Geosynthetics, J. Kuwano & J. Koseki (eds)

Study on the porous foam filter and its application in relief well of Yangtze River dike

Zhang, W.[1], Xu, J.[1,2], Bao, C.[1] & Zhu, G. [1]
1 Changjiang River Scientific Research Institute, Wuhan, China
2 Dept. of Hydraulic Engineering, Tsinghua University, Beijing, China

Keywords: porous foam filter, relief well, clogging, Yangtze River, dike

ABSTRACT: The relief well as a seepage control measure to reduce the water pressure of confined layer is used very often in Yangtze River dike. However, the clogging problem is a common phenomenon due to its intermittent running in complicated hydro-geologic environment of the Yangtze River. How to deal with the clogging or to prolong the run-life of relief well is an important topic for engineers. According to past experiences and research work on the clogging mechanism, a new pattern of relief well, in which the filter can be replaced if it is clogged, has been developed and used in Yangtze River Dike. The core of relief well is made of porous foam filter, and it can be knocked down conveniently. A series of experiments indoor have been carried out to understand its mechanism and to validate its affect. The origin of clogging and its process are also analyzed here in order to predict the performance of filter. Moreover, some results of field-tests executed in Yangtze River Dike have also been presented in this paper. It indicates that fine sand, clay, chemical mineral, colloid of bacteria, etc., may deposit mainly in porous foam plastic filter. Therefore, to replace or clean-up the clogged filter is a measure possibly to maintain the original permeability of filter and to keep long run-life for relief well.

1 INTRODUCTION

Relief well is installed for the purpose of relieving subsurface hydrostatic pressures that may develop within the pervious foundations of dams, levees, and hydraulic structures (Turnbull & Mansur 1953). Relief well system is particularly effective to control the seepage, prevent any significant sand boils or piping (Mansur et al. 2000). It has been used as a seepage control measure to deal with the problem of seepage under dikes through pervious foundations since 1950s in China (Zhang et al. 2000). However, Investigation revealed that the clogging of relief well was a serious problem depressing drainage capacity. For example, a number of relief wells were installed in 1958-1973 along the Jingjiang Dike (Sun et al. 1990). At the beginning, these relief wells were of good performance to reduce the uplift gradient of top stratum during flood time. Only 3 to 5 years after construction, however, the efficiency of most relief wells were decreased rapidly, even lost thoroughly, due to the clogging located on the well screen slots, or/and in the granular filter around well screen, further in the pervious stratum outside borehole.

It was found that there were three factors leading to the clogging in relief well or water well. Those were so-called mechanical or physical clogging, chemical clogging and biological clogging, according to the origin of clogging materials (Wu et al. 2005). The physical clogging is caused by the deposition of suspended solids in the hole of well screen slots, filter and substratum. The solids include clay, fine-sand, organic material (plant tissues) and other particles coming from stratum. The chemical clogging often occurs due to the hydro-chemical reaction of mineral ion in the groundwater, for example, the $CaCO_3$, $Fe(OH)_2$ or/and $Fe(OH)_3$ will deposit when the groundwater flows out. The biological clogging is commonly defined as colloid barrier caused by microbiological activity, such as iron related bacteria, sulfate-reducing bacteria and other types (David et al. 1995). In general, the biological clogging of well often in conjunction with physical and chemical clogging is encountered under a wide range of conditions.

Well washed or cleaned by mechanical surging combining with oxidizing solutions of chlorine bleach or hydrogen peroxide was often adopted to restore the drainage effect. However, the rehabilitation technique did not effectively remove all the clogging material, then, the specific capacity of well did not return to the original value, resulting in a steady decline over the long term (Harrie et al. 2003).

In 2000, based on investigation of hydro-geologic conditions in the mid-stream of Yangtze River, a new type of relief well was developed in order to delay the clogging process to prolong the relief well life. This is a kind of geosynthetics -- a porous foam filter to be used to insert in relief well instead of the traditional well screen. However, this porous filter is not completely fixed and can be drawn out and replaced. By cooperating with granular material putting in outside of the porous filter, the majority of clogging material will sink inductively in the porous filter probably. By replacing the clogged porous filter with a new one, the drainage capacity of relief well will be restored.

Some laboratory tests and field application had been done to verify its performance. In this paper, the test results and some field experiences on its application in Yangtze River dike are presented.

2 DESIGN OF RELIEF WELL

2.1 *Description of new relief well and its purpose*

The new pattern of relief well consists of two parts: fixed and removable as Fig.1. The fixed part is the same as traditional one, but the diameter of new relief well is bigger than that of traditional one. It includes a well screen which consisted of a hard PP pipe (diameter ϕ=400mm, the thickness of pipe wall t =10mm) with openings and a piece of geo-net around well screen, and a layer of granular filter (thickness t> 110mm). The removable part will be installed inside well screen after the construction of fixed part. It is made of a lightweight PVC pipe (diameter ϕ=280mm, thickness of pipe wall t= 4mm) with openings, and a block of porous foam (thickness t =50mm) surrounding lightweight PVC pipe.

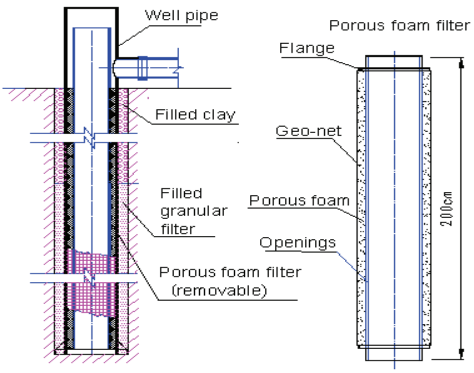

Figure 1 Sketch of relief well and its porous foam filter.

Harrie et al (2003) suggested that the clogging material of water well was concentrated as pore-reducing coatings around and between sand grains in the first 100 mm outside the borehole wall. However, with respect to relief well, especially in Yangtze River, the chief origin of clogging material is not the physical clogging by particles, but the chemical clogging in conjunction with microorganism activity. When groundwater flows out, the carbonate and iron hydroxide will occur inside and nearby well pipe, because of the release of subsurface hydrostatic pressure and the increase of oxygen density, showing as the formula (1) and (2). The process of chemical clogging is demonstrated in Fig.2 (a). Therefore, the initial chemical clogging material will be concentrated from well screen slot to granular filter, rarely outside borehole. Moreover, the habitat of bacteria also begins from the inside of granular filter to the outside.

$$Ca^{2+} + 2HCO_3^{-1} \longleftrightarrow CaCO_3 \downarrow + CO_2 \uparrow + H_2O \quad (1)$$

$$2Fe^{2+} + O_2 + 2H_2O \longleftrightarrow 2Fe(OH)_2 \downarrow \text{, or}$$
$$4Fe^{2+} + 3O_2 + 6H_2O \longleftrightarrow 4Fe(OH)_3 \downarrow \quad (2)$$

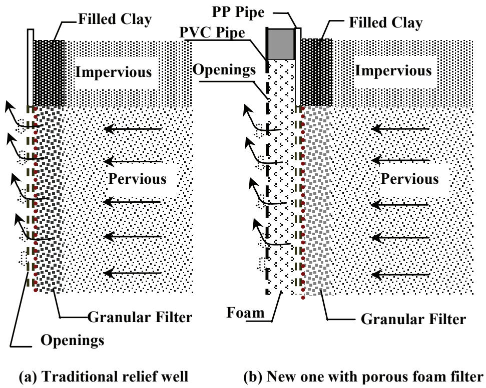

Figure 2 Diagram of the clogging process of relief well.

As we know, there is a mutation of water environment on the interface between the inside of well screen and the outside. The velocity and pressure of groundwater change evidently when it flows into well from subsoil layer. The chemical and physical clogging takes place because of peculiar environment adjacent to the periphery of well pipe. Instead of well screen and granular filter, the porous foam filter acts as transitional zone to bear the mutation of water environment, in order to reduce the deposition of carbonate, iron hydroxide, silt and other solids on the well screen slot and in granular filter, shown as Fig.2 (b).

2.2 *Materials for well*

Investigation revealed that one of the reasons of serious clogging happened in the Yangtze River was imputed to the wrong choice of well materials. In past time, most of relief wells were made of ferrous pipe. Moreover, the wire was selected to fabricate slots around opening well pipe. As well known, these materials can not withstand the corrosion by iron related bacteria in conjunction with hydrochemical reaction.

Based on mentioned above, it is essential that the new relief well should be fabricated from corrosion-resistant material where corrosive waters are expected. Therefore, the macromolecule synthetic materials, such as PVC, PP pipe, porous foam and nylon net, are the best choice to make new relief well.

2.3 *Porous foam filter*

The foam is selected to fabricate removable filter because of its high porosity and good corrosion-resistance. In 1980s, the porous foam had been applied as filter in the drainage hole within the soft-rock foundation of Gezhou Dam nearby Yichang city in China. The drainage hole has still kept good condition even over twenty years. Moreover, light porous foam is easy to be installed and knocked down, and it is suitable to tighten on the well screen because of its flexibility. The general properties of porous foam are listed in Table 1.

Table 1 Properties of porous foam.

Items of test	Unit	Test data
Density	kg/m^3	32.0
Tensile strength	kPa	107.2
Elongation ratio	%	195.0
Rebound ratio	%	41.5
Tear resistance	N/cm	2.0
Hydraulic conductivity	cm/s	5.68×10^{-1}
Equivalent opening	mm	0.49

The porous foam is made from polyurethane with adding vesicant. The porous foam block (size: 2000mm×880mm×50mm) is enlaced tightly around lightweight PVC pipe by thin geo-net. Therefore, the length of one porous foam filter unit is 2 meters. It can be linked one by one by ebonite bolt, depending on the depth of well.

2.4 *Granular filter*

Granular filter consists of coarse gravel. In order to prevent infiltration of substratum sands into the filter, the filter gradation must meet the requirement of soil retention, which is the 15 percent size of filter should not be greater than five times of the 85 percent size of the foundation material (ASCE 1993, Mao et al. 2005). For the design of new relief well, the gravel size should be bigger than that criteria to allow any clay, fine sand or organism, which entered in the filter, to flow out through the filter, rather than sinking in it. It is possible that a little bigger size grains of substratum around well would also move into the granular filter and deposit, if the 15 percent size of filter was greater than five times of the 85 percent size of the aquifer. It was found that the permeability of granular filter could not reduce considerably, even though the granular filter was filled up with the grains of sandy substratum.

In addition, it is impossible that a great amount of substratum grains and gravels enter into well, because there is a porous foam filter inside well screen. Therefore the stability of granular filter and substratum can be guaranteed easily. On the other hand, the max hydraulic gradient of groundwater around relief well is generally less than 1.0.

3 LABORATORY TESTS OF POROUS FOAM FILTER

According to the investigation of old relief well constructed after 1960s (Sun et al. 1990), it was found that the chemical clogging of iron hydroxide is the primary factor to shorten the run-time of relief well in Yangtze River. Therefore, a small scale experimental model was made to simulate the work condition of relief well. In order to identify the effect of porous foam porous, some tests with or without foam were performed in laboratory.

The content of total iron (Fe^{2+}, Fe^{3+}) in granular filter and foam filter was detected and presented in Table 2. The original content of total iron in the granular is 0.13%~0.20%. Results indicate the iron hydroxide was concentrated in the inner portion of granular filter if there was no foam filter. Contrarily, if there was a porous foam filter inside in granular filter layer, the iron hydroxide wouldn't be concentrated in the granular filter, but in the porous foam filter.

Table 2 Content of total iron (Fe^{2+}, Fe^{3+}) in filter (%).

Sample position		Test No.			
		CHY1-2	CHY2-1	CHY2-2	CHY2-3
In porous foam filter		-	7.35	6.07	6.25
granular filter	Inner portion	0.35	0.15	0.14	0.15
	Middle	--	0.13	0.15	0.16
	Outer portion	0.15	0.21	0.21	0.26

4 APPLICATION IN YANGTZE RIVER DIKE

In the early 2002, 105 relief wells were installed behind Jinnan Dike located in the mid-stream of Yangtze River. Among them, 9 relief wells are new type well with porous foam filters. The others are traditional type without porous foam filters. The materials of pipe of relief wells for both two types are the same, except a little difference of grain size of granular filter. For traditional type, the D_{15} of gravel filter is 2-4 times of the d_{85} of the aquifer, rather then 7-8 times for that of new type.

The results of pumping test to six neighboring relief wells are listed in Table 3. It indicates that the effect of new type is closed to that of traditional one. About three months after flood season, pumping test was done again in some wells. The data were not so different than before. The more important thing is the porous foam filters in the C32 relief well were knocked down, in order to check its characteristics and detect the clogging material and its location as well. Some photos of porous foam filter were taken, shown as Fig.3.

Table 3 Results of pumping test.

Type of well	Well No.	Well depth (m)	Discharge (m^3/h-m)	
			Test data	Average
Traditional type	C27	22	24.2	18.2
	C28	22	16.4	
	C29	22	14.1	
New type with porous foam filter	C30	22	16.0	17.4
	C31	22	18.4	
	C32	22	17.9	

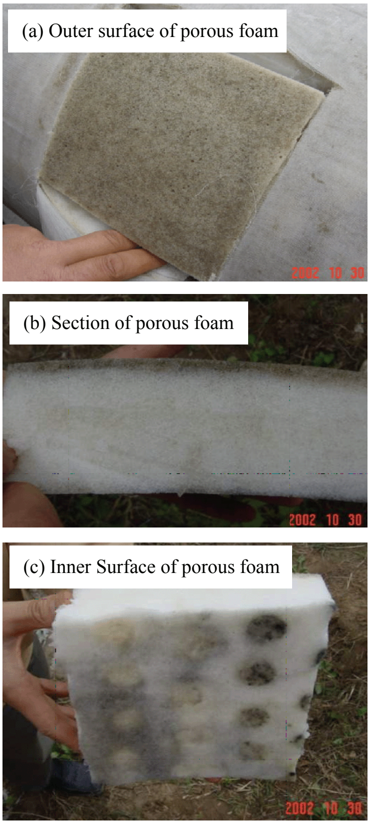

Figure 3 Photos of porous foam knocked down from C32 well.

From those photos, the outer surface of porous foam is gray, as Fig.3 (a), it is because of fine sand, silt and other soil grains retaining in it. Based on the chemical test, there is no more iron hydroxide existed. On the inner surface of porous foam, there is different color such as, black gray or aqua, at different depth under water, as Fig.3 (c), because of the variation of deposits of iron hydroxide, carbonate, in conjunction with the concentration of iron related bacteria and sulfate-reducing bacteria. The test indicates the hydraulic conductivity of porous foam is still bigger than 5×10^{-2}cm/s.

5 CONCLUSIONS

The preliminary attempt of using porous foam filter and other geosynthetic materials is to mitigate the clogging problem of relief well. The performance of porous foam filter has been verified initially by laboratory and field tests in the Yangtze River since 1980. The physical clogging material, such as clay, fine sand and other particles from aquifer are concentrated in the outer portion of porous foam filter. In contrast, the chemical clogging material, which consists of iron hydroxide and carbonate are concentrated in the inner portion. The habitat of iron related bacteria and others are also located in the inner portion. Therefore, to change the clogged porous foam filter is a measure possibly to restore the original permeability of relief well.

The solid particles from aquifer are also deposited in the granular filter. In general, even though the granular filter is filled up by solid particles without chemical and biological activities, the permeability of granular filter doesn't reduce a lot. At present, it is conjectural that there is no accumulation of chemical clogging material and the biological clogging material in granular filter. More research work need to be done in near future to validate and estimate the ultimate clogging term of porous foam filter.

REFERENCES

ASCE.1993. Design, construction and maintenance of relief wells, Manuals and Reports on Engineering Practice, n43315, pp1-84

David E.R., Judith M.S.1995. The role of bacteria in well clogging, Water resource, Vol.29, No.1, pp365~369

Harrie,T., Jan-Dik V. and Antoine G.J.2003. Well clogging by particles in Dutch well fields, American Water Works Association .Journal, Vol. 95, No.8, pp 112-118

Mansur, C.I., Postol, G., Salley, J. R. 2000. Performance of relief well systems along Mississippi River levees, Journal of Geotechnical and Geoenvironmental Engineering, Vol. 126, No.8, pp 727-738

Mao, C., Duan, X. and Feng, Y. 2005. Study on piping and filters: Part II. Filters, Rock and Soil Mechanics, Vol. 26, No. 5, pp 680-686, Language: Chinese

Sun H., Wu B. and Wang Y. 1990. Experimental study on the Physical chemical clogging of drainage well in Jingjiang dyke, Hydrogeology and engineering geology, 1990(5), pp15-17, Language: Chinese

Turnbull, W.J., Mansur, C.I. 1953. Relief well systems for dams and levees, American Society of Civil Engineers -- Proceedings, Vol. 79, No. 192, pp1-20

Wu C., Zhang W., and Sun H. 2005. Present situation on relief well clogging mechanism research, Journal of Yangtze River Scientific Research Institute, Vol.22, No.2, pp60-62, Language: Chinese

Zhang, J. ,Wu, Z., Xu, J. and Zhu, G. 2000. Analyses on effectiveness of relief wells for Anqing dike, Journal of Yangtze River Scientific Research Institute, Vol.17, No.4, pp38-40, Language: Chinese