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POST-DISASTER TRENCHLESS INSTALLATION OF WATER PIPELINES IN NAPA, CALIFORNIA

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1. ABSTRACT

On August 24, 2014, the largest earthquake (South Napa Earthquake) to hit the Bay Area since the Loma Prieta earthquake struck the City of Napa causing extensive damage to Napa's water distribution system. Hundreds of water main leaks were immediately repaired within a week, but several leaks located beneath Highway 29 were unable to be repaired and left isolated, reducing the City's ability to move water across the highway. To restore water service, the City abandoned the isolated leaks in place and installed new highway crossings using directionally drilled pipelines. Three crossings were originally identified for the project, however during design development another leak beneath the highway was identified and isolated and a fourth trenchless crossing was added to the project. Soil conditions at each of the four crossings consist of artificial fill and Pleistocene-aged alluvium, consisting predominantly of medium stiff to stiff clays interlayered with lesser loose to medium dense sands and gravels. Each directional drill is approximately 500 linear feet with 16-inch fusible PVC casings and 12-inch fusible PVC carrier pipelines. Design challenges include a pipeline alignment highly congested with existing utilities, a work area with residential and commercial businesses, and designing the pipeline beneath a planned large diameter microtunnel sewer pipeline that will be constructed shortly after the HDD installation. The project is funded through Federal Emergency Management Agency (FEMA) disaster mitigation funds, which created additional, unique challenges to implementing the project. This paper describes the geotechnical findings, design development, and administrative challenges to implementing a FEMA funded project.

2. INTRODUCTION

The City of Napa is located in northern California, approximately 50 miles north of San Francisco and is nearby several active earthquake faults (see Figure 1). Napa's water system serves a population of approximately 80,000 people through 370 miles of transmission and distribution pipelines. On August 24, 2014 at 3:20 a.m. the 6.0 Magnitude South Napa Earthquake struck 5 miles south/southwest of Napa and 7 miles below ground. Ground shaking was recorded at 0.80g in the City of Napa. Vertical ground deformation was recorded up to 10 centimeters (see Figure 2) and horizontal deformation over 1 foot. This was the largest earthquake to hit the Bay Area since the Loma Prieta earthquake in 1989. The earthquake caused substantial damage to above ground structures and more than 240 leaks were identified (see Figure 3). Luckily no damage occurred at the water treatment plants, pump stations, or dams and only 1 of the 12 storage tanks was damaged.

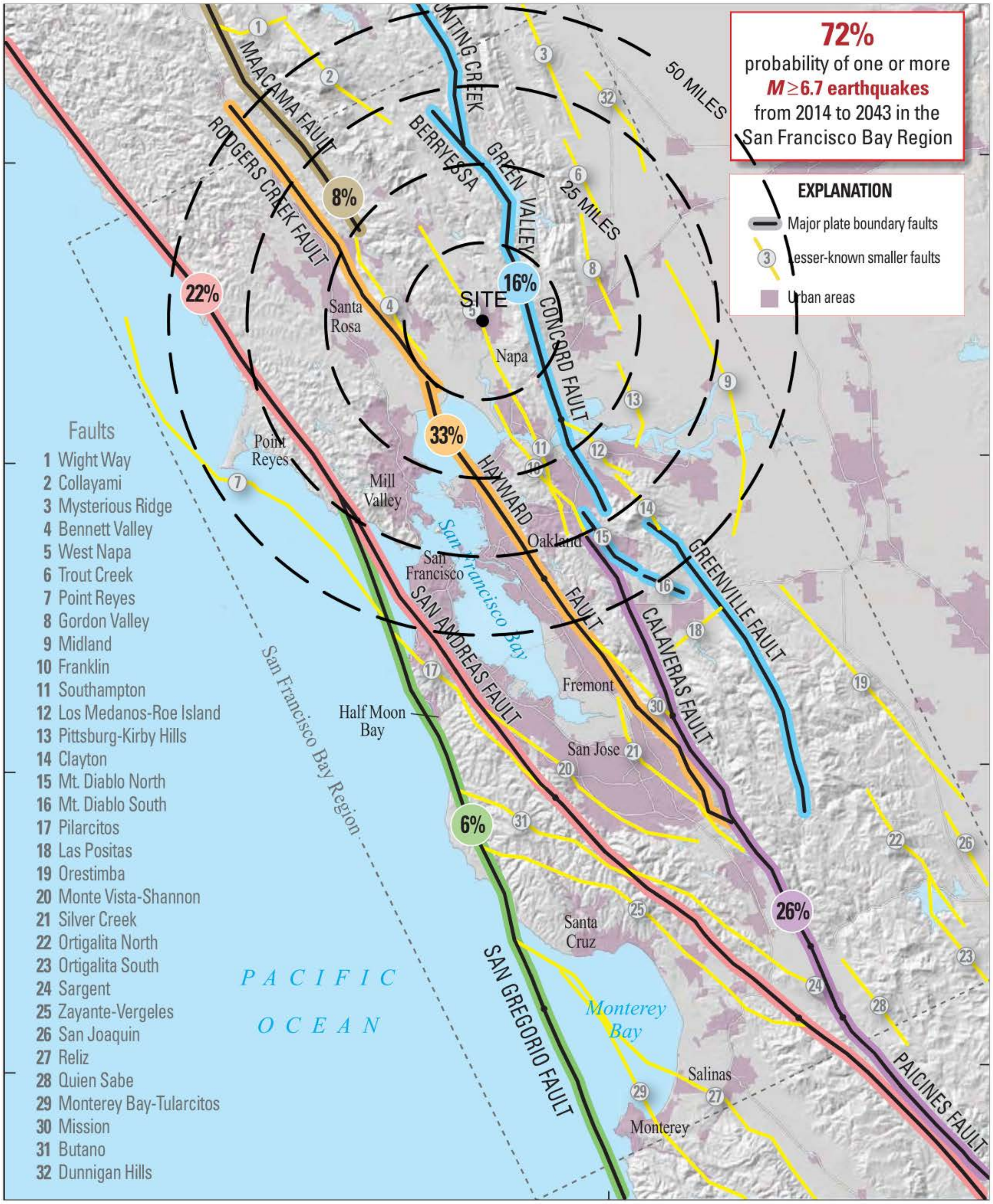

Figure 1: Project Vicinity and Nearby Faults

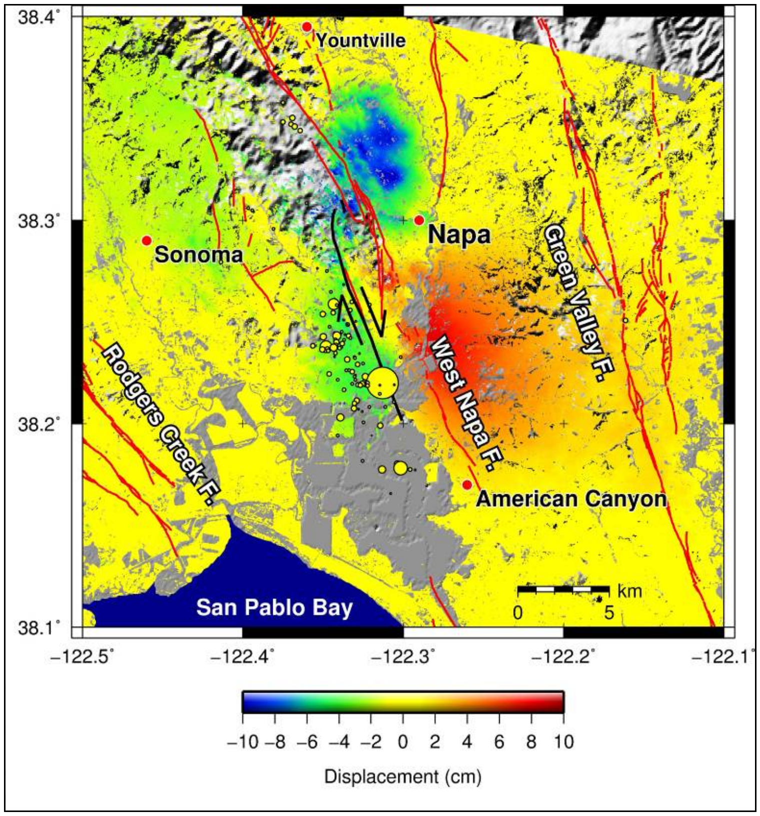

Figure 2: Ground Deformation from the South Napa Earthquake

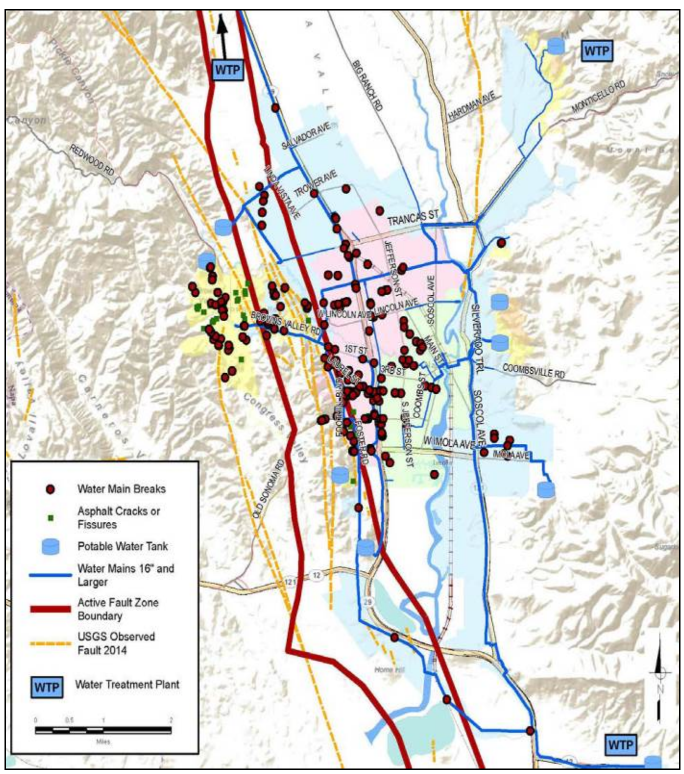

Figure 3: Earthquake Caused Water Pipeline Leaks

Several leaks were located beneath Highway 29 and because of their location beneath the highway, they were unable to be repaired and left isolated. This resulted in limiting the City's ability to move water across the highway, which is a natural physical barrier in the distribution system. The pipelines that crossed Highway 29 were originally installed when the highway was a two lane road, compared to it currently being a 4 line expressway. To restore water service, the City decided to abandon the isolated leaking sections of pipelines in place and install new highway crossings using directionally drilled pipelines.

4. THE FEMA PUBLIC ASSISTANCE PROCESS

In a catastrophic disaster, and if the state's governor requests, federal resources may be mobilized through the U.S. Department of Homeland Security's Federal Emergency Management Agency (FEMA) for federal assistance to state or local governments to pay part of the costs of rebuilding a community's damaged infrastructure. Federal assistance may include funding for debris removal, emergency protective measures and public services, repair or replacement of damaged public property, loans needed by communities for essential government functions and grants for public schools. In California FEMA coordinates with the California Office of Emergency Services (Cal OES) to implement the Public Assistance (PA) Grant Program.

There are several steps in the process to obtaining federal funding, all which must be followed. Below are the required steps, which are also shown in Figure 4.

1. A joint Preliminary Damage Assessment is conducted by FEMA, Cal OES, and local partners to determine losses and recovery needs.
2. The Governor requests federal assistance.
3. The President approves the request for federal disaster funding or FEMA informs the governor it has been denied. This decision process could take a few hours or several weeks.
4. Cal OES holds Applicants' Briefings to provide a general overview of the Public Assistance (PA) program and describe the application process.
5. Applicants submit a Request for Public Assistance to Cal OES within 30 days of the date of the declaration.
6. Kick-off Meetings for eligible applicants are held with FEMA, Cal OES and the local partner to provide a more detailed review of the program and specific applicant needs.
7. The applicant submits a List of Projects to Cal OES.
8. Damaged sites are documented using a Subgrant Application (Project Worksheet).
9. Eligible Project Worksheets are obligated.
10. Funding is disbursed through Cal OES to the applicant as appropriate.
11. Applicants are required to provide quarterly status updates for each large project.
12. Applicants must submit time extension requests prior to the last approved project deadline.
13. Applicants complete construction of their projects and notify Cal OES
14. Cal OES and FEMA complete a closeout of the application.

Figure 4: The FEMA Public Assistance Process

One of the biggest challenges with the federal funding process was changing the scope of the project. Repairs of these leaks were added to the federal funding list in early 2015. Three crossings were originally identified for the project, however during design development in 2016 another leak beneath the highway was identified, isolated, and a fourth trenchless crossing was added to the project. While the leak was identified after the earthquake, it is thought to have occurred from the earthquake. Modifying the overall project description caused a delay to the overall project of about a year. Reasons for the delay include justifying the earthquake as the cause of the leak and engaging FEMA staff, many of who were tasked with hurricane and flooding relief efforts. In addition, because of the change in project description, the overall project was re-reviewed, which resulted in additional scrutiny and review of each crossing. Ultimately, FEMA approval was granted in November 2017.

5. REGIONAL GEOLOGY

Napa County lies within the Coast Ranges geomorphic province of California. The regional bedrock geology consists of complexly folded, faulted, and sheared sedimentary, igneous, and metamorphic rock of the Jurassic-Cretaceous age (65-190 million years ago) Franciscan Complex. Within central and northern California, the Franciscan rocks are locally overlain by a variety of Cretaceous and Tertiary-age sedimentary and volcanic rocks which have been deformed by episodes of folding and faulting. The youngest geologic units in the region are Quaternary-age (last 1.8 million years) sedimentary deposits. These unconsolidated deposits partially fill many of the valleys of the region.

The upper portions of the valleys contain loose deposits of rock fragments, sands and silts, which have migrated by gravity downslope from the adjacent hillsides to form the colluvial deposits along the lower slopes and upper edges of the valleys. The lower portions of the valleys have been filled with finer grained alluvial material over time through the sediment transport process during rainfall events.

Regional geologic mapping by the California Geological Survey indicates the project site is underlain by alluvial deposits of Pleistocene age (more than 11,700 years old). Alluvial deposits are generally composed of poorly-sorted silt, sand and gravel deposited by streams and rivers, and can be in the forms of alluvial fans, stream terraces, and basin and channel deposits.

6. DESIGN OF THE HIGHWAY 29 CROSSINGS

Based on two recent, successful City projects, surface impacts, site constraints, and owner preference, the City decided that horizontal directional drilling using fusible PVC pipe was the preferred installation method and pipeline material (Figure 5). At each crossing, a 12-inch diameter pipeline is needed for hydraulic reasons. Caltrans requires a casing, so an 18-inch diameter casing was originally anticipated. However, after discussions with the pipeline manufacturer, a 16-inch diameter casing was selected with the weld beads removed from the interior of the casing pipe and exterior of the carrier pipe.

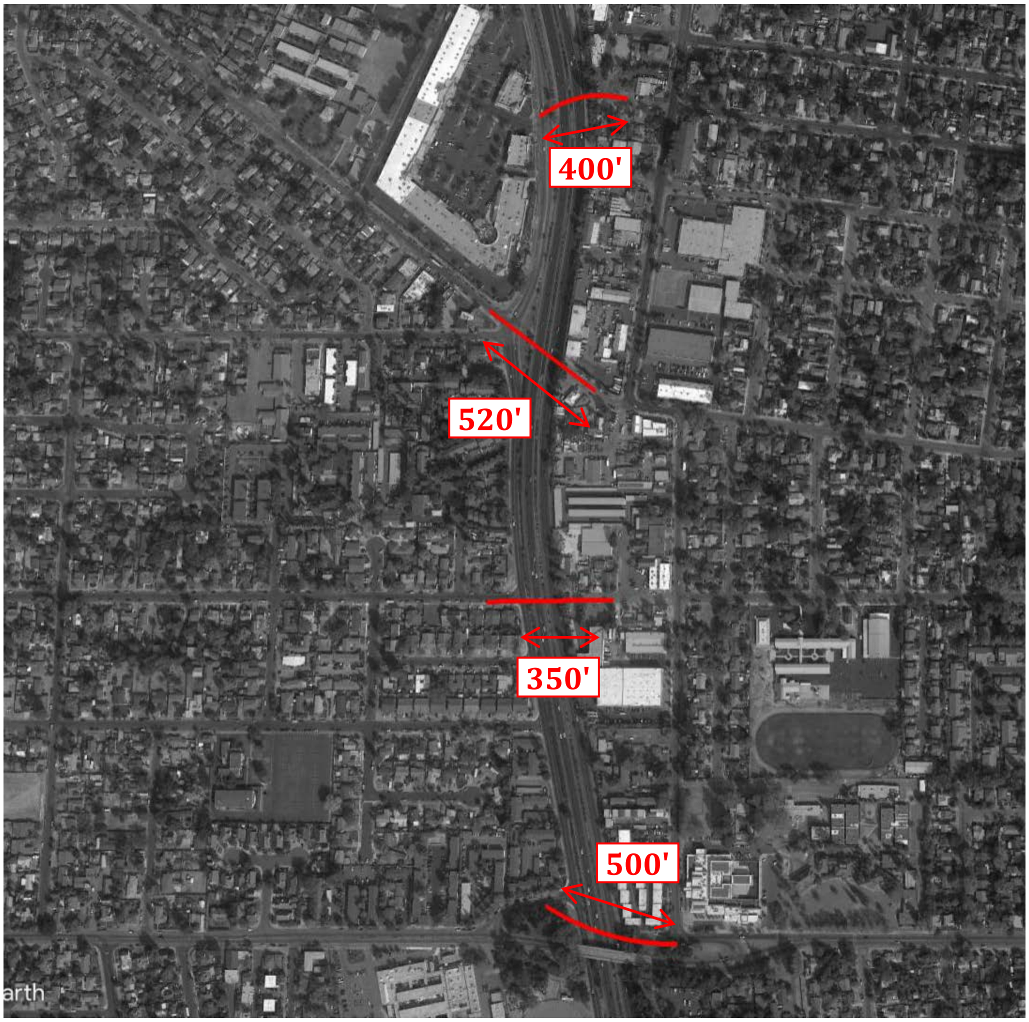

Figure 5: Locations of 4 HDD Installations Across Highway 29

The Caltrans encroachment permit for the water main undercrossings (Caltrans Encroachment Permits, Guidelines and Specifications for Trenchless Technology Projects, January 2015 and Chapter 600, Section 623, January 2009 of the Caltrans Encroachment Permits Manual) requires a casing for the pressurized 12-inch water mains. The casings will be 16 inches in diameter. The Caltrans Encroachment Permit Manual (Section 623.2) recommends a minimum depth of cover for a 16-inch HDD pipeline installation of 10 feet. However, in order to minimize systemic settlement and hydrofracture risks a minimum depth of cover on the order of 20 feet has been recommended and used in project design.

Given a minimum design depth of cover of 20 feet and the Caltrans easement widths described above the total HDD installation lengths will be on the order of 350 to 520 feet long (to accommodate entry and exit angles, radius of vertical curves, existing utilities and tangent lengths under the highway). The 12-inch water mains and 16-inch casing pipelines will consist of fusible PVC.

Subsurface soil conditions at the four Highway 29 undercrossings predominantly consist of medium stiff to stiff fine-grained, cohesive soils (silts and clays) with lesser interbedded coarse-grained, non-cohesive soils (sands and gravels). These soil conditions are conducive to HDD construction and are consistent with the soil conditions from the City's 2013 project as discussed in Section 2.3 above. Clean open graded gravels, cobbles or boulders were not encountered in the project geotechnical investigation. In the absence of such high risk (and sometimes fatal flaw) soil conditions, geotechnical conditions will not control HDD bore path design. The design of the four undercrossings bore paths was governed by:

- a minimum depth of cover beneath Highway 29 of 20 feet (to control hydrofracture and limit systemic settlement);
- A minimum depth of 10 feet below all Caltrans right-of-way;
- A Caltrans required skew angle of less than 30 degrees from normal;
- existing utility clearances;
- minimum bending radius for HDD drill rods (typically, radius in feet = 100 x rod diameter in
- inches);
- allowable minimum bending radius for the 16-inch C905, DR18 PVC casings of 363 feet;
- appropriate HDD rig set up and equipment area; and
- appropriate pipeline fusion and laydown area.

Two crossing locations include both a horizontal and vertical curve. While efforts were made to avoid these compound curves, the limited project space and other constraints necessitated them. The following equation, from the HDD Best Practices Manual, was used to derive the actual curve (combined horizontal and vertical curve):

$$Compound\_Radius = \sqrt{\left[\frac{\left(R_A{}^2 \times R_B{}^2\right)}{\left(R_A{}^2 + R_B{}^2\right)}\right]}$$

Constructing a compound curve directional drill was a concern during design development. To address this concern, the pilot bore steering operator was required to have previously completed installation of a compound curve drill. An interesting design note is the installation of the Old Sonoma Road crossing, which is located beneath a planned 36-inch diameter microtunnel installation of a sanitary sewer pipeline. Properties used to calculate formation limit and drilling fluid pressures are summarized in Table 1.

Table 1: Preliminary Design Formation Limit and Drilling Fluid Pressure Properties

	Properties	**Values**
Drilling Fluid and Drill Pipe Properties	Pilot Borehole Diameter	9.9 inches
	Drill Pipe Diameter	5.5 inches
	Drilling Fluid Unit Weight	11 lbs/gallon
	Drilling Fluid Viscosity	50 centipoise
	Flow Rate of Drilling Fluid at Drill Bit	29 pounds/100 ft^2
Soil Bore path Properties	Unit Weight	100-110 lbs/ft^3
	Friction Angle	34-38 degrees
	Cohesion	0-90 lbs/ft^2
	Shear Modulus	1,500-5,000 ksf

ASTM F1962 methods were used to estimate pulling loads and to confirm that pipe stresses would be within acceptable limits during installation. A maximum pulling force of 14,700 pounds was estimated to be required for pipe pullback, which included a safety factor of 2.0 to account for possible deviations from idealized conditions (e.g. from sloughing, design bore path deviations, and stoppages), and assuming the pipeline will be fully ballasted with water during pullback within a drilling fluid having a specific gravity of 1.5.

The project is scheduled for construction in spring / summer 2018.

9. SUMMARY

The City of Napa was rocked by a 6.0 earthquake in 2014. The City of Napa Highway 29 Water Main Replacement Project is an emergency replacement of critical water infrastructure that was damaged by the earthquake through the design of four (4) HDD installations beneath Highway 29 that will "reconnect" water service across the freeway. The design includes a 12-inch diameter fusible PVC carrier pipe and fusible PVC casing. Two of the four crossings include compound horizontal and vertical curves, which were unavoidable. The project is funded through Federal Emergency Management Agency (FEMA) disaster mitigation funds, which created additional, unique challenges to implementing the project such as obtaining approval to modify the project description due to damage discovered subsequent to the original request for aid. The biggest recommendation for other agencies in similar situations is to not change the project description with FEMA once it has been set.

10. ACKNOWLEDGMENTS

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