the subject property and the lot to the west. Damage to the replaced concrete street segment was observed at the eastern end of the repair along the curb.

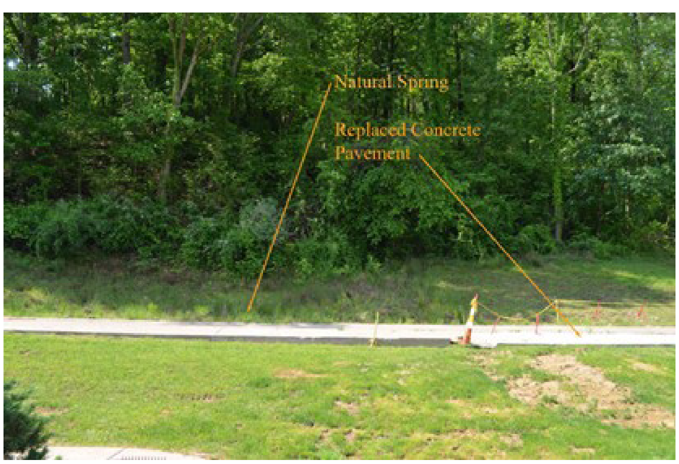

Figure 3
View of street and spring area at the southern boundary of the subject property from the front porch.

Water from a natural spring was found pooled in a depression across the street from the southwest corner of the subject structure. Water from the spring flowed westward approximately 45 feet in a poorly constructed swale before crossing via culvert under the street. A 6-inch water main extended with the street across the property frontage.

Because of previous experience with like properties in the area, A-FE was aware of problematic soils at the home site. It is this author's opinion that the local knowledge was beneficial to a more broad forensic approach in determination of the ultimate findings. A review of the soils conditions at the home site was conducted using the NRCS Web Soil Survey for the geographic location.

This review revealed that the site soils were of the Gilpin-Upshur (GRF) complex and Vandalia (VdD3) soil series that are fine-grained, well-drained soils with high plasticity indices and low strength and liquid limits on steep slopes (**Figure 4**)[6]. Gilpin-Upshur soils are clay loams, and Vandalia soils are loamy clays that each have high shrink-swell or linear extensibility characteristics. These soils are common on hillsides in the geographic region of the home and have a propensity for absorbing and retaining water that weakens the interior soil strength while increasing unit mass until failure as a debris flow-type landslide. The site was thus situated in a defined debris flow area. This activity should have been reviewed and the foundation/site conditions designed and constructed around the peril.

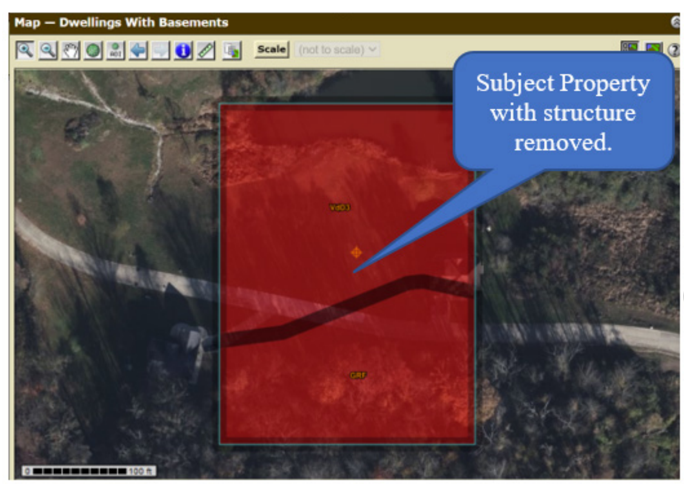

Figure 4
NRCS Web Soil Survey of soils on and around the subject parcel, "Soil Slippage Potential" hazard class "High" (red).
(U.S. Department of Agriculture, NRCS Web Soil Survey)

Wood platform framing techniques were used in constructing the home's structure. Due to the approximate 18-foot to 20-foot drop in elevation relief from the front street to back of the home, the walkout basement level floor system was constructed on a crawl space foundation with a platform framed floor system (**Figure 5**). The front basement (crawl-space) foundation wall utilized 12-inch concrete unit masonry on a poured concrete footing. Veneer masonry techniques were used to apply the brick exterior and construct the left and right basement walls. The crawl space floor was covered with a polyethylene vapor barrier.

The construction methods used resulted in an unbalanced load on the foundation system where the uphill foundation wall received the backfill equivalent fluid pressure, and the side walls provided active shear resistance. Based on the foundation configuration, the front foundation wall was under active conditions, and the lower walkout wall had to resist forces expressed through the structure with passive resistance — the pressure which the soil and wall developed in response to movement toward them.

Figure 5
Elevation relief from street to rear of home was approximately 20 feet along left side.

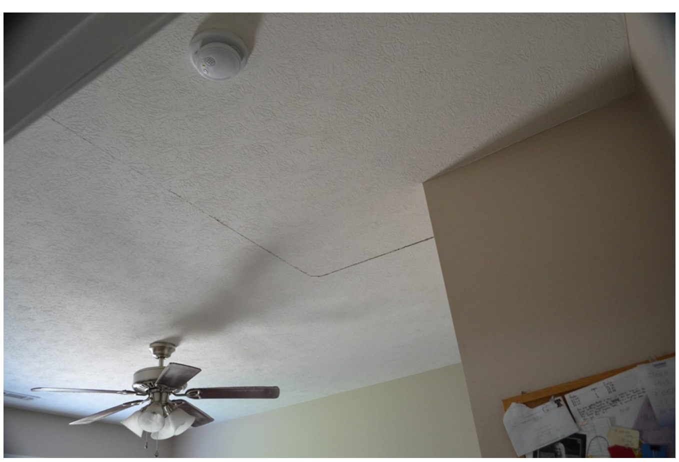

Figure 6
Ceiling of bedroom at right end of the structure with gapping between joints in the drywall field; joints had been previously repaired post-construction.

Cracking was observed in the drywall surfaces of the main level, particularly at the intersection of wall and ceiling surfaces, but occurred at most drywall joints in rooms on the right side of the structure (**Figure 6**). Walls extending left-to-right in the room were displaced rearward approximately ¾ inch at the base with drywall corner tape detached and stretched diagonally. The rear sashes of the front right bedroom's twinned window were broken out and filled with board insulation (**Figure 7**). Review of the window's exterior exhibited rearward displacement of the framed wall with an increased gap between aluminum frame at the front edge of 2 inches. The rear window frame jamb was distressed and distorted as the first level framing platform was forced rearward past the right side brick veneer.

Damage to the right side masonry veneer was not realized until viewing the right rear corner of the subject structure. Rearward movement of the wood framed basement level and main level floor platforms and associated rear wall framing fractured the brick veneer vertically at the corner and pushed the rear wall against the multi-level,

Figure 7
Right bedroom window jamb rolled beneath the right-side brick masonry veneer, buckled window screen and board insulation filling the sash space as protection against glass breakage.

wood-framed rear deck system. The structure of the wood deck system provided additional resistance to movement of the platform framing system toward the rear yard and lake (**Figure 8**).

Uneven gaps occurred at window and door openings of the rear wall plane. Doors of the rear elevation bound in their openings due to twisting of the jambs caused by movement of the structure.

Interior damages to the basement drywall surfaces resulted from rearward displacement of the front basement wall with vertical corners along the right side torn. Drywall applied to the right side wall remained generally in place while the drywall applied to lateral interior walls was drawn away from the corners by 2 or more inches.

The basement stair treads and risers connected the basement and main floor along the front basement wall. The front basement wall also provided foundation support for the rear garage wall. The stairway was twisted with an approximate 2-inch gap along the front foundation wall near the base (**Figure 9**). Though the garage foundation walls provided limited passive resistance to the active lateral pressure of the landslide soil bearing on the front wall, the passive resistance of the foundation and internal wood-framed structural system had succumbed and was succumbing to horizontal movement caused by the excessive active lateral pressure.

Distortion of interior doorways in the right half of the basement level was manifested as twisted door headers and jambs pinching the door leafs, causing binding of the doors. Floor elevations of the wood-framed basement floor were rippled under the compressive and torsional stresses from the front wall movement with variations exceeding 3 inches (either above or below level) in central floor areas of the right basement half; variations were less pronounced over the floor girders.

The front basement foundation wall included an offset in the medial region based on the room configuration and location of the front wall of the upper level. A divergent, tapering crack had developed in the inside corner between the front right wall segment and the rearward offset with an approximate $^{1}/_{8}$-inch gap at the top of the wall intersection and nearly ½ inch at basement floor level. The conditions indicated that the left wall was being pushed rearward at the base at a greater rate than the left segment with the opening crack, indicating that the central region of the basement retaining wall was forced rearward more

Figure 8
Right rear corner with vertical veneer fractured at the down-spout.

Figure 9
Lower stairway landing at the front foundation wall with an approximate 2-inch gap.

extensively than the left or right ends. The lower level floor system was being crushed as the front basement wall was twisted and forced back. Gaps between the floor sheating longitudinal butt joints caused each sheet's left corners to be tight against the front wall with the right edge of the sheathing ends gapped by approximately ¾ inch with the next sheet — a ratio of ¾:48.

Crawl Space Review

Basement level floor joists extended right to left and were found bowing in the crawl space — most notably along the right region of the home. The central floor girder supporting the right basement floor system was rotated with the top chord displaced to the right, the forward end forced out of the beam bearing pocket in the front block basement wall (**Figure 10**), and the wood fibers were crushed at the interface between joists and girder or the girder and piers.

Interior foundation piers in the right crawl space area leaned rearward approximately 2 inches, measured using a 29-inch level (**Figure 11**). Active water movement was observed beneath the polyethylene vapor barrier in the right crawl space region such that the soils of the floor were saturated, soft, and incapable of supporting load. As an example of the soil's condition, while gathering data, A-FE's knees sunk into the mud between 4 and 6 inches throughout most of the right side of the crawl space, while crawl space soil on the left remained reasonably firm and provided resistance to movement. The front foundation wall was broken at interior and exterior wall corners as well as vertical cracks in the field of the wall. Active water movement through the crawl space had eroded soil from beneath the rear foundation wall, leading to settlement in the foundation and breakage of the rear masonry wall and footing approximately 10 to 12 feet from the right rear corner below the lower deck.

Figure 10
Right-side floor system girder displaced from its bearing seat in the front foundation wall.

Figure 11
Right-side floor system pier measurement from plumb with active water surrounding the column.

Garage Observations

The effects of the structure's movement were exacerbated at the garage. Gaps between the driveway and structure caused by the foundation's lateral movement exceeded 3 inches to the left (west), away from the driveway and 1 inch rearward (**Figure 12**), were observed at the front corner along the right side of the garage. Caulking placed in the joints between the driveway and garage walls or floor was found torn and stretched. Inside the garage, a 1- to 1½-inch gap existed between the left and rear edges of the garage floor slab and adjacent foundation

Figure 12
Front right corner of structure at the garage with displacement of structure to the west manifested by gap with driveway and roof drainage down-spout leader connection.

walls (**Figure 13**). The gap at the garage door entrance increased from the rear jamb to the front jamb, indicating that the right-side masonry of the structure was somewhat restricted from movement as compared to the wood framing (**Figure 14**).

The drywall corner at the right rear of the garage was gapped by more than 1 inch, resulting from the living space and front foundation wall being moved away from the garage by the slipping front yard soil mass that extended beneath the garage. Electrical service to the property entered the right side underground with the distribution panel on the right garage wall at the right rear corner (**Figure 15**). Distribution wiring for the home extended from the panel through the corner to other areas of the home; condition of the wiring was not observable due to the wall finishes.

Figure 13
Garage floor separation of 1 to 1½ inches from rear and left foundation walls.

Figure 14
Front garage door jamb separation from brick masonry veneer because first level framing system was being forced rearward by connection to the front foundation wall.

Analysis of the Structure

Water from the spring upgradient from the subject structure provided constant water flow that had three cumulative consequences: increased the unit density of the restrained soil behind the foundation wall; reduced the internal friction of the soil structure; and increased hydrostatic pressure bearing on the front foundation wall. The home was not only forced rearward on its foundation but also rotated about the driveway retaining wall, generally at the right side based on the tapered gap between the garage floor slab and driveway slab (viewed north to south). Estimated movement by the structure was approximately 1 inch along the left side wall, approximately 3 to 4 inches of movement at the central region of the basement floor system, and 2 to 3 inches of movement rearward along the right side wall (**Figure 16**).

Considering all the observations and measurements of:

1. The separation of the garage floor from the adjacent foundation walls measuring more than 1 inch;
2. The separation of the garage from the concrete driveway;
3. Lateral movement measuring over 2 inches rearward of the first level platform framing along the right side wall in relation to the brick masonry;
4. The rear brick wall broken vertically at the corner as opposed to corbeled brick separation in the mortar joints about the right rear corner;

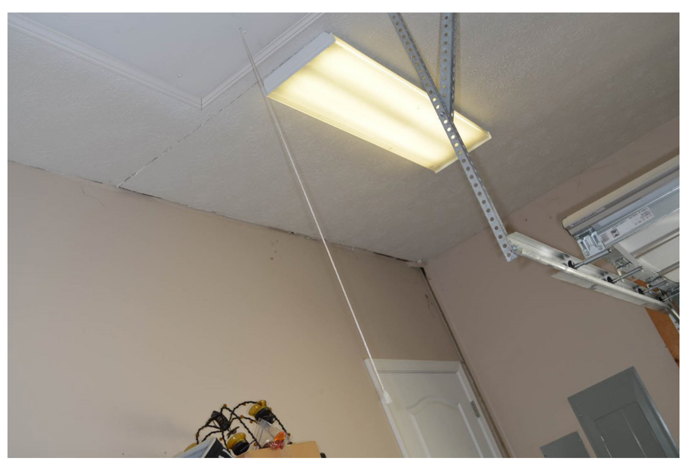

Figure 15
Right rear corner of the garage at the ceiling with displacement of structure manifest by gap with the ceiling and wall at the electrical distribution panel.

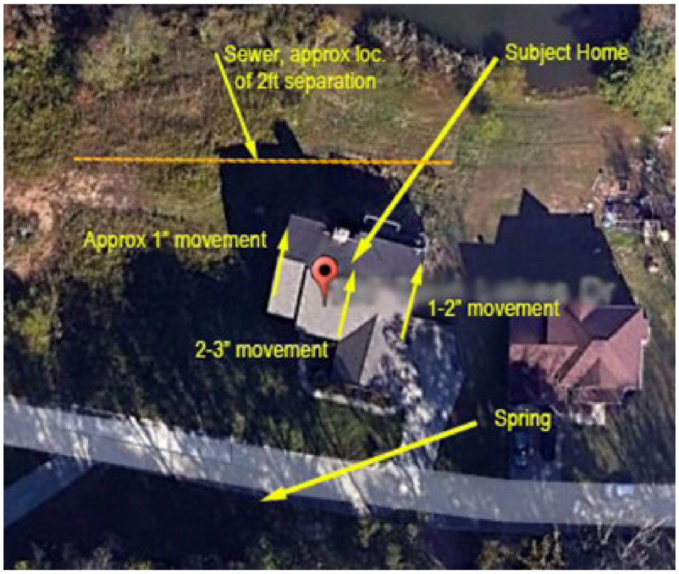

Figure 16
Site plan showing spring, street and lake in relation to structure and movement observations. (Aerial imagery from Map West Virginia, mapwv.gov)

5. Over 2½ inches of rearward displacement of the basement level framed floor system at the floor system girder support piers;

6. The distorted basement level floor system in the right half;

7. The extensive drywall damage with laterally stressed joint tears and gaps; and,

8. The tapered drywall joint cracks in the ceilings resulting from torsional stress,

the combination of movements demonstrated that the entire structure was enveloped in active soil mass movement. The manifestation was further that the home was resisting a debris flow landslide that, by their very nature, can result in catastrophic landslides that are sudden and deadly and capable of moving houses[7].

Since the front foundation wall was actively moving, the factor of safety was less than 1.0, based on the physical evidence — though a typical factor of safety for the design of retaining walls is 1.5 or greater for cohesionless backfill soils and 2.0 for cohesive backfill[8]. In the year following the initial visit and notification, the right side of the structure actively moved rearward over an additional 1½ inches.

Within the structure, the front basement wall (with the upper-level platform attached) was being driven rearward through the home and the rear wall of the structure. The wood deck system constructed at the rear of the structure and interior wall system of the basement level provided some additional resistance to total collapse of the structure. The two wood floor platform framing systems were also providing restraint against movement through the diaphragm effect across the field of the floor from end-to-end but were experiencing significant stress that extended beyond normal design parameters.

Structural support for the lower level platform was drastically reduced as the framing system was displaced by the differential sliding of the front foundation wall, and the tops of the supporting piers were driven rearward, causing point loading and localized fiber crushing of the wood girders as well as displacing supporting soils from beneath the pier footings. Basement floor joists were displaced and bowed from their installed alignment. The floor joist bowing and displacement resulted in undulation within the basement floor system with variations from level exceeding ±3 inches — values that exceeded acceptable deflections of L/360 under the loads applied for the nominal 13-foot span joists; deflection values of less than ½ inch would be acceptable under normal design loading. The central girder supporting the right side of the basement floor system was dislodged from its bearing in the front wall as the floor system slid and rotated.

Perpetual water movement through the crawl space was strong evidence that the natural spring affected a broad area, burdening the entire frontal region of the subject structure — not just the soil along the left side of the home. Water-inundated conditions of the crawl space floor weakened the soil structure sufficient to significantly minimize bearing support for the structure. Moreover, the supersaturated, soft, and yielding soil of the crawl space floor eliminated the possibility of using cribbing and shoring to provide safe work conditions for the workers conducting stabilization and/or remediation operations.

The rearward debris flow along the west side of the home caused a more than 2-foot lateral displacement in the sanitary sewer line just 15 feet away and downgradient from the northwest corner of the structure. Repair of the sewer occurred just a month before the site visit and was strong evidence that the debris flow was active. Northward movement of the northern half of the concrete street west of the home evidenced the head of the active slide area by the soil elevation drop and lateral concrete street displacement as compared to the southern half of the street.

The 6-inch water line serving the development followed the street and passed through the slip zone at or about the visible head of the landslide (at the center of the street) but geologically downgradient from the natural spring.

During the nighttime weather news of May 14, 2014, 1½ inches of precipitation was forecast to fall in the region of the home that triggered a series of questions for the author: (1) What if rainfall approaching 1½ inches fell on the development? (2) What if the 6-inch water line broke or separated? (3) What if the home's framing system ruptured?

The answers, which were terrifying, were: If 1½ inches of rain fell over most of the day, soil moisture content would be increased at the front of the home that would probably accelerate the debris flow along the west side of the home with the head extending across the street. Additionally, the soil moisture at the front of the home would increase the burden upon the already stressed front basement foundation wall and framing systems.

If the 6-inch water line in the street separated or broke in front of the home — much like the sewer line at the rear of the home had — water flow across the surface would increase the soil moisture content (already saturated to or near the liquid limit by the spring) at the separation site and within the front lawn of the home by two to five percentage points, enough to exceed the liquid limit of the soil since the natural spring provided continual wetting of the deeper, subsurface soils. Note: Liquid limit is the percentage of water contained in the soil whereby the soil changes from a liquid state to a plastic state based on the Atterburg Limits procedure, also known as the upper plastic limit. The resulting deep liquefaction could readily trigger a debris flow landslide, overwhelming the restraining capabilities of the foundation wall or structure.

If any component of the floor or rear deck framing systems ruptured or failed, a failure of any one of the components could probably trigger a chain reaction resulting in catastrophic failure and collapse of the structure; there would be nothing to resist the sliding movement of the front foundation wall and the retained soil with the house being pushed down the hillside in seconds.

Because the home:

1. Was directly involved in an active landslide;
2. Was moved, rotated, and damaged by the active landslide;
3. Was exhibiting significant and uncharacteristic stress within the wood framed structure that restrained added movement caused by the active landslide;
4. Could not be immediately stabilized safely;
5. Was downgradient from a 6-inch water line that passed through the active landslide area and would be subject to damage by the active landslide; and,
6. Was within a landslide that could be exacerbated by changes in environmental conditions.

collapse of the subject structure was probable, with the difference between possible and probable being that probable is that the statistical probability of an event occurring exceeds 50 percent. Because debris flow landslides can release suddenly without warning and are dangerous to life and property[7], the occupants were in immediate peril if they remained in the home. On the morning following the inspection, verbal notice was promptly given to the property owner's attorney of the determination of the structure's perilous conditions and of the threat to the occupants should they remain.

Verbal notice to the owner's attorney was promptly followed with a letter, which stated: "conditions in the home have deteriorated such that there is now an immediate danger to the life and health of the residents or occupants of the subject property. The health, safety and welfare of the home's occupants will be in peril when the structure, now deformed under severe stress and strain and resisting movement by an active landslide as well as being subjected to the effects imposed by differential settlement, succumbs. This home is unsafe for anyone to occupy for any purpose."

The letter described the observed conditions and hazards that existed and the probability of structural collapse. After the owner received notification from her attorney, she and her family immediately vacated the property. Had the owner not heeded the warning and vacated the property, this engineer had a duty to notify authorities having jurisdiction of the danger for the building occupants. It's not something you ponder; it's something you do as an engineer.

Despite the notice to vacate by the author, HW-E persisted in planning repairs to the home by contacting the writer, asking for recommendations for a contractor to assist. A letter responding to the request was sent in the days following that stated: “Unfortunately, I am not able to provide any recommendations pertaining to contracting firms who can stabilize this structure, without threatening the personal safety and well-being of their employees. Due to the level of instability observed during my visit on Wednesday, May 14, 2013, and the magnitude of movement induced stress within walls and each of the two wood framed floor platforms — manifest as bowed floor joists, displaced floor girders, twisted and shifted floor sheeting, and distorted wall surfaces and doors, to name a few — this home is unsafe for anyone to occupy the home for any purpose.” After receiving the letter, HW-E relented to the author’s findings, and the HWC paid the policy limits.

The engineers’ creed says, “as a professional engineer, I dedicate my professional knowledge and skill to the advancement and betterment of human welfare. I pledge to give the utmost of performance, to participate in none but honest enterprise, to live and work according to the laws of man and the highest standards of professional conduct, to place service before profit, the honor and standing of the profession before personal advantage, and the public welfare above other considerations. In humility and with need for Divine Guidance, I make this pledge[9].” We have to live the creed of the engineer and seek to protect life, health, and welfare first and foremost when evaluating a structure and faced with the question: “Should I notify the occupants to vacate?” We have to demonstrate concern for people more than property. Property can be replaced; people cannot.

Summary

During the four-plus years of occupancy, adverse conditions within the subject structure developed and deteriorated, ultimately presenting a threat to the life, safety, and welfare of occupants in the home and to the public visiting the property. The structure was constructed in an active landslide. It was being subjected to forces not considered in the design and to which it was not capable of restraining, resulting in the home being twisted and moved from its constructed location.

Engineers engaged by others to review conditions of the structure developed tunnel vision and focused on stabilization or repairs without comprehensively considering the structure’s stability and the safety of its occupants. The owner’s own engineer stated that the home was not structurally stable and presented options for stabilizing the structure; however, he did not, at that time, clearly indicate to the owner that there was an immediate threat to the health, safety, and welfare of the resident(s) or urge the owner to vacate to safety.

The notice issued to the owner’s attorney following the investigation of this home warned the occupants of a threat to their lives and stated that the home was unsafe for anyone to occupy for any purpose. The owner’s attorney notified the owner. Wisely, the owner and her family immediately vacated the premises. The notice continued to others unchanged, stated the peril, and urged others not to enter. Ultimately, the structure was razed. Had the attorney not notified the owner or had the owner not vacated, A-FE had an obligation to take further steps to protect the owner, her family, and other members of the public, including notifying authorities having jurisdiction.

Conclusions

For engineers applying their engineering training and science in design and construction of projects, experience is vital in developing critical thinking skills. These skills are needed in the field to systematically analyze process or system failures in order to safeguard life, health, and property and to promote the public welfare. Engineers must guard against focusing on a limited area or aspect of a problem without considering the entirety of the system, often known as “tunnel vision,” and must consider the whole system or structure in their evaluations.

Engineers must recognize when observed conditions in a structure or system threaten the life, safety, or welfare of the general public, the normal occupants, and those who might be engaged to effectuate repair. When engineers recognize such circumstances, they must give notice to all potentially at risk as a result of the imminent peril. Recognizing conditions that threaten to harm people requires engineers to broaden their perspectives, evaluate potential threats to the life, safety and welfare of the public, and consider the failure probabilities within the structure or system. When such threats are identified, the engineer must notify the client, occupants, and authorities having jurisdiction. When the question “Is the structure at risk?” is answered “yes,” then the engineer must recognize that the question “Should I give notice to vacate?” must also be answered “yes.”

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