KARST VOID MITIGATION FOR WATER QUALITY AND QUANTITY PROTECTION IN AUSTIN, TEXAS

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ABSTRACT

In an area of karstic aquifer usage, management of voids encountered during construction can mean the difference between adding a continuing source of groundwater contamination and protection of groundwater quality. City of Austin regulations and measures for void mitigation are reviewed in this document, and case studies of projects encountering significant features are summarized. The measures outlined are intended to prevent the future migration of potentially contaminated groundwater into the Edwards Aquifer and to preserve the hydrologic connections between the land surface and the water table and/or springs.

INTRODUCTION

Voids are common features of the karstic limestone and dolomite formations of the Edwards Group in Central Texas. They occur as interstitial cavities, solution-enlarged bedding plane cavities, solution-enlarged fractures, and cave passages. When voids are intercepted by construction activities, such as trenching or grading, the structural integrity and the hydrological function of the void may be compromised. For this reason, City of Austin regulations require that voids be reported so that the voids can be inspected and assessed for potential environmental impacts from the construction project. Water quality may be impacted if the void occurs within a trench for a wastewater line, a stormsewer line, a petroleum products pipeline, or an onsite wastewater treatment system. Water quantity may be impacted if the intercepted feature is a conduit that conveys water to the local water table or to a nearby spring.

If a void is encountered during construction, mitigation plans to reduce potential impacts must be submitted to the City of Austin before construction activities can resume. Plans must include reports of the hydrological characteristics of the void and revised construction plans that incorporate protective measures designed to minimize negative impacts. This paper outlines common mitigation measures associated with these plans and presents case studies where these measures have been implemented.

Four examples of recent void mitigation techniques implemented on various projects are presented: encasing wastewater lines in cement for the length of a void plus 1.5 m (5 ft) on either end; installing steel plates along trench walls and encasing stormsewer or wastewater lines in cement for the length of the voids; installing PVC pipe across the base of trenches in order to maintain flow along a karst conduit; and moving infrastructure away from subsurface voids. These measures are intended to prevent the future migration of potentially contaminated groundwater into the Edwards Aquifer and to preserve the hydrologic connections between the land surface and the water table and/or springs.

WHY IS VOID MITIGATION NECESSARY?

The purpose of a void mitigation plan is to design a means for sealing off cavities within karstic rock horizons in a manner that protects the hydrologic characteristics while ensuring the structural integrity of the cavity and the manmade structures installed adjacent to such cavities.

Water quality and water quantity protection of the Edwards Aquifer is important to Central Texans because the Edwards Aquifer is the most productive in the region, supplying water to domestic and municipal wells and also to springs that provide baseflow to surface water bodies. Void mitigation can preserve karst conduits that convey groundwater to springs or cave passages that are hydrologically connected to the water table. Preservation of these recharge paths helps to preserve the quantity of water entering the aquifer. Eliminating potential hydrologic connections between voids and potential pollutant sources, such as wastewater pipes or stormsewer pipes, helps to protect water quality. Rapid growth in the Austin area has resulted in a 50-percent increase in the number of voids reported annually from 1998 to 2000 (City of Austin, Watershed Protection Department internal data, 2000).

This paper describes the void mitigation process used by the City of Austin. Four examples of void mitigation plans are presented to illustrate various void mitigation techniques.

CITY OF AUSTIN VOID NOTIFICATION REQUIREMENT

The Environmental Criteria Manual (ECM) is the City of Austin's regulatory guide for implementing water quality ordinances codified in the Land Development Code. Appendix P-1 of the ECM instructs contractors to immediately report voids discovered during construction activities to a City of Austin Environmental Inspector. This requirement applies to any void that is greater than "one square foot in total area, or blows air from within the substrate and/or consistently receives water during any rain event." Appendix P-1 also requires inclusion of a note regarding void discovery on all construction plans for projects built over the Edwards Aquifer Recharge Zone (City of Austin, 2000).

INTER-AGENCY COORDINATION

Inter-agency coordination is necessary when a construction site is located in an area of overlapping jurisdictions or regulations of federal, state, or local agencies or a state-authorized groundwater district. These include areas regulated by the Texas Natural Resource Conservation Commission (TNRCC, now TCEQ) under the Edwards Rules (Title 30 of the Texas Administrative Code, Chapter 213), or within the boundaries of the Barton Springs/Edwards Aquifer Conservation District (BS/EACD), within an area that is potential habitat for endangered karst invertebrate species under U.S. Fish and Wildlife Service (U.S.F.W.S.) regulation, or within an area designated as the Edwards Aquifer Recharge Zone by the City of Austin Watershed Protection Department (Chapter 25-8 of the Land Development Code).

Most occurrences of voids are on private development projects. Standard procedures on private projects involve City of Austin Watershed Protection Department (WPD) staff inspection of the voids, discussions of possible mitigation measures with other agency staff (TNRCC or the BS/EACD or the USFWS), and coordination of recommendations to the developer's consultants. A void mitigation plan is then prepared by the owner's consultants and submitted to the City of Austin Watershed Protection Department (WPD) Environmental Review and Inspection Division and the Environmental Resources Management Division for review and approval. The TNRCC requires that a licensed Professional Engineer (P.E.) prepare void mitigation plans and affix an engineer's seal to the plans. Although this is not stipulated in the City of Austin's Land Development Code or in the ECM, it is suggested practice.

VOID INSPECTION, DESCRIPTION, AND DOCUMENTATION

Inspection of the void should occur soon after notification is made, in case its physical characteristics change significantly following exposure to light, air currents, heat, and stormwater runoff. Important features related to the hydrological function of the void may be altered or obscured if left open for several days. Information such as speleothem activity, the presence of pools of water, and the type of soil covering the void floor yield insight as to the amount of water entering and exiting the void and the possibility of nearby surface openings connecting to the void. Descriptions of the void, photographs, maps or sketches of its dimensions, and a site plan showing the location and footprint of the void are to be included in the void mitigation plan submitted with revised construction plans. It is helpful if the consultants conducting the assessment of the void have been involved in earlier phases of site permitting, particularly with completing overland surveys of the karst features on the property.

Typically, voids are intercepted during utility trenching operations and inspection of them requires training in confined space entry and trench and excavation safety techniques. City of Austin staff conducting void inspections receive this training. Trench sidewall safety devices are installed by the owner's contractors prior to anyone entering the trench.

TYPES OF VOIDS AND MITIGATION PLAN STRATEGIES

Most of the voids encountered during construction are limited in extent, but occasionally sizeable caves are found. Size classifications and indications of water movement ("hydrological connection") are used to characterize voids as three main types. These are:

- **Type 1** void is less than 0.6 m (2 ft) by 0.9 m (3 ft) by 0.9 m (3 ft) in volume and is hydrologically inactive (dry);

- **Type 2** void is greater than 0.6 m (2 ft) by 0.9 m (3 ft) by 0.9 m (3 ft) and is hydrologically active (water dripping from the ceiling or moving along the floor), but it is an isolated feature lacking evidence of obvious connections to the water table, or a spring, or to other subsurface voids ("interstitial void"); and

- **Type 3** void is greater than 0.6 m (2 ft) by 0.9 m (3 ft) by 0.9 m (3 ft) and is hydrologically active (water dripping from the ceiling or moving along the floor) and is probably connected to the water table or a spring.

Caves and solution-enlarged fractures (Type 2 or 3 voids) intercepted by construction activities have the potential to be connected to the Edwards Aquifer or to a spring. Void mitigation plans address how to protect our groundwater resources based on the type of void and the proposed utilities. An assessment of the void may determine that the best mitigation strategy is to move utility infrastructure or buildings and parking areas. Otherwise, suggested strategies for void mitigation include:

- Sealing off the opening along the face of the trench;
- Installing durable pipe at the base of the trench to allow continued conduit flow across the trench;
- Encasing utility pipe in concrete for the entire length of the void and a distance of 1.5 m (5 ft) on each end; and
- Placing large-diameter rock, sized 7.6 to 12.7 cm (3 to 5 inches) in diameter, by hand if possible, within the void to provide structural stability if the void will be located beneath a structure, roadway, or parking area.

The void type and the layout of facilities in the site construction plan will govern which mitigation plan strategies are used.

VOID MITIGATION PLANS

Following the inspection and assessment of the void, a mitigation plan is prepared. A mitigation strategy is developed from information such as the void size, the evidence of water activity within the void, the potential for connections to the Edwards Aquifer or a spring, and the design of the utility or structure.

The void mitigation plan should provide a generalized description of how the void will be sealed and how any porous, fractured zones will be sealed. The plan should be prepared by a Professional Engineer. who has expertise in structural and geotechnical engineering and design experience in Central Texas, particularly with projects constructed over the Edwards Aquifer Recharge Zone. Information from the void assessment, including photographs, field notes, maps, sketches, and geotechnical boring logs, should be submitted with the plan. It is the engineer's responsibility to prepare a plan prescribing void mitigation measures that maintain the integrity of the utility lines, buildings, and structures on site while preserving the hydrological characteristics of the caves/voids. The plan should provide material specifications and specific installation instructions for the closure procedure. Material specifications are required to be clear and readily apparent to contractors, particularly to personnel performing the work. Also, the engineer must revise the site plan to document the location of voids and mitigation measures used. Four recent case studies and the void mitigation plans for each are discussed below.

CASE STUDY 1. Lodge Cave, Parmer Lane, Austin, Texas

Lodge Cave was discovered on September 29, 2000, during trenching for a 1.8-m (6-ft)-diameter reinforced concrete pipe (RCP) stormsewer. The cave is an isolated feature ("interstitial void") that developed vertically along a fracture and horizontally along a fossiliferous, vuggy, friable horizon within the limestone. The "footprint" of the cave is approximately 21.4 m (70 ft) by 6.7 m (22 ft). The cave roof was intercepted by trenching equipment at a depth of approximately 3.1 m (10 ft) below grade. The cave interior was fairly dry, as evidenced by the abundant cave coral and popcorn formations, yet stalactites were dripping on September 29, 2000. Lodge Cave is considered a Type 2 void. Two-thirds of the cave will be beneath a future roadway.

The void mitigation strategies proposed by the engineering consultant included (Carter and Burgess, 2000):

- **Backfilling** 7.6 to 12.7-cm (3 to 5-inch) diameter rock at the base of the trench to support the 1.8-m (6-ft)-diameter RCP and to allow fluids to migrate along the cave floor;
- **Sealing off** the cave opening at the trench face with sand bags; and
- **Pouring a concrete slab** over the rock base that extends above the cave ceiling and for 1.5 m (5 ft) on each end of the cave opening. Dirt from the sidewalls of the excavation was removed by hand to ensure a strong bond between the limestone and the 17,237-kPa (2,500-psi) compressive strength concrete.

The void mitigation measures, installed on November 10, 2000, will prevent the leakage of untreated stormwater from the pipe into the cave where it could leak through fractures to the water table, which is at approximately 30 m (85 ft) below ground surface in this area. Sealing off the utility trench floor and walls from the cave will allow water traveling through the vadose zone to continue to migrate through the cave.

Photographs of Lodge Cave are shown in the Appendix.

CASE STUDY 2. Four Points Emergency Services and Fire Station Site, River Place Boulevard, Austin, Texas

Voids were encountered within a trench for a stormsewer pipe and within a pit excavated for septic system holding tanks. The void horizon occurred at approximately 1.2 to 2.4 m (4 to 8 ft) below ground surface (bgs). Caves were found on the adjacent tract, but no surface expressions of these voids were detected during the pre-construction karst survey. Disbelievers Cave, an endangered species cave that is habitat to the Tooth Cave ground beetle Rhadine persephone, is located 27.5 m (90 ft) from the property boundary of the Four Points Emergency Services and Fire Station Site (Four Points AFD) on an adjacent tract. Preservation of potential recharge paths within the Edwards Group limestones is important in the Bull Creek watershed, where most of the recharge occurs via micro-karst features (Johns, 1994).

A total of seven voids were intercepted along the trench for a 0.5-m (18-inch)-diameter RCP stormsewer. These ranged in size from 0.5 to 1.5 m (1.5 to 5 ft) in height and approximately 1.2 to 2.1 m (4 to 7 ft) in length and 0.3 to 1.4 m (1 to 4.5 ft) in width. The voids probably developed under phreatic conditions at or near the water table and are now active vadose zone features. Stalactites, stalagmites, flowstone, and cave popcorn were found in all of the voids (see example photographs in the Appendix). Tree roots, dark brown organic material, and spider webs found within one of the caves prompted a biological investigation, but no endangered karst invertebrate species were found.

Mitigation strategies for the Type 2 voids located adjacent to the stormsewer pipe included:

- **Bolting** 1.3-cm (0.5-inch) thick steel plates to the rock face surrounding the voids;
- **Sealing off** the opening between the steel plate and the rock face with cement mortar, latex caulk and/or gunnite; and
- **Backfilling** the space between the steel plates and the stormsewer with an air-entrained concrete ("flowable fill" as described in City of Austin Standard Specifications Item 402) for the length of each void plus 1.5 m (5 ft) on each end and to a height 0.3 m (1 ft) above the top of each steel plate.

A diagram of the mitigation method is provided in the Appendix.

Two voids and a vuggy horizon were encountered in the excavation for the septic system holding tanks. These voids occur within the same general horizon as those encountered along the stormsewer trench. The vuggy horizon is nearly continuous throughout the entire width of the 6.1 m by 6.1 m (20 ft by 20 ft) excavation. The voids and vugs are potential fluid migration paths to nearby Powerline Spring and Moss Gully Spring (Veni, 1998). Six geotechnical borings were cored in the vicinity of the septic system holding tanks to determine if voids were present below the floor of the excavation (HBC Engineering, Inc., 1999). Isolated weathered seams and 5-cm to 15-cm (2-inch to 6-inch) voids were intercepted at depths of 1.8 to 4.6 m (6.5 to 15 ft) bgs. This information suggested that an extensive void horizon was not present at a depth below the base of the septic system holding tanks. Project consultants and engineers determined that proceeding with void mitigation was a better alternative than attempting to relocate the tanks and/or redesigning the septic system, given site constraints and the project deadline.

The steel plate and backfill mitigation strategies were also used to seal off the voids found in the septic system holding tanks. In addition, 15.2 cm (6 inches) of "flowable fill" were poured over the entire floor of the excavation to form a "seal." Gunnite was sprayed over the walls of the excavation to seal off the vuggy horizon.

CASE STUDY 3. Lone Star Natural Gas Pipeline, Parmer Lane, Austin, Texas.

Trenching for a 0.3-m (12-inch) diameter natural gas pipeline along the northern right-of-way of Parmer Lane exposed 14 voids within a friable, sandy limestone bed and within 100 m (305 ft) of three endangered karst invertebrate species caves. The voids occurred at approximate depths of 1.1 to 1.7 m (3.5 to 5.5 ft) below ground surface and varied in length from 0.6 to 7.6 m (2 to 25 ft). The lateral extension of a typical void beyond the trench face ranged from less than 0.3 m to 6.1 m (1 to 20 ft). Several large voids intercepted by the trench appeared to be active vadose water conduits and probably drain to nearby Yett Creek. A cave cricket and a cave spider were found in two of the voids, prompting a biological investigation for the presence of endangered karst invertebrate species. The U.S.F.W.S. Austin field office coordinated the development and preparation of the void mitigation plan and included the City of Austin WPDRD as a cooperating agency.

Development of the void mitigation plan was intended to protect the habitat for endangered karst invertebrate species but was also suitable for the protection of water quantity and water quality. Multiple void mitigation strategies were employed to protect these naturally occurring **Type 3 voids** from the potential impact of a future natural gas leak while preserving the hydrological characteristics of the voids (Espey, Huston and Associates, Inc., 1998). The mitigation strategies included:

- **Sealing** the openings along the face of the trench with rocks and mortar;
- **Installing PVC pipe** encased in concrete across the base of the trench to allow air, moisture, and fauna movement between voids intercepted by the trench;
- **Constructing small clay dams** within the trench to prevent fluid migration along the floor of the trench;
- **Encasing the gas pipeline** with 0.4-m (**16-inch**) diameter polyethylene pipe for the entire length of the void horizon (732 m or **2,400 ft**); and
- **Sealing** the encasement pipe and venting it to the atmosphere to prevent below ground releases of a future gas pipeline leak or rupture.

Figure 1 in the Appendix provides a photograph taken during the mitigation installation and an illustration of the mitigation strategy used for voids intercepted on one side of the trench.

Other mitigation measures that were considered but not included in this void mitigation plan were:

1. Purchasing an offsite endangered karst invertebrate species cave to compensate for a potential “take” from caves adjacent to the pipeline,
2. Moving the pipeline to the southern right-of-way of Parmer Lane, and
3. Boring the pipeline at a depth below the known cave and void-forming strata.

CASE STUDY 4. Millennium Cave, La Cresada Drive, Austin, Texas

Millennium Cave was discovered on January 31, 2000, during excavation of a stormwater treatment sedimentation/filtration basin in the Village at Western Oaks subdivision. The trackhoe operator noticed a 0.4-m (15-inch) diameter opening in the rock and stopped to inspect the opening. He immediately moved the trackhoe back from the opening after seeing that it dropped approximately 4.3 m (14 ft) and widened out to the sides 4.6 m (15 ft) or more. A thorough inspection by a cave specialist revealed that the main chamber of a cave had been popped open. The chamber is approximately 16.2 m (53 ft) wide by 13.4 m (44 ft) long by 4.3 m (14 ft) deep. The cave contains many stalactites, stalagmites, and flowstone formations. No surface expression of Millennium Cave was present prior to its discovery, but two caves are located within 153 m (500 ft) in a designated karst preserve.

Void mitigation for Millennium Cave was fairly complex due to the size of the cave and the proximity of the sedimentation/filtration basin. City of Austin WPDRD staffers were concerned that construction of the sedimentation/filtration basin adjacent to the cave and over undetected voids would lead to future failure of the structure and that the WPDRD would have to repair the structure. The owner was concerned that a proposed wet pond, to be constructed within 762 m (2,500 ft) of the sedimentation/filtration basin, would intercept a cave during excavation. The owner proceeded with exploratory geotechnical cores in the vicinity of the wet pond.

Preliminary discussions between the owner and the WPDRD to move the sedimentation/filtration basin were unsuccessful. Next, discussions focused on resizing the sedimentation/filtration basin, installing a structural wall adjacent to Millennium Cave, conducting void collapse analyses, and drilling geotechnical cores in the vicinity of the sedimentation/filtration basin. The void collapse analyses relied upon the calculations presented in Ford and Williams (1989) and White (1988) and the thickness of the limestone beds measured in Millennium Cave (Trinity Engineering, 2000). Several of the cores intercepted a friable/void horizon between depths of 3.7 to 6.1 m (12 to 20 ft), including a 1.2-m (4-foot) void detected in one of the borings. Photographs of Millennium Cave are provided in the Appendix.

The WPDRD coordinated the development of the void mitigation plan with the assistance of the TNRCC. Specific measures included in the void mitigation plan are:

- **Installing a secured entry structure** over the artificial skylight entrance to Millennium Cave. The structure is to preserve the existing light, humidity, temperature, and air flow conditions within the cave;
- **Incorporating Millennium Cave within the boundaries** of the adjacent Western Oaks Karst Preserve;
- **Installing a structural wall** on the western end of the sedimentation/filtration with a vertical separation distance of 7.0 m (23 ft) from the bottom of the wall to an underlying cave passage;
- **Encasing or slip lining** the 0.5-m diameter RCP segments that are located over the “footprint” of Millennium Cave;
- **Applying sealant** to all joints of the splitter box structure installed west of Millennium Cave; and
- **Installing** a 0.3-m (1-ft)-thick clay liner (0.2 m (6 inches) is required by ordinance) below the sedimentation/filtration basin.

VOID MITIGATION IMPLEMENTATION

During installation of void barriers or other mitigation measures, photographs should be taken to document the installation and completion of these measures. Oversight during installation and construction of void mitigation measures can help ensure that the plan specifications are followed. The City of Austin retains copies of void mitigation plans for future reference on the project site and for evaluation of proposed mitigation plans for voids discovered on nearby sites. This information should also be retained by the site owner and by regulatory agencies overseeing the mitigation, and it should be submitted to utility companies responsible for the future maintenance of affected utility lines.

CONCLUSIONS

Construction activities occasionally intercept voids within the karstic limestone units of the Edwards Aquifer Recharge Zone in Austin, Texas. When voids are exposed, mitigation strategies are devised to protect the hydrological function of the void, to stabilize the structural integrity of the void, and to protect the structural integrity of adjacent utilities or structures. The goal is to protect these features in order to maintain the water quantity and water quality of the Edwards Aquifer in a way that is compatible with site development.

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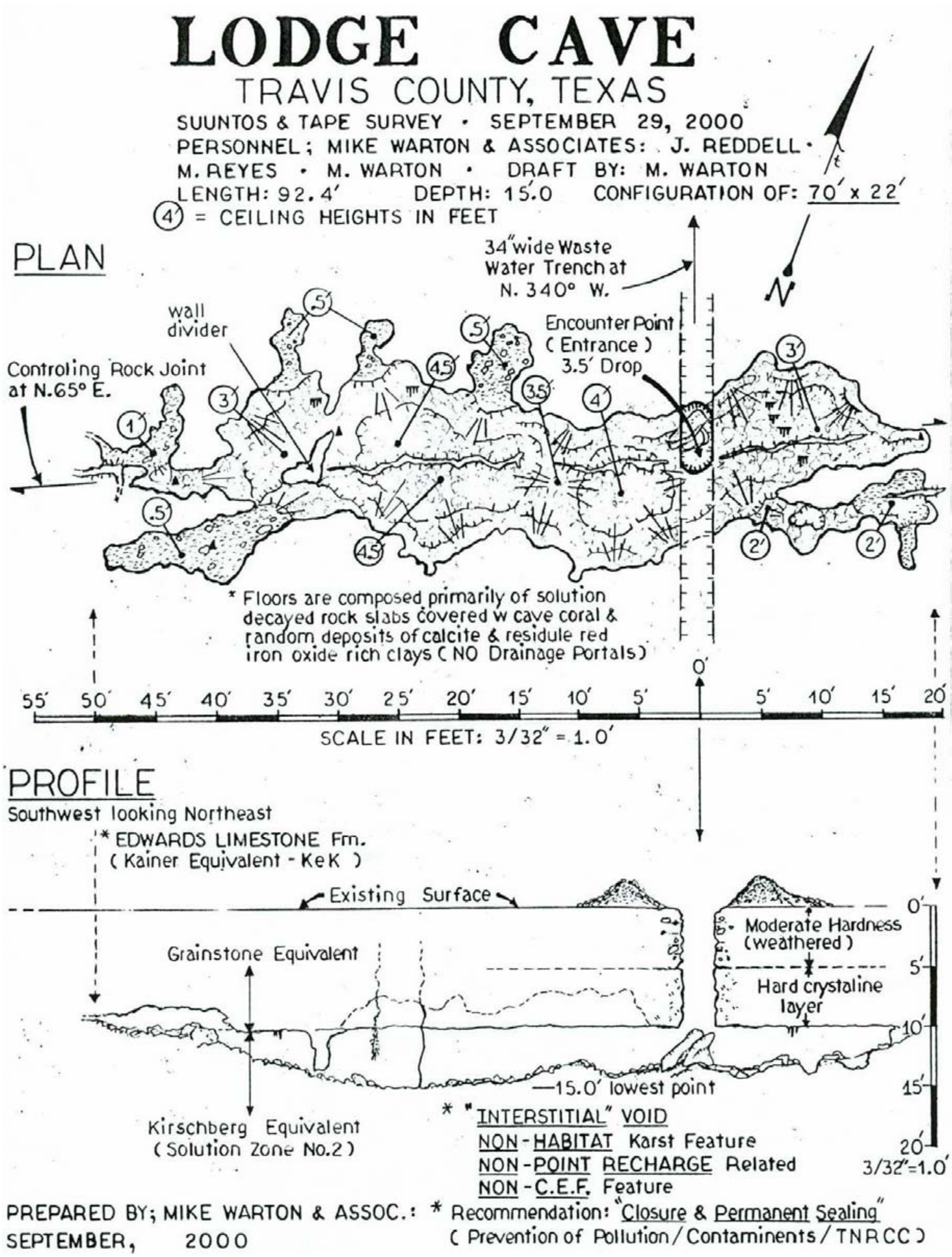
CASE STUDY 1. Lodge Cave, Parmer Lane, Austin, Texas.



Lodge Cave prior to sealing

Cave entrance, west side

Backfill floor of cave with 7 to 12-cm (3 to 5-inch) gravel

1.8 m (6 ft) diameter RCP stormsewer

Tamp gravel with trackhoe

Sand bags placed inside cave opening.

Concrete poured over gravel backfill

CASE STUDY 2. Four Points Emergency Services and Fire Station Site, River Place Boulevard, Austin, Texas.

Four Points EMS/ Fire Station, void C

Void interiors had active speleothems

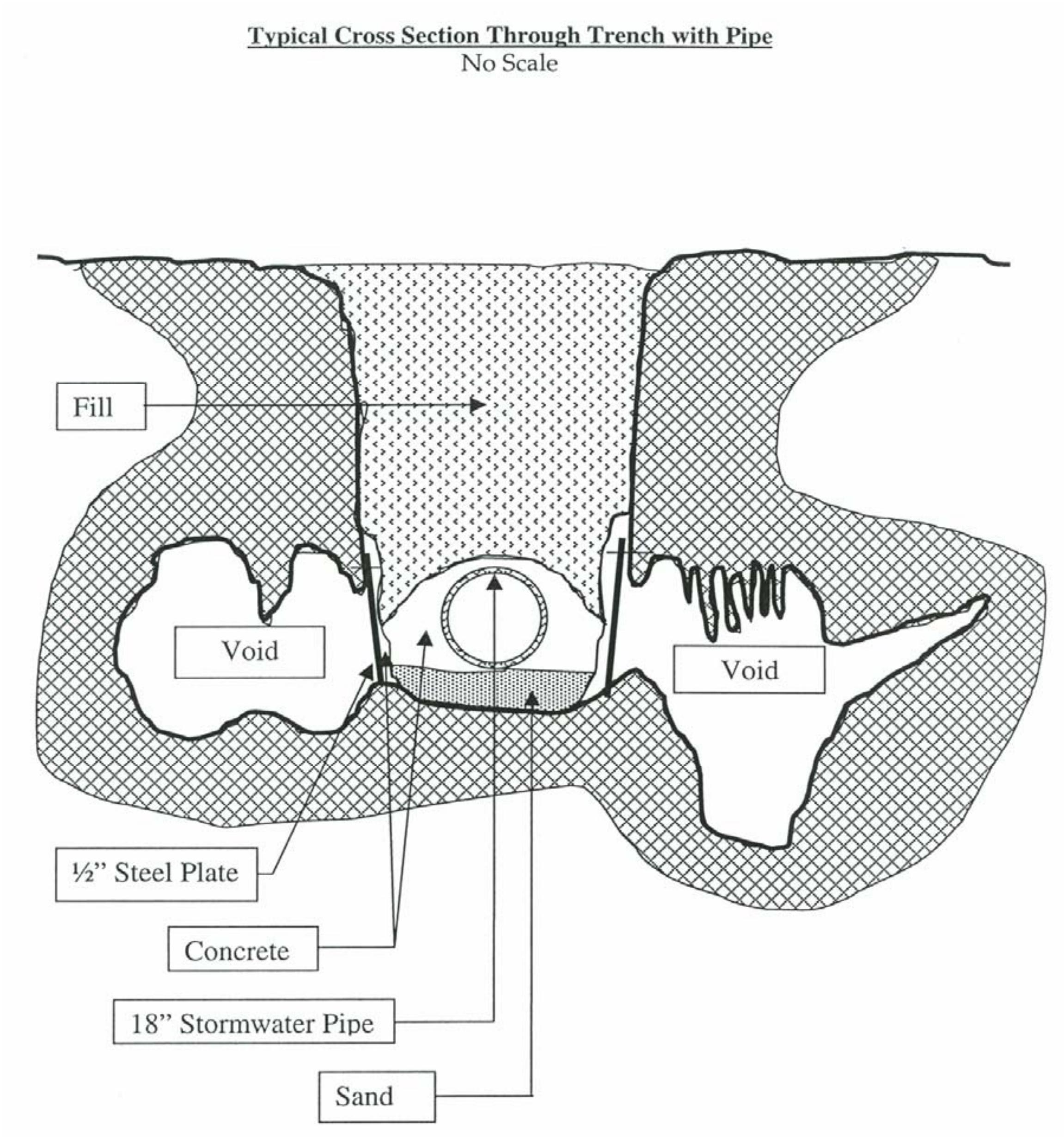
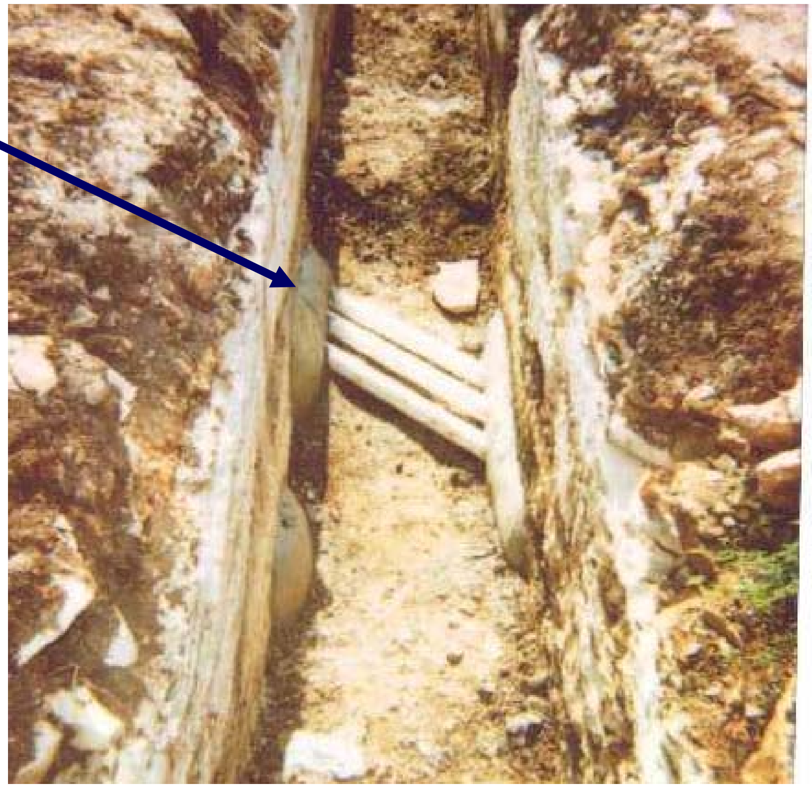


Diagram of proposed mitigation method for voids found along stormsewer trench at the Four Points EMS/Fire Station.

CASE STUDY 3. Lone Star Natural Gas Pipeline, Parmer Lane, Austin, Texas.

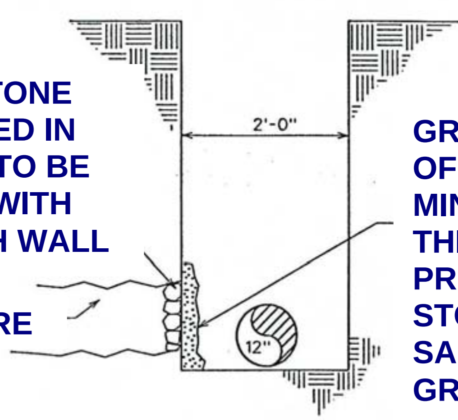
PVC pipe placed below natural gas pipeline to maintain hydrologic connection of void

Void closure, Lonestar Gas Pipeline, Parmer Lane, Austin, Texas



3"-4" STONE GROUTED IN PLACE TO BE FLUSH WITH TRENCH WALL

FISSURE



GROUT FACE OF FISSURE A MIN. OF 4" THICK, PRESSED INTO STONE WITH A SAND/CEMENT GROUT

NOTE: GROUT SHALL BE 9 SACKS OF CEMENT PER CY MIX.

CASE STUDY 4. Millennium Cave, La Cresada Drive, Austin, Texas.

Millennium Cave was found during excavation of a water quality pond, January 31, 2000.

Mike Warton entering the skylight opening in order to map the cave and to look for karst invertebrates.

Interior of Millennium Cave: 0.9-m diameter column, stalactites, stalagmites and cave coral

Millennium Cave is one of the largest and most “decorated” caves found during construction in Austin, Texas

Coring was conducted in the water quality pond excavation to identify possible voids and passages connected to Millennium Cave.

Interior of Millennium Cave