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# Design and Construction of Pressure Relief Wells for High Underground Water Canal Section of the Middle Route of the Large Water Transfer Channels

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**Abstract** The large water transfer channels has a total length of more than 1 000 km, spanning across the Huaihe River, the Yangtze River, the Yellow River and the Haihe River basins. During the preliminary design stage, the groundwater level was predicted based on the initial water level plus the groundwater level increase by precipitation infiltration and recharge in 1956 and 1996. However, after the rainfall in 2021 and 2023 to infiltrate and recharge groundwater, it is necessary to re-forecast the groundwater level. The Hebei section was taken as an example. Combined with the actual measurement of the historical maximum water level of the monitoring section and the inspection along the line, the water seepage of the canal slope was found. It is necessary to investigate the drainage system of the high groundwater level canal sections, take necessary treatment measures to improve the ability of the drainage system to cope with the rapid rise of high groundwater caused by heavy rainfall, and strengthen drainage measures for the risk parts of project safety in the high groundwater level canal sections, which are essential to ensure the safe operation of the middle route of the large water transfer channels.

**Key words** Large water transfer channels; High groundwater; Pressure relief wells; Design; Construction

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The section north of the Yellow River in the middle route of the large water transfer channels is arranged along the front of the Taihang Mountain. During the preliminary design phase, permanent drainage facilities such as pumping pump stations and strong pumping stations were adopted for high groundwater level canal sections. Since 2016, the middle route of the large water transfer channels has provided ecological replenishment to more than 50 rivers in northern China, significantly contributing to the management of groundwater over-extraction in North China and the ecological restoration of rivers and lakes. In some areas, groundwater levels have stabilized and begun to rise. During the flood season, a large amount of water flooding from the mountains to the channel is distributed in the lower part. When there is continuously heavy rainfall, the rainfall will be supplied in front of the mountain, and the lower water transmitting layer will have micro-pressure. Due to the presence of relatively permeable layers such as sand lens along the channel, and varying lithologies, the coefficient of permeability differs across sections. In areas with higher permeability, the groundwater level rises more rapidly, and may exceed the warning threshold (where the external water level is more than 10 cm higher than the internal channel water level). In the original design, the groundwater level of some canal sections is lower than the bottom of the canal, and drainage measures are not considered. As a result, the groundwater cannot be discharged into the canal due to the sealing effect of the composite geomembrane, leading to the top support failure of lining slabs. Due to the irregular distribution of sand lens and the lack of a consistent pattern in their depth relative to the surface, it is necessary to adopt a settled drainage measures such as a pressure relief well to ensure the safety of the lining slabs.

## 1 Design and technical requirements for pressure relief wells

**1.1 Working principle of pressure relief wells** The principle of pressure relief wells for draining infiltration water is as follows: through filter pipes, the infiltrated water flow from the canal dyke is directly imported into the well, rapidly reducing the underground pressure head. It prevents an increase in water pressure that could damage the lining structure, ultimately aiming to lower the groundwater level and reduce the extent of immersion, and preventing waterlogging damage[1 – 2].

**1.2 Design of pressure relief wells** At present, the high ground water canal sections of the large water transfer channels mainly employ a combined drainage system of "pumping drainage + gravity drainage". The drainage system is composed of water-based gravel layer, water collection pipe, connecting parts and decompression wells[3].

**1.2.1** Pressure relief wells. To rapidly lower the high groundwater level during shutdown maintenance or low-water operational conditions, pumping wells are installed at 20 m at the foot of the second-level channel slope. The well has a diameter of 300 mm,

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with the bottom elevation 9.0 m below the first-level berm. Inside the well, a DN200PVC collection pipe is used, with perforations around the pipe, and an opening rate of no less than 12%. The perforations are arranged in a plum-blossom pattern, and the pipe is wrapped with geotextile. The gap between the collection pipe and the well wall is filled with a mixture of coarse sand and fine gravel, with a mud content not exceeding 1%, and 50 cm of crushed stone is placed at the bottom of the collection pipe. The wellhead is equipped with a 50 cm × 50 cm × 40 cm ($L \times W \times H$) C30 concrete pedestal, and a steel protective casing is used to safeguard the wellhead. During heavy rainfall which results in sustained high groundwater levels, or during shutdown maintenance or low-water operation conditions, drainage is enhanced by using a mobile gasoline-powered pump to extract water until the groundwater level reaches the channel bed, at which point the pump is turned off.

**1.2.2** Drainage blind ditch. The interception sink is arranged under vertical drainage groove of the first-level berm, with a width of 0.5 m and a depth of 1.5 m. The lower part is sand gravel water layer (80 cm thick), and the upper part is a clay block and drainage ditch. DN200PVC water pipes are provided in the water collection layer of the sand, and one of the horizontal drainage pipes is set at 20 m intervals, connecting to the water collecting pipe. The horizontal drainage pipe adopts a DN200PVC pipe, the drainage and longitudinal slope is 1/100, the elevation of the horizontal drainage pipe outlet and the design water level of the general canal channel are flat. The collection pipe is perforated with an opening rate no less than 12%, arranged in a plum-blossom pattern, and the pipe is wrapped with geotextile. The horizontal drainage pipe mouth is set up a flap door to ensure that the channel water does not flow back when the high water level is running. The flap door uses a 30 cm × 30 cm glass reinforcement plate (3 mm thick), and the upper part is connected to the concrete structure with the wire.

### 1.3 Technical requirements

(1) When the groundwater level in the canal dyke reaches a certain high course, it is efficiently put in the laying pressure wells to reduce the pressure of the water head, so as to avoid abnormal conditions under the natural conditions of the original pipe surge and weak locations.

(2) The pressure relief well is the "safety protection barrier" of the dyke. With proper design and construction, it can play a protective role. However, if there are issues with the canal section, it may, at best, affect the water discharge and pressure relief effect, and at worst, cause damage to the underlying soil structure[4]. Therefore, geological survey must be done in the early stage, and the design should be organized by the design unit according to the actual situation. The pressure relief wells are located on the outside of the first-level berm of the primary canal. In order to ensure safety, the construction of pressure relief wells should be accelerated during the dry season, so that they are completed before the onset of the flood season.

## 2 Construction process of pressure relief wells

**2.1 Construction process** Preparation→surveying and setting out→drilling machine positioning→drilling into hole→putting the well pipe→backfill, washing, water-pumping test→protective device.

### 2.2 Surveying and setting out, drilling machine positioning

The axis and hole position of the pressure relief well are measured, and the drill is accurately placed at the determined well position. In addition, according to the measurement control network points, combined with the safety monitoring facility data, the well location measurement and laying out operation are completed, and then the steel barrel is buried. When the drill is in place, it should ensure that the drill maintains a stable state. The ruler is set on the drill rod so that the construction personnel will observe the actual depth in a timely manner during the drilling process.

The construction sites are mostly clay. When it is raining, it is not conducive to the smooth movement of the drill under the harsh environment. In this regard, it is advisable to choose a drill with lightweight characteristics.

### 2.3 Drilling into hole

**2.3.1** Reverse circulation hole formation. An reverse circulating rotary drill is used to make holes, and clear water is used for rotary drilling. During the process of drilling, the flow loss changes of flushing solution should be observed at any time. The supplement of the water should be adjusted in time with the flow loss of the rinse solution. Generally, the flushing fluid should be kept not lower than 1 m below the well. When drilling in a strata mainly based on clay, due to the thick drilling slurry and the low efficiency of drilling, some mud can be discharged at this time, and water should be replenished to adjust the mud density to a suitable state. The collapse and oblique holes should be treated in a timely manner during drilling process. When shrinking the hole, the drilling tool should be lifted to repair and expand the hole wall. Each impact should not be too long to prevent the jamming of a drilling tool, and reverse circulation rotary drill is used to drill down to the the required depth.

**2.3.2** Positive circulation hole formation. When the positive circulating rotary drill is used to make holes, the mud protection measures are adopted to maintain the stability of the hole wall and avoid collapse. The viscosity is the key influencing factor of the application effect of the wall protection mud, and the specifics should be based on the conditions of the ground layer. For clay layers, sand layers, and gravel-sand layers, the viscosities of the mud used are typically 18, 25, and 32 s, respectively.

The well hole adopts the combined operation of positive and reverse circulation, and 2 drill bits are adapted for the drill to meet the operating requirements of different drilling stages. The diameter of the initial formation drill bit is 90% of the design diameter of the pressure relief well, while the diameter of the reaming drill bit is consistent with the design diameter of the well.

During the drilling construction stage, the initial formation drill bit is used first. Once drilling into a specific depth, it is replaced with the reaming bit. After the mud is displaced, reaming begins from the upper section and gradually progresses downward, and the filter cake formed during the initial drilling phase is removed, to keep the hole in a relatively clean state.

**2.4 Well flushing and well casing installation** After drilling into the depth of design, the well casing consists of multiple sections and peripherals. The length of a single PVC plastic tube is 6 m long. When splicing, the PVC sleeve is used to weld them in one to form a complete and strict well casing. A guiding device is installed at the bottom of the well casing, and positioners are placed every 3 m along the well casing to secure it, ensuring that the well casing does not shift during subsequent construction processes.

**2.5 Backfilling with filling material and well washing**

**2.5.1** Backfilling with filling material. After installing the well casing, the gravel should be filled between the outside of the sand-free filtration well casing and the wall of the well, and it should be filled in slowly to prevent the crooked well casing. At a depth of approximately 1.50 m from the wellhead, a clay seal should be applied to prevent surface water and rainwater from entering the well.

Once the well casing is installed, gravel filling material should be promptly filled between the well casing and the soil wall. The particle size should be greater than the pore diameter of the filter, generally a fine gravel of with a diameter ranging from 3 to 8 mm. The gravel filter material must meet the requirements of the grade, and the particles beyond the upper and lower limits of designed gravels are removed. The qualification rate is greater than 90%, and the impurities content is not greater than 3%. The material should not be loaded directly by a loader; instead, it should be placed with a shovel to prevent uneven layering and impact on the well casing. The backfilling process should be completed continuously in one operation.

**2.5.2** Well washing. After cementing is completed, a parallel drilling tool is lowered, and an air compressor is used to create vibrations for well flushing. Once the water is clear and the sand is removed, the parallel drilling tool is retrieved, and a submersible electric pump is lowered to continue the well flushing until the water is clear and free of sand. For dewatering wells drilled using the impact drilling method, mud circulation is typically used during drilling. Well flushing should be conducted within 8 h after the casing is installed and the gravel pack is placed to prevent delays that could affect the dewatering efficiency.

The principle is that when compressed air is introduced into the lower part of the casing, a gas – water mixture is created inside the casing, which has a lower density (less than 1), while the surrounding mud – water mixture outside the casing has a higher density (greater than 1). This creates a pressure differential between the inside and outside of the casing. Under this pressure difference, the mud – water mixture outside the casing flows into the pipe, resulting in a gas – water – soil mixture inside the casing. As the gas volume increases, the density of the mixture decreases, and the three-phase mixture is continuously expelled from the well. The soil content in the filter material gradually decreases until the well is cleaned. When there is a significant amount of mud and sand inside the casing, the "air-lock boiling" method can be used. This involves repeatedly closing and opening the valve on the casing to allow the gas – water – soil mixture to disrupt the well wall filter cake. About 30 min after starting the well cleaning and then every 60 min, the valve should be closed for 2 – 3 min to trap the air, causing the water inside the well to boil. This process helps to damage the filter cake and reduce the adhesion between the mud-sand and the filter material. The cleaning continues until the water discharged from the casing changes from turbid to clear and the normal discharge rate is achieved. Well flushing should be performed within 8 h after the casing is installed, the filter material is placed, and the sealing is completed. The process should be carried out in one continuous operation to prevent prolonged delays, which could lead to the gradual aging of the well wall filter cake, making it difficult to remove and potentially affecting the infiltration efficiency.

**2.6 Pumping test** Following the aforementioned method, a pumping test is conducted after well flushing. The objectives of the pumping test are as follows: ① to observe the actual water level of the pressure relief well and scientifically determine the layout of upstream and downstream pressure relief wells; ② to rationally determine the recharge time for the pressure relief well and select appropriate pumping equipment; ③ to monitor the changes in nearby groundwater levels after draining from the pressure relief well and assess whether the groundwater level meets the requirement of being lower than the channel water level.

**2.7 Well pass device** The pressure relief well head assembly includes the well pedestal and a three-way valve device. After the well casing installation is completed and passes the pumping test, the construction of the well pedestal can begin. First of all, the excavation is carried out at the wellhead to the design elevation. After compaction and leveling, concrete is poured to form the protective pedestal. The well cover is typically made of stainless steel and is secured with a lock. Currently, there are a large number of pressure relief wells installed along the middle route of the South-to-North Water Diversion Project. In order to improve quality, increase efficiency, and enhance the pumping reliability, a solar-powered automatic pumping and drainage system has been independently developed. The system has shown excellent operational performance in the field.

## 3 Key process control and process optimization of pressure relief wells

### 3.1 Key process control

(1) Quality control of drilling. During the construction of the

pressure relief well drilling, the diameter of the hole formation is required to be not less than 275 mm. The holes are accurately measured by the commissioner to reduce the deviation as much as possible. After the drilling machine is in place, the pillow wood is set and fixed to ensure stability throughout the drilling process. The final drilled hole must meet the required standards in terms of hole position, diameter, depth, and wall verticality, otherwise it will be trimmed in time.

(2) Quality control of sleeve installation. PVC sleeve is used for the connection, and the connection site must be stable. After the connection and the screw fixation, the well casing needs to be completely straight, and the joints must be completely sealed. After that, the well casing was put into the hole, and was appropriately adjusted to stabilize it in the center of the drilling hole. It was temporarily fixed to avoid bias[5].

(3) Quality control of backfill. According to the construction requirements, high-quality fillers are selected. The grade should be continuous, and uniform backfill should be conducted. During the period, it should timely detect the recovery height, compare the actual measurement results and design requirements, and then make targeted adjustments to control the backfilling elevation deviation within the license range.

**3.2 Method optimization** According to the on-site geological survey, it was found that the stratum in the depth of the pressure relief well is more complicated in Cixian. With the sand layer, the holes are often collapsed or the protective sleeve cannot be pulled out. If no protective measures are taken, it will significantly increase the difficulty of well formation, and the collapse of the well wall is prone to occur during construction. For this situation, optimization measures are taken as follows:

(1) After various discussions, it is decided to use the response method of DTH drill + steel sleeve. In addition, it should optimize the construction time and method (timely extracting tube, filling) after hole formation, and minimize the squeezing force of the surrounding pebbles on the casing pipe. At the same time, when the pipe is pulled, it can properly irrigate the water around the pipe to play a lubrication effect.

(2) Due to the small gap between the well casing and the drilling hole wall, the backfilling of filter material must be careful and serious to ensure the quality. The filter material is evenly filled around the wall of the well. When the conditions permit, the catheter method is to extend the catheter into the bottom of the hole, and then pour the filter material. After the filter material is filled back to the predetermined elevation, and enters the viscous soil layer, and the filling amount of the filter material reaches 95% – 98% of the calculation amount, the dry clay balls are filled back. This section of well casing belongs to the water lift pipe section, and clay balls can be thrown in segments, and a steel pole is used to compact it until the mouth of the hole.

## 4 Conclusion

At present, the pressure relief wells are an effective measure to reduce the groundwater level during the operation stage of the middle route of the large water transfer channels, ensuring that the operation of the channel lining is safe. Its mature construction technology and methods provide useful references and experience guidance for the construction of water conservancy engineering under similar geological conditions, and provide technical guarantee for the safety, stability and efficient operation of the project. Through the optimization of the construction process and plan of the pressure relief well in the large water transfer channels, valuable project experience has been accumulated, and the advanced drilling technology, reasonable well-body design, and flexible well wall support strategy are screened, which is the key factor to ensure the smooth progress of the project. By improving the stability and reliability of the design and construction of the pressure relief wells, it can better serve the management and utilization of local water resources, lay a solid foundation for the sustainable development of society and the economy, and make a significant contribution to the long-term sustainability of hydraulic engineering projects.

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