BOODE
waterwell systems

QUALITY BOODE SINCE 1897

PVC Well Casing and Screen - Selection and Precautions

Acknowledgement to Mr. David Ball - Hydrogeologist, Dublin, Republic of Ireland

1. Introduction

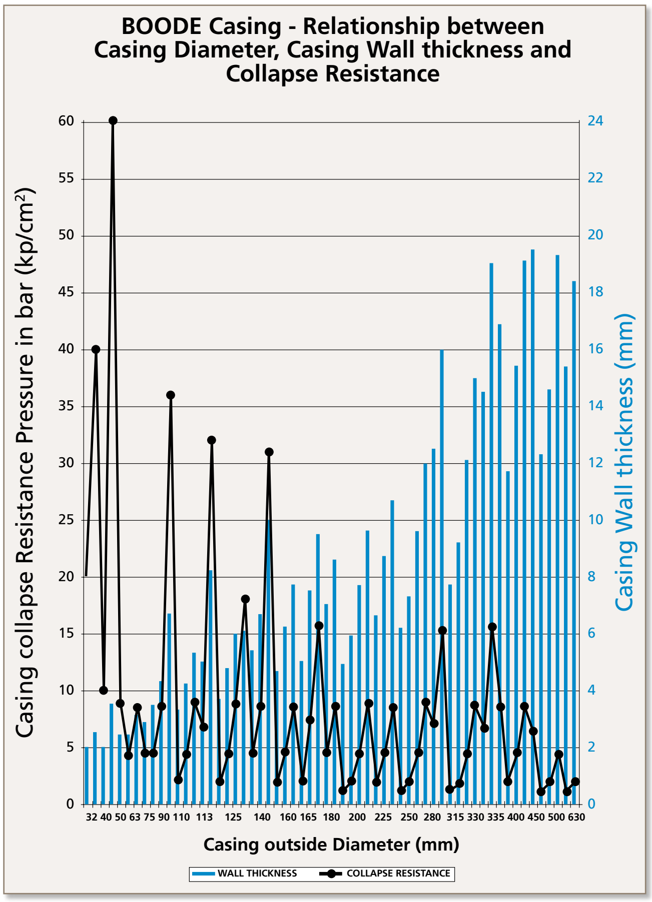
PVC Well casing and screen is widely used because it is light, strong, easy to install, durable, corrosion resistant and relatively inexpensive. The choice of any material depends upon its strengths and weaknesses in relation to the particular intended use. Conditions at a water well drilling site, and within a borehole, are generally aggressive. PVC casing and screen is easily able to withstand most conditions, but it is important for a driller, engineer or hydrogeologist to be aware of conditions or circumstances that might prejudice the integrity of the PVC and consequently the borehole. The purpose of this leaflet is to draw attention to these conditions and circumstances and the properties of PVC casing and screen. The aim is to provide a basis for the correct selection and handling of PVC casing and screen. The leaflet is based upon calculations, and field experience of drilling conditions and common practice.
PVC is a plastic. It has a low compressive and tensile strength relative to steel. It can be softened by heat, deformed by sudden or gradual stress and shattered by strong impacts. Generally PVC casing is stronger than PVC screen, and thick walled PVC casing is stronger than thin walled casing. PVC is much more flexible than steel, therefore it should be supported, both on the ground, and in the borehole. Its strength can be reduced by prolonged exposure to strong sunlight. It is attacked by solvents such as vinyl chloride. Volatile organic chemicals can pass through PVC by a process that is not fully understood.

Technical Data for Boode PVC and HDPE well screen and casing systems:

Mechanical and physical properties	PVC	HDPE
Tensile strength	7823 lbf/in2 55 N/mm2 (550 kp/cm2)	3129 lbf/in2 22 N/mm2 (220 kp/cm2)
Elasticity coefficient	426690 lbf/in2 3000 N/mm2 (30000 kp/cm2)	113800 lbf/in2 800 N/mm2 (8000 kp/cm2)
Specific gravity	78.5 lb/ft3 1.4 g/cm3	53.2 lb/ft3 0.95 g/cm3
Vicat softening temperature	176°F 80°C	257°F 125°C
Impact strength at 20°C/68°F	Rigid PVC approx. 5 Kj/m2 (cmkp/cm2) High impact resistant PVC approx. 15 Kj/m2 (cmkp/cm2)	>20 Kj/m2 (cmkp/cm2)
Colour	BOODE blue	- Natural (white) - Black

2. Determining the Strength of PVC water well casing

The strength of PVC casing is often described as collapse resistance. The strength, or collapse resistance, depends upon both the thickness of the wall of the casing and the diameter of the casing. A narrow diameter casing is stronger than a wide diameter casing with the same wall thickness. It is more difficult to deform narrow diameter casing. Narrow diameter casing usually maintains a perfectly circular circumference profile.
The specifications for the different sizes of casing manufactured by Boode are given in the technical specification brochure. Boode manufacture casing with a different wall thickness for each external diameter.
The figure below is a graph that shows the strength of PVC casing manufactured by Boode.
The graph plots the outside diameter of PVC casing, the alternative wall thickness for each diameter and the collapse resistance pressure.



The external diameter of each casing is given in millimetres along the bottom of the graph. The blue vertical bars show the wall thickness. The red dots show the collapse resistance pressure for each combination of diameter and wall thickness.
The graph shows that a 32 mm diameter casing with a 2mm thick wall has a collapse resistance of 20 bar, and the same diameter casing with a wall thickness of 2.5 mm has a collapse resistance of 40 bar. Whereas, on the right of the graph, a 630 mm diameter casing with an 18.4 mm wall thickness only has a collapse resistance of 1.9 bar.
It can be seen, that though the wall thickness increases with diameter, the collapse resistance generally decreases with diameter.

3. Pressures or Conditions that might deform or break PVC casing and Screen

PVC casing can be deformed or shattered by a various forces and under a range of conditions. Some of these occur naturally but many are created by lack of consideration during the design, construction and development stages of water well and monitoring well drilling. Below are descriptions of common stresses, forces and conditions that might deform or break PVC casing or screen.

3. 1. Hydraulic pressure

3.1.1 General Considerations and Hydraulic Pressure created by Water or Drilling Mud

Hydraulic pressure is usually exerted externally on PVC casing and screen. Whereas hydraulic pressure is exerted internally on water distribution pipes. Hydraulic pressures across a PVC screen are usually small, if the screen slots are fully open. There is usually a balance of pressure across an open screen. Hydraulic pressure on a screen only becomes a consideration when the screen and or gravel pack around a screen are clogged. In effect, a clogged screen becomes a section of plain (un-slotted) casing, but with the additional consideration that the wall of the screen is weakened by the slots.

PVC casing or screen can be deformed when the hydraulic pressure on the outside is much greater than inside. The issue is pressure difference, or differential pressure. An unacceptable differential hydraulic pressure can be created by an excessive weight or depth of water, or another fluid, such as cement grout or drilling mud, on the outside not being balanced by a sufficient weight or depth of water on the inside. Such conditions can occur inadvertently when an open ended string of PVC casing is pushed into soft mud in the bottom of the hole, and then an air-hammer rig is used to blow out all the water from inside the casing, before beginning to drill on, below the bottom of the casing. Suddenly, there is no column of water inside the casing to balance the column of water in the annulus around the casing. The casing is squeezed inwards, and usually, permanently deforms to an oval shape in cross section. The deformation is greatest at the bottom of the casing string where the differential pressure is greatest. See photograph.

It is easy and straightforward to calculate the static pressure difference between the outside and inside of a casing. The pressure exerted by a column of water inside the casing is the height of the column of water multiplied by the Specific Gravity. For ease of calculation the Specific Gravity of water is taken as 1.0 and temperature and salinity differences are not considered. The pressure exerted by 10 metres of water is approximately 1 bar, 1 atmosphere or 1 kilopound/cm^2.

The example below shows the annulus around the casing filled with bentonite drilling mud and only 10 metres of water inside the casing.

The calculated pressure of water inside the casing is 10 m x 1.0 = 1 bar

The calculated pressure exerted by the drilling mud outside the casing is 100 m x 1.05 = 10.5 bar.

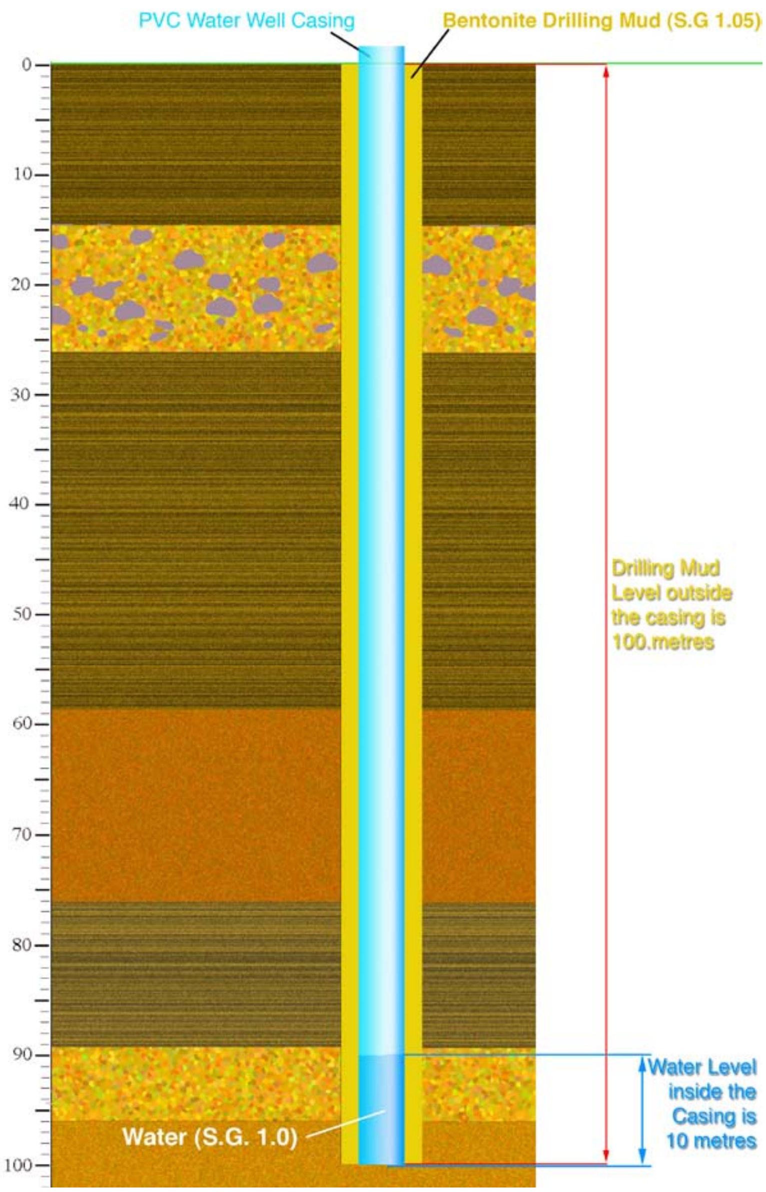
Therefore the PVC casing must be able to withstand a pressure difference at its base of at least 9.5 bar (10.5 bar - 1 bar). However, a factor of safety of 2:1 is recommended, therefore the casing ideally should be able to withstand a pressure of 19 bar. This could be a very strong, and probably expensive, thick walled PVC casing. A much less expensive alternative would be to ensure that the PVC casing is at all times filled with water. The differential pressure between 100 metres of mud in the annulus and 100 metres of water inside the casing would be:-

The calculated pressure of water inside the casing is 100m x 1.0 = 10 bar

The calculated pressure exerted by the drilling mud is 100m x 1.05 = 10.5 bar.

Therefore, the pressure difference would be just 0.5 bar and with a factor of safety of 2:1 it would be acceptable to use a casing that would be able to withstand a pressure difference of just 1 bar.

Example 1: Hydraulic Pressure created by drilling mud outside PVC casing



3.1.2. Hydraulic Pressure and heat created during Grouting

A cured, complete cement grout filled annulus around a PVC casing provides an excellent support for the casing against hydraulic pressures exerted by fluids in the aquifer. However, cement grout is injected as a fluid. The specific gravity of cement grout is much higher than water. It varies, depending on the cement water mix and the proportion of any additives, but it is usually between 1.75 and 1.85. In other words neat cement and water grout is nearly twice weight or density of water.

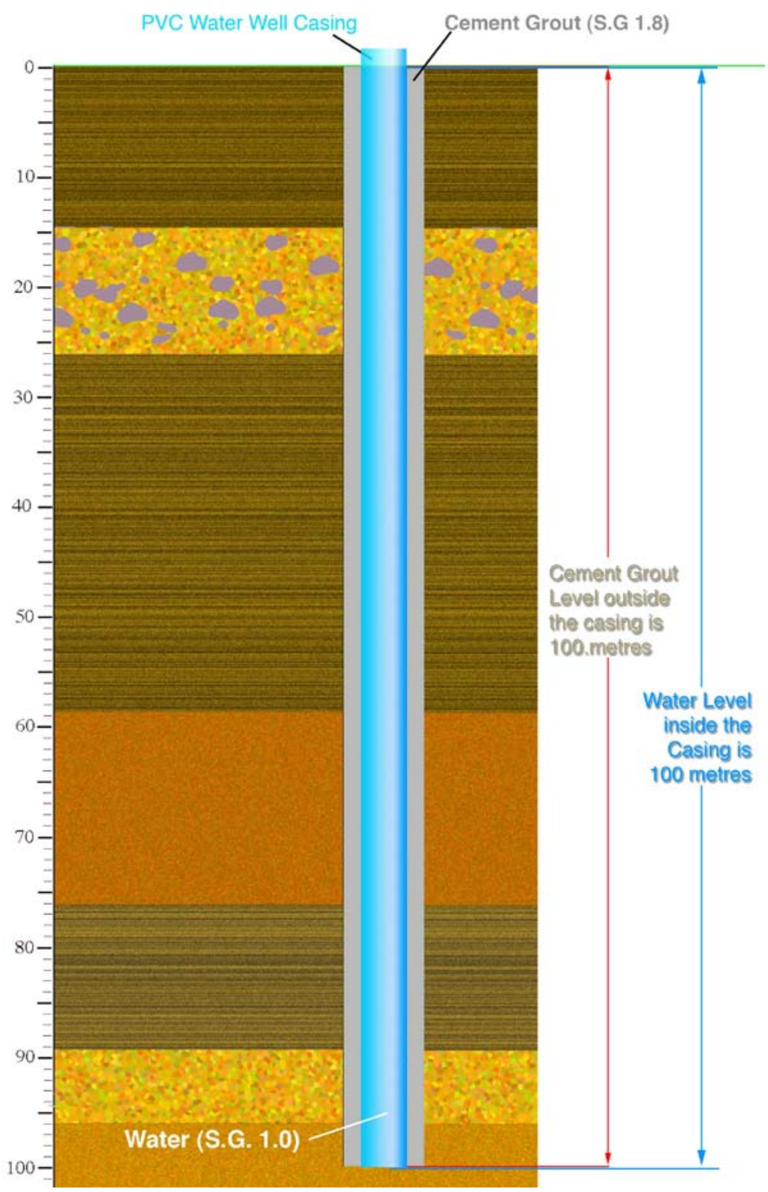
The figure below shows the same example as above, but in this case the PVC casing is filled with water and the annulus around the casing is filled with neat cement grout.

The calculated pressure of water inside the casing is 100m x 1.0 = 10 bar

The calculated pressure exerted by the cement grout is 100m x 1.8 = 18.0 bar.

Therefore, the pressure difference would be 8 bar, and with a factor of safety of 2:1 it would be acceptable to use a casing that would be able to withstand a pressure difference of 16 bar. For example, a Boode 125 mm outside diameter casing with a 7.5 mm wall thickness would have a collapse resistance of 18 bar.

Example 2: Hydraulic Pressure created by Cement Grout outside PVC casing

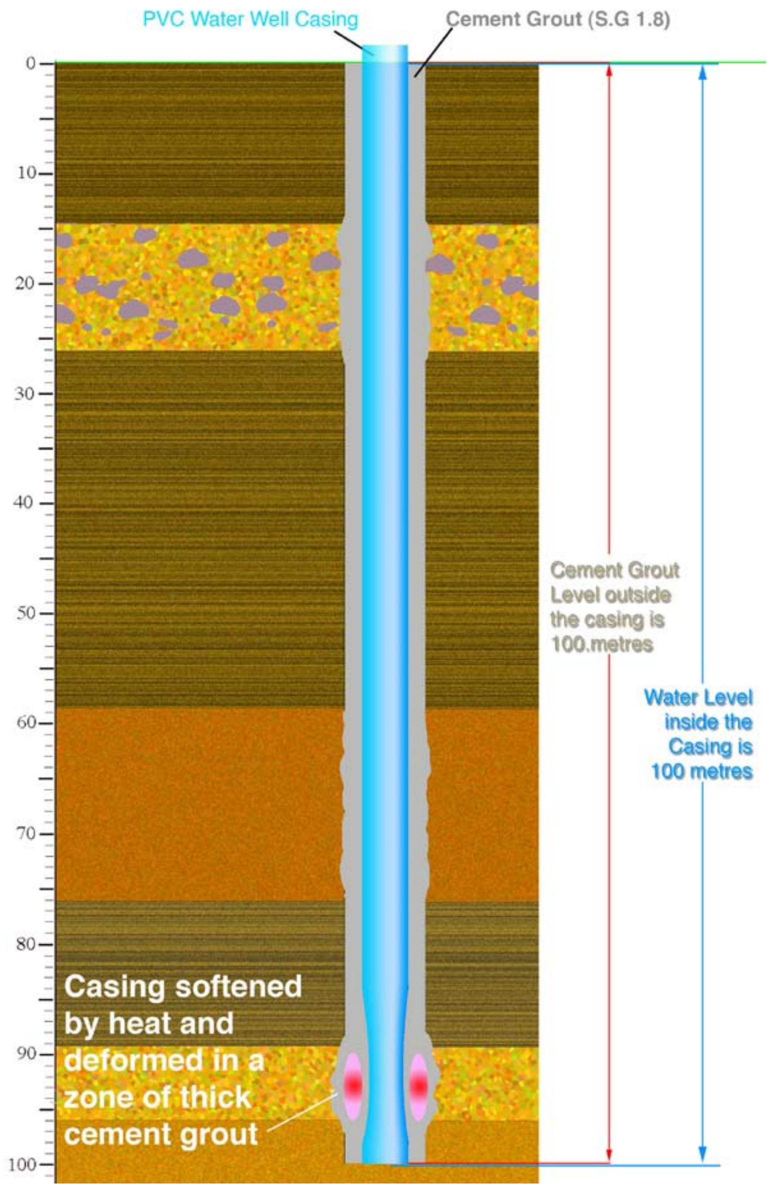


It is important to recognise that a chemical reaction takes place as cement grout cures, and goes hard. This chemical reaction produces heat, that can soften the PVC casing, and reduce its strength. PVC casing is not a good thermal conductor. Cement grout is also not a good thermal conductor. Therefore, the heat produced during the curing of the cement is not dissipated rapidly, and localised 'hot zones' can occur where the annulus around the casing is wide. These occur when the diameter of the drilled hole is irregular and over-sized, or when the hole has been drilled through rock containing cavities.

The Example 3 shows how casing can be deformed next to a wide diameter section of hole drilled through a soft formation.

The casing is deformed where the cement grout in the annulus is wide, and the hydraulic pressure created by the liquid grout is highest.

Example 3: Casing deformed by heat and hydraulic pressure in a wide zone of Cement Grout outside the casing

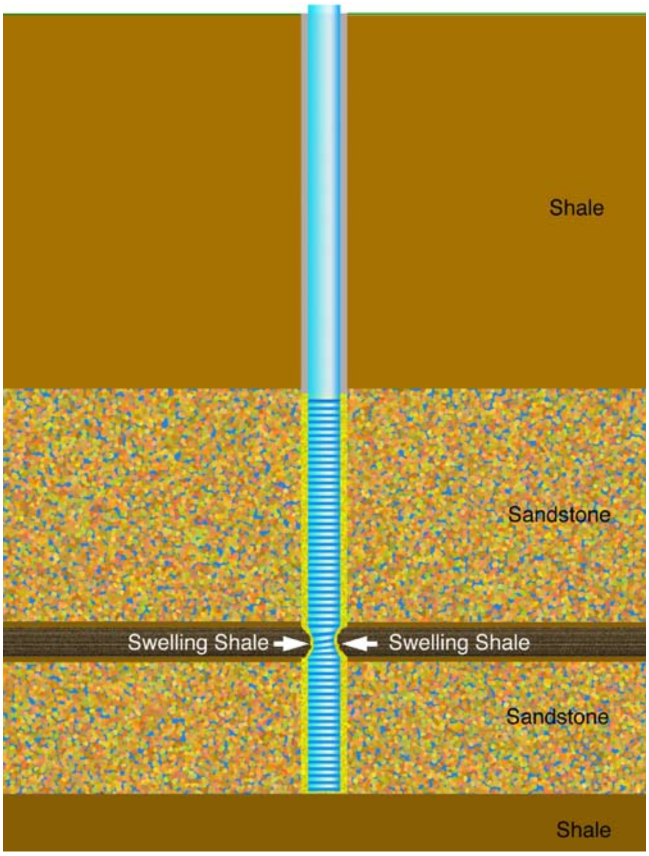


3.1.3. Formation Stress

PVC casing and screen can be deformed by external pressures arising from changes in the rock and soils outside the borehole. The drilling of a borehole alters pressures underground, and also exposes rocks or formations that expand when hydrated.

For example, some clays and shales can swell when exposed to water. It depends upon the chemistry of the clay or shale, and the chemistry of the water. The annular space around the casing or screen is often very small. Therefore the swelling does not need to be large before the clay or shale touches, and begins to exert a pressure on the PVC. The swelling can deform the casing, particularly if the pressure from the clay or shale is confined, by a sealed annulus above and below the formation. In other words the shale or clay can only expand laterally. Casing and screen can be deformed even if there is a gravel pack between the shale or clay and the PVC. The pressure is exerted against the gravel pack, which, in turn transfers the pressure onto the PVC. An example of deformation caused by swelling shale is shown in Example 4.

Example 4: Formation Pressure - Swelling Shale

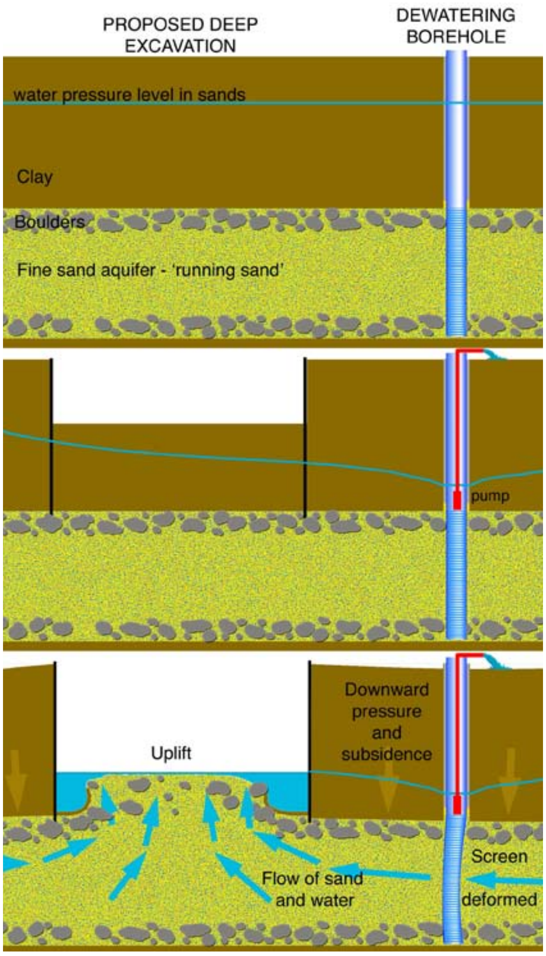


Casing and screen can be deformed or sheared if there is a sudden or progressive change in pressures away from the borehole. Example 5 shows three stages of and excavation through a thick, confining clay into a fine sand aquifer. It shows that unfortunately the sheet piling terminates in a layer of boulders at the top of the sand aquifer. Boreholes with a screen section in the sand are used to lower the piezometric head (upward water pressure) from the sand aquifer. The third stage shows a catastrophic geotechnical failure of the excavation floor. The thin clays at the base of the excavation are raised by the pressure in the aquifer. The base of the excavation fills with water, boulders and sand. The fine sand making up the aquifer matrix flows with the release of hydrostatic pressure, and under the weight of the confining clays. The aquifer matrix exerts a pressure as it moves. This lateral pressure, and the subsidence of the clay, bends the borehole screen.

It is therefore important to consider the integrity of the PVC casing and screen within the context of events outside the immediate vicinity of the borehole.

However, it is also important to recognise that the circumstances where the formation exerts excessive pressure are unusual. Slow progressive formation pressure usually only affects wide diameter casing and screen, whereas sudden formation movement will bend, shear or fracture all diameters of casing and screen.

Example 5: Formation Pressure exerted by Geotechnical Failure



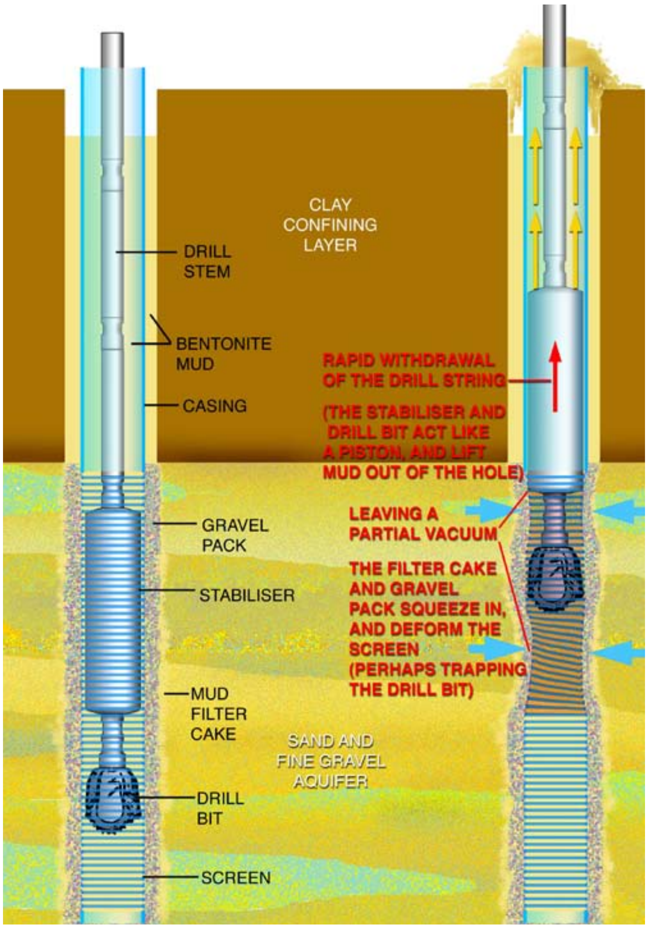
3.1.4. Sudden Internal Vacuum

Casing and screen can be deformed by pressure changes inside the casing and screen. It is easy to underestimate the negative pressure, or partial vacuum that can be inadvertently created by the movement of drilling tools inside a borehole. The drill string can occupy much of the internal volume of a borehole. The gap between the drill bit, stabiliser, or hammer body and the inside of casing and screen can be a matter of a few millimetres.
The first part of Example 6, on the left, shows a drill string consisting of drill bit, subs, stabiliser and drill pipe inside a bentonite mud filled hole. The gravel pack has been installed around the screen, but the hole has not been developed. The mud in the hole and the mud filter cake, are still supporting the sides of the hole.

The second part of Example 6 illustrates the effect of rapidly pulling the drill assembly up the hole, from the screened section into the cased section. The space between the stabiliser and the casing and screen is insufficient to allow mud to flow rapidly past the stabiliser. The stabiliser acts like a piston and pushes mud out of the top of the casing.

The space below the stabiliser and bit becomes a void, and a partial vacuum. The water from the aquifer cannot flow rapidly through the filter cake and the gravel pack, and the hydraulic pressure difference across the screen and gravel pack bends the screen inwards. Sometimes, the screen is severely deformed but remains intact. Sometimes, the sudden collapse of the screen against the drill bit, can trap the drill bit. The power of a modern drilling rig can easily overcome the strength of the PVC, and the drill string and bit can be removed, but, with the consequence, that the bars between the screen slots are broken. As a result, the gravel pack and the sand and gravel aquifer will flow through the broken screen. All the work carried out up until that moment, to construct a high quality, efficient, sand-free borehole, can be destroyed in a few, ill-advised seconds.

Example 6: Screen deformation created by partial internal vacuum



3.1.5. Vertical Pressure

An assembly of PVC casing and screen can be deformed by a vertical pressure from above. PVC casing is and screen is flexible, and if compressed from above will bend within the confines of the borehole.

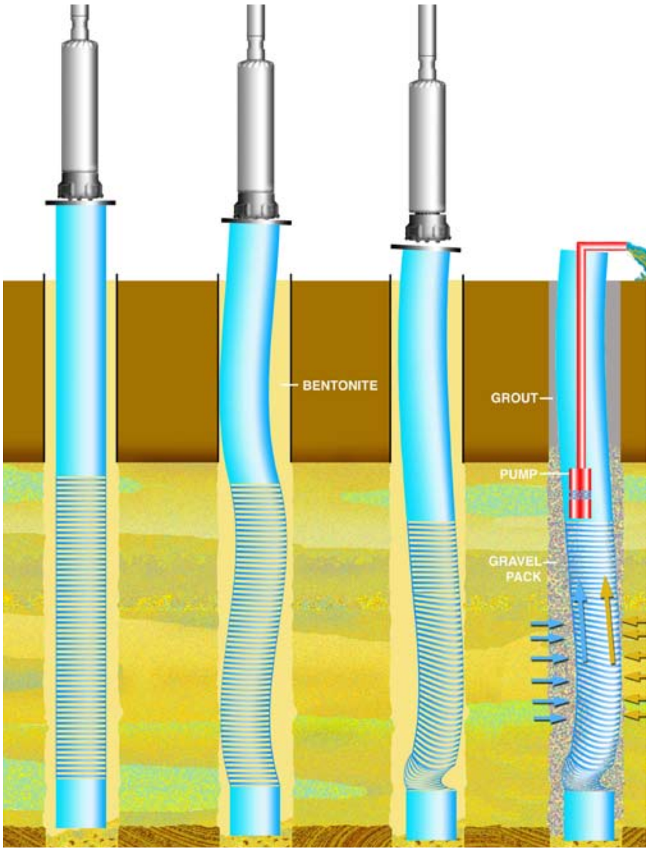
Example 7 illustrates the installation of a casing and screen assemblage into a borehole drilled with mud into a sand and gravel aquifer. It is often difficult to remove all the drill cuttings from a borehole. A casing and screen assemblage is usually fitted with a blank end cap at the bottom. The driller lowers the casing and screen into the borehole, but the sediment at the bottom prevents the complete installation to the total drilled depth of the borehole. The driller decides to put a casing drive-plate on top of the PVC casing, and use the drill bit to gently push the casing deeper into the hole. The casing appears to be going down (as shown in stage 2 of Example 7). However, the casing and screen actually are bending within the hole. This bending is not a permanent deformation. The casing and screen assemblage will straighten if the compression is removed. The apparent success often can encourage the driller to slightly increase the pressure. Suddenly the casing and screen seems to move easily to the bottom of the borehole. The casing does not spring back, straighten and rise out of the borehole when the weight of the drill bit is lifted off the casing drive plate. The casing and screen assemblage appears to have been successfully installed to the full depth of the borehole.

However, as is illustrated in the third step in Example 7, the pressure exerted by the rig has exceeded the strength of the screen. The screen has buckled and concertinaed at the bottom. The screen usually buckles and permanently deforms just above the more rigid short length of casing forming the end cap and sump.

The permanent deformation of the screen is not evident at the surface. A gravel pack still can be installed, and an airlift assembly or DTH hammer can be installed to near the bottom of the hole to develop the gravel pack and clean out the mud.

The upper part of the borehole is not severely deformed and relatively straight. A pump also can be installed into the upper pump chamber casing, as shown in the final step in Example 7. Superficially, it appears that the borehole has been constructed successfully and in accordance with the specification. However, the permanent deformation of the borehole becomes obvious when a pump test is carried out, or the borehole is put into production. The pumped water persistently contains fine sediment or sand, because there is no gravel pack around the screen on one side of the borehole. The borehole will never produce clear water unless a natural gravel pack can be developed in the aquifer in the sections where there is no gravel pack. Step 4 in Example 7 shows clear water flowing into one side of the borehole screen, whilst water containing fine sand and silt from the aquifer is freely flowing in on the other side of the screen.

Example 7: Deformation of the Borehole screen by compression



3.1.6. Lateral Compression and brittle failure after External Impact

Deep boreholes in hard bedrock are seldom perfectly straight and vertical. They are often a gentle, elongate helix. An assemblage of screw threaded PVC casing and screen is usually straight. Therefore, even with a 50mm, or 2 inch, annular space around the PVC, it is not unusual for the casing and screen to snag on irregularities in the sides, or shape of the borehole. PVC casing and screen cannot be driven down a borehole if it meets some resistance. It will bend, as shown in the above example, or shatter, if hammered against a solid bedrock obstruction. Sometimes, a PVC assemblage of casing and screen becomes trapped in a bedrock borehole, because fragments of rock become detached from the borehole sides, and become wedged between the casing and screen and the borehole wall. This is common when the borehole has been drilled through bedrock with lost circulation zones, by direct circulation mud drilling, or Down-The-Hole Hammer drilling. Drill cuttings or pieces of loose rock are flushed into cavities during the drilling but can be dislodged back into the hole when the casing and screen is installed. Pushing the casing and screen with these pieces of rock trapped in the annulus can cause the rock fragments to either break the PVC bars between the screen slots, or exert a lateral force that fractures or compresses the casing.

An extreme example is shown in Example 8 to illustrate how the weight of the casing and screen and rock trapped in the annulus can break a screen.

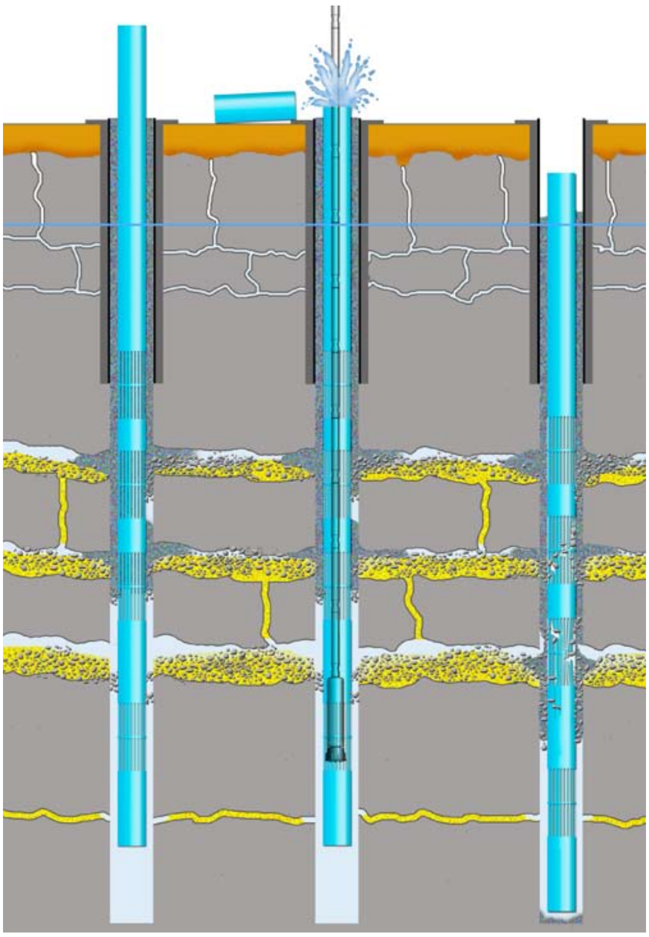
Example 8 shows a deep borehole drilled into massive hard limestone. There is a thin overburden or superficial layer above the bedrock. There are small fractures or karst cavities in the upper bedrock. There are large cavities or caves in the lower bedrock. Many of these cavities are open, high permeability conduits, but with sands clays and gravels deposited on the floor. The cavities are ‘lost circulation zones’, into which the drilling process has flushed rock cuttings and larger rock fragments. In stage 1, on the left of Example 8, some of the rock fragments have fallen back into the hole as the casing and screen were installed and bridged between the rock walls and the PVC. The PVC has become locked into position in the borehole without reaching the total drilled depth. The driller has decided not to push the casing down, but proceed with the installation of the gravel pack, even though the screen sections are not in the optimum position. The gravel pack cannot pass down beyond the blockages. Some of the gravel pack has flowed into the open space in the cavities or caves. The top of the casing above ground is removed in order for the driller to either install the drill string, or install an airlift assembly inside the casing to develop the gravel pack around the slots.

The airlift pumping and or surging loosens the rock and gravel pack bridge holding the casing and screen in place. The casing and screen, under its own weight falls down the hole. Stones and rock fragments in the annulus violently compress the screen and buckle, crack or fracture the PVC bars between the slots. This shown in step 3 in Example 8.

A consequence of fractured screen is that gravel pack material and sediments from the cavities can enter the borehole through the fractures and gaps in the screen. Therefore, it becomes very difficult to create a high yielding water supply borehole that provides sediment free water.

PVC screen can be broken from the inside, in a similar manner as the stones trapped in the annulus can break screen from the outside. Screen can be cracked or sections snapped off from the inside when, for example, part of the drill string, or a pump, is lost down the hole, and attempts are made to 'fish' for the lost equipment. The 'fishing tool' can wedge or snag between the lost equipment and the screen, and exert a sudden or gradual pressure that fractures the screen bars.

Example 8: Screen fracture from External Impact




Fragments of screen broken during 'fishing operations'

4. CONCLUSIONS

PVC casing and screen provide many advantages in borehole construction. The materials are light, easily handled and assembled, relatively inexpensive and not susceptible to corrosion. The material is effectively chemically inert, and therefore strong chemicals can be used during a borehole work-over to break down lime-scale or biofilms that might reduce the hydraulic efficiency of the borehole over time.

PVC casing and screen are, in many ways, the ideal material for use in water supply borehole construction. The purpose of this document has been to explain, and illustrate how the purpose and integrity of this ideal material can be compromised by ill-considered or inadvertent procedures. Hopefully, in conclusion, it is easy to see that the successful use of PVC casing and screen is not difficult, but it needs to be handled, installed and used with care, and an understanding of the forces or conditions that can have a negative impact.