SUBSIDENCE IN THE TEXAS CITY AREA

By

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The Texas City Area lies within the western Gulf Coastal Plain. This coastal area, which borders Galveston Bay, is a flat almost featureless plain that is bordered on its seaward side by a series of shallow lagoons that are separated from the open waters of the Gulf of Mexico by a more or less continuous line of barrier beaches. The land surface in the Texas City area rises from sea level on Galveston Bay to an altitude of about 16 feet a few miles inland. The average slope of the land surface from Texas City to Houston, a distance of about 40 miles, is one foot per mile.

In 1942 and 1943 during the course of routine leveling at the Pan American Refinery at Texas City, many of the traverses would not check out. Most of the descrepancies were small, so little attention was paid to the cause other than the probability of inaccuracies in leveling. During this time a few breaks occurred in the cast iron pipe of the water distribution system. Also clogging was noted in the sewage lines. In 1944 descrepancies in leveling traverses became increasingly large, and pipe failures and clogging of sewage mains occurred more frequently. It was observed that these rather unusual occurrences were taking place in the same general area. So in the fall of 1944 a complete leveling circuit was made of 13 bench marks and about 150 reference points within the refinery property.

Based on the assumption that the master bench mark, which rests on 30-foot pilings, was stationary, the survey revealed that the land surface in a large part of the refinery had subsided. A comparison of the 1944 levels with those obtained during a similar survey in 1938 showed a maximum settlement of 0.90 foot. The 1938 elevations were only a fraction of a foot lower than those obtained from the original survey for the refinery in 1933 and 1934.

In January 1945 an examination for evidence of subsidence was made of the land surface, buildings, and 10 water wells at the refinery. The only surficial evidence was found at the buildings housing Wells 6, 7, and 8. Cracks had developed in the concrete floor, radiating from

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the pump foundation at the well to the four corners of the building. Also the concrete supports of the horizontal discharge pipe from the wells had settled so that the pipe no longer rested on the supports. The space between the support and the pipe at Well 6 was about 4 inches. There was no evidence whatever of subsidence at the other 7 wells. Neither were there any cracks in the walls of the buildings.

In February 1945 a line of levels was run from the master bench mark at the refinery to the U. S. Coast and Geodetic Bench Mark at Lamarque, about 2.3 miles to the east, and tied back into the master bench mark. The levels revealed that the master bench mark had settled 0.69 foot, therefore, the maximum subsidence at that time was approximately 1.6 feet instead of the originally computed 0.9 foot.

In March 1945 a similar survey was made at the Carbide & Carbon Chemical Company, which adjoins Pan American Refinery on the west. The survey revealed that the entire plant property had subsided, the maximum settlement at that time being 1.2 feet. The casings of the 5 production wells had subsided with differential settlement at 3 wells similar to that noted at Pan American.

Ten surveys of bench marks were made at Pan American between May 1945 and November 1948; whereas, only one survey was made at the adjoining chemical plant. Because of the large amount of data available on the subsidence at the refinery, this paper deals chiefly with a presentation and analysis of these data.

Geology

The sediments immediately underlying the Texas City Area consist essentially of unconsolidated sand, sandy clay, clay, and silt of Pleistocene age. The formations, from the youngest to the oldest, are the Beaumont clay, the Alta Loma sand, and the Lissie sand. The formations dip southeastward at an estimated rate of 15 to 20 feet to the mile, so that the beds are encountered at progressively greater depths to the southeast.

The Beaumont clay averages about 825 feet in thickness at Texas City and can be subdivided into three members - an upper and a lower clay member and an intermediate sand member.

The upper clay member is made up of a series of clay and sandy clay beds containing numerous thin beds and lenses of fine-grained sand. The thickness of this zone ranges from about 400 to 450 feet.

The middle sand member consists of a series of rather thick beds of fine to medium-grained sand interbedded with lenses and layers

of clay and sandy clay. The interfingering lenses grade into one another laterally and vertically in short distances and the thinner beds may change character or pinch out within a few hundred feet. The clays near the middle of the zone have a maximum thickness of about 60 feet.

The lower clay member is composed of a relatively impermeable clay bed averaging about 75 feet in thickness. Thin lenses of sand and sandy clay occur near the base of the zone.

About 75 percent of the wells in the Texas City Area draw at least part of their supply from the sand member of the Beaumont. The yield of the wells drawing only from these sands ranges from 400 to 700 gallons per minute with specific capacities of 5 to 15. Results from a pumping test show a coefficient of transmissibility of 16,800 and a coefficient of storage of 1.86×10^{-4}.

The Alta Loma sand consists of a massive bed ranging from 150 to 200 feet in thickness and is composed principally of medium to coarse-grained sand. The formation contains numerous lenses of clay and sandy clay. A few of the logs show as many as 25 thin layers of clay. Most of the lenses, which are local in extent, are less than 10 feet thick; but a few are as much as 25 feet thick.

The Alta Loma sand is the most productive aquifer in the region. The maximum yield of wells drawing from the sand at Texas City is about 2,000 gallons a minute with specific capacities ranging from 18 to 40. Pumping test results show an average value of 151,000 for the coefficient of transmissibility and 4.2×10^{-4} for the coefficient of storage.

The Lissie sand underlies the Alta Loma and consists of a series of interbedded and lenticular sands and clays. Inasmuch as water from the Lissie in the Texas City area is too highly mineralized for most uses, there are no wells drawing from these sands.

Ground-Water Withdrawals and Decline in Artesian Pressure

Although withdrawals of ground water from wells at Texas City began in 1893, the first recording of rates of pumpage was made in 1930. The rate at that time was about 1.5 million gallons a day. With the beginning of operation by the Pan American Refinery in 1934, the rate of pumping increased to about 4 million gallons a day and continued a gradual rise as the facilities at the refinery were expanded. The withdrawals of ground water continued to increase as new industrial plants went into operation. The average daily pumpage from wells in the area was about 15 mgd in 1943, 19 mgd in 1944, and 25 mgd in 1945. This rate of 25 mgd was maintained more or less until August 1948, when the

ground-water supply was supplemented by surface water from the Brazos River. The present water demands are about 20 mgd from wells and about 8 mgd from surface water. The usage of surface water will be increased when reservoir facilities are completed.

The Texas City industrial area is approximately 3.5 miles long and about 1.5 miles wide, covering an area of a little over 5 square miles. The greatest concentration of ground-water withdrawals since 1934 has been at the Pan American Refinery. Approximately 75 percent of the pumpage in the area is from wells of the Pan American Refinery and the Carbide & Carbon Chemical Company. In 1947, which is typical of the past several years, 14.4 million gallons a day were withdrawn from 12 wells spaced over an area 7,200 feet long and 1,900 feet wide, which is less than one square mile.

In 1915 most of the wells in the Texas City area flowed under artesian pressure. The maximum pressure recorded in wells was sufficient to raise the water about 8 feet above the land surface. The head in both the Alta Loma sand and the sands of the Beaumont gradually declined and in 1931 the last well ceased to flow.

The artesian pressure in the Alta Loma sand has steadily declined with increased withdrawals until in 1945, the last available water level measurements, it was 124 feet below the surface in Well 6 at Pan American Refinery. The total decline in pressure from 1935 to 1945 was 106 feet or about 46 pounds per square inch. Undoubtedly the total decline up to the present time is greater than that recorded up to 1945.

The artesian pressure in the sands of the Beaumont has declined at a more rapid rate than that in the Alta Loma. The water level in Well 2 at Pan American Refinery declined from 25 feet below the surface in June 1933 to 175 feet in July 1945, a total of 150 feet or about 65 pounds per square inch in 12 years. The largest increment of decline occurred in 1941, when wells at Carbide & Carbon Chemical Company were put into operation.

Water levels in wells screened in both the Alta Loma and Beaumont as shown by Pan American Well 4 declined about 118 feet or 51 pounds per square inch between November 1933 and July 1945. The largest decline occurred during the early part of 1944 following a substantial increase in the rate of pumping at the Refinery.

Nature and Analysis of Subsidence

Based on surveys of bench marks in the Texas City area, the subsidence began sometime between 1938 and 1943. Indications from other data suggest that the subsidence probably started in 1941. The area of

settlement has completely enveloped the plants of Pan American Refining Company and Carbide & Carbon Chemical Company. The actual lateral extent of the subsidence cannot be ascertained because of the absence of bench marks outside the two properties; the approximate extent, however, is estimated to be about 2.5 miles east and west and about 1.75 miles north and south - a total of 4.4 square miles in area.

Contours of equal subsidence at Pan American refinery show the greatest subsidence to be in the immediate vicinity of Wells 2 and 3 and that the line of Wells 2, 3, 4, and 5 coincides with the central low of the affected area. The nature of the subsidence at the adjoining chemical plant is very similar, in that the greatest settlement occurs near the central wells at the plant. The maximum subsidence up to November 1948 was 2.67 feet at Pan American and 2.35 feet at Carbide & Carbon.

Two profiles, line A-A' and line B-B', across the refinery area show that the rate of subsidence between May 1945 and November 1945 was the greatest recorded, the maximum settlement during this period being 0.32 foot. Since November 1945 the land has settled at a rather uniform rate; the rate from August 1947 to November 1948, however, was slightly greater than that for the previous year. The nature of the subsidence has been closely analogous to the cone of depression in the piezometric surface of the water-bearing sands, being greatest near the center of withdrawal and becoming progressively less at greater distances outward from the center.

In the determination of the cause for the subsidence, the action of the casing of the wells during the period of activity presents the most revealing evidence. In the construction of the water wells, the pump or large diameter casing was cemented in place; in the older wells the cement extends upward from the bottom of the casing for a distance of 100 to 200 feet, and in the new wells the cement seal extends the full length of the casing. Thus, there is no question that the large diameter casing in all wells in the area of subsidence is cemented securely in place.

Of the 15 production wells at the Pan American Refinery and the Carbide & Carbon Chemical Company, 8 have less than 700 feet of pump casing and 7 have more than 700 feet of pump casing. There are two small diameter observation wells at the western edge of the chemical plant property. These wells consist of 990 feet of 3-inch casing and 15 feet of 3-inch screen. Also a dry oil well with over 2,000 feet of casing is just south of the Pan American property.

A study of the action of the casing in these 18 wells during the subsidence reveals the following facts:

1 - In 8 of the wells the pump casing is set above 700 feet. Settlement at these casings has been essentially the same as that of the brick structure around the well. The difference in the amount of subsidence between the casing and the corners of the building ranges from 0 to 0.07 foot.

2 - In 7 of the wells the pump casing is set below 700 feet and has settled less than the house around it. The difference in the total subsidence ranged from 0.14 to 0.68 foot and averaged 0.41 foot.

3 - The casing of the two observation wells at the Carbide & Carbon plant, which is set at 1,005 feet - the bottom of the Alta Loma sand, has remained stationary whereas two nearby bench marks have subsided 0.74 foot.

4 - The casing of the oil well south of the refinery area has also remained stationary, while a bench mark about 500 feet to the north has subsided almost one foot.

Based on these facts, the source of the subsidence occurs between a depth of approximately 700 feet and 1,000 feet. The upper limit is represented by the bottom of the shallow pump casing in wells such as Pan American Well 4 and the lower limit by the observation wells at the chemical plant. The amount of settlement in this 325-foot zone has not been evenly distributed. The average settlement of the casing in seven wells is 0.96 foot, whereas, the average settlement of the structures around these wells is 1.41 feet, revealing a differential settlement of 0.45 foot. Based on these values, it can be assumed that approximately 1/3 of the total subsidence has occurred between depths of about 700 and 800 feet and that the remaining two thirds has taken place between 800 and 1,000 feet.

In correlating these factors with geologic conditions, it is found that the basal Beaumont clay coincides with the 700 to 800 foot zone and that the Alta Loma sand occurs from about 800 to 1,000 feet. Following the same line of reasoning as stated above, about one third of the subsidence can be attributed to the basal Beaumont clay and two thirds to the Alta Loma sand.

The cause for this subsidence is the decline of artesian pressure within the two aquifers as a result of withdrawals of ground water from wells at Pan American Refinery and Carbide & Carbon Chemical Company. This decline in pressure in the affected area, which averaged about 50 pounds per square inch, allowed the weight of the overlying sediments to compress the confined clay strata within the aquifers. Thus, the clays within this zone became more dense and were reduced in thickness as

water was squeezed out into contiguous sands. This change in the thickness and character of the clays was translated at the surface into an area of subsidence, the depth of which approaches in magnitude the amount of compression.

This compression takes place gradually due to the slow rate at which water is released from clays. The lower the permeability and the thicker the clay, the longer it will take for the bed to compress under a given reduction in pressure. This fact may explain the difference in the amount of compression in the lower Beaumont and the Alta Loma. The Beaumont clay being about 75 feet thick has given its water up very slowly, whereas, the innumerable thin clay lenses within the Alta Loma sand reacted to the decline much more quickly. This is borne out by values obtained at Pan American Well 6. The amount of subsidence of the well casing was 0.45 foot from May 1945 to April 1948, whereas, the amount of subsidence of the surrounding structure was 0.65 foot. Nine values show the difference in subsidence at these two points becoming progressively greater.

As stated previously the configuration of the area of subsidence has more or less the same characteristics as the cone of depression in the piezometric surface caused by withdrawals from wells in the area. Thus, in the center of the cone of depression where the pressure change is the greatest, the total settlement has been the maximum; toward the outer edges of the cone, the pressure change is progressively smaller resulting in smaller total settlements.

Conclusions

The purpose of this paper is not to present a quantitative analysis of the subsidence but to report the occurrence and draw generalized conclusions from a study of the data.

1 - The subsidence which has been observed in the Texas City area was produced by the compression of massive and lenticular clays within the formations lying between depths of 700 and 1,000 feet. This effect in turn resulted from the reduction in artesian pressure within the two aquifers accompanying large withdrawals of ground water.

2 - The rate of subsidence, which at the present time is about 0.2 foot per year, should become progressively less with time. The decrease in the rate of pumping from wells in the area undoubtedly will further retard the rate of settlement; there will be, however, a pronounced lag in the reaction of the subsidence to the reduction in withdrawals. If the decrease in the rate of pumping is sufficiently

large, the land surface in the affected area should rebound, but under no circumstances will it regain its original position.

3 - The subsidence in the Texas City area has not caused alarm, neither has it brought forth any major problems. The extent of the problems has been and will continue to be clogging of sewage line, snapping of water pipes, and uneven overflow of cooling towers. The present structures are functioning normally and additional structures are under construction at the present time.

NOTE: The illustrations to accompany this paper are on file at my office.