Vacuum Testing Precast Concrete Manholes

Vacuum testing is a quick, safe and practical way to validate manhole system integrity. Manhole sections can be tested at the precast concrete plant prior to delivery or on site prior to backfilling. Here you will find not only how to perform vacuum testing, but you will discover the benefits and limitations of vacuum testing as well.

MEASURING PRESSURE

Having a general knowledge and understanding of atmospheric pressure and hydrostatic pressure is essential when performing a vacuum test in the field.

ATMOSPHERIC PRESSURE

Atmospheric air, or the air we breathe, is a gas composed primarily of nitrogen molecules (80 percent) and oxygen molecules (16 percent) that are bound to the earth by gravitational forces. Atmospheric pressure is defined as the force per unit area exerted against a surface by the weight of the air above that surface. Thus the atmospheric pressure varies with altitude above the earth's surface. Atmospheric pressure at sea level is 14.67 pounds per square inch (psi).

An alternative system of measurement (inches of mercury) is derived from the way in which atmospheric pressure is typically measured. If we insert one end of a vacuum-filled tube (see Figure 1) into a liquid and allow the liquid free access to the atmosphere, then the liquid will rise up the tube until the force exerted by the weight of the liquid column balances the atmospheric pressure. The denser the liquid used, the lower the height of the column. In initial experiments, liquid mercury (Hg) was used, and the corresponding column height was found to be 29.92 inches of mercury. (If water had been used, the column would be 408 inches – 34 feet – high.) The following relationships can be used to convert atmospheric pressure between the units of inches of mercury (in Hg) and pounds force per square inch of area (psi):

$$1\,in\ Hg = \frac{14.67\,psi}{29.92\,in\ Hg} = 0.49\,\text{psi} \approx 0.5\,\text{psi}$$

$$1\,psi\ air\ pressure = \frac{29.92\,in\ Hg}{14.67\,psi} = 2.04\,in\ Hg \approx 2\,in\ Hg$$

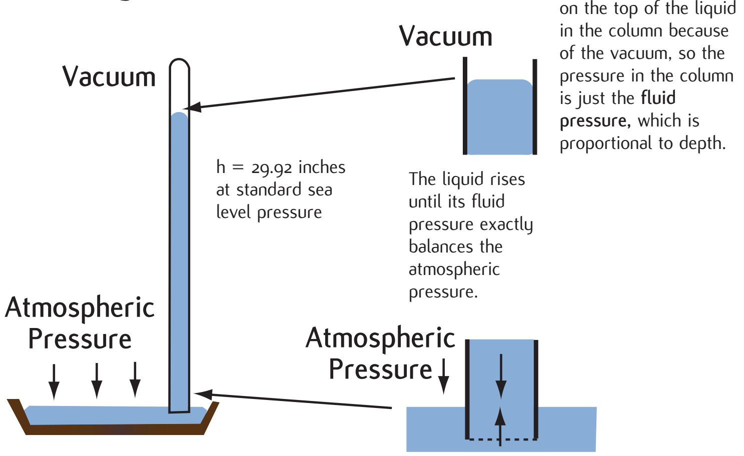
GAUGE PRESSURE

Most industrial gauges work on the Borden tube principal, which pressurizes a closed, curved tube and measures how much the tube tries to straighten out. The curved tube is surrounded by the atmosphere and therefore has 15 psi resisting the tendency to straighten. The gauge therefore measures the difference between the internal pressure trying to straighten the tube and the atmospheric pressure acting to resist the straightening. So if we read 35 psi on the gauge, there is really 50 psi being applied.

Normally we do not take atmospheric pressure into consideration in our everyday lives, since it surrounds us uniformly and universally – the same 15 psi exists internally as well as externally, creating a state of equilibrium as illustrated in Figure 2. However, to differentiate between the two measuring systems, we add the word "gauge" to measurements referencing atmospheric pressure as the zero point (i.e., psig) and the word "absolute" to measurements referencing full vacuum as the zero point (i.e., psia).

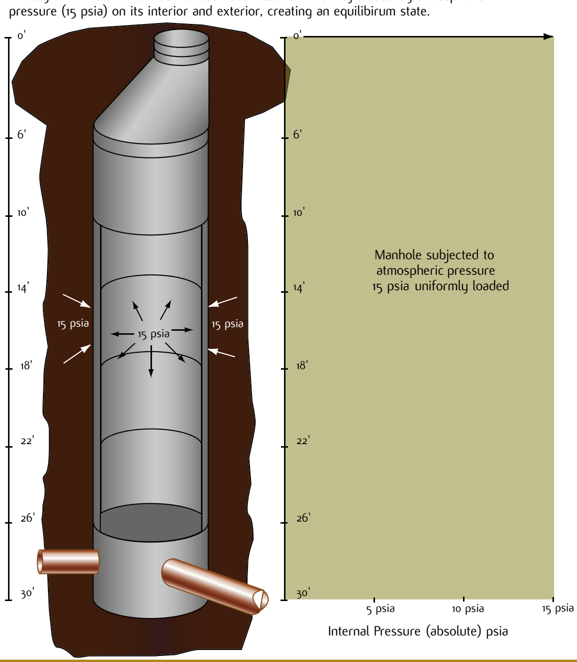
$$P_{absolute} = P_{gauge} + P_{atmosphere}$$

Mercury Barometer



Manhole Prior to Backfill

Initially a manhole which has not been backfilled is uniformly loaded by atmospheric pressure (15 psia) on its interior and exterior, creating an equilibirum state.



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HYDROSTATIC PRESSURE

The pressure created by a fluid is a function of the fluid's unit weight and the height (h) of the liquid column above a reference plane. Water, for example, has a unit weight of 62.4 pounds force per cubic foot, which corresponds roughly to 0.43 psig per foot of water column height. The pressure created by a 23-foot water column is roughly 10 psi gauge (psig) or 25 psi absolute (psia). Following are a series of expressions that illustrate the relationship between the unit weight of water and its corresponding gauge pressure per foot of water column height and the example solution for the pressure created by a 23-foot water column.

$$62.4\frac{lbs}{ft^3} * \frac{1\,ft^3}{1728\,in^3} * \frac{12\,in}{1\,ft} = 0.433\,\frac{psig}{ft}$$

Example:

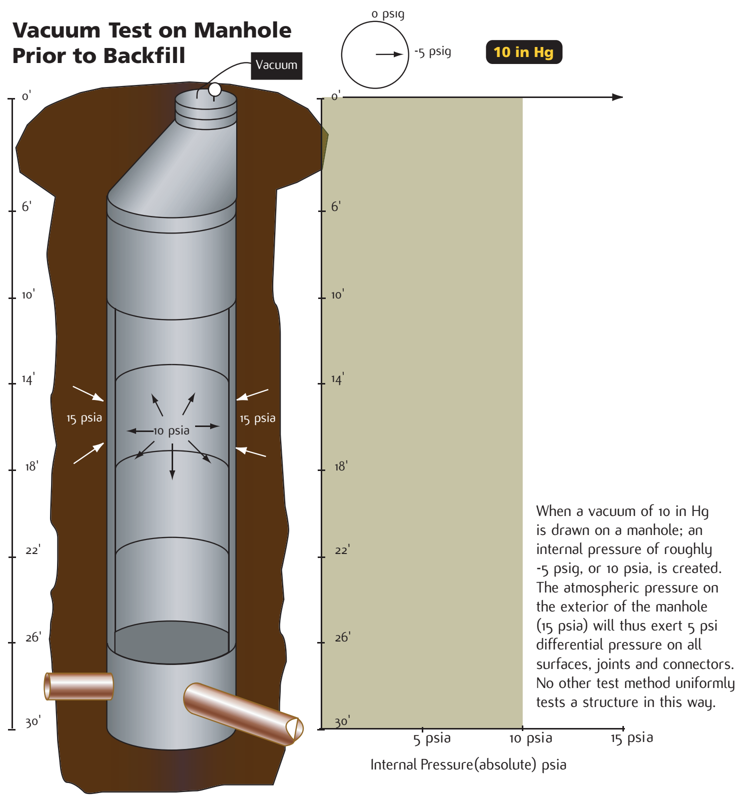
$$P_{Hydrostatic} = \gamma_{water} * h_{water\ column}$$

$$9.967\frac{lbs}{in^2} \approx 10\,psig = 62.4\frac{lbs}{ft^3} * 23\,ft * \frac{1\,ft^2}{(12\,in)^2}$$

or

$$9.959\,psig \approx 10\,psig = 23\,ft * 0.433\frac{psig}{ft}$$

Vacuum Test on Manhole Prior to Backfill



CREATING A VACUUM

Vacuum is defined as an absence of matter (molecules) in a defined volume of space. To produce a vacuum in the field we need to remove all the molecules of matter (air) from within an enclosed space (manhole structure). Initially a manhole which has not been backfilled is uniformly loaded by atmospheric pressure (15 psia) on its interior and exterior, creating an equilibrium state. To create a vacuum we use a pump, or venturi nozzle, attached to the manhole and attempt to "suck" out the air. It is almost impossible to produce a total vacuum. The closer we get to a full vacuum (29.92 inches Hg) the harder it gets to encourage the remaining molecules to leave.

In reality all we do is create a partial vacuum (somewhere between 0 inches Hg and 29.92 inches Hg), which in turn creates a pressure differential between the partial vacuum inside the manhole and the atmospheric pressure pressing against the exterior of the manhole.

When a vacuum of 10 inches Hg is drawn on a manhole, an internal pressure of roughly -5 psig, or 10 psia, is created. The atmospheric pressure on the exterior of the manhole (15 psia) will thus exert 5 psi differential pressure on all surfaces, joints and connectors as illustrated in the following animation. No other test method uniformly tests a structure in this way.

WHEN TO VACUUM TEST?

Many codes and specifications require that a vacuum test be performed after the manhole has been installed and backfilled. Testing after backfilling provides a degree of certainty that a watertight system has been installed. The major disadvantage is the fact that no industry standards exist for vacuum testing after the structure has been backfilled. Secondly, it is often difficult to determine the cause or locate and repair a system breech once the manhole has been backfilled.

The resolution to this problem is to perform a vacuum test prior to backfilling and, if necessary, again after backfilling.

See Appendix A: Suggestions for detecting leaks

VACUUM TESTING PRECAST CONCRETE MANHOLES

ASTM C1244

ASTM C1244, "Standard Test Method for Concrete Sewer Manholes by the Negative Air Pressure (Vacuum) Test Prior to Backfill," has been developed to govern the proper vacuum testing procedure for testing concrete manholes. ASTM C1244 clearly states that a vacuum test "is intended to be used as a preliminary test to enable the installer to demonstrate the condition of the concrete manhole prior to backfill."

When utilizing ASTM C1244, a vacuum of 10 inches Hg is drawn on the manhole after all lift holes are plugged, and pipes entering the manhole are temporarily plugged and securely braced. The time is measured for the vacuum to drop to 9 inches Hg. The manhole is accepted if the measured time meets or exceeds the values presented in Table 1 of ASTM C1244. If the manhole fails the initial test, it may be repaired by an approved method until a satisfactory test is obtained.

Note: The latest edition of ASTM C1244 shall be used for proper testing procedures and criteria.

VACUUM TESTING IN THE PRESENCE OF GROUND WATER

Vacuum testing after backfilling should be performed only after a successful non-backfill test has been completed in accordance with ASTM C1244.

CAUTION: Many people do not fully understand the effects of vacuum testing backfilled manhole systems in the presence of ground water. Vacuum testing backfilled manhole systems is not recommended, especially in the presence of ground water. Vacuum testing a manhole system that is already subjected to hydrostatic pressure may exceed the design limits of critical flexible connectors leading to a system failure.

If ground water is present, use the following information to determine if a reduction in vacuum pressure is warranted:

Note: For simplicity, the effects of soil pressure are not taken into account in the following information and examples. In reality, the actual in-place loads may be greater when in-place soil conditions (effective stress) are taken into consideration. To determine the actual loads induced on a backfilled structure, use the following information in addition to the actual in-place soil properties to properly calculate the effective stress at the critical location.

1. Depth to water table
2. Pressure rating for flexible connector
3. Depth to bottom-most critical connector

With this information, you can determine the theoretical in-place loads experienced by the deepest connector as outlined in the following example. If the combined pressure differential (vacuum and hydrostatic) between the interior and exterior of the manhole exceeds the connector's pressure rating, appropriate adjustments must be made.

XYZ County specifications require that all manhole systems be vacuum tested in accordance with ASTM C 1244 requirements after backfilling.
Manhole Diameter: 48 inches
Manhole Depth: 30 feet
Depth to Water Table: 8 feet
Acceptance Test: ASTM C 1244*
Resilient Connector: ASTM C 923**
Depth to Connector: 28 feet

* ASTM C 1244 requires a vacuum between 10 inches Hg and 9 inches Hg (-5 psig to -4.5 psig) be maintained for 74 seconds.
** ASTM C 923 requires resilient connectors to withstand a hydrostatic pressure of 13 psig when installed in a straight alignment and 10 psig when axial deflected 7 degrees.

External Pressure at Critical Depth (Hydrostatic pressure)

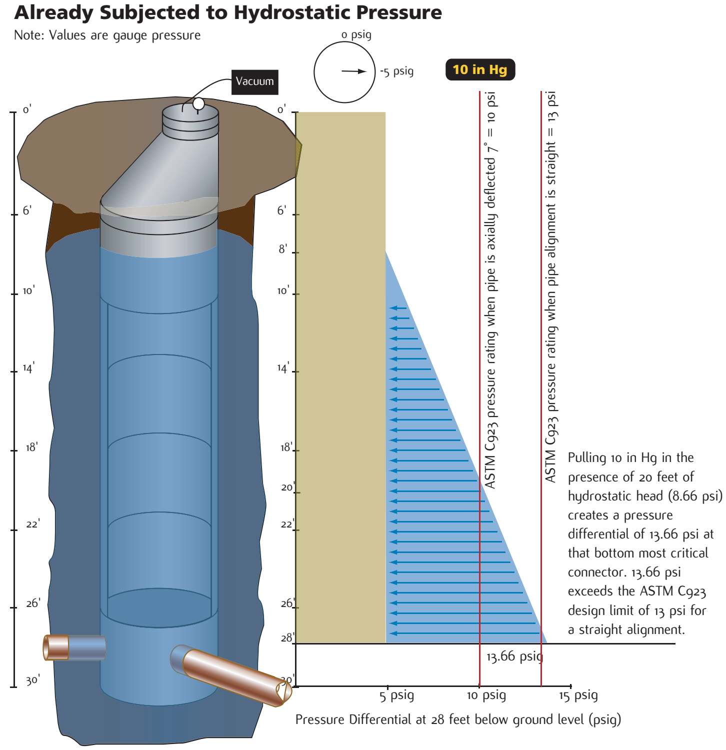
$$[(62.4\frac{lbs}{ft^3})*(28ft-8ft)]*\frac{1ft^2}{(12in)^2}=8.67\frac{lbs}{in^2}$$

or

$$0.433\frac{psi}{ft_{head}}*(28ft-8ft)=8.66psi_{Hydrostatic}$$

Vacuum Test on Backfilled Manhole Already Subjected to Hydrostatic Pressure

Note: Values are gauge pressure



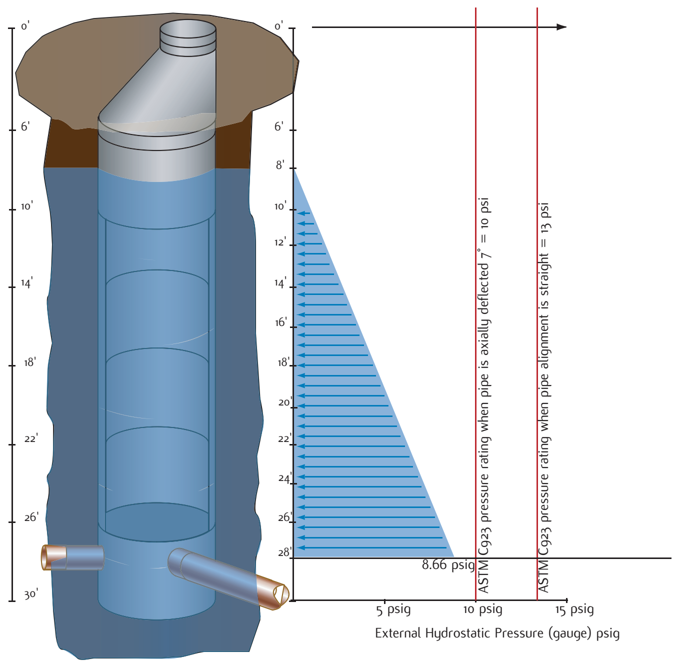
VACUUM TESTING PRECAST CONCRETE MANHOLES

Internal Pressure at Critical Depth (Vacuum pressure)

$$10\ in\ Hg * 0.5\frac{psi}{in\ Hg} = 5\,psi \approx -5\,psi_{Internal}$$

Effects of Hydrostatic Pressure on a Backfilled Manhole

Pressure experienced by ASTM C923 connector as groundwater table returns to normal level. 8' below ground level



Does the Pressure Differential Exceed the ASTM C 923 Pressure Rating?

$$8.66\,psi_{External} - (-5\,psi_{Internal}) = 13.66\,psi > \text{The ASTM pressure rating (13 psi)}$$

The combined vacuum test and in-place hydrostatic loads exceed the connector's pressure rating so appropriate adjustments must be made.

ADJUSTING VACUUM PRESSURE

Most flexible connectors have a pressure rating of only 10 psi when deflected, which is fairly common in a field installation; therefore we will use the more conservative 10 psi pressure rating as a base point. Drawing a vacuum of 10 inches Hg creates a pressure differential of 5 psi between the interior and exterior of a manhole system. A water column of 11.5 feet creates an additional 5 psi of external pressure. This ultimately creates a pressure differential of 10 psi at a connector located 11.5 feet under water when drawing a vacuum of 10 inches Hg.

A conservative rule of thumb is to reduce the vacuum by 1 inch Hg for every 1 foot of hydrostatic head between 12 feet and 21 feet. A vacuum test should not be performed when the hydrostatic head exceeds 22 feet.

Hydrostatic Head (ft)*	12	13	14	15	16	17	18	19	20	21	22
Vacuum Pressure (in Hg)	10	9	8	7	6	5	4	3	2	1	**

* Hydrostatic head above critical connector

**At 22 feet below the groundwater table, the connector is naturally subjected to 9.5 psi

Above Example Continued

Using the recommendation above, the testing agency should draw only 2 inches Hg to prevent overloading the flexible connector as illustrated in Figure 3.

External Pressure at Critical Depth (Hydrostatic pressure)

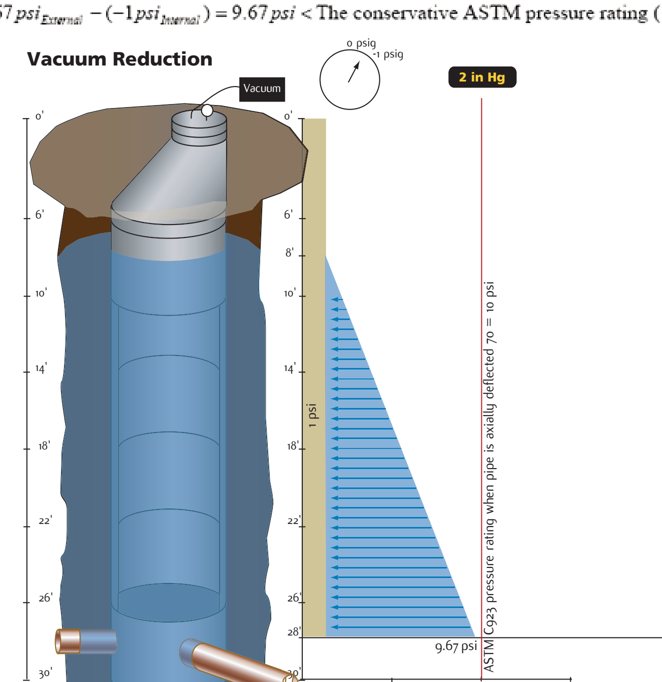
$$0.433\frac{psi}{ft_{head}} * (28\,ft - 8\,ft) = 8.66\,psi_{Hydrostatic}$$

Internal Pressure at Critical Depth (Adjusted Vacuum pressure)

$$2\ in\ Hg * 0.5\frac{psi}{inHg} = 1\,psi \approx -1\,psi_{Internal}$$

$$8.67\,psi_{External} - (-1\,psi_{Internal}) = 9.67\,psi < \text{The conservative ASTM pressure rating (10 psi)}$$

Vacuum Reduction



By reducing the vacuum to only 2 in Hg, a pressure differential of 9.66 is created which is below the ASTM C923 limit.

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APPENDIX (SUPPLEMENTAL INFORMATION)

A. DETECTING LEAKS:

Prior to Backfilling: Leaks, though rare, can be readily detected by finding the source of the hissing sound as air enters the manhole. Leaks can also be detected by spraying water on the exposed wall surface – infiltrating air will produce a dry spot. If the manhole fails the initial test, make repairs and retest until obtaining a satisfactory test.

After Backfilling: Leaks can be detected by spraying a soapy solution on the interior of the manhole. Solutions of 2 to 10 ounces of liquid soap per gallon have been recommended for ambient temperatures below 80 degrees F (27 degrees C). A similar solution with a few ounces of corn syrup is recommended for temperatures above 80 degrees F (27 degrees C). Bubbles will form at leaks. If the manhole fails the initial test, make repairs and retest until a satisfactory test is obtained. When adequate repairs cannot be made from the interior, exterior repairs should be made by means of excavation.

B. STAND PIPES:

The presence of ground water near a manhole can have a significant effect on the performance of a manhole system during a vacuum test as outlined above. To avoid damaging the installed system, an accurate measurement of the water table is required to account for hydrostatic loads. Install a stand pipe alongside the manhole stack during the backfill process. Once dewatering operations cease and the water table stabilizes, measure the water level by lowering a chain or measuring tape into the stand pipe.

C. PRESSURE RATINGS:

ASTM pressure ratings shall be used unless the manufacturer provides sufficient data indicating a higher rating.

ASTM C 923, “Standard Specification for Resilient Connectors Between Reinforced Concrete Manhole Structures, Pipes and Laterals”

> This specification covers the minimum performance and material requirements for resilient connectors used for connections between reinforced concrete manholes conforming to Specification C478 and pipes, between wastewater structures and pipes, and between precast reinforced concrete pipe laterals.
>
> This specification requires that resilient connectors withstand 13 psi of hydrostatic pressure for straight aligned pipes and 10 psi of hydrostatic pressure for axial deflected pipes and laterals.

ASTM C 1478, “Standard Specification for Storm Drain Resilient Connectors Between Reinforced Concrete Storm Sewer Structures, Pipe, and Laterals”

> This specification covers the minimum performance and material requirements for resilient connectors used for connections between precast reinforced concrete storm sewer structures conforming to Specification C 478 and pipes, and between precast reinforced concrete pipe and laterals for storm drainage systems.
>
> This specification requires that resilient connectors withstand 6 psi of hydrostatic pressure for straight and axial deflected pipes and laterals.

D. OTHER TEST METHODS

Prior to the introduction of vacuum testing, manholes were typically tested for watertightness in accordance with:

ASTM C 969, “Standard Practice for Infiltration and Exfiltration Acceptance Testing of Installed Precast Concrete Pipe Sewer Lines”

ASTM C 924, “Standard Practice for Testing Concrete Pipe Sewer Lines by Low-Pressure Air Test Method”

ASTM C 969 may take up to 72 hours or more to complete, while ASTM C 924 presents a potential safety hazard if the line is not prepared properly and if procedures are not followed. Test pressures must also be adjusted to account for groundwater tables when using ASTM C 924 with a maximum testing limit of 5 psi gauge pressure, in which case ASTM C 969 is to be used. ASTM C 969 also has limitations in the fact that the structure is not uniformly tested.

DISCLAIMER