ALMEDA TUNNEL – PAST, PRESENT AND FUTURE

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The Almeda Road sanitary sewer is the primary trunk sewer delivering wastewater to the Almeda Sims Wastewater Treatment Plant. It serves approximately 15 square miles including River Oaks, Greenway Plaza, the Medical Center, and the Astrodome area. Most of the flows in the trunk are from the North MacGregor Pump Station that discharges to the tunnel at Old Spanish Trail.

The tunnel is approximately 28,000 feet in length and consists of 72-inch and 84-inch diameter monolithically cast in place (MCIP) concrete sewer. The alignment is along the west edge of the Almeda Road with an invert ranging from 35 to 45 feet below ground. The capacity of the 84-inch section, flowing full is approximately 100.0-mgd, without surcharge, assuming a Manning's ***n*** of 0.016. The maximum recorded flow is approximately 65.0-mgd.

The construction was completed in 1977 using tunneling techniques with primary lining consisting of steel ring beam and timber lagging installed behind a tunnel boring machine. The sewer which formed the secondary and permanent liner was a cast-in-place, rigid, and thick walled (9 ± inch), monolithic reinforced concrete pipe. The pipe design did not incorporate a mechanical or spray on protective liner for corrosion protection. Construction occurred through wet silty sands and sandy silts. Dewatering appears to have been employed in an attempt to stabilize wet soil conditions.

In late 2008, pavement depressions were noticed on Almeda Road. On separate occasions in 1991 and 2002, the trunk sewer experienced significant failures, including street collapse, which required various forms of repair, at a significant cost to the City, to return the line to effective service. When depressions were noted in late 2008, COH rapidly assembled a team consisting of City personnel, consulting engineers and contractors to assess the damage and begin design of the repairs. The proactive measure taken by the City prevented a complete pavement failure and saved the City millions of dollars and provided citizens uninterrupted usage of the Almeda Road.

On all three occasions, the failure was noted along the southern 5,600 LF (from Airport Boulevard to the Almeda WWTP) of the tunnel. The project team evaluated the cause of failure, designed and implemented the solution and identified measures to prevent future failures. The evaluation and design were conducted after each failure, and on all three occasions the cause and remedy were identical.

The evaluation included televising or manual inspection of the tunnel, review of original construction methods, obtaining current and historic geotechnical investigation, fault study, site assessments, and operation and maintenance histories of various utilities within the Almeda Road right-of-way.

Evaluation of the sewer data indicated that the failure was not corrosion related.

Two primary failure scenarios were considered:

- An active radial fault associated with the Pierce Junction salt dome
- Construction or performance problems associated with the subsurface soil conditions along the alignment.

A geologic fault study was conducted in 1992 to evaluate the probability of an active fault traversing the sewer alignment. A review of geologic literature, infra-red altitude photo imagery for potential fault features, and site reconnaissance to identify structural distress and/or topographic features which may have been formed as a product of fault activity were studied in detail. The study concluded that the possibility of an active fault traversing the area was unlikely.

Extensive geotechnical investigation was conducted on all three occasions. A review of the subsurface soil conditions in the vicinity of the failure indicated that the sewer failure zone lies in very fine silty sands under hydraulic pressure. The top 20-feet of soil are composed of clay, and the next 25-feet are composed of sandy silts. At the depth where the sewer is located, the soil profile varies along the length from stiff clay in the downstream reach of the profile to fine sandy silts in the area of the failures and upstream. The exhibit on page 3 includes the profile of the 84-inch sewer and the zone of loose silt.

The fine clayey silts and sandy silts through which the line was constructed are known to be difficult to dewater. It is likely that the original construction operation battled extremely wet conditions through segments of the silty material even with a dewatering system in place. Where these wet conditions existed, the result was a reduction in the ultimate strength of the concrete.

The television tapes of the line showed transverse cracks spaced in some case as close as every 4 to 5 feet, but more generally every 12 to 15 feet. Inflow exists at almost all of these cracks to varying degrees. The cracks appear to coincide with the spacing of steel ring beams in the ring beam and lagging tunneling technique. The concrete thickness is slightly reduced at the ring beam and thus slightly weaker. No filter material was employed either around the primary tunnel exterior or around the inner monolithic pipe to cut off material from being carried into the line at these points of inflow.

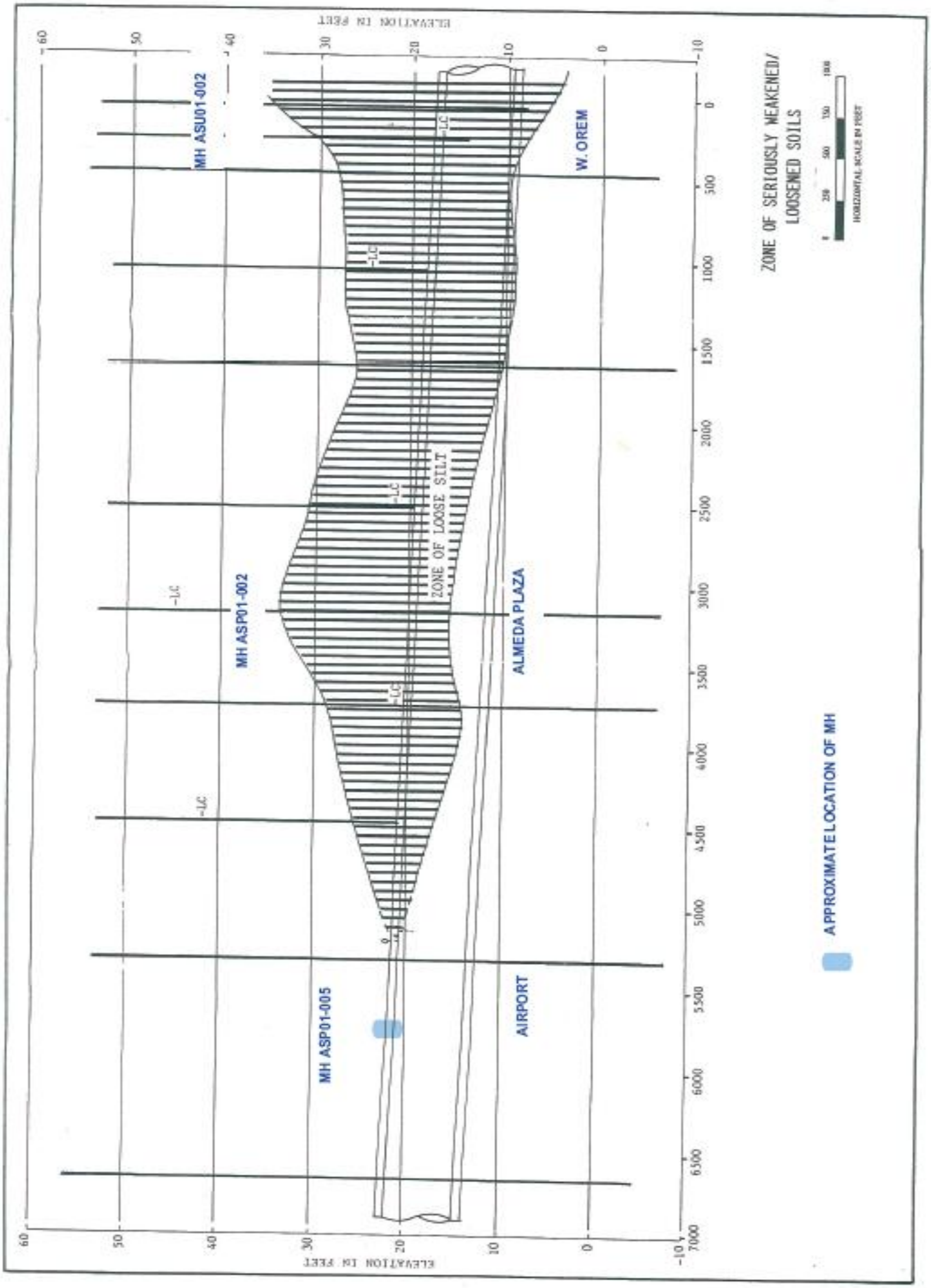


EXHIBIT 2
ZONE OF SERIOUSLY WEAKENED/
LOOSENED SOILS
MH ASU01-002
W. OREM
ZONE OF LOOSE SILT
MH ASP01-002
ALMEDA PLAZA
MH ASP01-005
AIRPORT
APPROXIMATE LOCATION OF MH
ELEVATION IN FEET

Small cracks in the concrete sewer allowed the very fine soil particles to leak into the sewer. The loss of these fine particles weakened the soil supporting the pipe and the pipe had to act as a bridge over the weakened section. Since the sewer pipe was not designed to act as a beam, additional cracks were formed. The cracks accelerated the loss of soil and soil strength. The continuing loss of soil strength accelerated the development of new cracks and enlargement of existing cracks.

When the extent of weakened soils exceeded the bridging capacity of the upper clay layer, a large plug of the clay failed and collapsed onto the interceptor. The sewer structure failed catastrophically, and a cave-in appeared at the surface above.

On all three occasions, the failure was due to a gradual removal of the fine grained silty soils through transverse cracks in the 84-inch sewer line which ultimately resulted in the surface collapse and sink hole. Faulting is not believed to be a contributing factor in the failure. This southern 5,600 LF of the tunnel alignment is embedded in the fine grained silty soil and experienced failure.

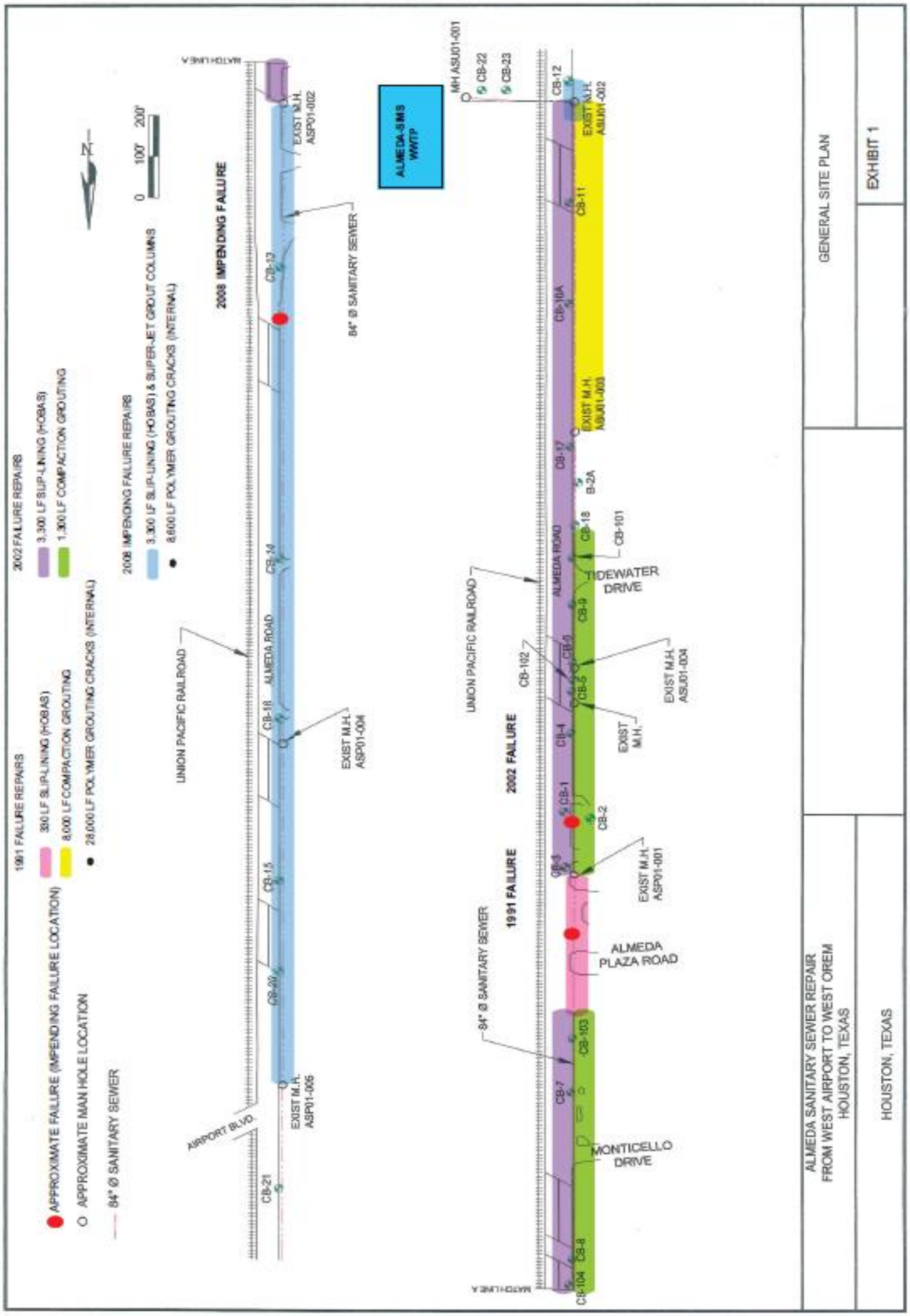
Several methods were reviewed for repair of the failed section. A key concern with the line repair was the condition of the silty sands which contributed to the existing failure both in the bedding zone and below. The weak soils had to be either removed or stabilized for any repair method considered.

Slip lining was employed to rehabilitate the tunnel after each failure. The external soil in the southern 6,000 LF of the tunnel was stabilized using compaction grouting and/or super-jet grout columns. The entire length (28,000 LF) of the tunnel was internally grouted in 1992. The City has spent approximately $18.0 million on the repair of the tunnel since 1991.

The exhibit on page 5 indicates the limits of rehabilitation and soil strengthening on separate occasions.

The lessons learnt include the importance of geotechnical investigation, hiring personnel with historical knowledge, traffic issues, and team effort and citizen involvement. Periodic monitoring of the tunnel and the surface conditions are of paramount importance.

With the rehabilitation of the tunnel, strengthening of the soil, and the arresting of leakage into the sewer, the City should not experience any challenges in the operation and maintenance of the Almeda tunnel.



APPROXIMATE FAILURE (IMPENDING FAILURE LOCATION)
APPROXIMATE MAN HOLE LOCATION
84" Ø SANITARY SEWER
1991 FAILURE REPAIRS
390 LF SLIP-LINING (HOBAS)
8,000 LF COMPACTION GROUTING
28,000 LF POLYMER GROUTING CRACKS (INTERNAL)
2002 FAILURE REPAIRS
3,300 LF SLIP-LINING (HOBAS)
1,300 LF COMPACTION GROUTING
2008 IMPENDING FAILURE REPAIRS
3,300 LF SLIP-LINING (HOBAS) & SUPER-JET GROUT COLUMNS
8,600 LF POLYMER GROUTING CRACKS (INTERNAL)
2008 IMPENDING FAILURE
84" Ø SANITARY SEWER
UNION PACIFIC RAILROAD
ALMEDA ROAD
AIRPORT BLVD.
ALMEDA-SIMS WWTP
1991 FAILURE
2002 FAILURE
ALMEDA PLAZA ROAD
TIDEWATER DRIVE
MONTICELLO DRIVE
ALMEDA SANITARY SEWER REPAIR FROM WEST AIRPORT TO WEST OREM HOUSTON, TEXAS
GENERAL SITE PLAN
HOUSTON, TEXAS
EXHIBIT 1