Thermal Sciences

Exponent®

San Francisco Gas Event

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Prepared for

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Contents

Acronyms and Abbreviations

AAR	after-action report
CI	cast iron
CPUC	California Public Utilities Commission
CGI	combustible gas indicators
DOT	Department of Transportation
EOC	Emergency Operations Center
GC	General Construction
GDCC	Gas Distribution Control Center
GEC	Gas Emergency Center
GERP	Gas Emergency Response Plan
GSR	Gas Service Representative
HP	high pressure
I&R	Instrumentation and Regulation
IC	Incident Commander
LP	low pressure
M&C	Maintenance and Construction
MAOP	maximum allowable operating pressure
NOP	normal operating pressure
OEC	Operations Emergency Center
PG&E	Pacific Gas and Electric
PL	plastic
SFFD	San Francisco Fire Department
SFPD	San Francisco Police Department
SHP	semi-high pressure

Limitations

At the request of PG&E, Exponent has conducted an investigation of the gas leak and subsequent explosion that occurred on November 27, 2017, on Mission Street in San Francisco, California.

Exponent investigated specific issues relevant to this incident, as requested by PG&E. The scope of services performed during this investigation may not adequately address the needs of other users of this report, and any reuse of this report or its findings, conclusions, or recommendations presented herein is at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

We have endeavored to accurately investigate all areas within our scope identified during our investigation. If new data become available or there are perceived omissions or misstatements in this report regarding any aspect, we ask that they be brought to our attention as soon as possible so we have the opportunity to address them.

Executive Summary

On the morning of Monday, November 27, 2017, an explosion occurred at a residential building at [redacted], San Francisco. At the time of the explosion, PG&E employees were en route to respond to a reported gas leak in the area. Exponent was retained by PG&E to perform a causal evaluation of the incident, to review construction records and applicable company standards associated with the gas facilities in the incident area, and to evaluate PG&E's emergency response to the incident.

As part of the investigation, Exponent performed multiple site examinations, witnessed multiple pressure tests of PG&E's gas facilities, reviewed PG&E construction records, reviewed applicable codes and standards, performed laboratory testing of exemplar gas fittings and equipment, and performed interviews of witnesses to the incident, including members of the San Francisco Fire Department (SFFD) and PG&E employees who were involved in the emergency response or who had knowledge of relevant information. The following is a summary of Exponent's conclusions to date.

Incident Investigation

At 9:52 AM on Monday, November 27, 2017, the SFFD received a gas odor complaint on the 3900 block of Mission Street in the Bernal Heights neighborhood of San Francisco. The SFFD arrived on scene minutes later, observed signs of a gas main leak, started evacuating buildings, and notified PG&E. Two PG&E Gas Service Representatives (GSRs) were dispatched to the site. At approximately 10:14 AM, an explosion occurred in a rowhouse at [redacted] (incident house), on the east side of the street. The explosion broke second-floor windows and the garage door, and propelled the garage door into the street. A neighbor reported observing an orange fireball being ejected from the garage. There was no subsequent fire at the incident house following the explosion. The first PG&E GSR arrived at 10:20 AM and saw signs of a gas main leak. Another GSR arrived shortly thereafter. The first of several PG&E Maintenance and Construction (M&C) crews arrived at 10:30AM. An M&C Supervisor arrived at 10:33AM and assumed the role of PG&E Incident Commander (IC). An Operations Emergency Center (OEC) was opened in the PG&E San Francisco office and communicated with the IC. The Gas Emergency Center (GEC) in San Ramon unofficially activated and acted in a support capacity to the OEC. PG&E engineers in the Gas Distribution Control Center (GDCC) started reviewing maps and preparing primary and backup gas isolation plans that were then shared and discussed with the GEC, OEC, and IC. The first isolation plans were shared with the IC at 10:57AM. Isolation strategies were reviewed and discussed with field personnel. The final isolation plan was selected at 11:54 AM and it involved closing two mainline valves and excavating and using squeeze tools on plastic mains at two locations. The gas was shut in and the mains on the 3900 block of Mission Street were flat (down to atmospheric pressure) at 12:50 PM.

Exponent participated in multiparty site examinations at or near the incident house on November 27, 2017, December 1, 2017, and December 19, 2017. The site examinations

included examinations of the interior and exterior of the incident house, observation of excavations in the area, and pressure testing of PG&E's gas facilities. At the request of PG&E, Exponent performed laboratory pressure testing of exemplar gas fittings and components. Exponent also performed interviews with eyewitnesses, neighbors, and PG&E employees who responded to the incident.

At the time of Exponent's initial site examination on November 27, 2017, the building showed signs of damage consistent with an internal explosion. The ground level and second-floor rear windows were broken, and the second-floor front windows had been pushed out of the window frames and one was found lying on the sidewalk with window glass strewn across the street. The garage door had been blown out of the door frame and was found lying in the middle of Mission Street. Inside the ground level of the house, there was damage to the ceiling and walls of the front of the garage and entryway. Some of the exposed paper lining material in the garage wall showed light thermal damage consistent with high temperatures of brief flame exposure inside the wall cavity. Several penetrations were observed in the garage floor, including a cable/data wire conduit and a floor drain. A gas riser and manifolded meter set with five gas meters was present in the garage. There were no signs of leakage of the riser or meter set. On the second floor, several interior doors and walls were damaged, and there was extensive damage to the floor directly above the damaged ceiling in the garage. A wall-mounted heater was installed in a location central to the floor damage with the pilot flame control in the ON position. There was a hole in the floor below the heater on the second floor and several holes in the garage walls that could have provided a path for gas to travel from the garage to the heater.

At the time of the incident, all of PG&E's gas mains in the area were high pressure distribution mains, and had a normal operating pressure (NOP) of 50 psig. There was a 6-inch steel distribution main that ran along the east side of Mission Street and fed services to the east side of the block, including the incident house. A 6-inch plastic distribution main ran along the west side of Mission Street and fed services on the west side of the block. The two mains were connected with a 3-inch cross-tie across from College Terrace and directly in front of the incident house. The steel main dead-ended at the southern end of the block. After the gas was shut in, an unmapped valve was identified on the cross-tie between the 6-inch steel main and the 6-inch plastic main. The valve was located near the location where the cross-tie connects to the steel main.

Following the incident, gas mains were pressure tested using air, and excavations were performed to identify the leak location and to assess the condition of the affected gas facilities. The probable leak area was identified as a section of Mission Street located several houses south of the incident house. Bar holes were created in the pavement and a location was identified as the probable leak location based on the volume of air coming out of the holes. An excavation was performed at the probable leak location, which was above the 6-inch steel main. When the steel main was uncovered, an abandoned service line was found extending northwest from the steel main. The service line consisted of a steel service tee, a section of steel pipe, a steel-to-plastic transition fitting, and plastic pipe extending west toward the 6-inch plastic main and toward a house located at [redacted], on the west side of the street. A section of plastic pipe was previously cut out of the service line, leaving an uncapped service stub on the steel main. A dislodged rubber X-Pander plug was found inside the service tee. A

later excavation determined that the other end of the abandoned service line was capped at the location of the 6-inch plastic main.

Records Review

A review of PG&E's construction records, USA tickets for the incident area, and historical aerial photos was performed. Based on this review, it was determined that the following relevant construction had taken place in the incident area:

- **Pre-1987—**Two cast-iron (CI) mains provided gas to the 3900 Mission block.
  - East side of street—10-inch low-pressure (LP) CI main had been installed in 1938.
  - West side of street—16-inch semi-high-pressure (SHP) CI main had been installed in 1926.
- **1987—**A gas service record indicates that a leak was repaired on the 1 ¼-inch service line to [redacted]. Service fed from the CI LP main on east side of Mission St.
- **1992—**The 10-inch CI LP main on the east side of Mission Street was replaced with a 6-inch steel LP main on GM 4944914. The 2-inch plastic service to [redacted] was installed.
- **1996—**The 16-inch CI SHP main on the west side of Mission Street was replaced with a 6-inch high-pressure (HP) plastic (PL) main on GM 1670215.
- **2003—**A 2-inch PL main was installed on College Terrace on PM 30267521 and was associated with Rule 20 work to underground electrical distribution facilities.
- **2003—**The service line to [redacted] was transferred from the steel main to the plastic main on Mission Street on PM 30767522. The X-Pander plug was inserted into the incident service tee. The service line was likely cut at the steel main and was left uncapped at this time.
- **2013—**The steel 6-inch main was uprated from LP to HP service. The X-Pander plug was in place at this time. Uprate drawings do not show the incident service stub.
- **2017—**Leak occurs at the incident service stub on the steel main.

Analysis

The historical construction work that was performed in the leak area was compared with applicable state and federal codes and PG&E company standards. The work performed to transfer the service line for [redacted] from the 6-inch steel main to the 6-inch plastic main left the service stub and the abandoned service line uncapped. This was not consistent with PG&E company standards from the time the work was performed. In addition, PG&E company standards required that X-Pander plugs be removed from the service tee, that completion plug be reinstalled in the service tee, and that a protective sleeve be installed over plastic stubs after work was completed. These steps were not taken. In addition, the PG&E standard for uprating pipelines requires that PG&E employees "Locate any existing services to be converted to high pressure, and services to be replaced by direct burial or insertion. All stub mains and services must be located and shown on the map." The standard does not clearly

define “stub mains and services”; as a result, it is not clear whether the incident service stub should have been included on the uprate drawings, but it was not included on the drawings.

Exponent reviewed PG&E’s emergency reponse to the incident and compared it with company standards and industry best practices. From an organizational perspective, PG&E’s response to the incident was generally consistent with the PG&E Gas Emergency Response Plan (GERP). The incident was classified as a Level 2 (Elevated) emergency. During the emergency response, an Operations Emergency Center (OEC) was officially activated in the PG&E San Francisco office and the Gas Emergency Center (GEC) in San Ramon was unofficially activated, which is consistent with a response to a more significant Level 3 (Serious) emergency. Due to the level of damage, the incident meets criteria that required reporting to the California Public Utilities Commission (CPUC) and Department of Transportation (DOT). The incident was reported to the DOT at 11:50 AM and CPUC at 12:00 PM. Within 20 working days of the incident, PG&E produced an After Action Report that evaluated its own emergency response as required by the PG&E GERP.

After PG&E M&C crews arrived on scene, it took 150 minutes to shut in the gas to the affected mains. This is longer than the target time of 117 minutes outlined in the GERP. The increased time to shut in the gas was the result of multiple factors, including the complicated pipeline network existing at the leak location. Two parallel and cross-tied mains had to be shut down simultaneously, which resulted in increased time to develop a shutdown plan that could be implemented safely. The primary shutdown plan that was developed first involved squeezing the cross-tie and could not be implemented due to concerns over the safety of personnel using digging equipment at that location. Three more complicated alternative shutdown plans were then developed and discussed with the GEC, OEC, and IC. After the M&C crews received the final emergency isolation plan, the gas was shut in approximately 56 minutes later. The field crews and engineers developing shutdown plans were not aware of an unmapped valve on the cross-tie. Had they known about it, they could have considered using it in their shutdown plans.

Certain aspeects of the evacuations that were performed were consistent with PG&E’s standards for emergency response. Prior to PG&E’s arrival, the SFFD had closed the street to the general public for a distance of 220 feet south of the incident house to the corner of Bosworth Street and Mission Street and for a distance of approximately 450 feet north of the incident house to the corner of College Avenue and Mission Street. The SFFD had also evacuated the four houses south of the incident house and the four houses north of the incident house. PG&E was not involved in performing these evacuations but was informed of their status by SFFD. A PG&E leak survey crew arrived and surveyed for gas migration and reported no migration outside of the area that had been evacuated. This is consistent with PG&E’s guideline of evacuating structures where the gas concentration is greater than 2% in air. The distance that the public was held back to the south was less than the 330 feet (100 meters) distance recommended by the DOT Emergency Response Handbook for keeping unauthorized persons away. In addition, the SFFD was reportedly evacuating houses by ringing doorbells, which is not consistent with PG&E’s standard for Gas Event Evacuation.

Conclusions

Based on the analysis described in this report, Exponent has reached the following conclusions:

1. The explosion that occurred on 11/27/17 at [redacted] was caused by an underground gas leak at an uncapped 2-inch service stub on a 6-inch steel PG&E distribution main on Mission Street.
    a. The gas leak began when a rubber X-Pander plug that had been inserted into the service tee dislodged on 11/27/17.
    b. The exact gas migration path was not determined, but gas possibly migrated into the structure through floor penetrations in the garage.
    c. Damage to the garage and second floor is consistent with a natural gas and air mixture accumulating in the garage and also between the floor joists above the garage and igniting.
    d. The likely ignition source was the second-floor heater pilot flame.
2. The service stub on the steel main was most likely created in October 2003 when the 2-inch service line to [redacted] was transferred from the 6-inch steel main to the 6-inch plastic main. It is likely that at that time the rubber plug was inserted into the service tee and the plastic line was cut near the steel main and the stub of pipe on the steel main was left uncapped.
    a. The 2-inch service line was installed at the time of the installation of the steel main in 1992.
    b. The 2-inch service line was likely cut and the stub was left uncapped in 2003 when the service was transferred from the 6-inch steel main to the 6-inch plastic main. A rubber plug was likely used to stop off the line while the service was transferred and the plug was left in the service tee.
    c. The 6-inch steel main was uprated in 2013, 10 years after the plug had been installed in the service tee.
    d. The plug held until the day of the incident, when it dislodged, creating a large gas leak.
    e. Historical aerial photos show that the only fresh pavement visible at the leak location appeared in the late-2003/early-2004 timeframe. Therefore, it is unlikely that work was done in the immediate area of the service tee and uncapped stub between the time of the service transfer and the incident.
3. The work that was performed by PG&E to transfer the service lin[redacted] from the steel main to the plastic main does not appear to have followed company procedures:
    a. The cut stub end was not capped.
    b. The cut end of the deactivated service line near the steel main was not sealed.
    c. An X-Pander plug was left inside the service tee.
    d. A completion plug was not installed in the service tee.
    e. A protective sleeve was not installed over the plastic stub.
    f. Overall, the deviations from PG&E procedures appear consistent with work that intended to deactivate the service to [redacted] but that was interrupted or otherwise left incomplete.

4. X-Pander plugs can hold low pressure for extended periods of time and can also dislodge at pressures consistent with high-pressure distribution systems. Benchtop pressure tests were performed using new X-Pander plugs and a Mueller tee.
    a. A plug held 11 inches of water column (WC) for a period of an hour with no signs of leaking and without dislodging.
    b. When the pressure was increased rapidly, the plugs dislodged at pressures that ranged from 15 to 116 psig. The pressure required to dislodge the plugs depended on the torque that was used to install them.
    c. Extended duration testing at 60 psig showed that plugs tended to dislodge after a few minutes of sustained pressure.
    d. The testing did not investigate time-dependent factors such as corrosion in the steel pipe, creep strain, or rubber embrittlement. Additional testing would be needed to understand these effects.
5. In terms of response organization, PG&E's response was consistent with the guidelines in the GERP.
    a. Event was classified as a Level 2 (Elevated) emergency, which called for a possible OEC activation.
    b. San Francisco OEC activated and GEC unofficially activated, which was consistent with a more significant Level 3 (Serious) emergency.
6. Evacuation procedures were performed by SFFD in consultation with PG&E and in a manner that was partially consistent with PG&E procedures and industry best practices.
    a. The houses that were evacuated were consistent with PG&E procedures for evacuating buildings.
        i. Leak survey crews were on site searching for gas migration. Gas was observed to be migrating north on Mission Street.
        ii. PG&E standard TD-6100P-04 requires that houses be evacuated if the gas concentration is greater than 2%. No unevacuated buildings were observed to have a gas concentration in air of greater than 0.6%.
    b. The SFFD went door to door ringing doorbells to notify building occupants. This is not consistent with PG&E company standards for evacuations because electric doorbells can be an ignition source.
    c. The evacuation distance to the south of 220 feet was less than the distance of 330 feet recommended by the DOT Emergency Response Guidebook.
7. Shutdown plans were implemented in a manner consistent with company procedures.
    a. Mainline valves were operated by employees with appropriate qualifications.
    b. Pipe squeezing procedures were operated in a manner consistent with company procedures and industry best practices.
8. The time of 150 minutes for PG&E workers to shut in the gas was longer than PG&E's target time of 117 minutes outlined in the GERP. The increased time to shut in the gas was the result of multiple factors, including the complicated pipeline network existing at the leak location.
    a. Two parallel and cross-tied mains had to be shut down simultaneously, which resulted in increased time to develop a shutdown plan that could be implemented safely.

b. The primary shutdown plan involved squeezing the cross-tie and could not be implemented due to concerns over personnel safety at that location, so three more complicated alternative shutdown plans were developed.
c. After the M&C crews received the final emergency isolation plan, the gas was shut in approximately 56 minutes later.

9. An unmapped valve was found on the cross-tie on Mission Street. If PG&E crews and emergency center staff had known about the valve, they could have considered it in their shutdown plans.

Background

At 9:52 AM on Monday, November 27, 2017, the San Francisco Fire Department (SFFD) received a gas odor complaint at or around [redacted], San Francisco (incident house), which is located in the Bernal Heights neighborhood. The house at [redacted]. The general area is shown in Figure 1, with the incident house indicated in red.

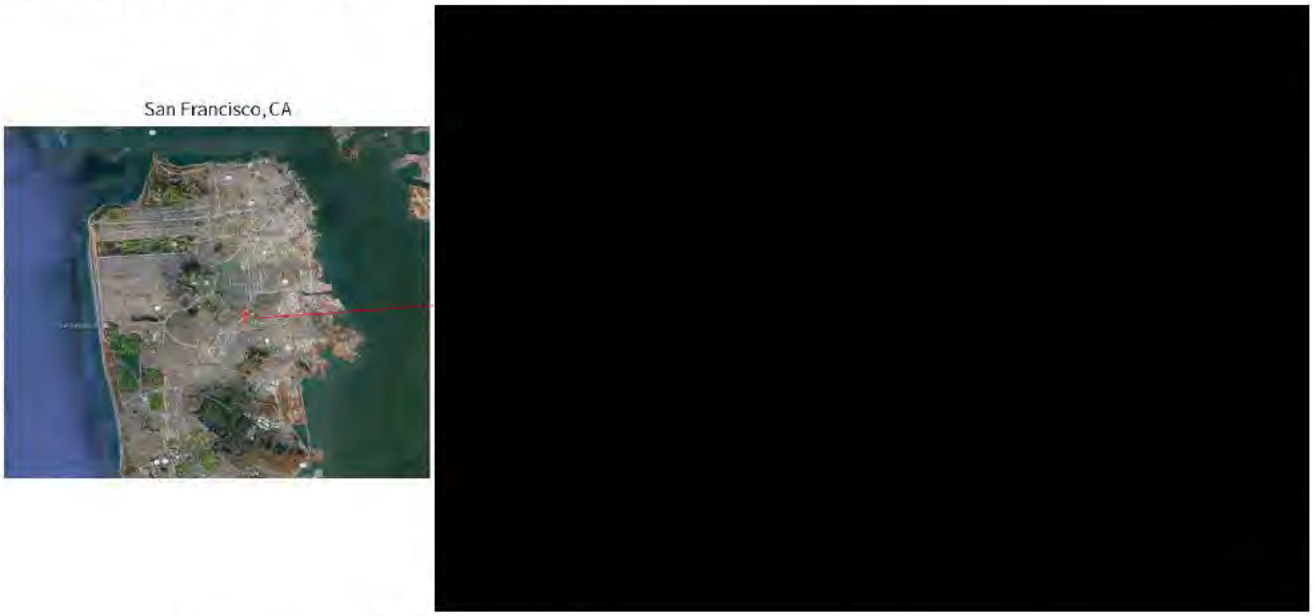

Figure 1. Aerial image of [redacted] San Francisco.

Upon arrival, the SFFD determined that there was an underground gas leak and started to evacuate nearby buildings.[2] The SFFD notified PG&E of the gas leak at 9:57 AM.[3] PG&E received additional gas odor complaints, at least one of which was for a gas odor inside a structure.[4] A PG&E Gas Service Representative (GSR) was dispatched to the site at 10:04 AM.[5] A second GSR was dispatched to the site shortly thereafter.[6] At approximately 10:14 AM, an explosion occurred at [redacted] that blew out the garage door and second-floor windows.[7] There was no report of a subsequent structure fire following the explosion. At 10:16 AM, PG&E dispatch received a call from the SFFD advising them of an

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1 NFIRS Incident Report Number 17138832, November 27, 2017.

2 NFIRS Incident Report Number 17138832, November 27, 2017.

3 CPUC Form 420 for incident.

4 Interview with PG&E Gas Service Representative #1, December 14, 2017.

5 PG&E Incident Report Order Detail, FO ID# 5572325648.

6 Interview with PG&E Gas Service Representative #1, December 14, 2017.

7 Interview with SFFD Incident Commander on November 27, 2017.

explosion.[8] PG&E gas dispatch received another call from SFFD at 10:17 AM requesting an expedited response.[9] Multiple PG&E Maintenance and Construction (M&C) crews were dispatched to the site.[10] PG&E GSR #1 arrived at 10:20 AM,[11] saw gas bubbles coming up from the street, and requested an M&C crew.[12] The first PG&E M&C crew arrived at 10:30 AM.[13] A PG&E M&C supervisor arrived at 10:33 AM and assumed the role of Incident Commander (IC). PG&E engineers started reviewing maps and preparing primary and backup gas isolation plans. The first isolation plans were shared with the IC at 10:57 AM. Isolation strategies were reviewed and discussed with field personnel. The final isolation plan was selected at 11:54 AM and involved closing two mainline valves and excavating and using squeeze tools on plastic mains at two locations.[14] The gas was shut in and the mains on the 3900 block of Mission Street were flat at 12:50 PM.[15]

Exponent arrived onsite at 12:30 PM on the day of the incident and began photodocumenting the scene and performing interviews with witnesses and first responders.

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8 Timeline document received from PG&E (Timeline of Explosion Incident Mission Street.docx).

9 Timeline document received from PG&E (Timeline of Explosion Incident Mission Street.docx).

10 Interview with M&C Supervisor, December 13, 2017.

11 PG&E Incident Report Order Detail, FO ID# 5572325648.

12 Interview with PG&E Gas Service Representative #1, December 14, 2017.

13 PG&E Incident Report Order Detail, FO ID# 5572325648.

14 Timeline document received from PG&E (Timeline of Explosion Incident Mission Street.docx).

15 PG&E Incident Report Order Detail, FO ID# 5572325648.

Incident Investigation

Exponent participated in multiparty site examinations at or near the incident house on November 27, 2017, December 1, 2017, and December 19, 2017. The site examinations included examinations of the interior and exterior of the incident house, performing excavations in the area, and pressure testing of PG&E's gas facilities. At the request of PG&E, Exponent performed laboratory pressure testing of exemplar gas fittings and components. Exponent also performed interviews with eyewitnesses, neighbors, and PG&E employees who responded to the incident.

Examination of Incident House

The incident house was a three-story, wood-framed rowhouse that had a parking garage on the ground level, two apartments on the second floor, and two apartments on the third floor. The incident house is shown prior to the incident in Figure 2.

Figure 2. [redacted], prior to incident. Image from Google Maps. Image date: November 2016.

At the time of Exponent's initial site examination on November 27, 2017, the third-floor windows at the front and rear of the building were observed to be undamaged. The second-floor rear windows were broken, and the second-floor front windows had been pushed out of the window frames and one was found lying on the sidewalk. Window glass from the second-floor front windows was strewn across Mission Street. On the ground level, the garage door had been blown out of the door frame and was found lying in the middle of Mission Street. Four automobiles were present in the garage. The ground-level rear windows were broken. Overall, the lower two levels of the incident house showed exterior damage that was consistent with an explosion occurring within the house. There were no outwardly visible signs of a fire occurring prior to or after the explosion. The front of the incident house is shown after the incident in Figure 3.

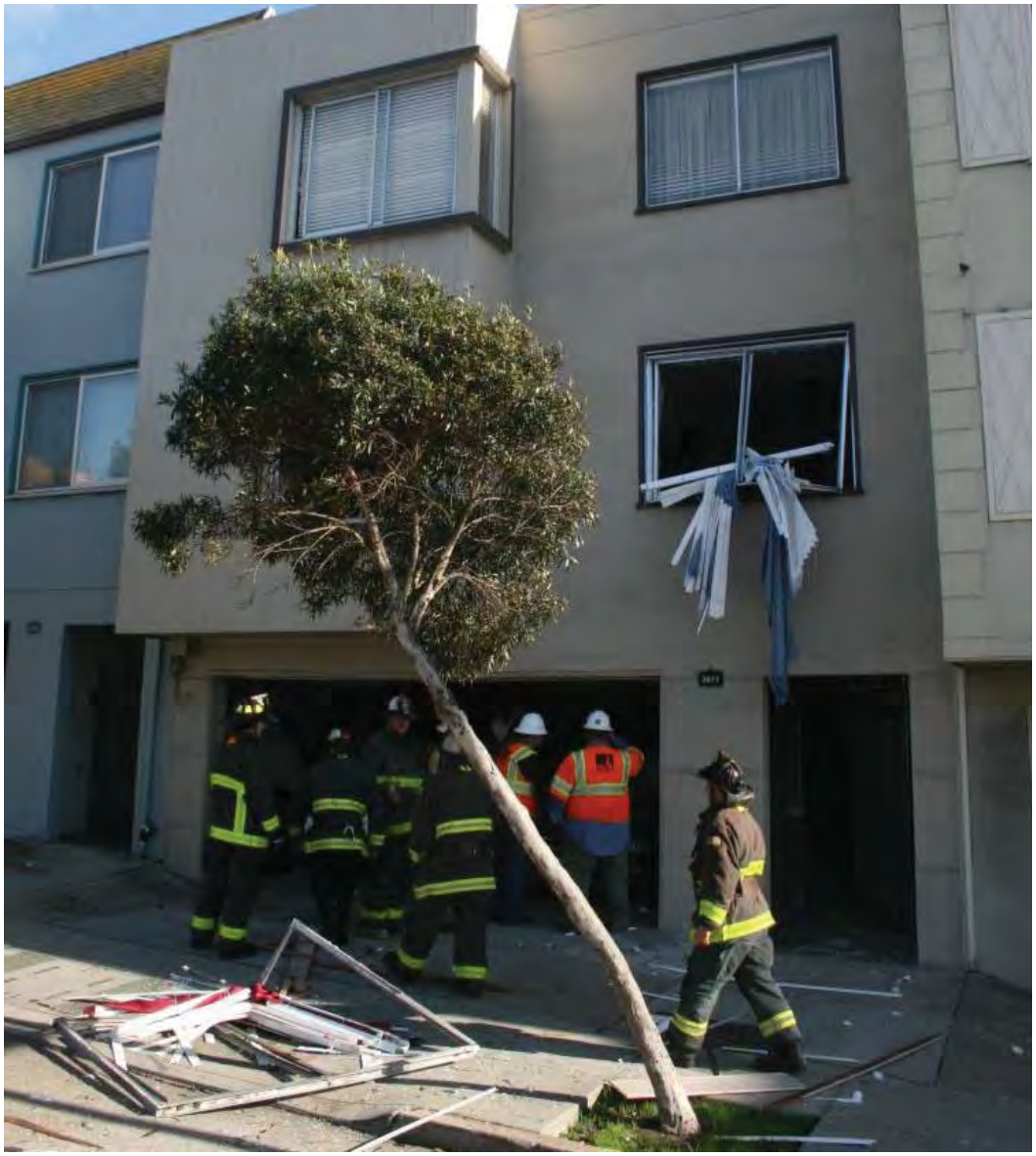

Figure 3. Front of [redacted], after the incident. Photograph taken by Exponent on November 27, 2017.

Examinations of the interior of the incident house were performed by Exponent on November 27, 2017 and December 1, 2017. The floor plan for the garage level of [redacted] is shown in Figure 4. The floor plan for the second floor is shown in Figure 5. The third floor had a similar layout to the second floor. The third floor did not exhibit significant damage and was not examined in detail.

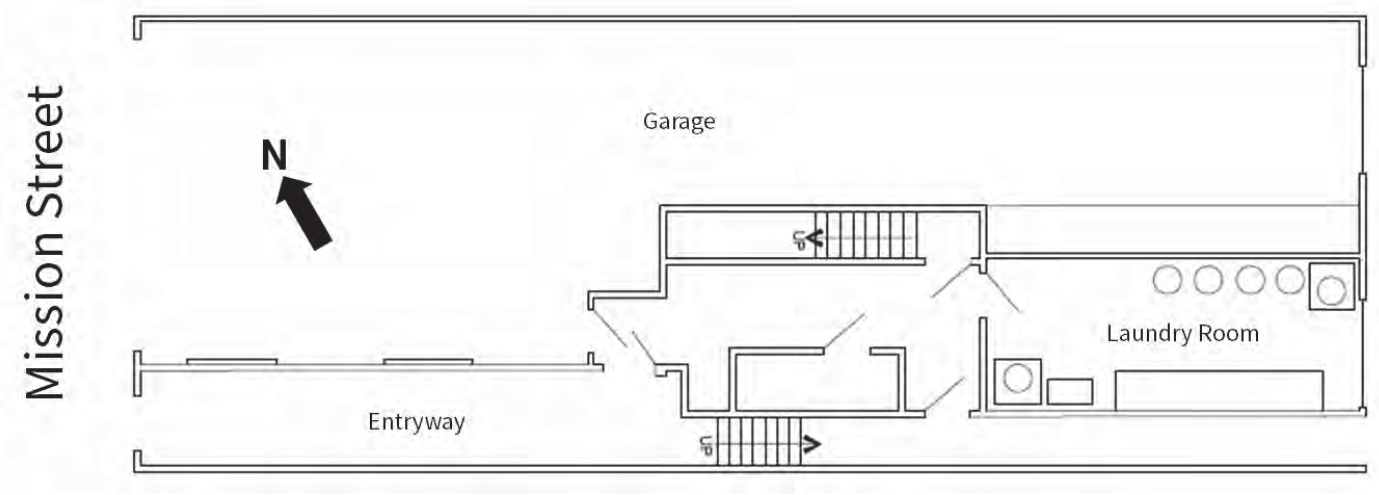

Figure 4. Floor plan for garage level at [redacted].

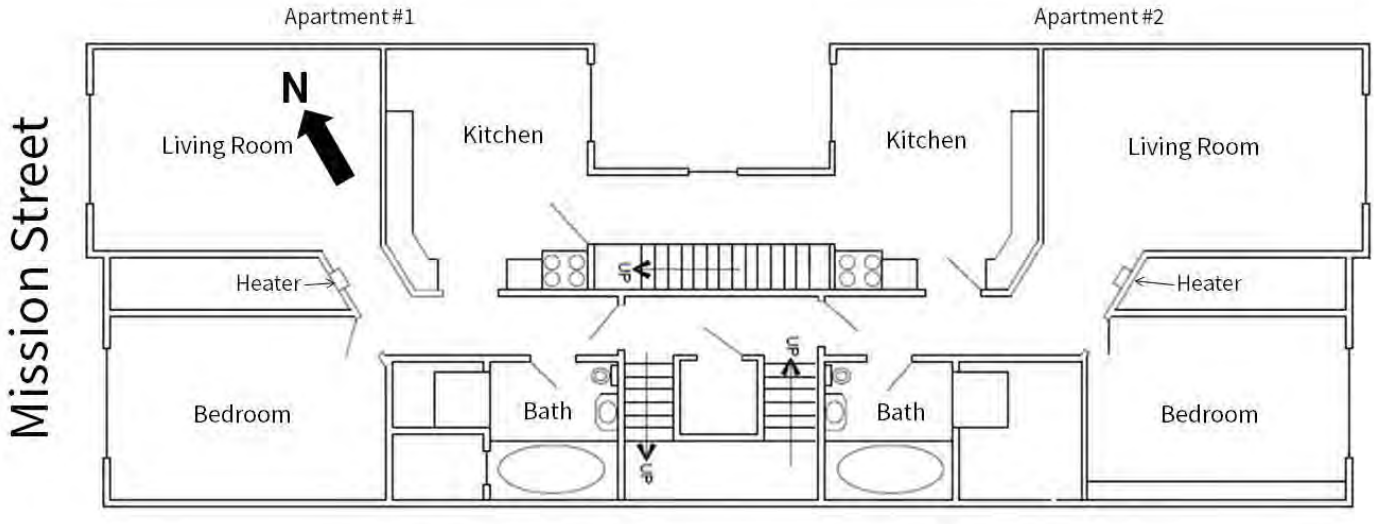

Figure 5. Floor plan for second floor at [redacted].

A gas riser and manifolded meter set with five gas meters was located just inside the garage door and against the south wall. The gas meter set is shown in Figure 6. The gas meter set had an Itron B531 twin parallel gas regulator with internal relief valves and vent lines that extended to the exterior of the building. The riser shutoff valve located downstream of the regulator had been shut prior to Exponent's examination of the garage. The riser and meter set did not show

any obvious signs of damage or leakage. The building electrical meters were located on the south wall of the garage next to the gas meters and are shown in Figure 6. The red arrows in the figures indicate the location and orientation of the photograph.

Figure 6. Gas meter set in garage at incident house. Photo taken by Exponent on November 27, 2017.

The garage walls and ceiling were constructed of cement plaster on metal lath. Portions of the ceiling and wall plaster had collapsed near the front of the garage and damaged two of the automobiles parked in the garage. The ceiling plaster that fell down broke the windshields and crumpled the roof sheet metal of the two automobiles parked in the front of the garage. The damaged walls and ceiling in the garage are shown in Figure 7 through Figure 9. There were signs of thermal damage to the paper lining behind the wall studs on the north side of the garage, as shown in Figure 9. The rear (east) of the garage, shown in Figure 10, showed no signs of thermal damage, and the walls showed no signs of damage. The glass window at the rear of the garage was broken. The floor joists above the garage showed no signs of thermal or structural damage. The floor boards in Apartment 1 above the garage were visible from the

garage and were significantly damaged, as shown in Figure 11. The front entryway to the building was next to the garage. The entryway led to the main stairway to the upper level apartments. The walls and ceiling of the front entryway exhibited damage from the explosion, as shown in Figure 12. A laundry room was located in the rear of the building and contained five gas-fueled water heaters and a clothes washer and dryer. The exterior window in the laundry room was broken out.

Figure 7. Front of garage at incident house. Photo taken by Exponent on November 27, 2017.

Figure 8. North side of garage at incident house. Photo taken by Exponent on November 27, 2017.

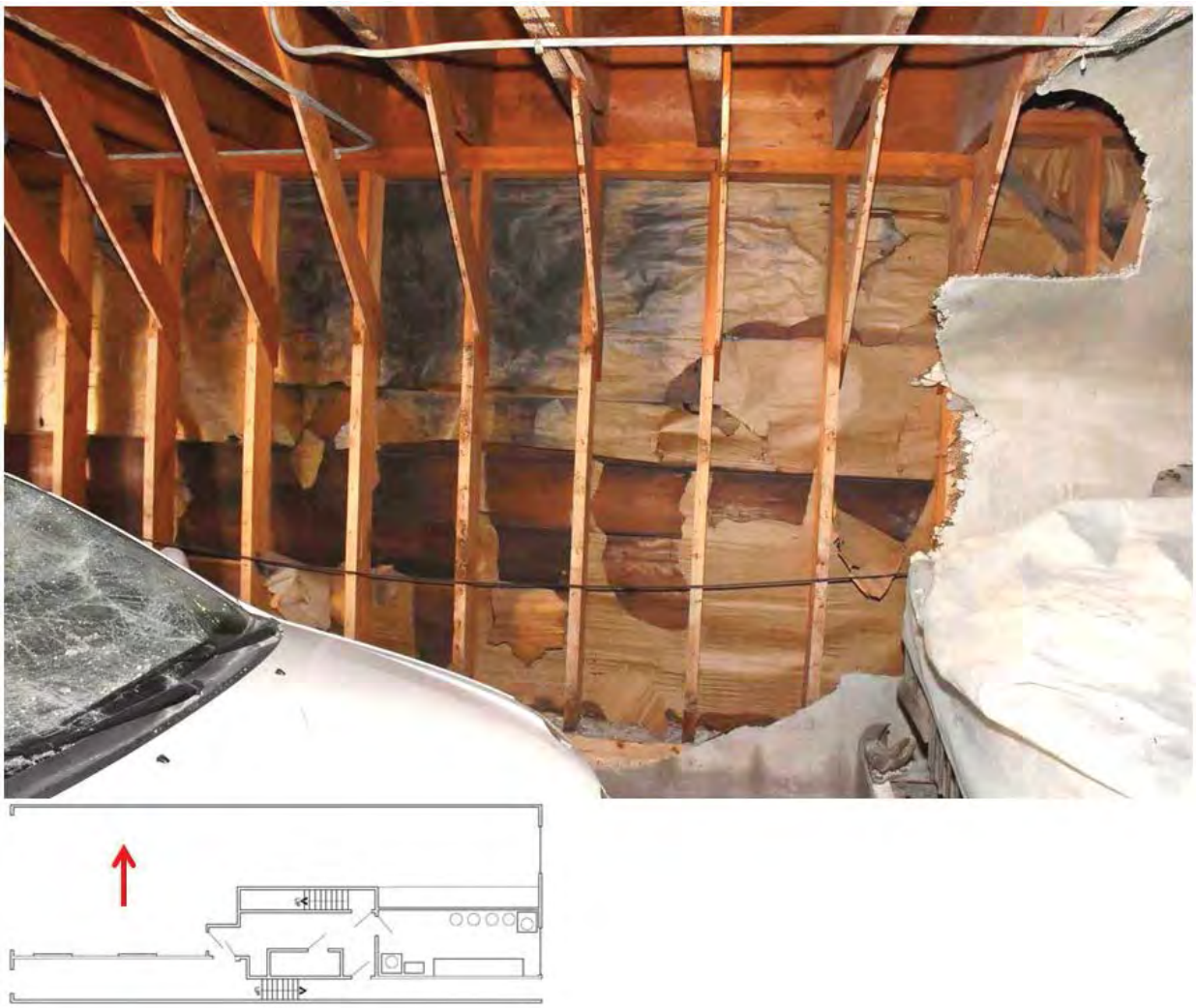

Figure 9. Thermal damage on north wall of garage at incident house. Photo taken by Exponent on December 1, 2017.

Figure 10. Rear (west end) or garage. Photo taken by Exponent on December 1, 2017.

Figure 11. View (facing up) of ceiling in garage with damaged floor boards visible in background. Photo taken by Exponent on December 1, 2017, at location indicated with a red circle.

Figure 12. Damage to wall and ceiling in front entryway. Photo taken by Exponent on November 27, 2017.

The second floor contained two units, Apartment 1 in the front and Apartment 2 in the rear. Apartment 2 showed low-order damage consistent with an overpressure. The entry door to the apartment opened inward and had a broken door frame. The kitchen exterior window was broken out. The exterior windows in the rear of Apartment 2 were broken out.

Apartment 1 showed significantly more damage than Apartment 2. The bathroom door in Apartment 1 was broken in, as shown in Figure 13. The bathroom exterior window was also broken as shown in Figure 13. The kitchen floorboards in Apartment 1 had been pushed up and were observed to be loose. The kitchen exterior window was also broken. The most severe damage in Apartment 1 was concentrated in the front of the apartment near the bedroom and living room. The floor in the bedroom had been been severely damaged, and the floorboards were dislocated and scattered. The damage to the bedroom floor is shown in Figure 14. The living room in Apartment 1 showed very severe damage to the floor. The floorboards had been dislocated and scattered, and in some locations only the floor joists remained. The furniture in the living room had been displaced and upended. The living room is shown in Figure 15. The

front windows in Apartment 1 were also broken out, and the sheetrock walls were damaged in several locations.

Figure 13. Bathroom in Apartment 1. Photo taken by Exponent on December 1, 2017.

Figure 14. Bedroom floor in Apartment 1. Photo taken by Exponent on December 1, 2017.

Figure 15. Living room in Apartment 1. Photo taken by Exponent on December 1, 2017.

The damage vectors observed in the garage and on the second floor was overlaid on the building floor plans and is shown in Figure 16 and Figure 17. The floor and ceiling damage is shown in yellow, and damage vectors (such as broken windows, doors, and walls) are shown as purple arrows.

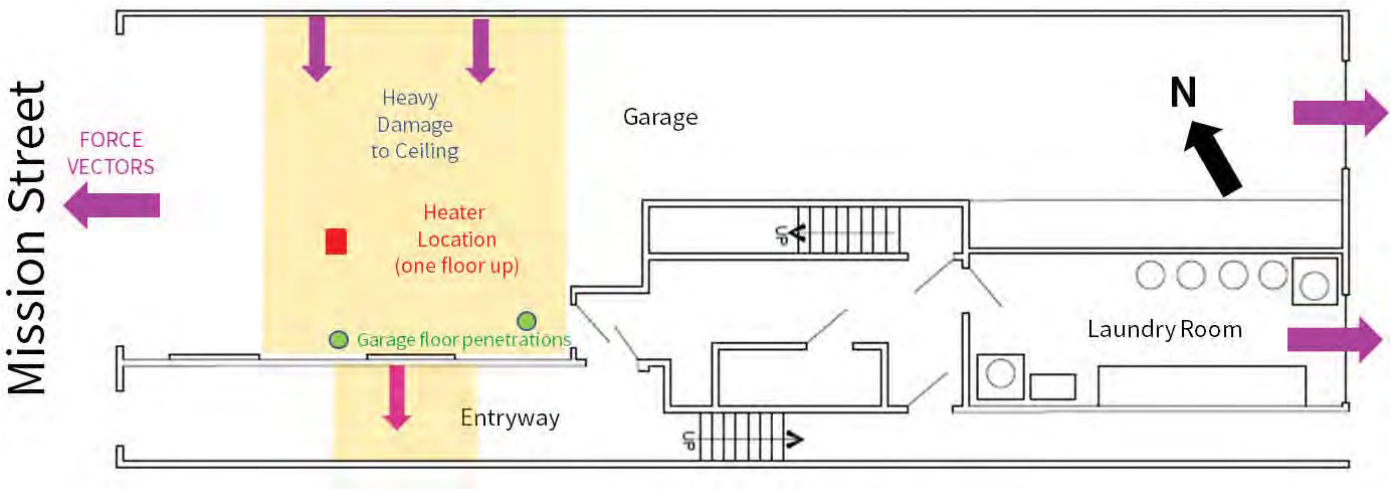

Figure 16. Damage vectors in garage of incident house.

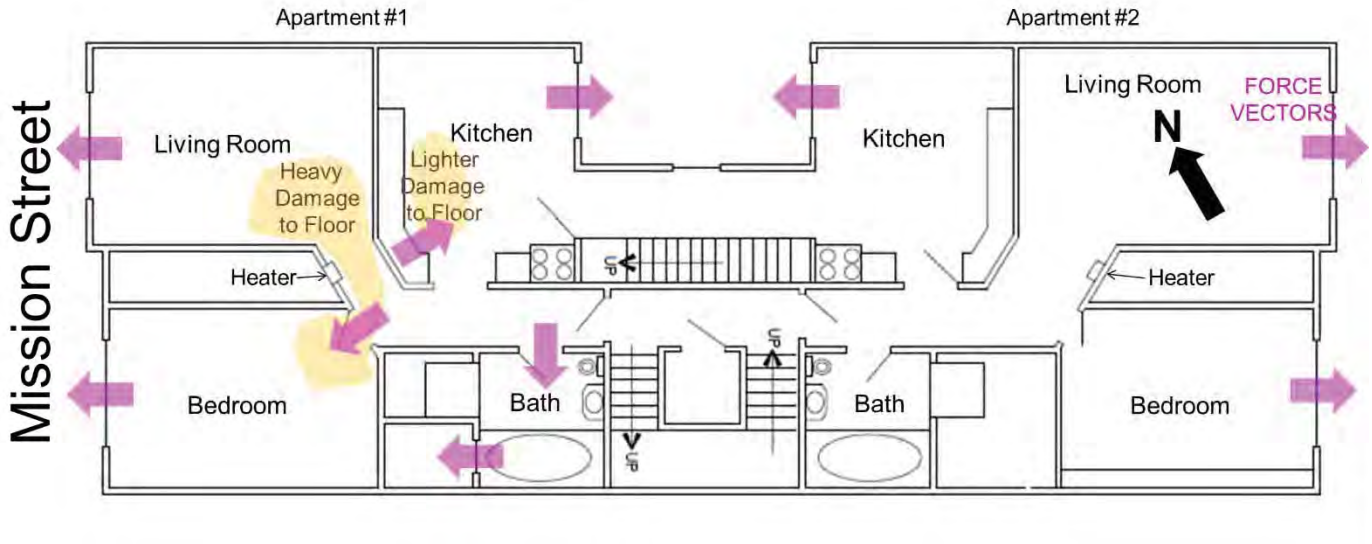

Figure 17. Damage vectors in second floor of incident house.

PG&E Gas Facilities

The distribution plat sheet (D-Plat) for the 3900 block of Mission Street, with annotations added, is shown in Figure 18 and Figure 19. At the time of the incident, all of the gas mains in the area were high-pressure distribution, and had a normal operating pressure (NOP) of 50 psig.[16] There was a 6-inch steel distribution main that ran along the east side of Mission Street and fed services to the east side of the block. A 6-inch plastic distribution main ran along the west side of Mission Street and fed services on the west side of the block. The two mains

[16] CPUC Form 420 for incident.

were connected with a 3-inch cross-tie across from College Terrace and [redacted] There were also 2-inch plastic mains running along St. Mary's Avenue and College Terrace that were fed from the 6-inch plastic main. At the top of the block, the 6-inch plastic main and 6-inch steel main were connected with a 2-inch plastic main. A 4-inch plastic main in College Avenue was also fed from the 6-inch plastic main.

Figure 18. PG&E distribution plat sheet (annotations added by Exponent) for lower half of 3900 block of Mission Street.

Figure 19. PG&E Distribution plat sheet (annotations added by Exponent) for upper half of 3900 block of Mission Street.

After the gas was shut in, an unmapped valve was identified on the cross-tie between the 6-inch steel main and the 6-inch plastic main. The valve was located near where the cross-tie connects to the steel main. The unmapped valve is shown in Figure 20.

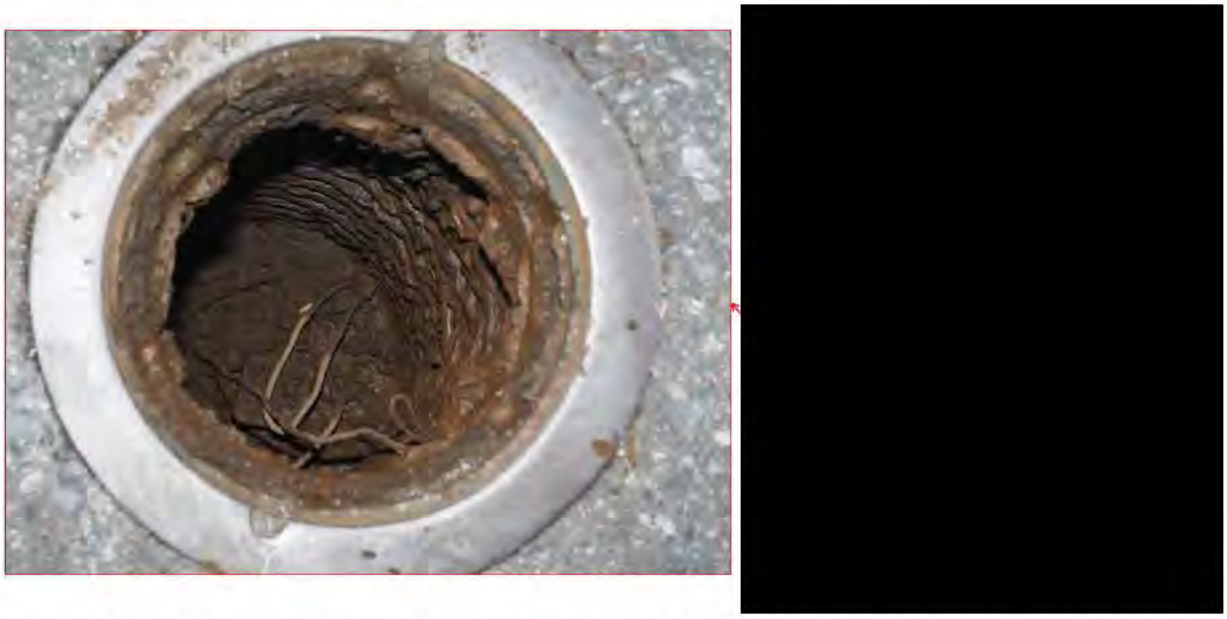

Figure 20. Unmapped valve on cross-tie. Square valve operator faintly visible in the mud. Photos taken by Exponent on November 27, 2017.

Following the incident, excavations and pressure tests were performed to identify the leak location and to assess the condition of the affected gas facilities. On the day of the incident, after the gas was shut in, the steel main was isolated using one of the isolation squeeze points at the top of Mission Street and by operating the unmapped valve on the cross-tie. The steel main was pressurized with air from a compressor on a PG&E crew truck. The compressor was operated at full throttle and the pressure in the main increased and leveled off at 0.5 psig. Leak detection fluid was applied to cracks in the street to identify the leak area. An area in front of [redacted] was identified as the probable leak area. Bar holes were created in the pavement and a location was identified as the probable leak location based on the volume of air coming out of the holes.

The steel main was excavated at the location labeled "Excavation #1" in Figure 21. When the main was uncovered, an adandoned service line was found extending northwest from the steel main. The service line consisted of a 2-inch steel Mueller service tee, a short section of 2-inch steel pipe, a plastic-to-steel transition fitting, a short section of 2-inch orange TR418 plastic pipe, a 2-inch fusion coupling, and a section of 2-inch yellow plastic pipe extending toward [redacted]. The abandoned service line is shown in Figure 22. When the service line was uncovered, there was a 6-inch-long section of orange TR418 plastic pipe that wascut previously, leaving an uncapped opening at the end of the stub. The cut section of pipe was found in the dirt adjacent to the cut pipe. The cut section of TR418 pipe is shown on the lefthand side of Figure 22, along with the fusion coupling that was cut out by PG&E on the day of the incident. The short piece of steel pipe, transition fitting, and orange TR418 plastic pipe were most likely a manufactured assembly. The plastic coupling was likely installed to connect the assembly to the yellow plastic service line. The yellow plastic pipe had a date code of "120591." The service tee was removed, and Exponent retained the tee and two pieces of plastic pipe.

Figure 21. Locations of excavations performed after the incident.

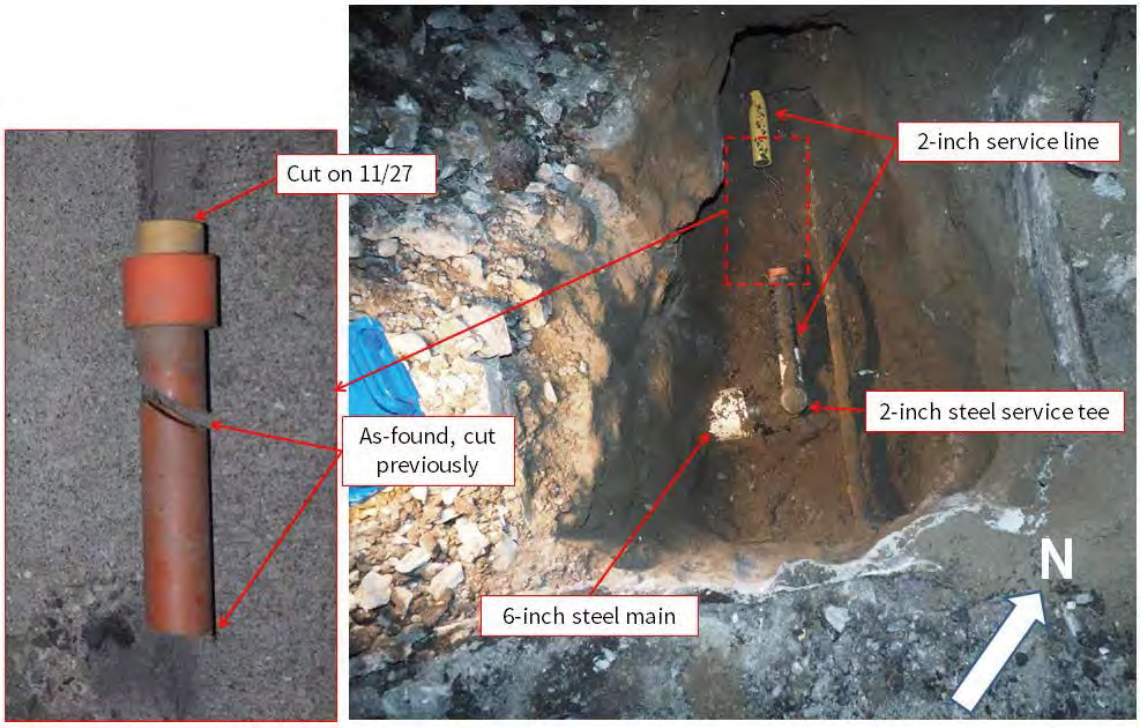

Figure 22. Abandoned service line uncovered at Excavation #1. Photos taken by Exponent on November 27, 2017.

The completion cap was removed from the service tee and a rubber plug was found inside the tee. The uncapped stub and the rubber plug are shown in Figure 23 through Figure 26. A significant amount of rust was inside the upper portion of the service tee, as shown in Figure 25. The open end of the stub was found with a roughly cut outlet, as shown in Figure 26.

Figure 23. Rubber plug found inside service tee.

Figure 24. Service tee from at leak location.

Figure 25. Rubber plug found inside service tee.

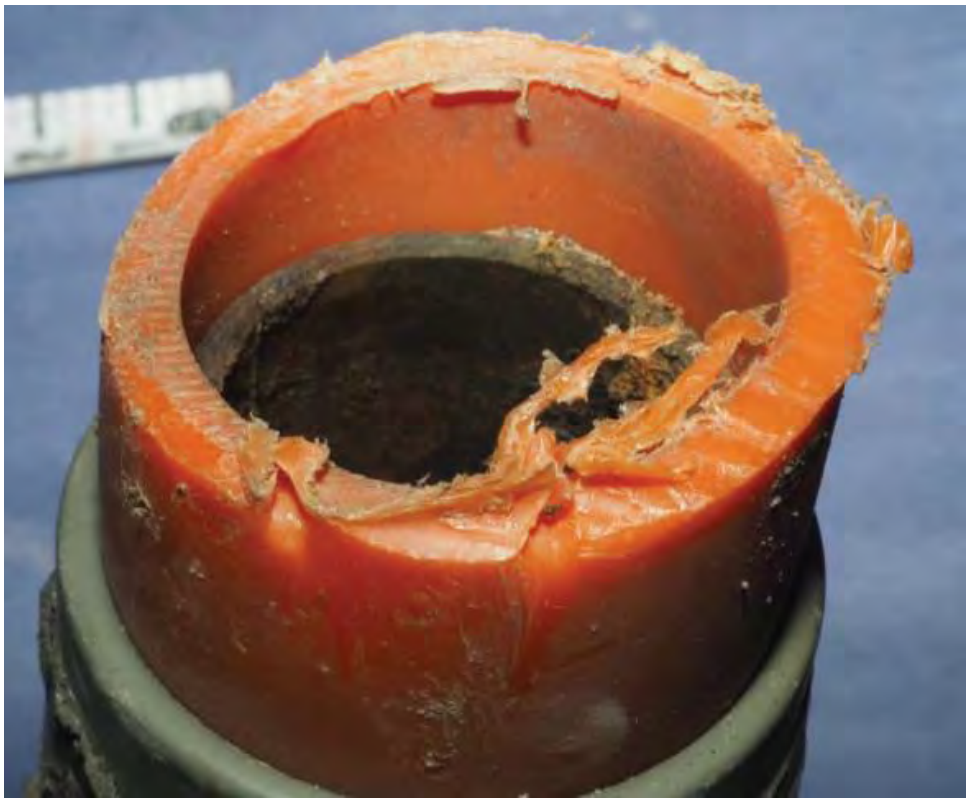

Figure 26. Cut end of stub as found.

On December 19, 2017, excavations were performed at locations 1 and 2 (shown in Figure 21). The excavation at location 1 was performed first, and cameras were inserted into the abandoned 2-inch service line. Based on the camera examination, it was determined that there was some type of plug or cap on the end of the 2-inch service line at the approximate location where it crossed the 6-inch plastic main. An excavation was performed at location 2 (shown in Figure 21), and it was discovered that the west end of the of the plastic service was sealed with an Uponor socket fusion cap, as shown in Figure 27. A prior squeeze point was identified adjacent to the socket fusion cap, based on the pipe being oval shaped at that location. A Constab cap fitting was installed on the east side of the abandoned service line, and the line was pressure tested with air at 60 psig for 5 minutes and no leakage was observed.

Figure 27. End cap on west end of abandoned 2-inch plastic service line.

The annular space between the existing ½-inch plastic service to [redacted] and its 2-inch plastic casing was also examined using a boroscope. The annular space was observed to contain standing water and vegetation roots. The boroscope was able to be inserted until just before the curb valve.

Additionally, on the day after the incident, the steel main was pressure tested at 105 psig for 60 minutes[17] before being put back into service. No leaks were reported.

Interviews

Exponent performed interviews with neighbors, eyewitnesses, members of the SFFD, and PG&E employees who responded to the incident or who had knowledge that was germane to the investigation. The information gathered from the interviews is summarized in this section.

Neighbor at [redacted] on 11/30/17

- This neighbor lives at [redacted] with his wife and child.
- He did not smell gas or hear anything out of the ordinary on Sunday, November 26, 2017, the day before the incident. The heat and hot water was working.

[17] Per PG&E SAP records.

- On the day of the incident, he reported the following:
    - Was leaving the house, and smelled gas inside the stairwell. Immediately he knew that it was a problem.
    - Walked outside and saw there were no construction crews nearby. He saw bubbles coming up from the pavement at the edge of the sidewalk in front of his house. Further south on Mission Street he saw larger bubbles coming up from the pavement.
    - Went inside the house and went to the PG&E website, which instructed him to call 911.
    - Approximately 2–5 minutes after first smelling gas, he called 911. The call lasted approximately 2 minutes. Approximately 2–3 minutes later he heard sirens outside.
    - When the SFFD arrived, the neighbor approached them on two occasions to ask what he should do to remain safe. The SFFD had blocked the sidewalks on Mission Street but the street was not closed to vehicle traffic. The SFFD did not appear concerned and instructed him to go inside and close the windows and to evacuate if he smelled gas inside the apartment. The SFFD told him that they would ring his doorbell if they needed him to evacuate.
    - He decided to evacuate, and he and his wife left on foot with their child. He was speaking with a member of the fire department when he saw his wife reenter the building to get something from the garage.
    - He was standing on Mission Street approximately two houses uphill (north) of their apartment and facing toward [redacted] when the explosion occurred.
    - He heard a "boom" and observed a pear-shaped fireball emerge from the garage at [redacted]. He saw broken glass flying across the street.
    - At the time of the explosion, his wife and child were in the garage at [redacted]. The entryway in their building shares a wall with [redacted]. His wife was physically unhurt but shaken. She was capable of having a conversation right away and did not report any significant ringing in her ears.
    - The wall in their entryway had some damage, but the garage was not damaged.
    - After the explosion, they quickly left the area.
    - They did not observe the SFFD evacuating houses prior to the explosion.

Tenant in Apartment 3 at [redacted]

- Prior to the incident, the tenant was in his apartment with his wife. He was outside at approximately 8:00 AM and did not smell gas.
- Immediately prior to the explosion, his doorbell rang and he came to the front door. He smelled gas in the hallway. The explosion occurred prior to his reaching the front door of the building.
- He went outside after the explosion. The SFFD was there. He saw bubbles coming out of the pavement.
- He went back into the apartment to get his wife and they left the building.
- He did not recall any recent construction on the street.

SFFD Incident Commander on 11/27/17

- On the morning of the incident, the SFFD received a complaint of gas odor.
- The SFFD was dispatched at 9:53 AM and arrived on scene a few minutes later.
- After arriving, the IC could immediately smell gas and saw water bubbles coming up through holes in the pavement. The IC saw bubbles from the corner bus stop near Mission and Murray Street to the streetlight in front of 3975 Mission Street.
- The SFFD engine was parked at the intersection of Mission and Bosworth when the explosion occurred. The explosion occurred at 10:14 AM and sounded like a "bang."
- After the explosion occurred, the IC opened the garage doors of adjacent houses.
- No injuries were reported.

PG&E Gas Service Representatives on 12/14/17

- On the morning of the incident, emergency response calls were received for gas odor inside a house and outside a house on the 3900 Block of Mission Street.
- Two GSRs were diapatched to the site.
- Upon arrival, they observed that an explosion had occurred. The garage door was blown out and was lying in the street and some of the front windows were blown out. No signs of a fire were visible.
- Upon arrival, the SFFD had already blocked off Mission Street to vehicle and foot traffic.
- The GSRs used combustible gas indicators (CGIs) to measure gas concentrations in the street. The measured 100% gas at the cracks in the pavement in front of the incident house.
- Gas bubbles were observed coming out of the ground for a distance of at least five feet on either side of the incident house.
- When the PG&E M&C crews arrived, the GSRs assisted the crews with the incident response by closing curb valves and other assigned tasks.
- In general the GSRs reported having all of the tools and support that they needed, but one reported that it would have been helpful to have a tool to remove covers for curb valves.

PG&E M&C Crews on 12/13/17

- The San Francisco M&C Supervisor received a call from Gas Dispatch at approximately 10:20 AM on November 27, 2017, informing him of the explosion.
- Multiple M&C crews mobilized and went en route to the site. The first M&C crews arrived at approximately 10:30 AM. The M&C Supervisor arrived at 10:33 AM.
- The odor of natural gas was detectable a block north at Richland and Mission Street.
- When the M&C crews arrived, the explosion had already occurred. The garage door and second-floor windows were blown out, and there was debris in the street. The odor of natural gas was immediately apparent at the site.

- A PG&E GSR was on site already and reported measuring gas in some of the buildings on the east side of Mission Street.
- The SFFD was observed to be ringing doorbells to evacuate the nearby houses.
- The M&C Supervisor assumed the role of PG&E IC upon arrival. He met with the SFFD and SFPD and discussed evacuations. The SFFD had evacuated houses on the east side of Mission Street from the corner of Murray and Mission Streets up to 3955 Mission Street. This was determined to be appropriate.
- The SFPD had a relatively small role in the response and primarily controlled access to the site. Vehicle and foot traffic was blocked to the public on Mission Street from Bosworth Street to College Avenue and also blocked at St. Mary's Street at Marsilly Street.
- An Operations Emergency Center (OEC) was opened at the PG&E office at 2180 Harrison Street by the San Francisco / North Bay Superintendent.
- The OEC requested a General Construction (GC) crew to assist with the emergency response.
- Based on the amount of gas leaking and the location of bubbles, the PG&E M&C crews thought that the leak was on the 6-inch steel main.
- The crews discussed the possibility of squeezing the cross-tie in front of the house, and the M&C crews did not consider that to be a safe option.
- An initial plan was developed, and the crews started to dig in four locations where they planned to squeeze the gas mains. Things were very chaotic. The M&C Supervisor was receiving instructions from individuals at the OEC and the Gas Emergency Center, and some of the instructions were confusing.
- The M&C Supervisor later received instructions to change plans and implement the Alternative 3 shutdown plan, which involved closing two valves and squeezing mains in two locations.
- A M&C crew squeezed the 2-inch plastic main at the top of Mission Street. A GC crew assisted with digging the 6-inch plastic main at the top of Mission Street, which was then squeezed by another M&C crew.
- MSA gas detectors were used in the excavations, and they did not alarm.
- The pipe and squeeze tools were grounded and operated at one inch per minute.
- Two PG&E Instrumentation and Regulation (I&R) workers closed Valve #333 and Valve #3098.
- The M&C Supervisor received a text message that the last main was being squeezed at 12:42 PM. The lines were completely flat by about 12:50 PM.
- The steel main was pressure tested before being put back into service on Tuesday November 28, 2017.
- The OEC was deactivated around 3:30 or 4:00 PM on Tuesday.
- In general, the M&C responders reported having all of the tools and support they needed, with a couple of exceptions. Per M&C responders:
    - It would have been helpful to have received a notification when the initial gas odor complaint was received.
    - It would have been helpful to have received the shutdown plan sooner.

- Historically, PG&E had shutdown books that listed the shutdown valves for a certain area and that were updated every time the plat sheet was updated. These can be helpful in emergencies.

PG&E Leak Survey Crews on 12/18/17

- Leak survey crews arrived after the explosion and before the gas was shut off.
- The crews observed gas to be coming out of the cracks in the pavement and noticed a gas odor.
- They were instructed to survey the area and look for gas migration.
- The leak survey crews used Detecto Pak-Infrared Combustible Gas Indicators (DP-IR CGIs).
- Gas concentrations were checked at locations such as sewers and vaults.
- The gas concentration in nearby houses was checked if the occupants complained about a gas odor.
- The highest concentration of gas in air measured in a building was 0.6%.
- In general leak surveyors reported having all of the tools and equipment they needed. However, some leak surveyors reported:
  - It may have been helpful to have radios or walkie-talkies to communicate during the emergency response. They used cell phones, which worked well.
  - Getting to the incident location is difficult because PG&E crews are not permitted to use flashing lights to cut through traffic.

Interview with PG&E San Francisco / North Bay Superintendent on 01/23/18 and 01/30/18

- The superintendent learned about the incident from the M&C supervisor on the morning of the incident.
- He started working at the PG&E San Francisco office right away. Key personnel were available to assist within 15–20 minutes.
- An Operations Emergency Center (OEC) was opened at the San Francisco office. They communicated with the Gas Distribution Control Center (GDCC) to develop isolation plans. A plan was developed after approximately 1.5 hours. The plan involved operating two valves and squeezing mains in two locations.
- The GEC was unofficially opened at Bishop Ranch in a support capacity.
- Gas Control was sending shutdown plans to the OEC; the plans would be reviewed with the GEC and the M&C Supervisor, who was acting as IC in the field.
- The initial shutdown plan rejected because of the proximity of the cross-tie to the incident house.
- Alternative Shutdown Plan 1 was rejected because it was determined to be much slower than Alternative Shutdown Plan 3.
- Alternative Shutdown Plan 2 was rejected due to the fact that it involved operating a large number of valves. There were only a handful of I&R workers onsite who had the appropriate operator qualifications (OQ's) for operating mainline valves. It would have

taken a long time for them to shut all 14 valves in the shutdown zone. Different valves will have different keys and different numbers of turns. You need to have someone familiar with the valves operating them. In addition, if just one of the valves is not able to be closed, then the shutdown plan may not work. Sometimes you will find that a vehicle is parked over a valve and it cannot be operated. In some cases, the valves have been paved over and are difficult to locate. For these reasons, Alternative Shutdown Plan 2 was not selected.

- Alternative Shutdown Plan 3 was selected because it was determined to be the fastest plan. The plan was modified to eliminate one of the orinal planned three valves.
- It was reported that the PG&E Mobile Command Vehicle (MCV) took a long time to arrive due to a lack of driver. It would have been useful to have the MCV sooner to use as a central organizing location.

Interview with PG&E GC Foreman from 2003 Construction Job on 12/28/17

- The foreman did not recall the exact details of the job that performed work in the area of the leak. He was running crews of 25 men around that time.
- The work that was performed on Mission Street around 2003 was performed by GC gas crews.
- He reported that the normal practice for cutting and capping low-pressure service lines during that time period would be to:
    - Use a Grunsky bag to remove the completion cap and completion plug from the tee and insert a plumber's plug to stop off the service.
    - Cut the service about a foot from the main and remove ~18 inches of pipe to allow a threading machine to be used to thread the end of the service.
    - The plumbers plug would typically be left in place.
    - If a plastic fusion cap was going to be installed, they would need to leave ~4-5 inches of plastic pipe on the end.
    - He expects that a service like the incident service line would typically have been capped by welding a steel cap onto the steel pipe.
- It was not normal practice at that time to leave long stubs. Crews were instructed to take it back to the source main and cut and cap it there. Guidance was to cut and cap the service ~1 foot from the main.
- If PG&E crews performing the work are OQ'd, then there would be no inspection required and he would not have personally inspected this work.
- For the incident service line, he thinks that the service would have been transferred to the plastic main by squeezing and capping the plastic service pipe, transferring the service, and then relighting the pilots before cutting the service line at the steel main.

Interview with PG&E San Francisco / North Bay General Construction Superintendent on 1/23/18

- The Superintendent has used plumber's plugs, similar the one found at the leak location, many times.
- Plugs are typically used on low-pressure distribution systems with a Grunsky bag.

- Many tees in San Francisco don't have a completion plug (for example, shop tees) and you would need to use a Grunsky bag and plug to stop off the line.
- They are typically installed fairly tightly but not too tight. If they are installed too tight, you may not be able to get them out.
- This type of plug was never intended to be left in place holding pressure.
- This type of plug was sometimes left in place if a steel main was being abandoned. The stub would still have to be capped, though. A steel stub would need to have a steel cap welded on.
- He recalls two occasions in which plugs were left in place and a gas leak resulted when the main was uprated:
    - On one occasion, a main was being uprated, and several stubs were found to be leaking. The stubs had rubber plugs in the service tees, and the stub outlets were bull-nosed and leaking. All of the services on the main had to be dug up and examined.
    - On another occasion, a main was being uprated in increments with gas in the 1991–1993 timeframe. Crews were bringing the pressure up in 10 psi increments when a leak occurred. They found that two Aldyl-A service lines had been plugged and cut and the plugs were left in the service tees. The stubs were left uncapped. As the pressure was being increased, the plugs had popped up and some gas leaked out.

Records Review

Exponent reviewed the construction records for the PG&E gas facilities on the 3900 block of Mission Street to determine a construction history timeline. The records reviewed included distribution plat sheets for the area, Gas Service Records for [redacted], job documents for the installation of the 6-inch steel main and 6-inch plastic main on Mission Street, job documents for electrical work performed to underground overhead services, and job documents for the uprate of the 6-inch steel main in 2013. In addition to PG&E records, Exponent reviewed historical USA tickets for the 3900 block of Mission Street, and historical aerial photos of the area.

The PG&E gas facilities in the immediate leak area at the time of the incident are shown in Figure 28. There is a deactivated 10-inch cast-iron main on the east side of Mission Street and a deactivated 16-inch cast-iron main on the west side of Mission Street. A 6-inch high-pressure steel main runs along the east side of Mission Street and feeds services on the east side of the street, including the incident house. A 6-inch plastic main runs along the west side of Mission Street and feeds services on the west side of the street, including [redacted] A 2-inch plastic main inserted into 3-inch pipe runs along College Terrace and is fed from the 6-inch plastic main.

Figure 28. PG&E gas facilities in the immediate leak area. Leak location indicated with a red circle.

The oldest available gas service record for the house at [redacted] is a leak repair report dated 1987. At that time, there was a 10-inch low-pressure cast-iron main on the east

side of Mission Street feeding services on the east side of the street, and there was a 16-inch semi-high-pressure cast-iron main on the west side of Mission Street feeding services on the west side of the street. At this time there was also a 3-inch plastic low-pressure main in College Terrace that was fed from the 10-inch cast-iron low-pressure main on the east side of Mission Street.The gas service record shows an existing 1 ¼-inch long side steel service line to [redacted] being fed from the 10-inch low pressure cast iron main on the east side of the street.

In 1992, job GM 4944914 installed the 6-inch steel main on Mission Street and deactivated the 10-inch cast-iron main. At the time of installation, the 6-inch steel main was operating at low pressure. The job docs indicate that the 10-inch cast-iron main had been installed in 1938.[18] Job GM 4944914 installed 815 feet of 6-inch steel main on Mission street, deactivated the 10-inch cast-iron main, transferred the feed for the 3-inch plastic main on College Terrace from the 10-inch cast-iron main to the new 6-inch steel main, and replaced multiple services from the 10-inch cast-iron low-pressure main to the 6-inch steel low-pressure main, including the services for the incident house and [redacted] Based on the printline on the abandoned 2-inch plastic service line, it was likely installed at that time and on this job. The new facilities were placed into service on March 20, 1992.

In 1996, job GM 1670215 installed the 6-inch plastic main on Mission Street, deactivated the 16-inch cast-iron semi-high-pressure main, and transferred multiple services, not including the incident house or [redacted], from the 16-inch cast-iron main to the new 6-inch plastic main. The job documents show that the service to [redacted] and the 3-inch plastic low-pressure main on College Terrace were fed from the 6-inch steel LP main at that time.Work on the new facilities was completed on May 31, 1996.

In 2003, multiple PG&E jobs performed work on the 3900 block of Mission Street as part of Rule 20 work. Job 30223376 performed work to replace overhead electrical distribution lines with underground facilities. This job does not appear to have affected gas facilities and did not perform any work at the leak location. Job GM 30267521 installed new mains in the area, including a 2-inch plastic main on College Terrace that was inserted into an existing 3-inch main. The new mains were placed into service on July 15, 2003. The construction drawings for this job show the service line to [redacted] as being fed from the 6-inch steel main. The drawings also list the installation year as 1976, which is likely incorrect. The service line appears to have been installed in 1992. The construction drawings also show that a long stub of 3-inch plastic pipe fed from the 6-inch steel main was left in place in front of the incident house. This stub was formerly part of the 3-inch main on College Terrace. An associated gas service record (PM 30267522) transferred the service to [redacted] from the 6-inch steel main to the 6-inch plastic main. The gas service record indicates in the "C/O data" field that 33 feet of service line were removed from service. This amount is equal to the distance from the house to the plastic main and appears to indicate that a long stub may have been left in place. The sketch on the document indicates that the job planned to cut and cap the service line at a location near the steel main, but no measurements were provided. The document

[18] GM4944914 6in Steel.pdf, p. 60.

indicates that a 1 ¼-inch steel service line was expected, but a correction was added to indicate that the existing service line was 2-inch. The transfer occurred on October 30, 2003.

In 2013, job PM 30945050 uprated the maximum allowable operating pressure (MAOP) of the 6-inch steel low-pressure main from 10.5 inches of water column (WC) to 60 psig. The uprate was performed using gas, and the pressure was increased in 15-psi increments. The map of the facilities being uprated shows a long stub on the 6-inch steel main in front of the incident house and does not show a stub at the leak location. The construction drawings do not show a valve on the stub. After the uprate, the 6-inch steel main was connected to the 6-inch plastic main by tying the long stub into the plastic main.

Aerial photographs taken between 2003 and 2017 were examined for signs of excavations in the incident area. The photographs were obtained from Google Earth, the US Geological Survey (USGS), and Pictometry, and are shown in Appendix C. The photographs show the following events:

- **12/31/2003:** Signs of recent excavations are visible at the 6-inch plastic main and the 6-inch steel main in front of [redacted].
    - This is consistent with the work performed to transfer the service from the steel main to the plastic main in October 2003.
    - These are the only visible signs of excavations along the service line to [redacted].
- **~2006:** The 3900 Block of Mission Street was repaved.
- **02/23/2014:** Signs of excavations from the 2013 uprate are visible at the south end of the steel main and at the plastic main in front of College Terrace.

USA tickets for the incident area were reviewed. There were five available tickets:

- September 2013—PG&E gas main work (uprate job)
- September 2013—PG&E gas main work (uprate job)—Extension
- October 2015—PG&E work, “drill for ground rods”
- January 2016—PG&E installation of cathodic protection
- March 2017—Water main repair at 3983 Mission Street

The September 2013 work performed an excavation very close to but slightly south of the leak location. Aerial photosgraphs do not show any signs of excavations at the leak location during the other timeframes listed in the USA tickets.

Construction Timeline

Based on the records review described in the previous section, Exponent has created the following timeline of construction activities on the 3900 block of Mission Street (Table 1).

Table 1. Construction activities on 3900 block of Mission Street.

Pre-1987	Two cast-iron (CI) mains provide gas to the 3900 Mission block. • East side of street—10-inch low-pressure (LP) CI main installed in 1938[1]. • West side of street—16-inch semi-high pressure (SHP) CI main installed in 1926
1987	Gas service record indicates leak repaired on service to [redacted]. Service is shown as 1 ¼-inch steel line fed from CI LP main on east side of Mission Street.
1992	10-inch CI LP main on east side of Mission Street replaced with 6-inch steel LP main on GM 4944914. The 2-inch plastic service to [redacted] was installed.
1996	16-inch CI SHP main on west side of Mission Street replaced with a 6-inch high pressure (HP) plastic (PL) main on GM 1670215.
2003	2-inch PL main installed on College Terrace on PM 30267521 which is associated with Rule 20 work to underground electrical distribution facilities.
2003	The service line to [redacted] was transferred from steel main to PL main on Mission St on PM 30767522. X-Pander plug inserted into service tee. Service line was likely cut at steel line and left uncapped at this time.
2013	Steel 6-inch main uprated from LP to HP service. X-Pander plug was in place at this time.
2017	Leak occurs at uncapped service stub on steel main.

Work Performed and Company Standards

Exponent reviewed standards that apply to the work that PG&E performed on the 3900 block of Mission Street prior to the incident. This section contains a summary of some of the most relevant standards and compares them to the work that was performed.

Code/Standard Reviewed	Approved or Effective Date	Description
Gas Standard C36.1— *Grunsky Bag Method for Stopping off Low Pressure Service Tees (Rev. 00)*	4/20/2000	Steps for procedure used to stop flow to incident abandoned service stub.
Gas Standard A-93.2— *Deactivation of Plastic Services (Rev. 01)*	04/09/2003	Specific standards for deactivating plastic services, applies to incident stub.
Utility Operations Standard S4129— *Deactivation of Gas Facilities*	01/2002	General standards for deactivation of gas lines.
Utility Procedure TD-4125P-03— *Revising the MAOP of Pipelines Operating at 60 psig or Less (Rev. 1a)*	03/31/2012	Applicable to uprating of incident gas main to 60 psig.
49 CFR § 192.727	08/19/1970	Federal regulations for abandoning services, applies to incident stub.

Gas Standard C36.1— Grunsky Bag Method for Stopping off Low-Pressure Service Tees (Rev. 00)

The incident gas leak occurred when an expansion plug become dislodged and provided a leak path for gas into the abandoned service stub. Gas Standard C36.1 describes the process of using a pressurizable bag (Grunsky bag) to install an expansion plug. The bag is used to minimize gas leakage during installation.

The procedure involves using the Grunsky bag and a wrench to install an expansion plug (sometimes referred to as an X-Pander or X-Pando plug, or colloquially as a plumber's plug), for the purpose of temporarily stopping gas flow through a ¾-inch to 2-inch service tee. Doing so enables the downstream section of the service to be purged and safely worked on. After work is complete, GS C36.1 calls for the expansion plug to be removed and the completion

plug and cap to be reinstalled. It also cautions that the procedure should not be used if the line pressure exceeds 10 inches WC.

When PG&E transferred the service line to [redacted] from the steel main to the PL main in 2003, an X-Pander plug was installed into the service tee but it was not removed and the completion plug was not reinstalled, as GS C36.1 states should have been done following completion of the work. Then, when the PL main was uprated in 2013, the X-Pander plug was exposed to pressures in excess of 10 inches WC, which GS C36.1 warns against.

Gas Standard A-93.2— Deactivation of Plastic Services (Rev. 01)

Gas Standard A-93.2 details procedures for cutting, capping, and deactivating plastic service lines, such as the service line to [redacted] that PG&E deactivated while switching from the steel to PL main in 2003. Sections 2 and 3 of the standard apply to service tee connections and Mueller tapping tee connections, respectively.

Section 2 describes procedures for cutting and capping a service tee connection, whether steel or plastic. The basic steps in the procedures for a plastic service line are as follows:

- Gas flow is to be stopped off at the service tee or squeezed off.
- Pressure in the service line is then relieved and a soap test is performed to ensure complete stoppage of flow in the service line.
- The service pipe is to be cut four to five inches downstream from the service tee connection.
- Approved mechanical or fusion end caps are to be installed on each cut end.
- The tee is to be repressurized and a soap test is performed to ensure that the new installation is free of leaks.
- If plastic stubs remain, a protective sleeve is to be reinstalled on the tee outlet.

Section 3 applies to Mueller tapping tees, such as the incident service tee, and refers to Section 2. Section 3 advises that the preferred method for cutting off service downstream of a Mueller tee is to cut and cap the plastic service line as described above.

The incident service stub, which once provided service to [redacted] was found cut downstream of the Mueller tapping tee, and neither the stub end nor the near end of the abandoned service line was capped. Per the recommendations of Gas Standard A-93.2, both cut ends of the pipe should have been capped and a protective sleeve should have been installed on the remaining stub. The incident service line had a pressure-containing cap on the far end (near the 6-inch plastic main) but did not have a cap on either the stub or the end of the abandoned service line near the 6-inch steel main. A figure from GS A-93.2 (shown here in Figure 29) illustrates a properly deactivated Mueller tee with a steel-to-plastic transition fitting. A pressure-containing end cap and sleeve, such as that shown in Figure 29, was not installed on the incident service stub. Notice that unlike the service line deactivated by PG&E in 2003 (shown in Figure 22), the GS A-93.2 illustrates a cap at the end of the service stud and a protective sleeve installed. The cuts that were made in the service line left less than 1.5 inches

of plastic pipe remaining on the end of the stub. This is not enough plastic pipe to attach a mechanical end cap or a fusion end cap. GS A-93.2 permits the stub to be sealed with a cap welded on the steel pipe, as shown in Figure 30. A steel cap was not attached to the end of the incident stub.

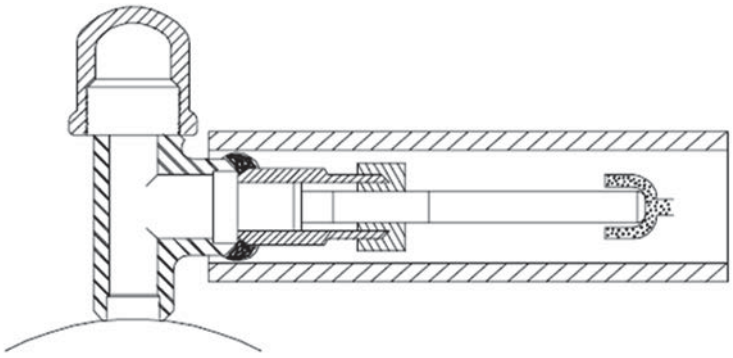

Figure 29. Figure 5 from GS A-93.2 showing a properly deactivated Mueller tee with steel-to- plastic transition fitting.

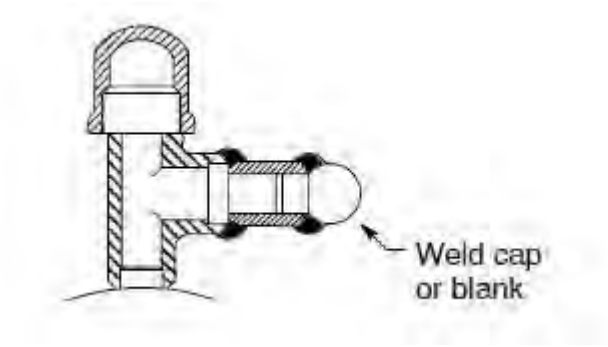

Figure 30. Figure 7 from GS A-93.2 showing a properly deactivated Mueller tee with a welded cap.

Utility Operations Standard S4129—Deactivation of Gas Facilities

UO Standard S4129 establishes responsibilities, procedures, and requirements for deactivating PG&E gas lines in conformance with requirements of 49 CFR Part 192.727. The standard applies to gas distribution services, such as the service line to [redacted] that was deactivated in 2003.

Section 2 states that service stubs shall be cut off at the main within one year if identified as not needed in the future. According to interviews with personnel involved in construction activities, it was common PG&E practice to cut off stubs at the main immediately after they were created during service transfers such as that performed on the incident service line in

2003. Aerial photos of the incident area, which are included in Appendix C, provide evidence that excavations were performed in the area of the incident Mueller tee in 2003. Therefore, it is likely that the service stub was cut off in 2003 within months of the service line transfer to [redacted], which is acceptable timing according UO Standard S4129.

Attachment 1, Section 3, Item A states that all pipe sections to be deactivated shall be cut as close to the main connection as practicable and that the open end of the deactived pipe shall be sealed. The incident service line stub was cut close to the main, but its open end was not sealed as required byUO Standard S4129.

Attachment 1, Section 6, Item A of UO Standard S4129 establishes a requirement that, when a cut is necessary per Attachment 1, Section 3, a section of pipe is to be removed and both remaining exposed ends are to be sealed. Further, Item C lists acceptable methods of sealing the pipe ends. Table 2 summarizes the acceptable methods. None of these methods were used to seal the deactivated incident pipe stubs.

Table 2. Approved pipe sealing methods during deactivation of gas facilities according to UO Standard S4129.

Table 1. Approved Pipe Sealing Methods

Method	Transmission/ Gathering	Distribution
Crush or flatten the pipe-end and seal-weld the opening.	x	x
Weld a plate or a weld a cap over the opening.	x	x
Seal with concrete or mortar products.	x	x
Securely seal with a tightly driven redwood plug (2 inches or smaller). See GS&S A-81.		x
For copper pipe, flatten and bend to 180 degrees.		x
Seal with polyurethane foam cast in place.		x
For plastic pipe, use either fusion or mechanical caps to seal pipe or use methods 3., 4., and 6. above (see GS&S A-90 and A-93.2).		x
For low-pressure cast iron or steel pipe, install a mechanical blanking head.		x
Securely seal with a tightly fitting, outside-diameter-seal plastic end cap.		x

Utility Procedure TD-4125P-03— Revising the MAOP of Pipelines Operating at 60 psig or Less (Rev. 1a)

Utility Procedure TD-4125P-03 provides steps for changing the MAOP for gas distribution pipelines operating at 60 psig or less. It is applicable to PG&E's uprate of the incident steel 6-inch main line in 2013. The basic procedure for uprating distribution gas pipelines is given in Section 2.

Section 2 states that,

- A written plan must be prepared describing the method of uprating required for the pressure system.
- PG&E employees must "Locate any existing services to be converted to high pressure, and services to be replaced by direct burial or insertion. All stub mains and services must be located and shown on the map."
- The CPUC must be notified of proposed upratings.
- Revisions to MAOP must be included in updated versions of affected company documents.
- Overpressure protection device settings and capacities must be reviewed and revised, if necessary.
- Records must be retained for the life of the affected pipelines.

During the review of records, Exponent found that the small incident stub was not indicated on the drawings produced at the time of the uprate. TD-4125P-03 does not define "stub mains and services," and it is not clear whether the incident service stub would fall under this category. Exponent reviewed numerous documents and drawings related to PG&E's 2013 uprate of the incident main line, the details of which were found to be consistent with the guidance provided by standard TD-4125P-03. Appendix B provides a list of documents reviewed.

49 CFR § 192.727

Title 49 of the Code of Federal Regulations, Part 192.727, sets federal standards for deactivation of gas pipelines. The regulation applies to PG&E's deactivation of the incident [redacted] service line in 2003.

49 CFR § 192.727(b) requires that all abandoned piping must be disconnected (cut) from all gas supply and sealed at the ends. The [redacted] service abandoned by PG&E in 2003 wasnot sealed at the east end (close to the steel main); therefore, the abandonment did not comply with 49 CFR § 192.727 (b). This was not a contributing factor to the gas leak and explosion.

Emergency Response Evaluation

Based on a review of documents provided by PG&E, incident reports, and interviews with witnesses to the incident, Exponent created the following timeline of the incident:

Day	Time	Event
11/27/17	9:52 AM	San Francisco Fire Department (SFFD) received a gas odor complaint at or around [redacted].[19]
11/27/17		Upon arrival, SFFD determined that there was an underground gas leak and started evacuating nearby buildings.[20]
11/27/17	9:57 AM	SFFD notified PG&E of gas leak[21]
11/27/17	10:04 AM	PG&E Gas Service Representative (GSR) was dispatched to the site.[22]
11/27/17		A second PG&E GSR was dispatched to the site.
11/27/17	10:14 AM	Explosion occurred at [redacted].[23]
11/27/17	10:16 AM	PG&E dispatch received a call from SFFD informing them of an explosion.[24]
11/27/17	10:17 AM	PG&E dispatch received a call from SFFD requesting an expedited response.[25]
11/27/17	10:20 AM	First PG&E GSR arrived onsite
11/27/17		GSR saw bubbles coming from the ground and requested M&C crew.[26]
11/27/17	10:30 AM	First PG&E M&C crew arrived onsite.[27]
11/27/17	10:33 AM	PG&E M&C supervisor arrived onsite and assumed the role of Incident Commander (IC).
11/27/17	10:57 AM	PG&E engineers shared the first isolation plans with the IC.
11/27/17	11:50 AM	PG&E reported incident to the DOT.[28]

[19] NFIRS Incident Report Number 17138832, November 27, 2017.

[20] NFIRS Incident Report Number 17138832, November 27, 2017.

[21] CPUC Form 420 for incident.

[22] PG&E Incident Report Order Detail, FO ID# 5572325648.

[23] Interview with SFFD Incident Commander on November 27, 2017.

[24] Timeline document received from PG&E (Timeline of Explosion Incident Mission Street.docx).

[25] Timeline document received from PG&E (Timeline of Explosion Incident Mission Street.docx).

[26] Interview with PG&E Gas Service Representative #1, December 14, 2017.

[27] PG&E Incident Report Order Detail, FO ID# 5572325648.

Day	Time	Event
11/27/17	11:54 AM	Final isolation plan selected that involved closing two mainline valves and squeezing plastic mains in two locations.[29]
11/27/17	12:00 PM	PG&E reported incident to the CPUC.[30]
11/27/17	12:30 PM	Exponent arrives onsite to begin direct cause investigation in coordination with the CPUC.
11/27/17	12:50 PM	Gas shut in and mains on 3900 block of Mission Street are flat.[31]

Federal and State Regulations

Federal regulations for natural gas pipelines are contained in Title 49 of the Code of Federal Regulations, Part 192 (49 CFR § 192). Under these regulations, each natural gas pipeline operator is required to prepare a manual of written procedures for emergency response.[32] The manual is required to be reviewed and updated at intervals not exceeding 15 months, but at least once each calendar year.[32] The emergency response manual must, at a minimum, address the following:[33]

1. Receiving, identifying, and classifying notices of events that require immediate response by the operator.
2. Establishing and maintaining adequate means of communication with appropriate fire, police, and other public officials.
3. Providing prompt and effective response to a notice of each type of emergency, including the following:
    a. Gas detected inside or near a building.
    b. Fire located near or directly involving a pipeline facility.
    c. Explosion occurring near or directly involving a pipeline facility.
    d. Natural disaster.
4. The availability of personnel, equipment, tools, and materials, as needed at the scene of an emergency.
5. Actions directed toward protecting people first and then property.
6. Emergency shutdown and pressure reduction in any section of the operator's pipeline system necessary to minimize hazards to life or property.
7. Making safe any actual or potential hazard to life or property.

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[28] DOT Form No. 20170117-16740 submitted by PG&E at 11:50 AM on December 21, 2017.

[29] Timeline document received from PG&E (Timeline of Explosion Incident Mission Street.docx).

[30] CPUC Form No. 420, Filed by Pacific Gas & Electric Co. at 12:00 PM on December 27, 2017.

[31] PG&E Incident Report Order Detail, FO ID# 5572325648.

[32] 49 CFR § 192.605.

[33] 49 CFR § 192.615.

8. Notifying appropriate fire, police, and other public officials of gas pipeline emergencies and coordinating with them both planned responses and actual responses during an emergency.
9. Safely restoring any service outage.
10. Beginning action under 49 CFR §192.617,[34] if applicable, as soon after the end of the emergency as possible.
11. Actions required to be taken by a controller during an emergency in accordance with 49 CFR §192.631.[35]

Additionally, each operator shall:[36]

1. Furnish its supervisors who are responsible for emergency action a copy of that portion of the latest edition of the emergency procedures established under paragraph (a) of this section as necessary for compliance with those procedures.
2. Train the appropriate operating personnel to assure that they are knowledgeable of the emergency procedures and verify that the training is effective.
3. Review employee activities to determine whether the procedures were effectively followed in each emergency.
4. Establish and maintain liaison with appropriate fire, police, and other public officials to:
    a. Learn the responsibility and resources of each government organization that may respond to a gas pipeline emergency;
    b. Acquaint the officials with the operator's ability in responding to a gas pipeline emergency;
    c. Identify the types of gas pipeline emergencies of which the operator notifies the officials; and
    d. Plan how the operator and officials can engage in mutual assistance to minimize hazards to life or property.

Additionally, PHMSA Advisory Bulletin ADB 12-09 was issued in 2012 to remind pipeline operators to be able to contact public safety answering points (PSAPs) along their pipelines.[37]

California state safety requirements for intrastate natural gas pipelines are contained in the California Public Utilities Code, Sections 950–978 (PUC § 950–978).[38] The CPUC requires that owners and operators of California intrastate transmission and distribution pipelines establish emergency response plans that are compatible with 49 CFR§192.615.[39] The emergency response plans must include requirements for emergency shutdown, emergency response coordination, and liaison and pre-incident planning with local fire departments.[39]

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[34] 49 CFR § 192.617 addresses the investigation of failures.

[35] 49 CFR § 192.617 addresses control room management.

[36] 49 CFR § 192.615.

[37] https://www.phmsa.dot.gov/pipeline/regs/advisory-bulletin (last accessed 2 February 2018).

[38] PUC § 950.

[39] PUC § 956.

Additionally, the state fire marshal and chief fire official of local fire departments of areas where pipelines are located must be given access to the National Pipeline Mapping System.[39] At least once each calendar year, owners and operators must meet with local fire departments and review contingency plans for emergencies.[40]

PG&E Emergency Response Guidelines

PG&E's emergency response protocols are outlined in internal documents such as the Gas Emergency Response Plan[41] (GERP) and numerous documented standard procedures. The GERP contains safety-related information for emergency responders that includes general guidance, incident specific guidance, and target response parameters for emergency response activities.

Outside agencies notify PG&E of emergencies through Gas Dispatch and Scheduling (Gas Dispatch).[42] Upon notification of an incident, Gas Dispatch will send a first responder to the site. The first responder will typically be a single GSR. If the GSR needs assistance, the Field Supervisor will be notified by Gas Dispatch.[42] If the incident is of significant severity, then additional resources may be requested.[42]

The GERP defines incident severity using a rating scale from one to five. The five levels of incidents are:[43]

- Level 1—Routine
- Level 2—Elevated
- Level 3—Serious
- Level 4—Severe
- Level 5—Catastrophic

Incidents of Level 1 severity will trigger the activation of an on-scene Incident Command Post (ICP), in which the Incident Commander will coordinate response activities and communications.[44] Incidents of Level 2 severity and higher can trigger a local PG&E Operations Emergency Centers (OEC) to activate.[44] Each PG&E division headquarters maintains an OEC for emergency response coordination.[44] Once activated, the OEC will coordinate the emergency response and may require a Public Information Officer and/or the use of a Mobile Command Vehicle (MCV).[45] An MCV can also be used as an ICP or alternate OEC.[46] Level 3 (optional), Level 4, and Level 5 gas incidents trigger the PG&E Gas

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[40] PUC § 956.5.

[41] PG&E Gas Emergency Response Plan Version 6.0, Last Revised 12/31/16.

[42] PG&E Gas Emergency Response Plan, Version 6.0, pp. 3-16.

[43] PG&E Gas Emergency Response Plan, Version 6.0, pp. 3-11 – 3-15.

[44] PG&E Gas Emergency Response Plan, Version 6.0, pp. 3-9.

[45] PG&E Gas Emergency Response Plan, Version 6.0, pp. 3-12.

[46] PG&E Gas Emergency Response Plan, Version 6.0, pp. 3-10.

Emergency Center (GEC) in San Ramon to activate.[47] The GEC is staffed by an incident support team that assists the emergency response in coordination with the activated OEC(s).[48] In dual-commodity (gas and electric) Level 4 or Level 5 emergencies, or in some cases for dual-commodity Level 3 emergencies, the PG&E Emergency Operations Center (EOC) will activate.[49]

Gas events that meet the following criteria must be reported to the CPUC and DOT:[50]

- Any fatality or injury necessitating overnight hospitalization
- Property damage estimated at $50,000 or more
- Emergency shutdown of a liquid natural gas (LNG) facility
- All explosions
- Gas loss of 3 million cubic feet or more
- Major media on scene
- Damage that results in a release of gas

The following reporting timeframes are applicable to CPUC and DOT reportable events:[51]

- For DOT: Report within 1 hour after PG&E gas employees are aware of the incident and have arrived on the scene.
- For CPUC: Report within 2 hours (during working hours) or 4 hours (during nonworking hours) after PG&E gas employees are aware of the incident and have arrived on the scene.

The GERP contains supplemental emergency response guidance for a range of incident types. The guidance provided for fire/explosion incidents contains steps to assess and minimize hazards, parties to notify or coordinate with, and issues to consider.

To **Assess/Minimize Hazards** during a fire or explosion incident, the GERP recommends:[52]

- If safe, shut off gas if it poses a danger and/or stop the escape of gas by controls or repairs.
- Assess if gas is accumulating or burning.

The GERP recommends that the following parties be **Notified or Coordinated** with during a fire or explosion incident:[52]

- Notify and coordinate continuously with any activated emergency centers.

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47 PG&E Gas Emergency Response Plan, Version 6.0, pp. 2-31.

48 PG&E Gas Emergency Response Plan, Version 6.0, pp. 2-32.

49 PG&E Gas Emergency Response Plan, Version 6.0, pp. 2-36.

50 PG&E Utility Procedure TD-6100P-04, Rev 0, p. 3.

51 G&E Utility Procedure TD-6100P-04, Rev 0, pp. 3-4.

52 PG&E Gas Emergency Response Plan, Version 6.0, p. B-19.

The GERP recommends that the following issues be **Considered** during a fire or explosion incident:[52]

- Isolate the line.
- Work with local first responders (FD/LE) to determine if fire should be extinguished or allowed to burn.
- If unknown, determine where gas is coming from. Use intrinsically safe leak detection instrument in this process.
- Determine if gas is migrating into nearby buildings or enclosed spaces using intrinsically safe leak detection instrument.
- Continuously re-evaluate and assess incident site, ensure that evacuation distances are safe, secure perimeter to prevent unauthorized entry to the area, and stay upwind of the site.
- Determine extent of damages, what areas and what facilities were damaged and/or affected.
- Keep customers, governmental agencies and representatives, the news media, and other constituencies informed.
- Check the status of personnel for injuries and arrange treatment or transport as necessary.
- Make sure all PG&E personnel on-site are accounted for. Advise Emergency Center or Gas Control of any deaths or injuries.
- If not previously requested, request a PSS[53] to liaison with police/fire and local emergency services.

When it is necessary to shut off the flow of gas to mains and services during an emergency, PG&E has the following target response times:[54]

- 117 minutes for gas mains
- 50.2 minutes for service lines

PG&E Standard TD-6100P-04[55] provides guidelines for evacuating structures during a gas leak event.

PG&E typically performs after-action reports (AARs) after exercises, trainings, emergency deployment of an MCV (on a case-by-case basis), Level 2 or higher incidents, and high-profile incidents.[56] AARs can include performance evaluations conducted immediately after an incident (hotwash)[56] as well as critiques of issues related to safety, preactivation, incident command system (ICS), field response, communication, post event issues, areas for improvement, and best practices.[57] AARs are to be performed within 20 working days of a

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[53] Public Safety Specialist.

[54] PG&E Gas Emergency Response Plan, Version 6.0, p. 5-2.

[55] PG&E Utility Procedure TD-6100P-04.

[56] PG&E Gas Emergency Response Plan, Version 6.0, p. 7-1.

[57] PG&E Gas Emergency Response Plan, Version 6.0, p. 7-2.

Level 2 or higher incident.[56] At the conclusion of an AAR, a report is created and distributed to various stakeholder groups.[56]

PG&E procedures for squeezing polyethylene pipe are outlined in Utility Work Procedure WP4170-02 *Squeezing Polyethylene (PE) Pipe*. These procedures include:[58]

- Do not squeeze the pipe more than once at the same point.
- The squeeze point must be a minimum of three pipe diameters from the nearest fitting or fusion.
- Ground the squeezer.
- Close and release the squeezers at a maximum rate of 1 inch per minute.
- Install a PVC support clamp on all exposed squeeze points for 1 ¼-inch and larger Aldyl-A pipe.
- Install pressure gauge taps before squeezing mainlines.

PG&E GSRs and leak survey crews use Sensit Gold G2[59] and DP-IR[60] CGIs. Sensit Gold G2 CGIs are listed as intrinsically safe for Class 1, Division 1, Group C and D, T3 hazardous locations.[61] DP-IR CGIs are listed as intrinsically safe for Class 1, Division 1, Group D, T3 hazardous locations.[62] Locations where natural gas is present in ignitable concentrations under normal operating conditions are classified as Class 1, Division 1, Group D hazardous locations.[63] T3 temperature class equipment will produce a maximum surface temperature of 200 deg C (392 deg F).[64]

Industry Best Practices

The US DOT publishes the Emergency Response Guidebook, which is intended for use by first responders during the initial response effort of transportation incidents involving dangerous goods and hazardous materials. The Emergency Response Guidebook recommends, as an immediate precautionary measure, isolating the leak area for a distance of at least 100 meters (330 feet).[65] The Emergency Response Guidebook does not provide any recommendations for the use of squeeze tools.

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58 PG&E Utility Work Procedure WP4170-02 *Squeezing Polyethylene (PE) Pipe.*

59 PG&E Utility Procedure TD-6100P-23, Attachment 1, *Sensit Gold G2*.

60 PG&E Utility Procedure TD-4110P-25, *Heath Detecto Pak-Infrared (DP-IR™) Leak Detector*.

61 Sensit Gold G2 User's Manual, p. 1.

62 DP-IR User's Manual, p. 7.

63 National Fire Protection Association, NFPA 70-2011, National Electrical Code, Section 500.5.

64 National Fire Protection Association, NFPA 70-2011, National Electrical Code, Table 500.8.

65 US DOT, 2016 Emergency Response Guidebook, p. 168.

The National Emergency Number Association recommends that public safety answering points (PSAPs) instruct callers who are near suspected underground natural gas leaks to stay at least 100 meters (330 feet) away from the leak.[66]

Squeeze tools are instruments that can be used to stop the flow of gas or liquid in polyethylene pipes by compressing the pipe between parallel bars until the inside surfaces make contact.[67] Voluntary industry standards for squeeze tools include:

- ASTM F 1563-01 Standard Specification for Tools to Squeeze-off Polyethylene (PE) Gas Pipe or Tubing (ASTM F1563),
- ASTMF1734 – 03 (reapproved 2009) Standard Practice for Qualification of a Combination of Squeeze Tool, Pipe, and Squeeze-Off Procedures to Avoid Long-Term Damage in Polyethylene (PE) Gas Pipe (ASTM F1734).
- ASTM F 1041-02 (reapproved 2016) Standard Guide for Squeeze-Off of Polyolefin Gas Pressure Pipe and Tubing (ASTM F1041),

ASTM F1563 describes standard specifications for squeeze tools. Due to the low electrical conductivity of polyethylene and the increased velocity of gas flowing through the squeeze point, static charge can build up and can represent an explosion hazard.[68] Per ASTM F1563, squeeze tools shall include electrical grounding features or recommendations for controlling static electricity discharge. ASTM F1734 is a standard practice that can be used by squeeze tool manufacturers, pipe manufacturers, and gas utilities to develop squeeze-off procedures for polyethylene pipe to avoid long-term damage to the pipe.[69] Typically, squeeze tool gap stops are set so the tool cannot compress the pipe walls more than 30%.[70] ASTM F1041 provides guidelines for the operation of squeeze tools. These guidelines include:[71]

- Squeeze tools shall conform to ASTM F1563.
- Pipe should be squeezed at a rate of 2 inches per minute or less until the flow stops or mechanical stops are reached.
- Squeeze-off should be performed in a separate bell-hole isolated from blowing gas.
- The squeeze tool should be ground, and a soapy water solution should be applied to safely dissipate static charges.
- Squeeze-off should be performed at a location that is at least three pipe diameters or 12 inches, whichever is greater, from any fusion joint (1.5 diameters from any butt-fusion joint) or mechanical fitting.

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66 National Emergency Number Association, Pipeline Emergency Operations Standard/Model Recommendation, 2010.

67 Performance Pipe, Technical Note PP 801-TN.

68 Performance Pipe, Technical Note PP 801-TN.

69 ASTMF1734 – 03 (reapproved 2009) *Standard Practice for Qualification of a Combination of Squeeze Tool, Pipe, and Squeeze-Off Procedures to Avoid Long-Term Damage in Polyethylene (PE) Gas Pipe,* p. 1.

70 ASTMF1734 – 03 (reapproved 2009) *Standard Practice for Qualification of a Combination of Squeeze Tool, Pipe, and Squeeze-Off Procedures to Avoid Long-Term Damage in Polyethylene (PE) Gas Pipe,* p. 2.

71 ASTM F 1041-02 (reapproved 2016) *Standard Guide for Squeeze-Off of Polyolefin Gas Pressure Pipe and Tubing.*

- Squeeze-off should not be performed twice at the same location.

The American Gas Association (AGA) issued a technical note that contains recommendations for first responders for gas pipeline incidents. Their recommendations include the following "Do's" and "Don'ts" for gas pipeline incident response:[72]

- Do's
  - Notify the gas company immediately while en-route—utilize the gas company expertise.
  - Approach upwind.
  - Treat all gas leaks as potentially hazardous.
  - When in doubt, evacuate structures.
  - Protect people first, property second.
  - Evacuate surrounding structures as needed.
  - Look for multiple gas leaks even if the gas has ignited.
  - Explain company policy on nonemployee shutoff for above-ground meter valves. (Some companies train responders to shutoff meter sets.)
  - Use only properly calibrated detection equipment.
  - Establish detection equipment action levels.
  - Always anticipate and expect that an explosion could occur.
  - Use only intrinsically safe communications.
  - Address natural gas ventilation practices
- Don'ts
  - Don't park over the location of the leak.
  - Don't park over manhole or valve covers or storm drains or too close to structures.
  - Don't park in front or downwind of emergency locations.
  - Don't use open flames (flares, smoking, other sources).
  - Don't operate any in-ground or underground valves.
  - Don't operate doorbells, light switches, or other electrical devices that are potential ignition sources (pagers, cell phones, radios).
  - Don't turn off venting relief valves.
  - Don't extinguish gas fires until fuel sources have been secured and shut off.
  - Don't turn on gas valves.
  - Don't shut off gas service to industrial facilities without knowledge of the effect. Shutting off gas service may cause additional damage to the industrial facility.
  - Do not attempt to make repairs to gas facilities.
  - Do not ventilate structures with nonintrinsically safe fans/blowers.

[72] American Gas Association, Technical Note - Industry Considerations for Emergency Response Plans, March 2012, pp. 6-7.

Discussion

Federal and State Regulations

Exponent reviewed PG&E's emergency response plans and did not identify any areas in which PG&E's plans did not meet the applicable requirements.

Organization/Response

From an organizational perspective, PG&E's response to the incident was consistent with the PG&E GERP. The incident was classified as a Level 2 (Elevated) emergency. During the emergency response, the San Francisco–based Operational Emergency Center (OEC) was officially activated and the Gas Emergency Center (GEC) was unofficially activated, which is consistent with a response to a Level 3 (Serious) emergency.

Due to the level of damage, the incident meets criteria that requires reporting to the CPUC and DOT. PG&E's Incident Commander arrived on scene at 10:33 AM and assessed the situation. While gas isolation plans were being finalized, the incident was reported to the DOT at 11:50 AM. Ten minutes later, the incident was reported to the CPUC (at 12:00 PM). According to PG&E's reporting guidelines,[73] reportable events such as this one are to be reported to the DOT and CPUC within 60 and 120 minutes of being aware of the incident and personnel arriving onsite. Within 20 working days of the incident, PG&E produced an after-action report (AAR) that evaluated its own emergency response as required by the PG&E GERP.

Evacuations

During the incident, the San Francisco Fire Department (SFFD) evacuated the general public from the area surrounding the house. When PG&E M&C Supervisor arrived at 10:33 AM, he met with the SFFD Incident Commander and was told that the houses on the east side of Mission Street from approximately Murray to 3955 had been evacuated. Reportedly, the SFFD rang doorbells to inform occupants to evacuate. The San Francisco Police Department (SFPD) helped control traffic and prevent the public from entering the incident area by closing Mission Street from Bosworth Street to College Avenue and by closing St. Mary's Avenue at College Avenue, as shown in Figure 31. A PG&E leak survey crew arrived and were instructed to look for signs of migrating gas. The leak survey crew did not report measuring gas concentrations greater than 2% at any of the houses that were not evacuated.

[73] TD-6100P-02, Rev. 0, PG&E Gas Event Evacuation Procedure for Gas Service Representatives, Published 7/16/2014.

Figure 31. Map of incident evacuation area with road closures marked. Houses reportedly evacuated prior to PG&E M&C Supervisor's arrival onsite at approximately 10:33 AM are highlighted in orange.

The DOT Emergency Response Handbook recommends keeping unauthorized persons back for a distance of 330 feet (100 meters). The Bosworth Street and College Avenue closures were about 450 and 220 feet away from the incident area, respectibly. The closure at St. Mary's and College was about 530 feet away from the incident area. Therefore, the southwest Mission Street closure at Bosworth Street was closer to the incident location than DOT recommends, and the other closure locations were adequate per DOT recommendations.

PG&E procedures for evacuating buildings[74] require that buildings be evacuated if there is a gas concentration in the air of 2% or greater or a carbon monoxide concentration of 200 ppm or greater. The PG&E leak survey team that arrived before the gas had been shut in was tasked with looking for gas migration. The team observed that gas was migrating north up Mission Street but did not observe gas concentrations greater than 0.6% in any houses that had not been evacuated.

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[74] TD-6100P-02, Rev. 0, PG&E Gas Event Evacuation Procedure for Gas Service Representatives, Published 7/16/2014.

Gas Shutdown Procedure

The shutdown procedure used to isolate the gas main in a manner that was consistent with the GERP and industry best practices.

Selection of Plan

PG&E engineers spent a little over an hour selecting a shutdown plan to implement. They considered four different plans; the primary plan is outlined in Figure 32. The primary plan involved squeezing 2-inch plastic pipes at two different locations on Mission Street. Gas services to 20 customers would have been affected by the plan. It was not implemented due to safety concerns. In particular, one of the two squeeze points was a cross-tie located in the middle of the street, right in front of the incident house. Gas was present in the area, and it would have been unsafe for excavation crews to work.

Figure 32. Primary shutdown plan that was not implemented.

After an incident, an unmapped shut-off valve, photos of which are shown in Figure 20, was discovered on the cross-tie, in the same area that the primary plan proposed the cross-tie be squeezed. If PG&E engineers had known about the unmapped valve, then they could have considered the option of sending personel into the area to close the valve, as opposed to excavating and squeezing the pipe at that point, as part of the primary plan.

Alternative Shutdown Plan 1, which is outlined in Figure 33, was considered but not implemented. It would have involved squeezing plastic pipes at five different locations and closing one mainline valve. Gas services to 105 customers would have been affected by the plan.

Figure 33. Alternative Shutdown Plan 1, which was not implemented.

Alternative Shutdown Plan 2, which is outlined in Figure 34, was considered but not implemented. It would have involved shutting 14 different valves. Gas services to 1,904 customers would have been affected by the plan.

Gas mainline valves are not always accessible. It is common for cars to park on top of them, blocking access to PG&E personel. Sometimes, road work crews pave over them. Alternative Plan 2, if it were to have been implemented, could have been spoiled by complications occuring in the process of shutting even only one of the 14 valves. If spoiled, attempting the plan could have led to lengthy delays in shut-in. Further, PG&E only had a small number of workers onsite with the appropriate operator qualifications to operate mainline valves, so executing the plan in a timely manner, especially faster than Alternative Shutdown Plan 3, would also have been a challenge. For these reasons, PG&E decided not to implement Alternative Plan 2.

Figure 34. Alternative Shutdown Plan 2, which was not implemented.

Alternative Shutdown Plan 3, which is outlined in Figure 35, was chosen and implemented to shut in the gas. It involved squeezing plastic mains in two different locations and shutting two shut-off valves. The plan affected gas service to 470 PG&E customers. Alternative 3 was chosen because it was determined to be safer than the primary plan and because it was determined to be faster and more likely to succeed than Alternative Plan 1 or 2. PG&E selected the plan for implementation at 11:54 AM on 11/27/2017.

Figure 35. Alternative Shutdown Plan 3, which was chosen and implemented to shut in the gas.

Execution of Plan

PG&E crews completed their execution of the shutdown plan and verified that the gas main at the 3900 block of Mission Street was flat by 12:50 PM on 11/27/2017, which was 56 minutes after the plan was selected for implementation, 150 minutes after the first PG&E employee arrived onsite (GSR #1). When it is necessary to shut off the flow of gas to mains during an emergency, PG&E has a target response time of 117 minutes.[75] Therefore, PG&E took about 33 minutes longer than its target time to shut off the flow of gas.

The squeeze-off procedures used on the Mission Street and College Avenue gas main locations were performed so as to isolate the gas in the incident area in a manner that was consistent with the GERP and industry best practices. The squeeze-off procedures were performed in a bell-hole at a location isolated from any blowing gas. During the excavation to expose the gas main, a gas analyzer was used to monitor the air in the excavation. The squeeze tool and pipe were grounded appropriately during the squeeze-off procedure to prevent a static electric discharge. PG&E employees who operated the squeeze tool had the appropriate operator qualifications.

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[75] PG&E Gas Emergency Response Plan, Version 6.0, p. 5-2.

Conclusions

Based on the analysis described in this report, Exponent has reached the following conclusions:

1. The explosion that occurred on 11/27/17 at [redacted] was caused by an underground gas leak at an uncapped 2-inch service stub on a 6-inch steel PG&E distribution main on Mission Street.
    a. The gas leak began when a rubber X-Pander plug that had been inserted into the service tee dislodged on 11/27/17.
    b. The exact gas migration path was not determined, but gas possibly migrated into the structure through floor penetrations in the garage.
    c. Damage to the garage and second floor is consistent with a natural gas and air mixture accumulating in the garage and also between the floor joists above the garage and igniting.
    d. The likely ignition source was the second-floor heater pilot flame.
2. The service stub on the steel main was most likely created in October 2003 when the 2-inch service line to [redacted] was transferred from the 6-inch steel main to the 6-inch plastic main. It is likely that at that time the rubber plug was inserted into the service tee and the plastic line was cut near the steel main and the stub of pipe on the steel main was left uncapped.
    a. The 2-inch service line was installed at the time of the installation of the steel main in 1992.
    b. The 2-inch service line was likely cut and the stub was left uncapped in 2003 when the service was transferred from the 6-inch steel main to the 6-inch plastic main. A rubber plug was likely used to stop off the line while the service was transferred and the plug was left in the service tee.
    c. The 6-inch steel main was uprated in 2013, 10 years after the plug had been installed in the service tee.
    d. The plug held until the day of the incident, when it dislodged, creating a large gas leak.
    e. Historical aerial photos show that the only fresh pavement visible at the leak location appeared in the late-2003/early-2004 timeframe. Therefore, it is unlikely that work was done in the immediate area of the service tee and uncapped stub between the time of the service transfer and the incident.
3. The work that was performed by PG&E to transfer the service line for [redacted] from the steel main to the plastic main does not appear to have followed company procedures:
    a. The cut stub end was not capped.
    b. The cut end of the deactivated service line near the steel main was not sealed.
    c. An X-Pander plug was left inside the service tee.
    d. A completion plug was not installed in the service tee.
    e. A protective sleeve was not installed over the plastic stub.
    f. Overall, the deviations from PG&E standards are consistent work that intended to deactivate the service to [redacted] but that was interrupted or otherwise left incomplete.

4. X-Pander plugs can hold low pressure for extended periods of time and can also dislodge at pressures consistent with high-pressure distribution systems. Benchtop pressure tests were performed using new X-Pander plugs and a Mueller tee.
    a. A plug held 11 inches of water column (WC) for a period of an hour with no signs of leaking and without dislodging.
    b. When the pressure was increased rapidly, the plugs dislodged at pressures that ranged from 15 to 116 psig. The pressure required to dislodge the plugs depended on the torque that was used to install them.
    c. Extended duration testing at 60 psig showed that plugs tended to dislodge after a few minutes of sustained pressure.
    d. The testing did not investigate time-dependent factors such as corrosion in the steel pipe, creep strain, or rubber embrittlement. Additional testing would be needed to understand these effects.
5. In terms of response organization, PG&E's response was consistent with the guidelines in the GERP.
    a. Event was classified as a Level 2 (Elevated) emergency, which called for a possible OEC activation.
    b. San Francisco OEC activated and GEC unofficially activated, which was consistent with a more significant Level 3 (Serious) emergency.
6. Evacuation procedures were performed by SFFD in consultation with PG&E and in a manner that was partially consistent with PG&E procedures and industry best practices.
    a. The houses that were evacuated were consistent with PG&E procedures for evacuating buildings.
        i. Leak survey crews were on site searching for gas migration. Gas was observed to be migrating north on Mission Street.
        ii. PG&E standard TD-6100P-04 requires that houses be evacuated if the gas concentration is greater than 2%. No unevacuated buildings were observed to have a gas concentration in air of greater than 0.6%.
    b. The SFFD went door to door ringing doorbells to notify building occupants. This is not consistent with PG&E company standards for evacuations because electric doorbells can be an ignition source.
    c. The evacuation distance to the south of 220 feet was less than the distance of 330 feet recommended by the DOT Emergency Response Guidebook.
7. Shutdown plans were implemented in a manner consistent with company procedures.
    a. Mainline valves were operated by employees with appropriate qualifications.
    b. Pipe squeezing procedures were operated in a manner consistent with company procedures and industry best practices.
8. The time of 150 minutes for PG&E workers to shut in the gas was longer than PG&E's target time of 117 minutes outlined in the GERP. The increased time to shut in the gas was the result of multiple factors, including the complicated pipeline network existing at the leak location.
    a. Two parallel and cross-tied mains had to be shut down simultaneously, which resulted in increased time to develop a shutdown plan that could be implemented safely.

   b. The primary shutdown plan involved squeezing the cross-tie and could not be implemented due to concerns over personnel safety at that location, so three more complicated alternative shutdown plans were developed.
   c. After the M&C crews received the final emergency isolation plan, the gas was shut in approximately 56 minutes later.
9. An unmapped valve was found on the cross-tie on Mission Street. If PG&E crews and emergency center staff had known about the valve, they could have considered it in their shutdown plans.

Appendix A

Exponent Testing of X-Pander Plugs

Introduction

Exponent performed pneumatic pressure tests on new 1.5 inch diameter rubber X-Pander plugs installed in an exemplar 2-inch Mueller service tee. The plugs tested were similar to the plug that was found dislodged in the abandoned 3976 Mission Street service tee.

The X-Pander plugs were installed in one end (left) of the pipe apparatus shown in Figure 36, and compressed air was injected into the other end (right). The plugs were installed using an X-Pander plug wrench. Photos of an X-Pander plug and the X-Pander wrench are shown in Figure 37 and Figure 38.

The air injection system was capable of providing a maximum pressure of 116 psig. Based on the principles of Pascal's law, the force that the pressurized air exerted on the plug acted in the direction of dislodging the plug (toward the left in Figure 36) and was proportional in magnitude to the air pressure. At the maximum pressure of 116 psig, about 365 pounds of force acted on the plug. At 60 psig, about 190 pounds of force acted on the plug.

The exemplar tee was constrained as shown in Figure 36. A completion plug was installed in the service tee to restrain dislodged plugs. Pressure gauges were used to monitor air injection pressure, and a rotometer was used to monitor the airflow rate through the pipe assembly.

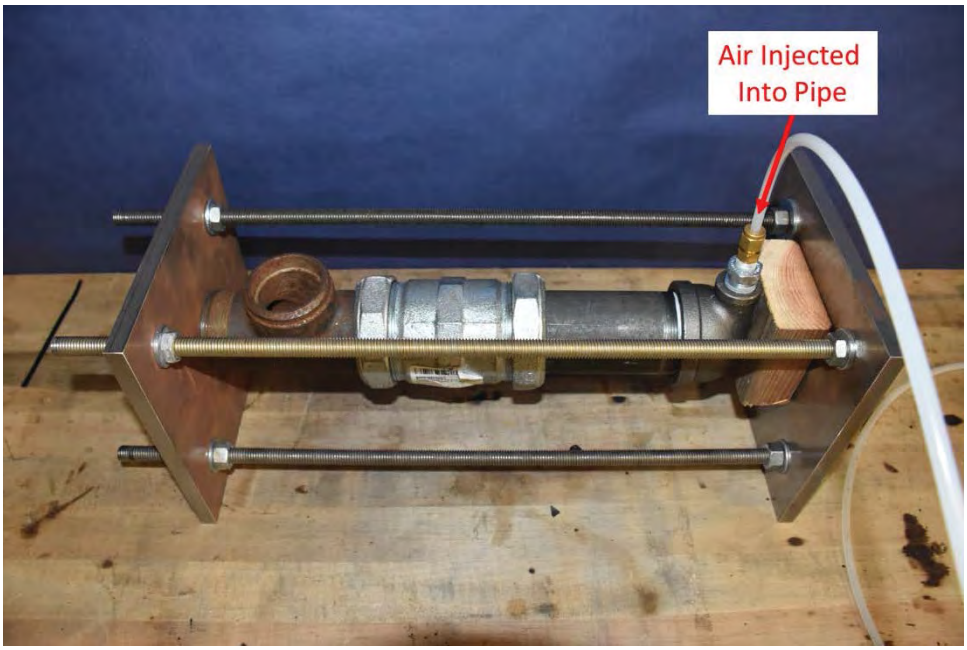


Figure 36. X-Pander plug pressure test apparatus.

Figure 37. X-Pander plug in an unexpanded state.

Figure 38. X-Pander plug mounted on an installation tool.

A clean pipe assembly and a new set of plugs were used for testing. After being installed, the plugs sealed well, as long as they remained in their installed position. However, during many of the tests, the air pressure was increased to a high enough level that the plug became dislodged, at which point it would release its seal with an audible popping sound. After that, air freely flowed through the unsealed apparatus and the test would be stopped.

A photograph of an installed plug is shown in Figure 39, and a photograph of the same plug, after becoming dislodged, is shown in Figure 40.

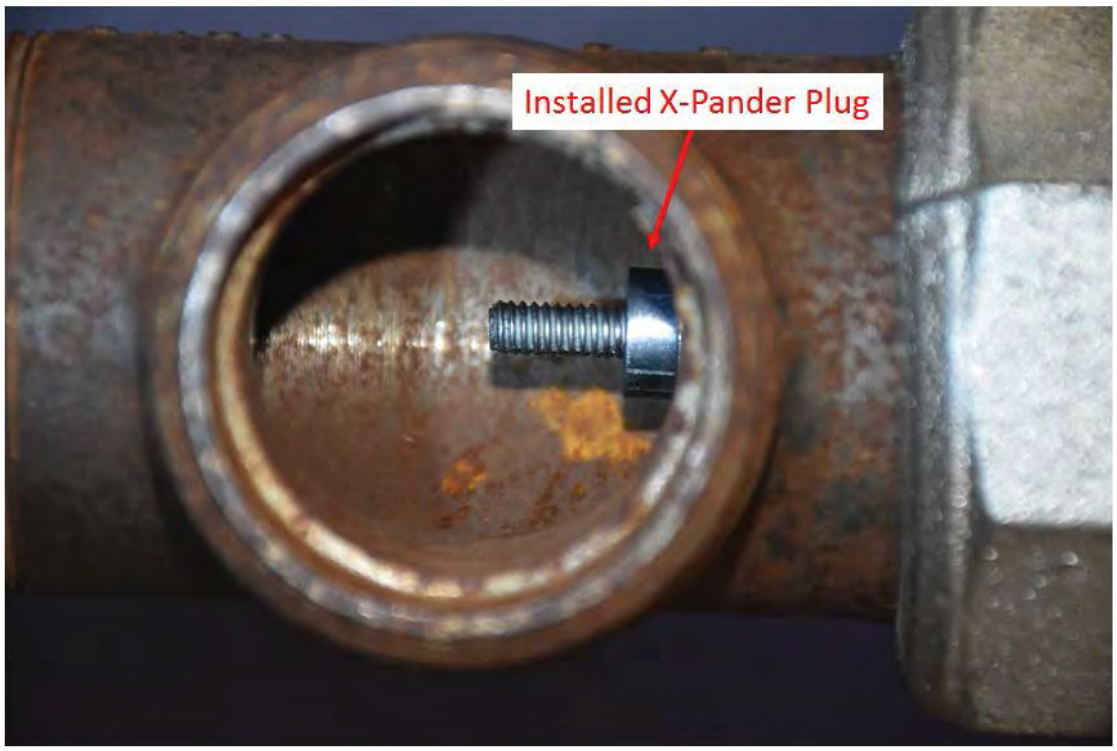


Figure 39. X-Pander plug pressure test apparatus with plug installed.

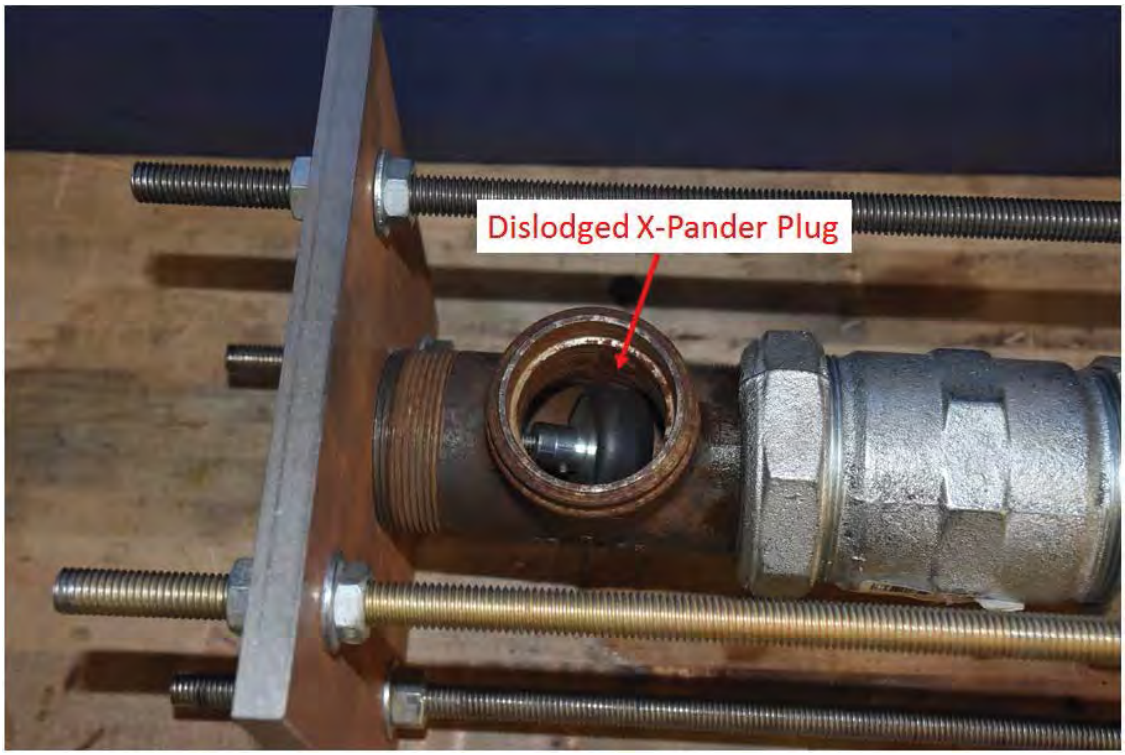


Figure 40. X-Pander plug pressure test apparatus with dislodged plug.

Four different test procedures were performed:

- Installation torque tests: Torque measurements were made to assess the magnitude and variability of installation torque that different personnel can use when installing X-Pander plugs.
- 11″ WC extended duration tests: A one-hour test to assess the plug's ability to remain seated at low (11″ WC) pressure, when only torqued to minimal tightness.
- Maximum pressure tests: Air pressure was rapidly increased (approximately 20 psi per minute) until the plug dislodged. These tests were used to assess the maximum pressure that the plugs could withstand before becoming dislodged.
- 60 psig extended duration tests: Extended duration tests to assess the plug's ability to remain seated at 60 psig pressures.

X-Pander Plug Installation Torque

Six different Exponent personnel torqued an X-Pander plug into the pipe tee assembly to a level that was thought to be "tight." The torque that they applied to the plug was measured and used to assess the magnitude and variability of installation torque that different personnel can use when installing the X-Pander plugs. Five of the personnel were male and one was female; their physical stature ranged from smaller than average to larger than average. During each of the six tests, the tightening torque was quantified by counting the number of visible threads on the installed plugs and comparing the thread count to a previously determined torque vs. thread-count calibration.[76] All of the tests were performed using the same plug.

The results of the test are summarized in Table 3.

Table 3. X-Pander plug installation torque results from tightening tests. All values are rounded to the nearest increment of 5 in-lb.

Average [in-lb]	55
Standard Deviation [in-lb]	10
Minimum [in-lb]	40
Maximum [in-lb]	70

The six individuals tightened the plugs to 40–70 in-lb of torque. The average tightening torque was 55 in-lb.

[76] The calibration was generated by sequentially tightening the plug to quantified levels with a torque wrench and counting threads. All personnel tightened the same plug into the test apparatus at approximately the same location (depth) within the tee.

Although the same plug was used during the plug installation torque tests, many different plugs were used during subsequent pressure testing, and plug-to-plug variability was observed in the turning resistance of the threads. Some of the plugs tightened to snug[77] with minimal effort (approximately 10–20 in-lb of torque), whereas others required 30–40 in-lb. Some plug threads were stripped by tightening by hand. Some of the plugs experienced thread failures at torques as low as 60 in-lb.

Experienced plug installers are likely to restrain from over-tightening the plugs to levels near their upper torque limits (approximately 70 in-lb) since the plug threads are so easily damaged at such torques. Even if an installer were to be perfectly consistent in the practice, tightening all plugs to the same torque and feel, the sealing ability of plugs will vary due to the differences in thread turning resistance, among other factors.

Low-Pressure (11″ WC) Testing

A plug was torqued to 30 in-lb and then pressure tested at 11″ WC (0.4 psig) for one hour. The plug did not leak or dislodge during the one hour test. This result is as expected, considering that the low pressure subjected the plug to about a pound of dislodge force. It is likely that a well-installed X-Pander plug could remain seated at 11″ WC for a long period of time.

Dislodge Pressure Testing

Seven different plugs were torqued to 30–60 in-lb, and pressure was increased rapidly—at approximately 20 psi per minute—until the plug dislodged. The results are summarized in Figure 41.

[77] Just tight enough so the plug is capable of holding itself in place but not at final torque (“tight”).

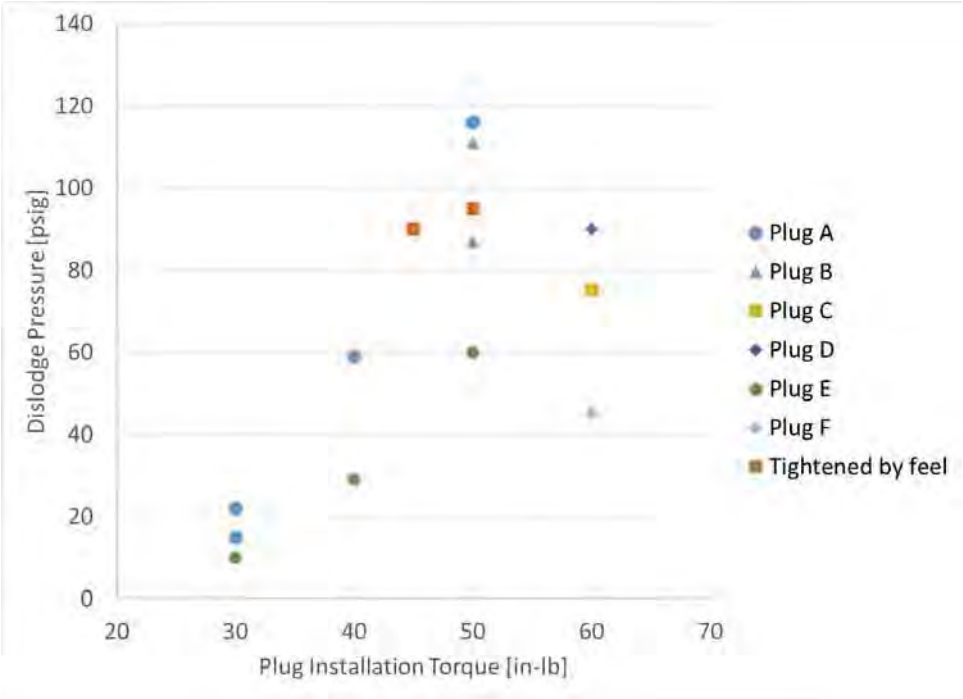


Figure 41. X-Pander plug installation torque vs dislodge pressure results.

Many of the plugs were tested more than once, and multiple data points are shown in the same bullet symbol and color on Figure 41. Six of the plugs (Plug A to F) were tightened with a torque wrench to 30–60 in-lb, as indicated in the figure. One of the plugs (tightened by feel) was tested twice after being tightened by two different people to what they felt was "tight." The installation torques listed for the "tightened by feel" tests was estimated based on the number of visible threads on the installed plug and an established relationship (pre-test calibration) between the number of visible threads and the tightening torque.

Plugs torqued to 30–40 in-lb dislodged at 10–29 psig. Plugs torqued to 45–50 in-lb dislodged at 60–116 psig. These results show that dislodge pressure tends to increase as the torque increases from 30 in-lb, which is barely snug, to 50 in-lb, which is approximately the torque that most individuals tightened the plugs to by feel. Dislodge pressure did not increase when the torque was increased from 50 in-lb to 60 in-lb. Two tests were attempted at 70 in-lb, but neither test could be performed because the plug threads stripped during torquing.

Extended Pressure (60 psig) Testing

Six different plugs were torqued and pressure tested at 60 psig until the plug dislodged. Pressure was ramped up to the 60 psig target rapidly during these tests at a rate of about 20 psi per minute. Table 4 displays the results.

Two plugs were torqued to 50 in-lb. Both dislodged after 7 minutes at 60 psig.

Three of the plugs were torqued to 60 in-lb. One of the plugs dislodged at 45 psig while pressure was being ramped up. One plug dislodged a few seconds after 60 psig was reached. One dislodged after 12 minutes at 60 psig.

Two tests were performed in which the individuals installed the plugs to what they felt was tight by feel. The plugs dislodged after 5 and 12 minutes at 60 psig.

The tests showed that after a few minutes of being pressurized at 60 psig, new, recently installed X-Pander plugs tend to become dislodged. It should, however, be recognized that the plug that was found dislodged in the abandoned [redacted] service stub was in place for over a decade and was pressurized to 60 psig for a few years before becoming dislodged. The fact that the incident plug remained installed for years and the test plugs dislodged after minutes suggests that either (1) the effects of aging on plug dislodge characteristics are significant or (2) the hardware tested does not adequately represent the incident hardware.

The incident plug and pipe tee had experienced aging effects (such as corrosion, creep strain, and embrittlement, over the many years that it was installed), which the new plugs tested in this study did not. Further, the plugs used in these tests were purchased recently, and the plug installed in the incident service line was designed and manufactured before 2004. Therefore, the test plugs and incident plug may differ in design or material composition. These effects are beyond the scope of the current study.

Table 4 Extended duration pressure test results.

Test #	Torque	Time Until Dislodge
1	50	7 min
2	50	12 min
3	~50	5 min
4	50	7 min
5	60	<1 min
6	60	12 min

Conclusions

- An installer is likely to torque a 1.5-inch X-pander plug to approximately 40–60 in-lb.
- X-Pander plug threads typically fail (strip) when torqued to 60–70 in-lb.
- X-Pander plugs, even if installed using a low torque (~30 in-lb) are likely to contain a pressure of 11″ WC for long periods of time.
- X-Pander plugs can dislodge and leak when the pressure is rapidly increased to pressures that range from 10 to 116 psig, depending on how tightly they were installed.

    - Plugs torqued to 30–40 in-lb dislodged at 10–29 psig. This torque range is snug but not as tight as most personnel tightened the plugs to by feel during the plug installation torque tests.
    - Plugs torqued to 45–50 in-lb dislodged at 60–116 psig. This torque range is consistent with what more than half of the personnel tightened the plugs to by feel during the plug installation torque tests.
    - Increasing plug torque beyond about 50 in-lb did not increase the dislodge pressure. Some of the personnel tightened the plugs to 60–70 in-lb during the plug installation tests. More often than not, the plug threads failed when attempting an installation torque of 70 in-lb.
- It can take a few minutes, if not longer, for an X-Pander plug to dislodge under constant pressure conditions.

Appendix B

Documents Received from PG&E

Documents Received from PG&E

- Gas Service Records
- PHMSA Incident Notification Report
- Email
- CPUC Form 420 Report for incident
- After Action Report
- Leak survey records
- Incident situation report
- Job documents for PM 30223376 (Rule 20 work)
- Job documents for PM 30945050 (uprate job)
- Distribution plat sheet
- Gas Standard A-93.2 Rev 00
- Gas Standard A-93.2 Rev 01
- Gas Standard C-36.1
- Operator qualifications
- Employee contact information
- Emails
- Emergency shutdown plans
- Phone records
- USA tickets
- Incident Situation Reports
- Pressure test records
- Job documents for GM 1670215 (installation of 6-inch plastic main)
- Job documents for GM 469399 (installation of 3-inch plastic main)
- Job documents for GM 4944917 (installation of 6-inch steel main)
- SAP Records
- Leak Survey/Repair/Inspection records
- Gas meter records for [redacted]
- As build drawings for repair work
- Job documents for PM 30267521 (installation of 2-inch plastic main)
- Pressure history
- Restoration plans
- Operating change records
- Gas Standard TD-4125P-03
- Gas Standard TD-6100P-04
- Gas Standard TD-9500P-16
- Timeline document
- Gas Standard UO-S4129
- Camera inspection videos

Appendix C

Aerial Photos of Incident Area from 2003 to 2017

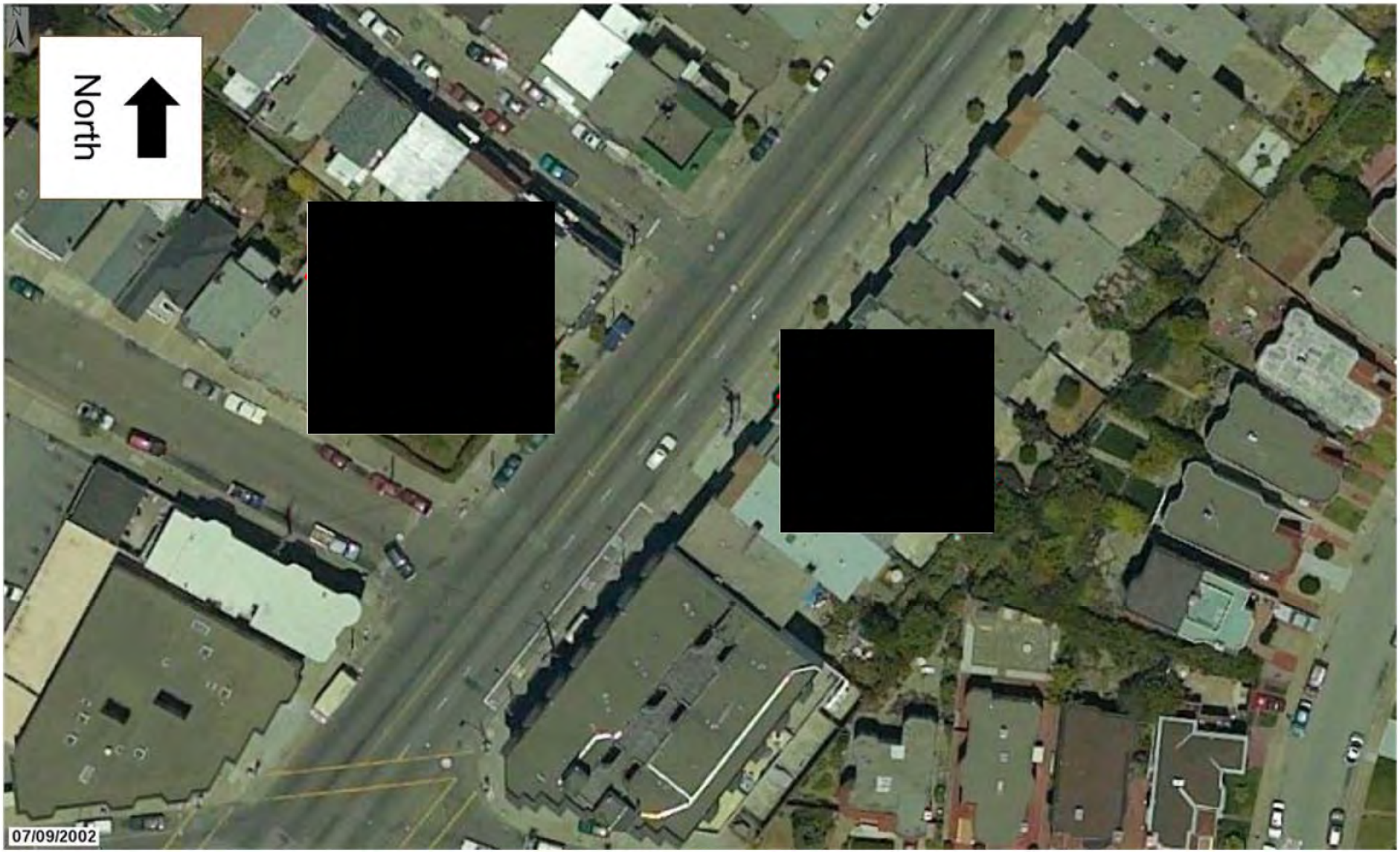


Figure 42. Aerial photograph taken by Pictrometry of the 3900 Mission Stree block on July 9, 2002.

Figure 43. Aerial photograph taken by Google Earth of the 3900 Mission Street block on Septemb

Figure 44. Aerial photograph taken by Google Earth of the 3900 Mission Street block on Decemb

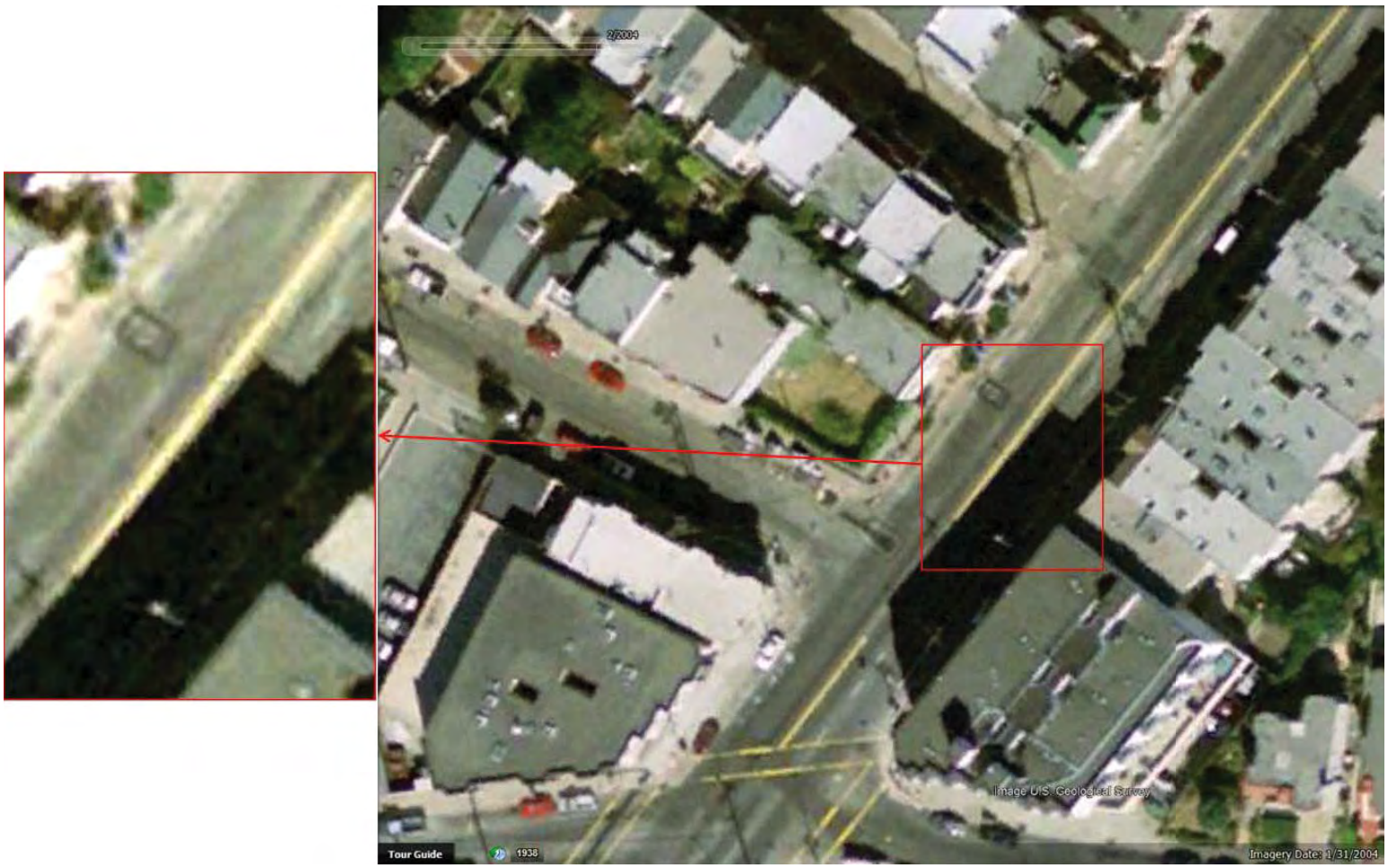


Figure 45. Aerial photograph taken by Google Earth of the 3900 Mission Street block on January

Figure 46. Aerial photograph taken by Pictrometry of the 3900 Mission Street block on August

Figure 47. Aerial photograph taken by Pictrometry of the 3900 Mission Street block on Septemb

Figure 48. Aerial photograph taken by USGS of the 3900 Mission Street block on June 1, 2

Figure 49. Aerial photograph taken by Pictometry of the 3900 Mission Street block on April 28

Figure 50. Aerial photograph taken by Google Earth of the 3900 Mission Street block on June

Figure 51. Aerial photograph taken by Google Earth of 3900 Mission Street block on May 1,

Figure 52. Aerial photograph taken by Google Earth of the 3900 Mission Street block on August

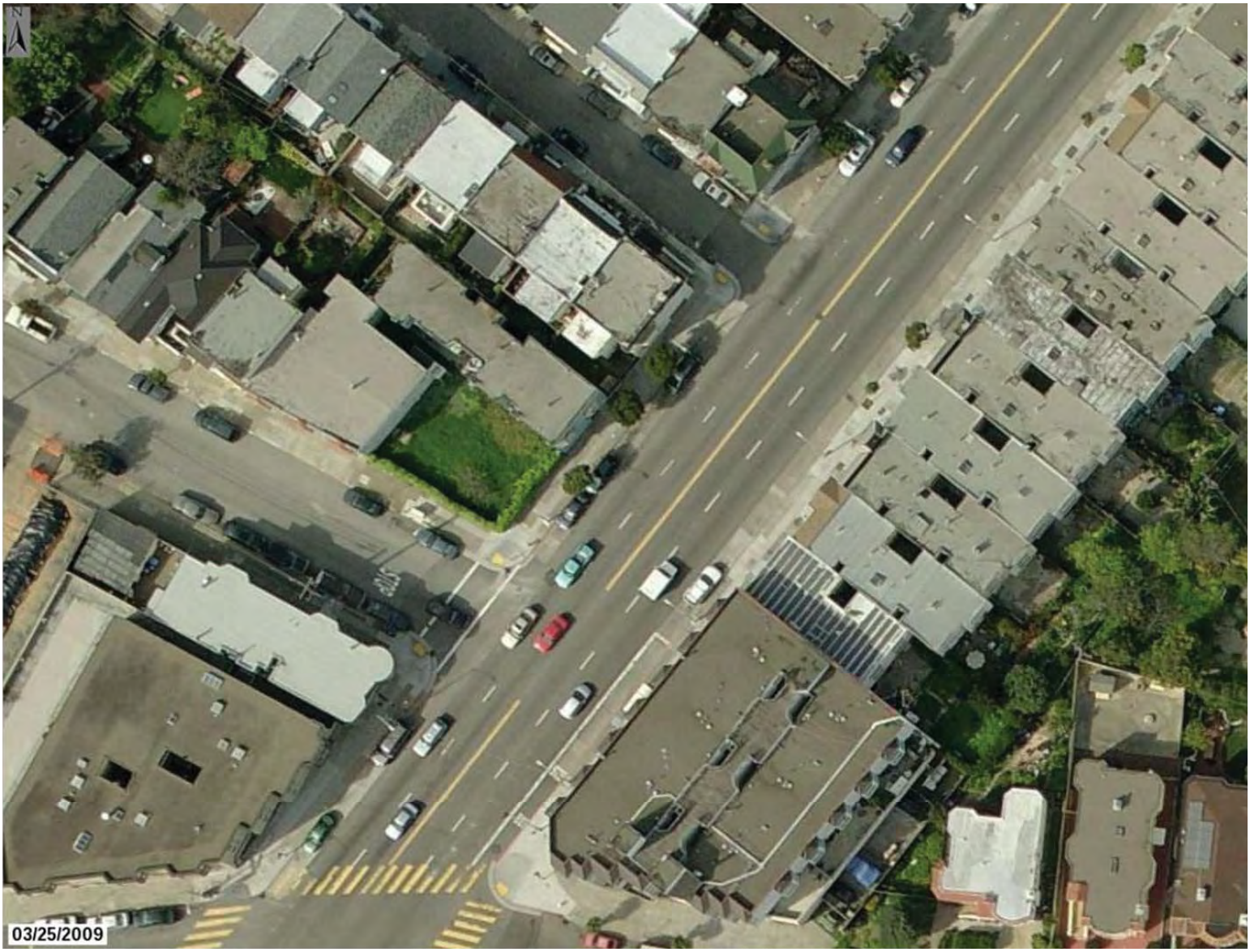


Figure 53. Aerial photograph taken by Pictometry of the 3900 Mission Street block on March 2

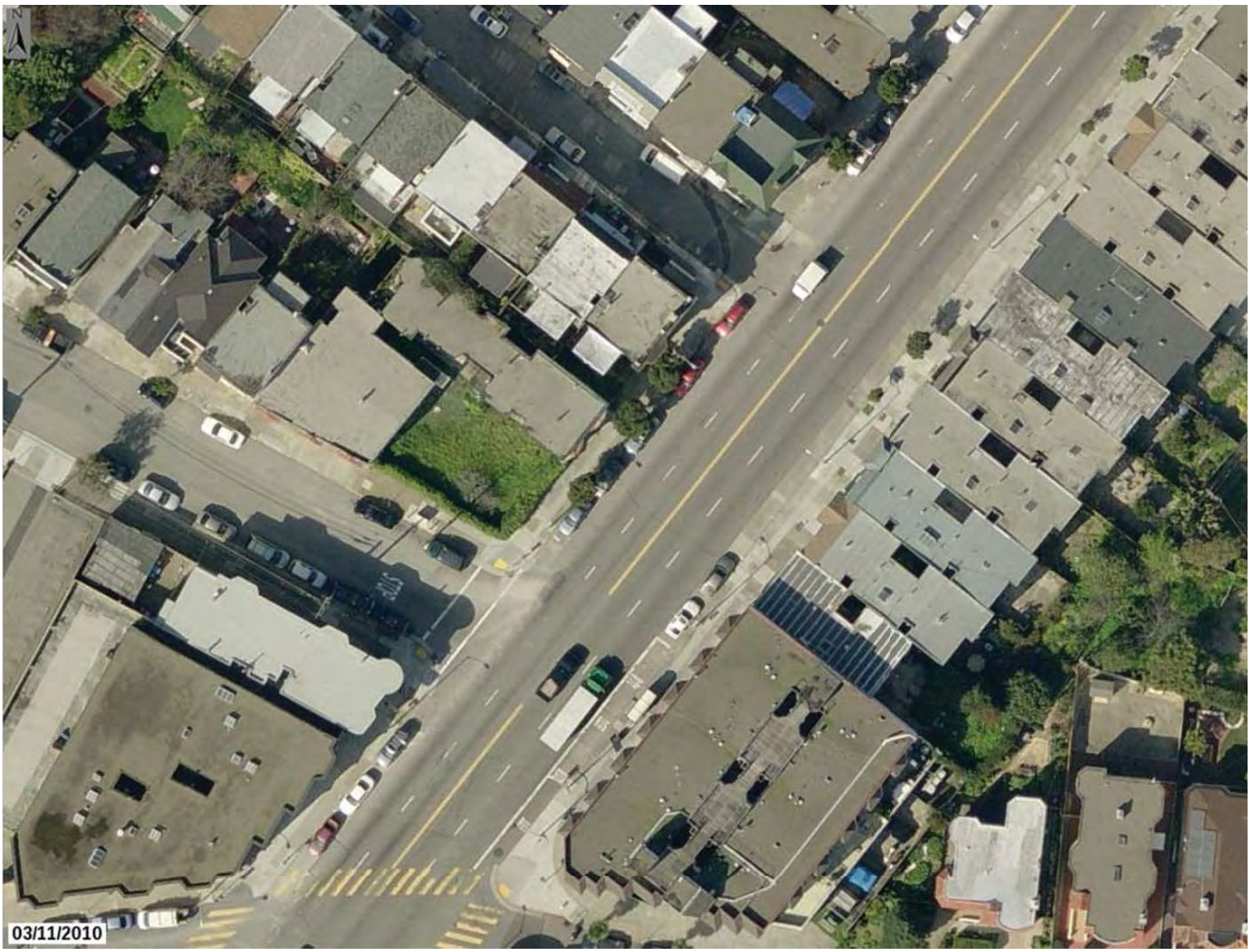


Figure 54. Aerial photograph taken by Pictometry of the 3900 Mission Street block on March 1

Figure 55. Aerial photograph taken by Google Earth of the 3900 Mission Street block on Septemb

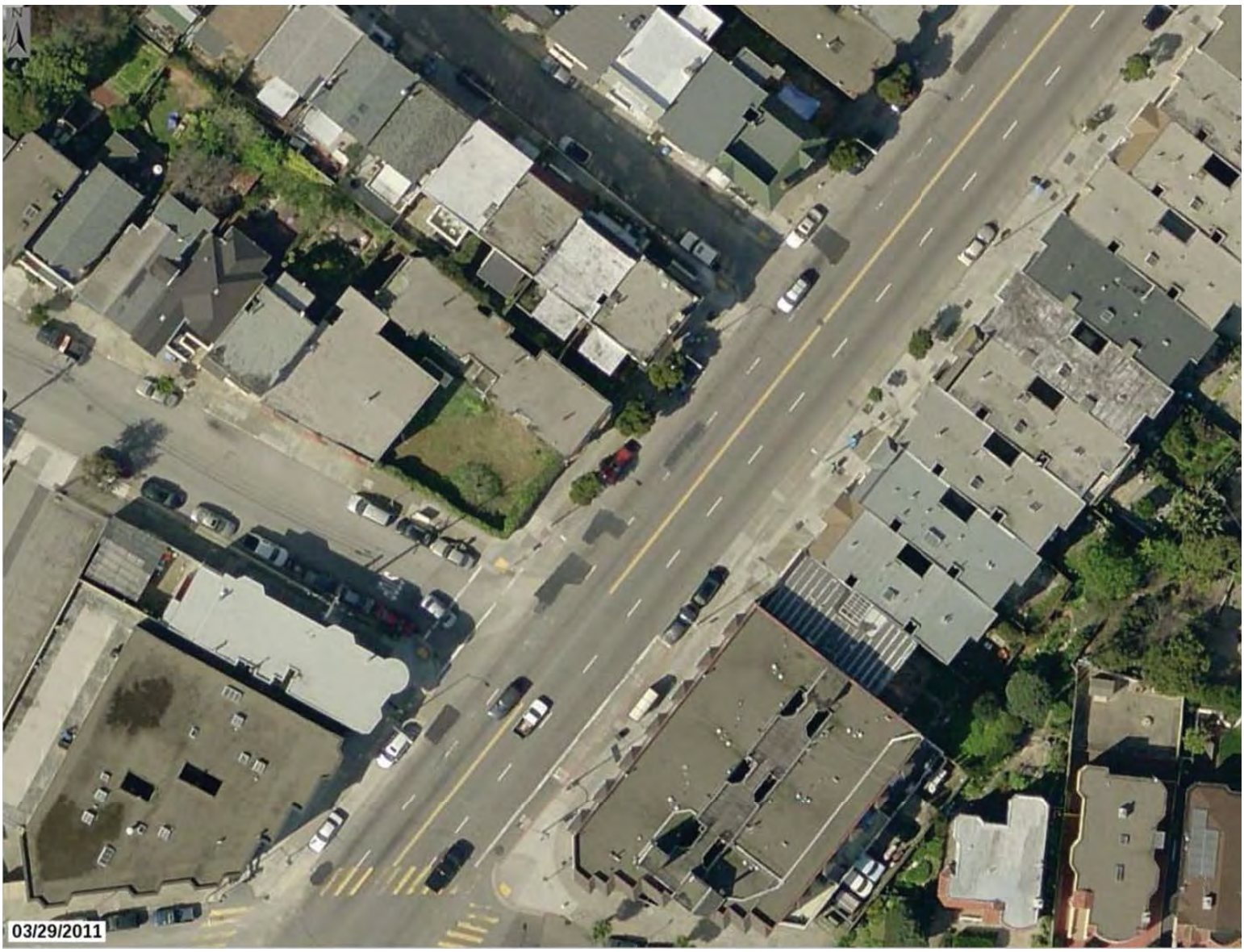


Figure 56. Aerial photograph taken by Pictometry of the 3900 Mission Street block on March 2

Figure 57. Aerial photograph taken by USGS of the 3900 Mission Street block on April 9, 2

Figure 58. Aerial photograph taken by Google Earth of the 3900 Mission Street block on May

Figure 59. Aerial photograph taken by Google Earth of the 3900 Mission Street block on Octobe

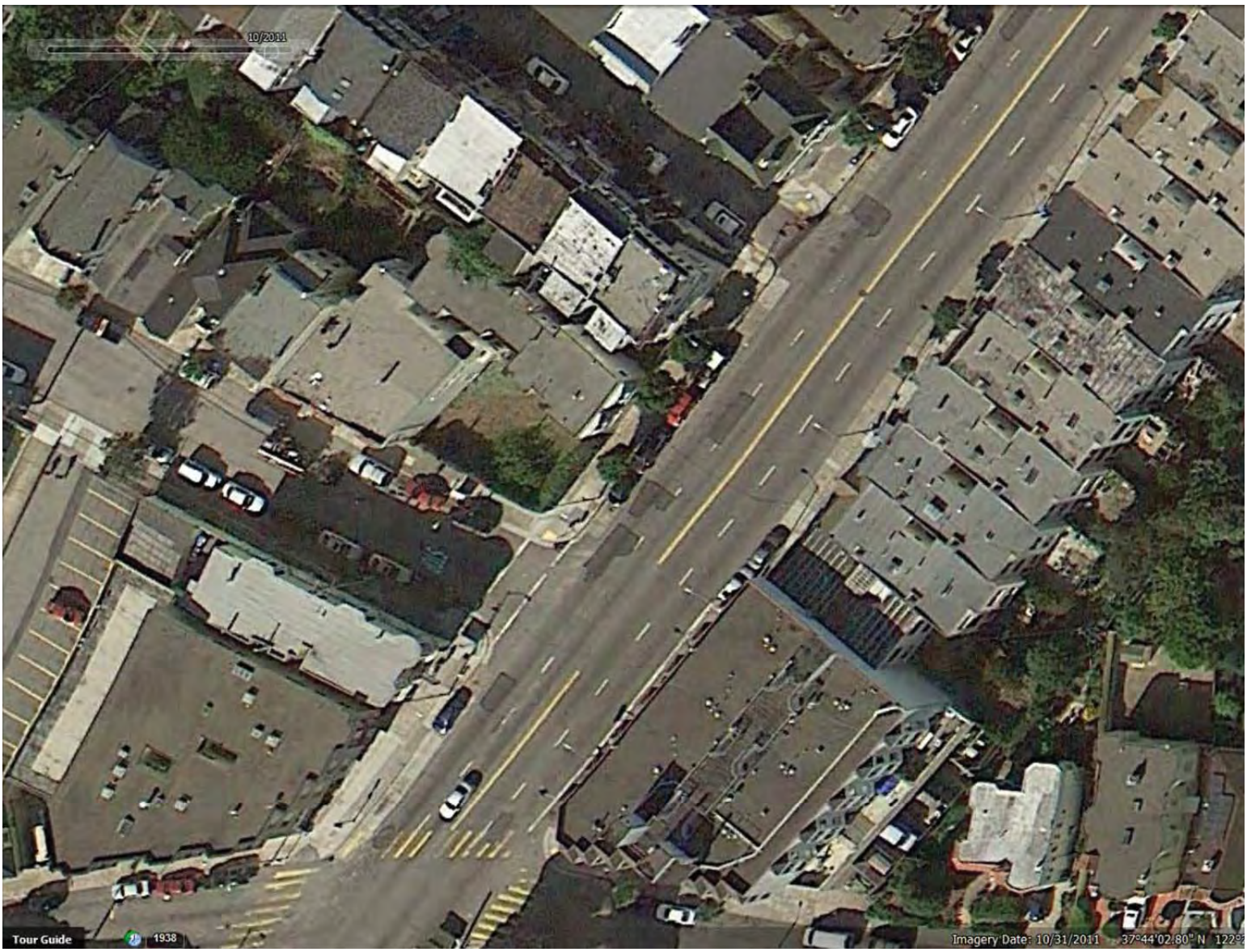


Figure 60. Aerial photograph taken by Google Earth of the 3900 Mission Street block on Octobe

Figure 61. Aerial photograph taken by Pictometry of the 3900 Mission Street block on May 18

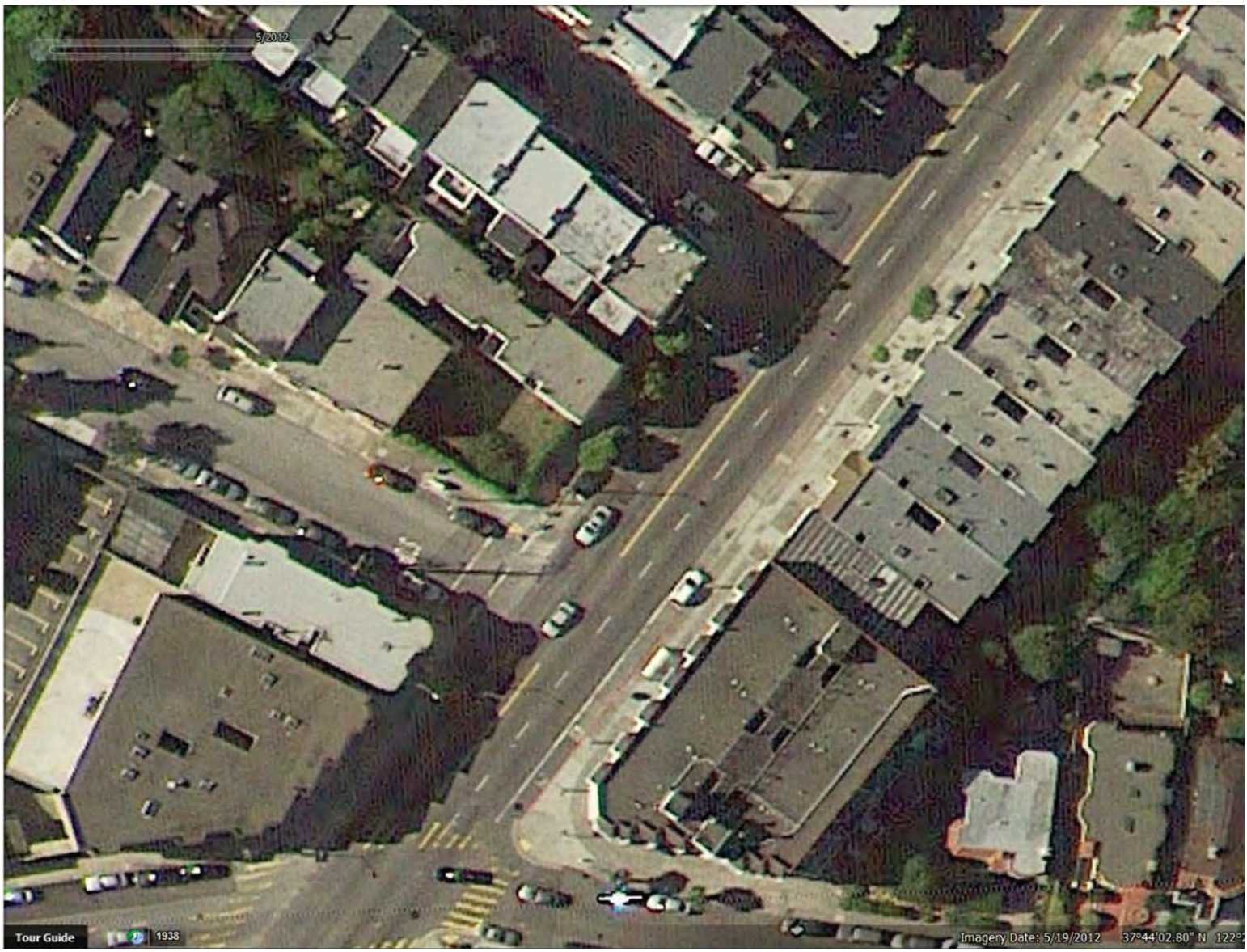


Figure 62. Aerial photograph taken by Pictometry of the 3900 Mission Street block on May 19

Figure 63. Aerial photograph taken by Google Earth of the 3900 Mission St block on April 15

Figure 64. Aerial photograph taken by Google Earth of the 3900 Mission Street block on June

Figure 65. Aerial photograph taken by Pictometry of the 3900 Mission Street block on June 1

Figure 66. Aerial photograph taken by Google Earth of the 3900 Mission Street block on June

Figure 67. Aerial photograph taken by Pictometry of the 3900 Mission Street block on June 1

Figure 68. Aerial photograph taken by USGS of the 3900 Mission St block on February 20,

Figure 69. Aerial photograph taken by Google Earth of the 3900 Mission Street block on Februar

Figure 70. Aerial photograph taken by Google Earth of the 3900 Mission Street block on April

Figure 71. Aerial photograph taken by Google Earth of the 3900 Mission Street block on Novemb

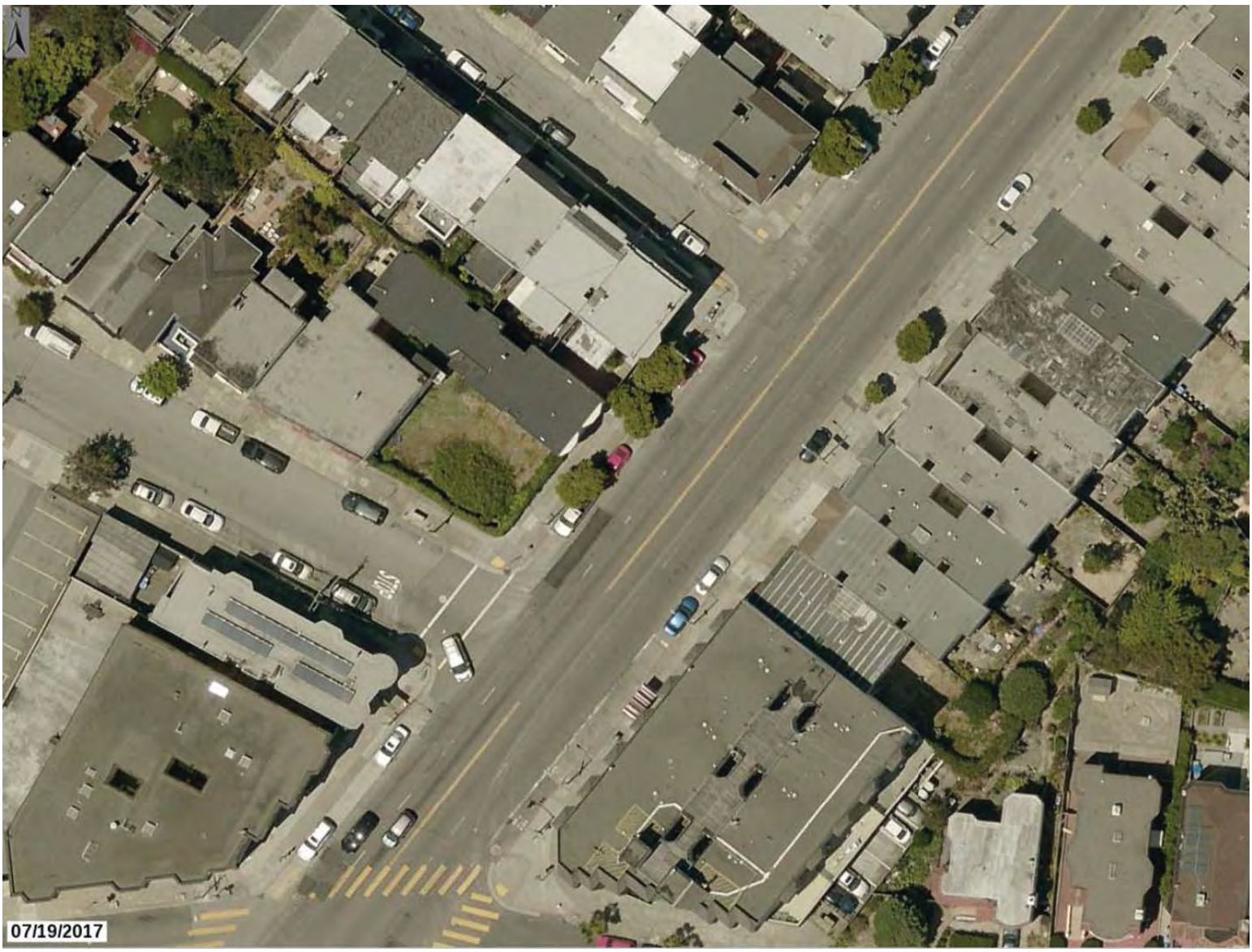


Figure 72. Aerial photograph taken by Pictometry of the 3900 Mission Street block on July 19

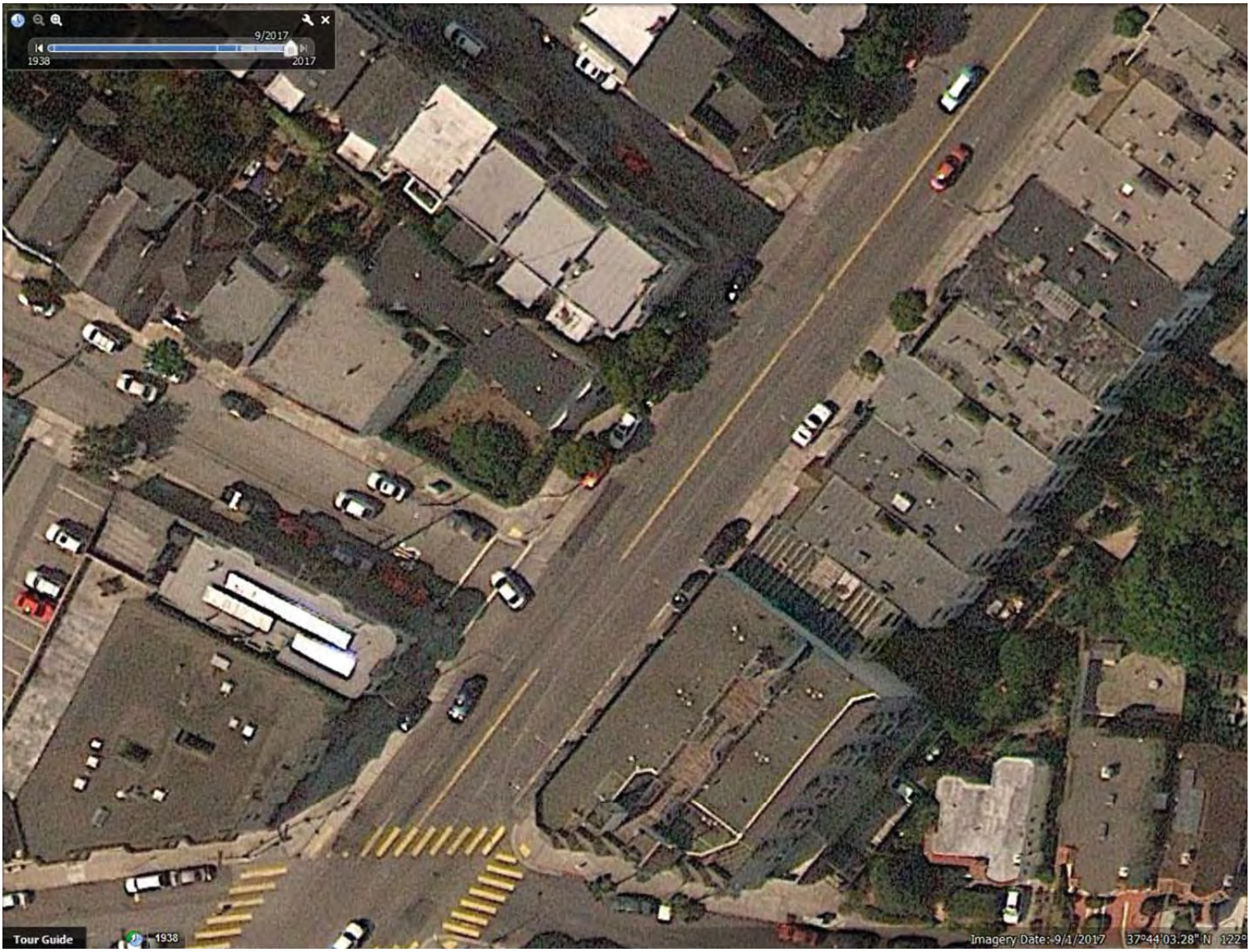
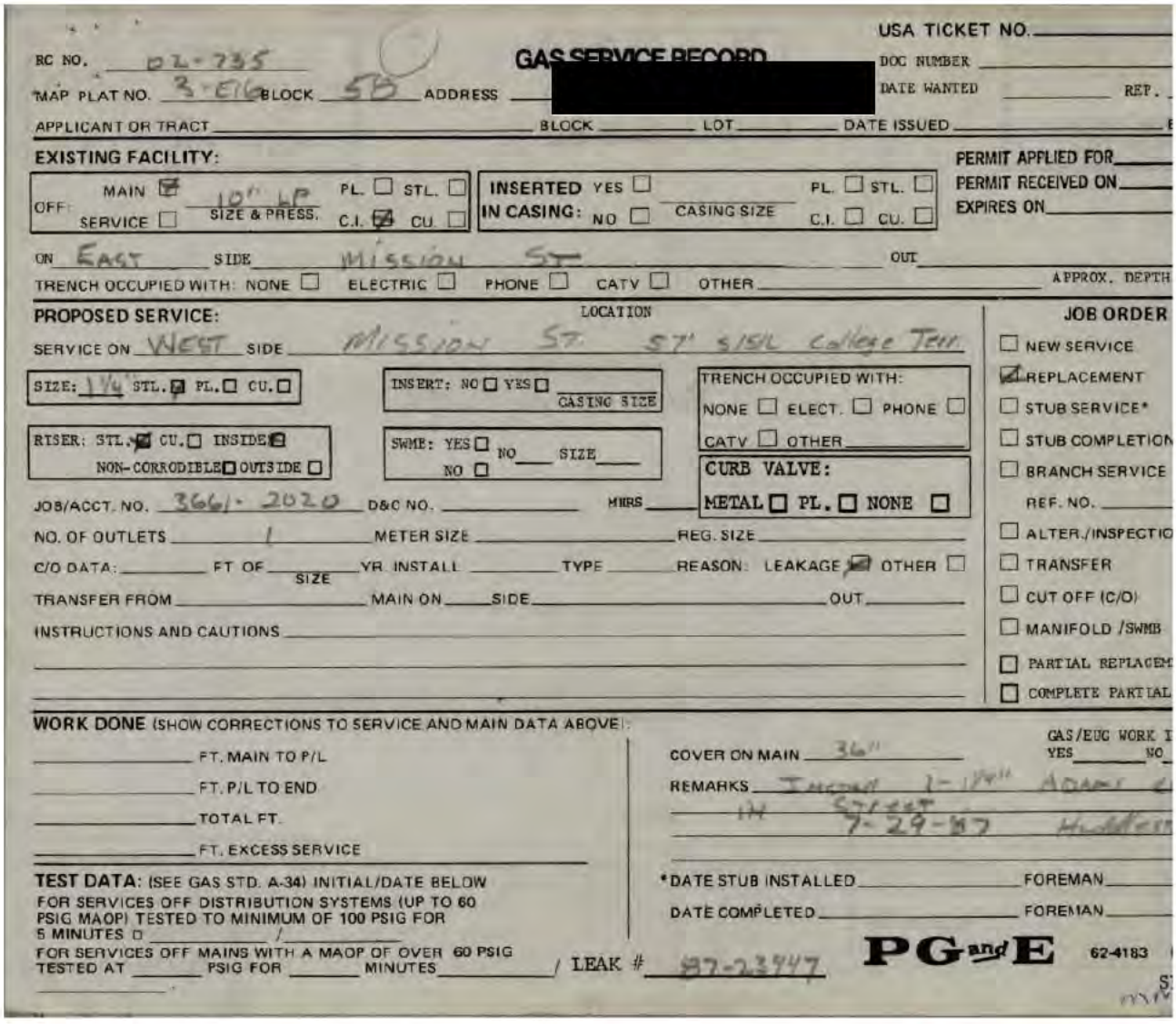


Figure 73. Aerial photograph taken by Google Earth of the 3900 Mission Street block on Septeml

Appendix D

Selected Documents from Records Review



GAS SERVICE RECORD

USA TICKET NO.

RC NO. 82-735 DOC NUMBER

MAP PLAT NO. 3-E16 BLOCK 58 ADDRESS [redacted] DATE WANTED REP.

APPLICANT OR TRACT BLOCK LOT DATE ISSUED

EXISTING FACILITY:

OFF: MAIN ☑ SERVICE ☐ 10" LP SIZE & PRESS. PL. ☐ STL. ☐ C.I. ☑ CU. ☐

INSERTED IN CASING: YES ☐ NO ☐ CASING SIZE PL. ☐ STL. ☐ C.I. ☐ CU. ☐

PERMIT APPLIED FOR

PERMIT RECEIVED ON

EXPIRES ON

ON EAST SIDE MISSION ST OUT

TRENCH OCCUPIED WITH: NONE ☐ ELECTRIC ☐ PHONE ☐ CATV ☐ OTHER APPROX. DEPTH

PROPOSED SERVICE: LOCATION

SERVICE ON WEST SIDE MISSION ST. 57' S/SL College Terr.

SIZE: 1¼" STL. ☑ PL. ☐ CU. ☐

INSERT: NO ☐ YES ☐ CASING SIZE

TRENCH OCCUPIED WITH: NONE ☐ ELECT. ☐ PHONE ☐ CATV ☐ OTHER

RISER: STL. ☑ CU. ☐ INSIDE ☐ NON-CORRODIBLE ☐ OUTSIDE ☐

SWME: YES ☐ NO ☐ NO SIZE

CURB VALVE: METAL ☐ PL. ☐ NONE ☐

JOB/ACCT. NO. 3661-2020 D&C NO. MHRS

NO. OF OUTLETS 1 METER SIZE REG. SIZE

C/O DATA: FT OF SIZE YR. INSTALL TYPE REASON: LEAKAGE ☑ OTHER ☐

TRANSFER FROM MAIN ON SIDE OUT

INSTRUCTIONS AND CAUTIONS

JOB ORDER

☐ NEW SERVICE
☑ REPLACEMENT
☐ STUB SERVICE*
☐ STUB COMPLETION
☐ BRANCH SERVICE
REF. NO.
☐ ALTER./INSPECTIO
☐ TRANSFER
☐ CUT OFF (C/O)
☐ MANIFOLD /SWMB
☐ PARTIAL REPLACEM
☐ COMPLETE PARTIAL

WORK DONE (SHOW CORRECTIONS TO SERVICE AND MAIN DATA ABOVE):

FT. MAIN TO P/L

FT. P/L TO END

TOTAL FT.

FT. EXCESS SERVICE

COVER ON MAIN 36"

GAS/EUC WORK I YES NO

REMARKS Inserted 1-1¼" Adapt

7-29-87

TEST DATA: (SEE GAS STD. A-34) INITIAL/DATE BELOW

FOR SERVICES OFF DISTRIBUTION SYSTEMS (UP TO 60 PSIG MAOP) TESTED TO MINIMUM OF 100 PSIG FOR 5 MINUTES ☐ /

FOR SERVICES OFF MAINS WITH A MAOP OF OVER 60 PSIG TESTED AT PSIG FOR MINUTES / LEAK # 87-2347

*DATE STUB INSTALLED FOREMAN

DATE COMPLETED FOREMAN

PG and E 62-4183

Figure 74. Front of Gas Service Record for [redacted], dated July 27, 1987.

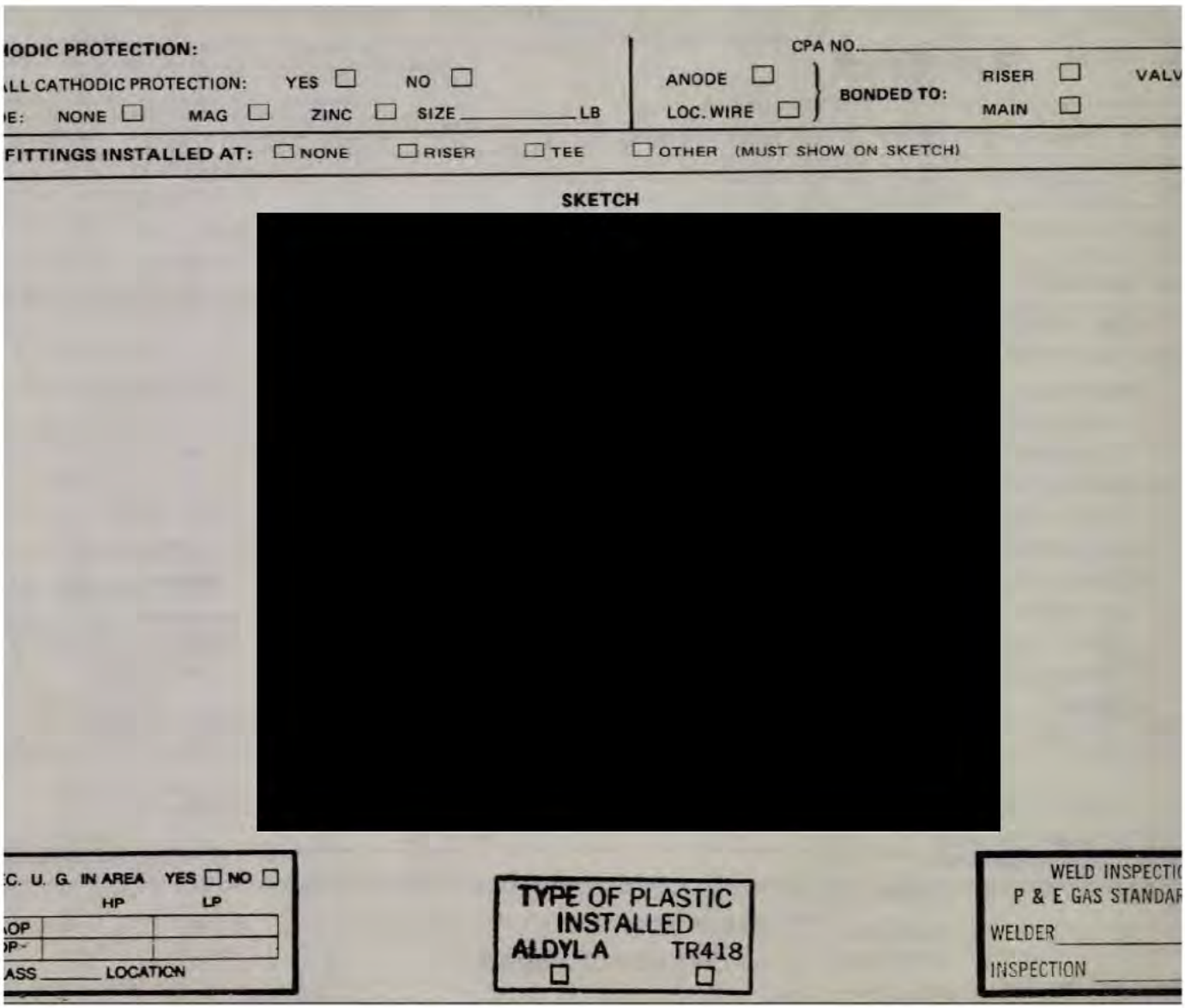


Figure 75. Back of Gas Service Record for [redacted], dated July 27, 1987.

Figure 76. As-built drawing G-95446 for installation of 6-inch steel main on Mission Street on job GM 4

Figure 77. Annotated enlarged section of as-built drawing G-95446 showing work performed on Mission Str GM 4944914.

Figure 78. As-built drawing G-94991s1 for the installation of the 6-inch plastic main on Mission Street or

Figure 79. As-built drawing G-94991s2 for the installation of the 6-inch plastic main on Mission Street or

Figure 80. Annotated enlarged sections of as-built drawings G-94991s1 and G-94991s2 showing work perfo
Street in 1996 on job GM 1670215.

Figure 81. As-built drawing 30223376s9 for the installation of the 2-inch main on College Terrace in 200

Figure 82. Annotated enlarged section of as-built drawing 30223376s9 showing work performed on Mission Terrace in 2003 on job 30267521.

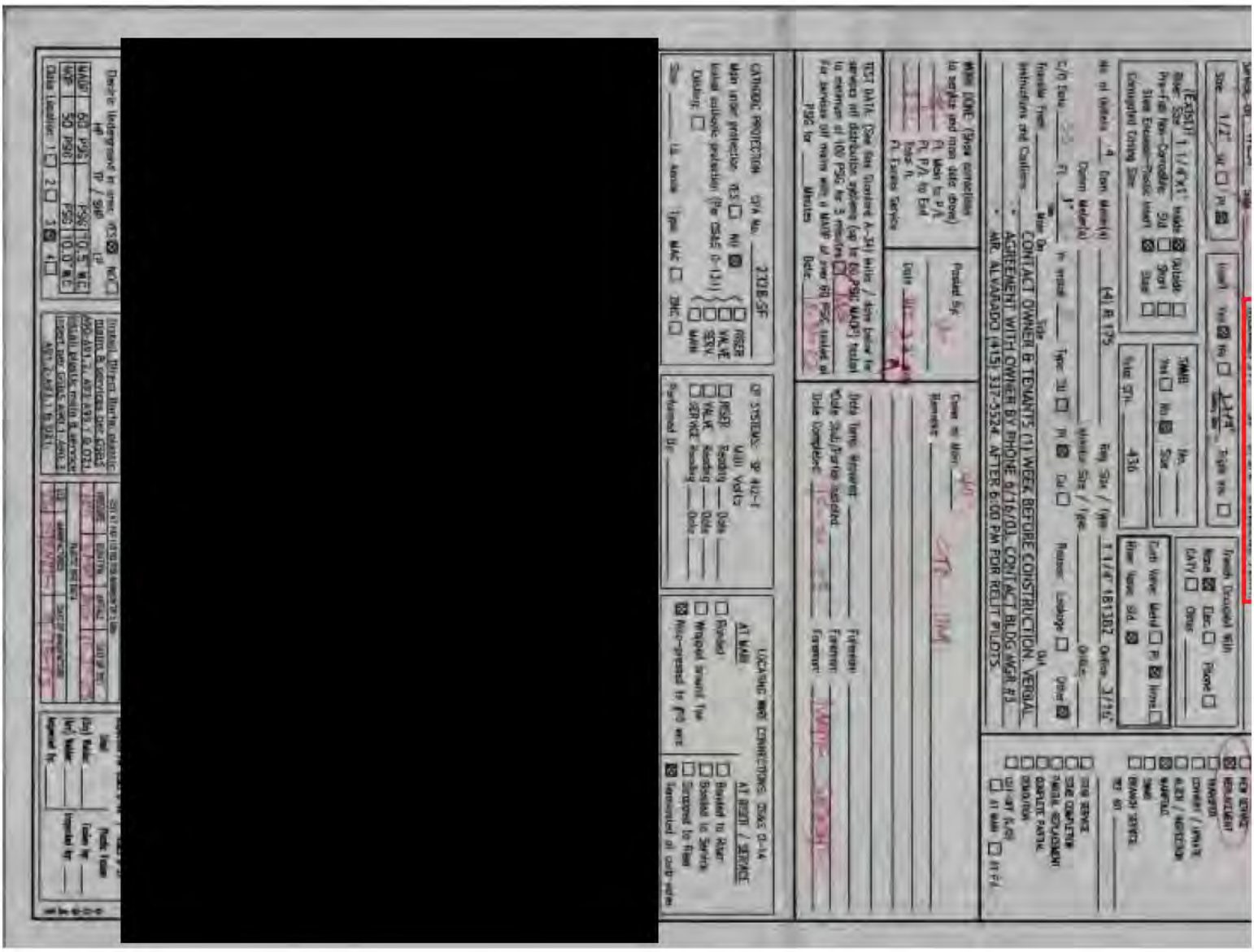
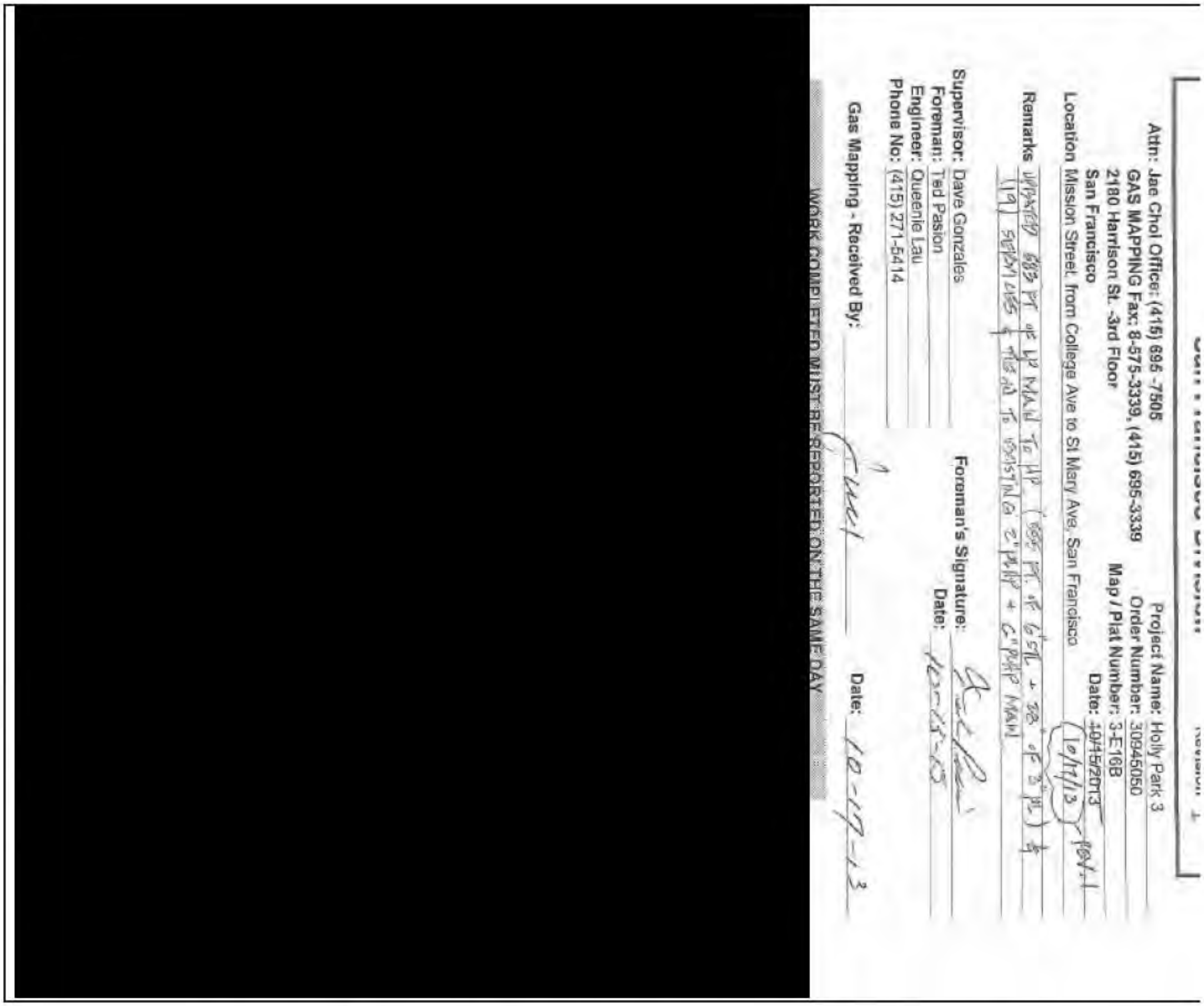


Figure 83. Gas Service Record for [redacted] showing transfer of service from 6-inch steel main t
in 2003.

Figure 84. Drawing showing facilities on Mission Street that were uprated on job PM30945050

Figure 85. Annotated enlarged section of drawing showing facilities on Mission Street that were uprated on 2013.


[redacted]

Attn: Jae Choi Office: (415) 695 -7505
GAS MAPPING Fax: 8-575-3339, (415) 695-3339
2180 Harrison St. -3rd Floor
San Francisco

Project Name: Holly Park 3
Order Number: 30945050
Map / Plat Number: 3-E16B
Date: ~~10/15/2013~~ 10/17/13 REV. 1

Location Mission Street, from College Ave to St Mary Ave, San Francisco

Remarks UPDATED 683 FT OF 12 MAIN TO HP (695 FT OF 6 STL + 22' OF 3" PL) & (19) SERVICES & TIE-IN TO EXISTING 2" PLHP + 6" PLHP MAIN

Supervisor: Dave Gonzales
Foreman: Ted Pasion
Engineer: Queenie Lau
Phone No: (415) 271-5414

Foreman's Signature:
Date: 10-15-13

Gas Mapping - Received By:
Date: 10-17-13

WORK COMPLETED MUST BE REPORTED ON THE SAME DAY

Figure 86. Operating change drawing for uprate work performed on job GM 30945050 in 2

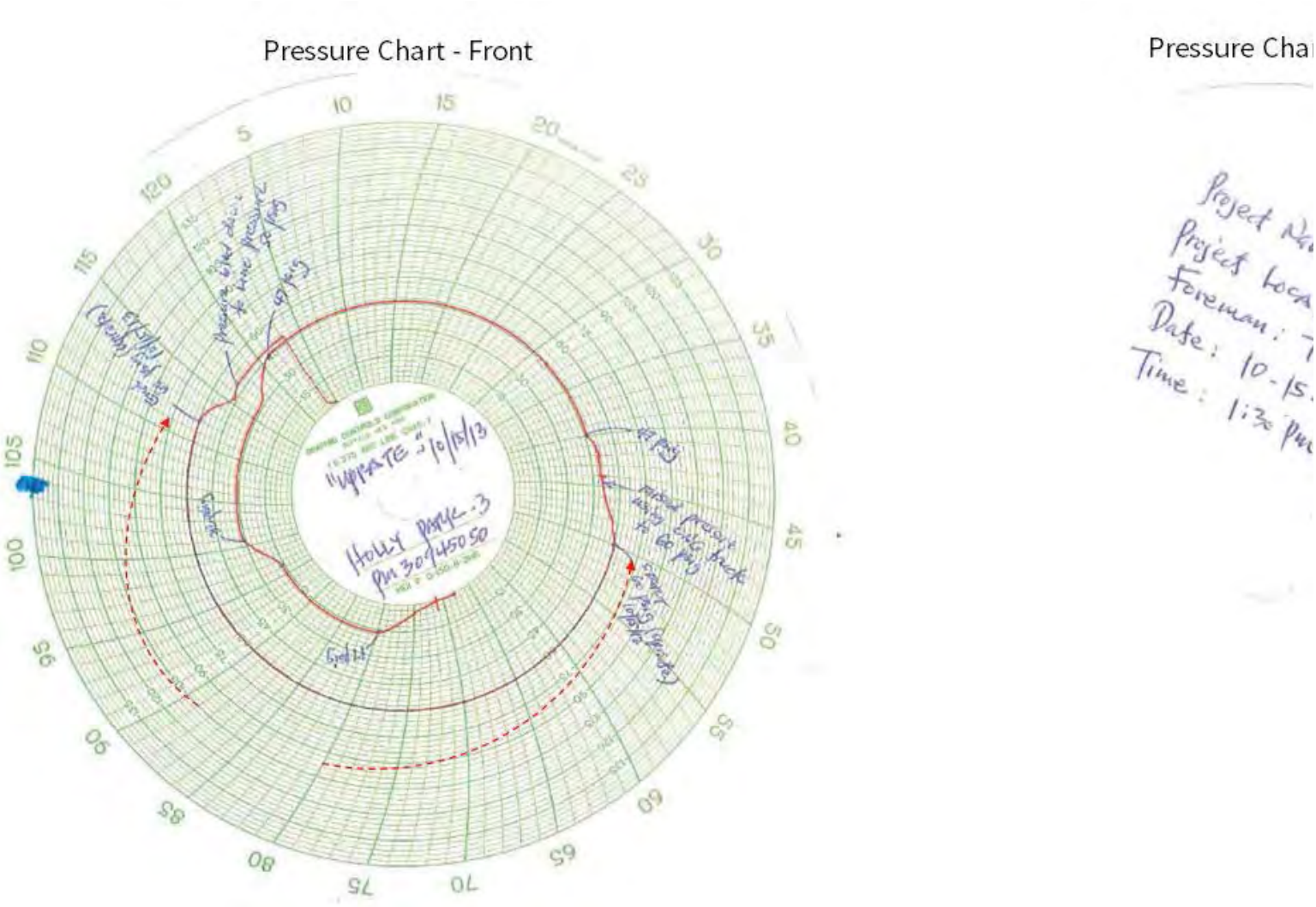


Figure 87. Front and back of pressure chart for uprate performed on job PM 3094505C