Performance evaluation of improved subsurface drainage system

Shaoli Wang
shaoliw@iwhr.com

Outline

1. Background
2. Materials and methods
3. Results and discussion
4. Conclusions
5. Acknowledgement
1. Background

- Floods are major natural disasters in China, causing significant agricultural losses
- South China is prone to surface and subsurface waterlogging. Surface ponding is common after heavy rainfall events, accompanied by water table rising
- Farmland shortage and agricultural pollution provide more opportunities and high requirements to subsurface pipe drainage

Conventional subsurface pipe drainage is quite limited to reduce flood damage. In order to increase the efficiency of subsurface drainage, an improved subsurface drainage is proposed, with less land occupied, high drain discharge and environment-friendly

The specific objective of this study was to evaluate the performance of improved subsurface drainage under different ponding water depths, filter widths, water table depths, soil mediums, and outflow conditions
2. Materials and methods

2.1 Structure

- Based on structures of open ditch and subsurface pipe drainage
- Laying high permeability materials (gravels or slags or wood chips or crop stalks et al) as filter above drain pipe
- Backfilling 30~40cm original soil as plow layer
- Similar structure to ‘French drain’

2.2 Experiment design

Drain discharge is an important index to evaluate the subsurface drainage performance.

What factors impact the drain discharge? How these factors affect the drain discharge?

Clogging of the drain pipe is the main factor affecting pipe working life and drain discharge.

For graded sand and gravel filter, how to choose its specification? How to lay it? (layered or mixed, with or without geotextile, around the filter or pipe, et al)
2. Materials and methods

2.2 Experiment design for discharge

Table 1 Composite experiment design

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Water table depth (cm)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0 (D/Saturated soil)</td>
</tr>
<tr>
<td>B: Filter width (cm)</td>
<td>0</td>
</tr>
<tr>
<td>C: Ponding depth</td>
<td>7cm</td>
</tr>
<tr>
<td>D: Outflow condition</td>
<td>Free</td>
</tr>
<tr>
<td>E: Soil medium</td>
<td>Coarse-sand</td>
</tr>
</tbody>
</table>

- Conducted with a plexiglass cylinder.
- 192 group experiments were conducted.
- Drain discharge and hydraulic conductivities were measured.

Table 2 Hydraulic conductivity measurement

<table>
<thead>
<tr>
<th>Soil texture</th>
<th>Filter width (cm)</th>
<th>Hydraulic conductivity (cm/s)</th>
<th>( k_0/k )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soil medium ( k )</td>
<td>Filter ( k_0 )</td>
<td></td>
</tr>
<tr>
<td>Coarse-sand</td>
<td>0</td>
<td>0.02929</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.02505</td>
<td>0.2806</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.02405</td>
<td>0.2917</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.02475</td>
<td>0.2313</td>
</tr>
<tr>
<td>Fine-sand</td>
<td>0</td>
<td>0.00139</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.00128</td>
<td>0.1024</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.00144</td>
<td>0.1063</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.00135</td>
<td>0.0980</td>
</tr>
</tbody>
</table>

The ratio of hydraulic conductivity between filter and soil medium is \( k_0/k = 78 \) in fine-sand and \( k_0/k = 10 \) in coarse-sand (on average).
2.Materials and methods

2.2 Experiment design for clogging defense

Filter specification was chosen based on Terzaghi’s criteria.

17 group experiments were conducted, including three types: no defense (soil), layered filter, mixed filter, two kinds of geotextile A (38g/m²) and B (75g/m²).

Table 3 Experiments on clogging defense

- The geotextile was laid around the pipe (down-A or B) or on the filter-soil contact surface (up-A or B) or both, such as LAD (layered-A geotextile-Down).

- Dynamic discharge and mass of soil clogging and loss were measured.

Non represents no geotextile, up and down stand for the geotextile around the filter and drain pipe respectively.
3. Results and discussion

3.1 Effects of filter width on drain discharge under free outflow and saturated soil

- Drain discharge of improved subsurface drainage increases obviously with increasing filter width.
- The greater the hydraulic conductivity gaps between soil and filter, the more effective the improved subsurface drainage is.
- Trendlines of discharge were roughly parallel among different ponding depths.

![Graph showing variation of drain discharge with filter width under different ponding depths](image)

3.2 Effects of submerged outflow on drain discharge in saturated soil

- Submerged discharge in fine-sand medium decreased about 20% than that of free outflow in both improved and conventional subsurface drainage under the same ponding depth and filter width.
- Submerged discharge of improved subsurface drainage was obviously larger than conventional ones.
- When filter width varied from 2cm to 6cm, submerged discharges were corresponding to 1.74, 2.04 and 2.38 times of free discharge in conventional subsurface drainage.

<table>
<thead>
<tr>
<th>Outflow condition</th>
<th>Conventional</th>
<th>Improved</th>
</tr>
</thead>
<tbody>
<tr>
<td>free</td>
<td>0.505</td>
<td>1.152</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.337</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.527</td>
</tr>
<tr>
<td>submerged</td>
<td>0.401</td>
<td>0.879</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.029</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.203</td>
</tr>
</tbody>
</table>

![Table 4 Drain discharge under 7cm ponding depth(cm^3/s)](image)
3. Results and discussion

3.3 Effects of water table depth on drain discharge under free outflow

- Drain discharges decreased with water table depth increase for both improved and conventional subsurface drainage.
- When water table depth was $2D$, the discharge of conventional subsurface drainage was about 80% of that at 0cm ($0D$) water table depth in fine-sand texture.

Fig 5. Effects of water table depth on free discharge under 7cm ponding depths

- Conventional subsurface drainage was quite limited in a deep GW area. The improved subsurface drainage was still functioning until water table depth was 5 times of drain depth.
- For conventional subsurface drainage, the curves presented as a straight line with a reverse slope. While for improved subsurface drainage, the curves were divided into two phases in coarse-sand and three phases in fine-sand.
3. Results and discussion

3.4 Effects of water table depth on submerged discharge

- The reduction percentage increased with increasing water table depth.
- The greater the water table depth, the more obvious the influence of submerged outflow is.

![Fig 6. Effects of water table depth on submerged discharge](image)

3.4 Effects of water table depth on the ratio of drain discharge and seepage quantity into GW

- The ratio decreased with the increase of water table depth and increased with the increase of filter width.
- More water recharged the groundwater when soil permeability was large.

![Fig 7. Effects of water table depth on the ratio of drainage and seepage quantity into GW](image)
3. Results and discussion

3.5 Clogging defense by geotextile or filter measure

- The attenuation of drain discharge from small to large was LN<NB<MN<NA. The effect of LN defense was the best, next was NB.

- The effect of clogging defense by layered filter was better than mixed one.
- No matter for layered or mixed filter, setting geotextile around the pipe is more effective than single clogging defense measure.
- The discharge attenuation by setting the geotextile both around the pipe and filter-soil contact surface was the largest (LBB and MBB).

Fig 8. Discharge attenuation under single clogging defense measure.

Fig 9. Discharge attenuation under multiple clogging defense measures.
3. Results and discussion

3.5 Soil clogging and loss

- No defense measure leads the largest soil loss.
- Soil clogging is larger when geotextile is on the filter-soil contact surface.
- In view of discharge attenuation, soil clogging and loss, LBD is the best defense measure, next is LAD.

![Fig10. mass of soil clogging and loss](image)

4. Conclusion

- Improved subsurface drainage has a larger drain discharge than conventional subsurface pipe drainage. It has advantages of less land occupied and lower maintenance costs.
- Filter width impacts drain discharge remarkably, which should be chosen by comprehensive considering the cost and benefit.
- Terzaghi’s criteria could be used effectively in filter design of improved subsurface drainage. And layered filter with reasonable geotextile around drain pipe is the most effective structure for preventing clogging and soil loss.
4. Conclusion

- It can be predicted that the improved subsurface drainage, combined with open ditches, will be an effective way for surface and subsurface waterlogging control in farmland.

5. Acknowledgement

- This work was funded by the Major Program of National Science and Technology Support Plan of China (No.2012BAD08B00), and supported by the National Natural Science Foundation Program of China (No.51279212).
- We also thank all staff for offering experiment sites and giving suggestions.
Thank you for your attention!