Research on the Adaptability of Helicoidal-Ramp Type Drop Shafts

Recherche sur l’adaptabilité des puits de chute de type rampe hélicoïdale

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RÉSUMÉ

Un puits de chute de type rampe hélicoïdale installé sur des regards de visite de systèmes d'assainissement (appelés ci-après “DRS”) est un ouvrage de chute à haute charge qui dissipe l’énergie hydraulique pour que l’eau atteigne le fond sans force excessive. Toutefois, l’augmentation des profondeurs et des débits, la diversification des méthodes de transfert des eaux vers les DRS, et les contre-mesures d’entraînement d’air ont fait apparaître de nouveaux problèmes. Dans cette étude, la direction des flux entrants et les contre-mesures d’entraînement d’air ont été examinées et vérifiées par des essais sur modèles hydrauliques.

La partie supérieure d’entrée d’eau d’un DRS est généralement un raccordement cylindrique à une conduite, mais une autre méthode de raccordement aux réservoirs d’eau est de plus en plus utilisée : au niveau des conduites aval, les méthodes actuelles posent le problème des impacts des remous qui endommagent les installations et génèrent du bruit et des vibrations. Pour remplacer cette approche, un raccordement par mur déflecteur a été examiné. Les entraînements d’air associés au débit d’entrée d’eau sur des regards de visite de grande hauteur peuvent causer des problèmes tels que le dysfonctionnement des conduites, des remous ou des dommages aux regards de visite. Les essais ont permis de vérifier l’utilité de systèmes d’aération et d’acquérir de nouvelles données sur la longueur requise des conduites de prise d’air en fonction de la distance de flottaison de l’air dissout, et l’efficacité des conduites d’assainissement installées au droit des conduites de prise d’air.

ABSTRACT

A helicoidal-ramp type drop shaft installed at high head drop connection manholes on sewage systems (below referred to as “DRS”) is a high head drop work which efficiently absorbs energy to allow water to fall gently to the bottom. However, a variety of new problems have appeared as the depths and flow discharge have increased, methods causing water to flow into DRS diversified, and air entraining countermeasures have been taken. In this research, the direction of the inflow and air entraining countermeasure was examined and verified by hydraulic model testing.

The top inflow part of a DRS is basically a cylindrical pipe connection, but another water tank connection method is coming into wider use. Concerning tank connection, current methods have problems which are backwater impacts on the upstream pipe, damaging facilities and producing vibration and noise. As an inflow shape to replace this approach, a training wall connection method was examined.

Air-entraining according to water from a high-head manhole can cause problems such as a decrease in the pipe’s functioning, gush of the sewage or damage of the manhole. The testing verified an air exhaust system’s functions and obtained new knowledge concerning the required length of the air intake pipes according to the dissolved air flotation distance, and the effectiveness of drainage pipes installed at bends in the air intake pipes.

KEYWORDS

High head drop work, drop shaft, increasing depth, training wall connection method, entrained air countermeasure
1 PURPOSE

In recent years, the depth of underground drainage sewer pipes has been steadily increasing. The Helicoidal Ramp Type Drop Shaft (DRS) method is increasingly used in high head drop applications. Meanwhile, the uses of DRS have also changed, with a variety of new challenges posed by greater depths and higher flow rates, increasingly diverse methods of channelling water flows into DRS, actualization of problems in construction and maintenance, and air entraining countermeasures. This study seeks to investigate these challenges and verify them through hydraulic model testing.

2 ABSTRACT OF DRS

DRS is composed of an Entrance Section, Upper Helicoidal Ramp, Middle Hollow Section, Lower Helicoidal Ramp, and Exit Section (Figure 1). It absorbs energy efficiently and allows water to fall gently to the bottom by creating and sustaining an artificial spiral flow in the Helicoidal Ramp. DRS prevents scouring of manholes, reduces the quantity of entrained air, mitigates noise and vibration, allows a smaller manhole area, and enables work to be completed more quickly.

3 RESEARCH CONTENT

3.1 Flow discharge measures

The first stage of the study involved a questionnaire survey with municipal government authorities in Japan on the diameter of DRS used (Figure 3). It can be seen that there were no results in excess of 2,800 mm in the period up to 2002. Therefore, a diameter of 2,800 mm or less has provided coverage thus far. This figure has been increased to 3,000 mm, resulting in a flow discharge increase of approximately $3 \text{ m}^3/\text{s}$.
3.2 Correspondence to head drop

Figure 4 shows the survey findings on head drop. Results for head drop in excess of 40 m are not shown here. The Middle Helicoidal Ramp has been developed in anticipation of deeper installations in the future. As shown in Figure 5, it is designed to replicate the helical flow in the Middle Hollow Section. It has been trialled in the past and the specifications have been validated. For a head drop 28 times (28D) the DRS diameter the Middle Helicoidal Ramp was trialled. Therefore, it should be possible to provide up to 84 m as the maximum application caliber of 3,000 mm.

On the other hand, past coverage is assumed to be about 45 m or less based on head drop 16.5D and a maximum application caliber of 2,800 mm to be able to apply the internal extractor type DPS. Since a separate review was not conducted, it was assumed to be about 45 m or less for the purpose of this study. This is because there are no instances of construction in excess of 45 m to date, and it is not sufficient to verify the strength of the material and the volume of air.

3.3 Diversification of inflow methods (hydraulic model testing of tank connection methods)

3.3.1 Background and purpose

The top inflow part of DRS is basically a cylindrical pipe connection. The trend is increasingly towards water tank connections where the tank-shaped wash bulkhead is installed such that water flows in from all directions. This approach offers superior workability in relation to connection and less restriction on the diameter of manhole (see Figure 6). However, there is little consistency of shape due to the lack of design specifications. This study therefore seeks to verify the water tank connection method through experimentation in order to determine the optimum shape.
3.3.2 Problem

The water tank connection method allows inflow from all directions. This differs from the direct tube connection method with single direction insertion as shown in Figure 7. Flow decreases when changing from the open channel under pressure, and the water level of the water tank rises. Flow increases when the water level rises and a large volume flows at once; as the water level decreases, the flow decreases in proportion. The water level changes through this repetition as depicted by the arrows in Figure 8 (vertical direction), and this can potentially cause a pulsing effect. The mixed air also contributes to this complex behavior.

![Figure 7 Intake flow from all direction](image1)
![Figure 8 Function of water level](image2)

3.3.3 Experiment case

3.3.3.1 Inflow shape

It is thought that the problem could be addressed by installing a training wall as shown in Figure 9, to make the flow of the inflow part one direction and obtain the round tube connection method with the same water level and flow quantity. To this end, the experiment was conducted with the case of the water tank connection method and the second case (training wall connection method) with a training wall installed.

![Figure 9 Positioning of training wall](image3)
![Figure 10 Positioning of training wall for eccentricity case](image4)

3.3.3.2 Direction of inflow

The results show a further case with DRS at an off-center position as shown in Figure 10. The experiment with the training wall installed verified the case with eccentricity (both left and right).

3.3.3.3 Flow discharge condition

Flow discharge was assumed to increase (1.2 Qd) by approximately 20% above the design flow discharge (1.0 Qd) to a steady shape in addition to the round pipe connection concept.

3.4 Experimental equipment

Figure 11 shows the experimental equipment, while Figure 12 illustrates the experimental design. The water tank parameters were selected on the basis of the highest occurrence rate among 76 results (no eccentricity was 84% in 76 results). Eccentricity was assumed to be a condition of moving the center of DRS to the right and left 0.2Ds relative to the intake pipe center axis. (Eccentricity of <=0.2Ds was 95% in 76 results.)
3.5 Results of experiment

3.5.1 Round pipe connection method (Standardized form, Reference)

As Figure 13 shows, in the wide range exceeding 1.0 Qd – 1.2 Qd, a steady stream regime can be attained in the round tube connection method that is the state of the standardized form.

3.5.2 Water tank connection method

- Circle: As Figure 14 shows, flows greater than 1.0 Qd cause fluctuations of the water surface at the length cycle in the water tank. (The backwater effect on the upstream pipe, facilities damage, vibration and noise was caused by the pressure fluctuation.)
Figure 14 Holding tank stage-discharge characteristics-holding tank, cylindrical profile

- Rectangle: As Figure 15 shows, flows greater than 1.0 Qd cause fluctuations of the water surface at the length cycle in the water tank. However, the phenomenon differs considerably from circle case from the water level flow discharge characteristic in the water tank. Standardization of the water tank connection method is difficult because the inflow part stream regime is highly dependent on the water tank shape.

Figure 15 Holding tank stage-discharge characteristics-holding tank, rectangular profile

3.5.3 Training wall connection method

- Training wall method (no eccentricity): Steady flows up to 1.2 Qd were obtained through installation of a training wall as shown in the following photograph (upper row) (see Figure 16).

Figure 16 Holding tank stage-discharge characteristics-training wall, no eccentricity

- Training wall method (left eccentricity): In the left eccentricity case, unstable regions were prevented at flows of up to 1.2 Qd by installing a training wall as shown in the following photograph (see Figure 17).
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Figure 17 Holding tank stage-discharge characteristics-training wall, left eccentricity

- Training wall method (right eccentricity): In the right eccentricity case, unstable regions were prevented at flows of up to 1.2 Qd by installing a training wall as shown in the following photograph (see Figure 18).

Figure 18 Holding tank stage-discharge characteristics-training wall, right eccentricity

3.6 Summary
In situations where the round pipe connection method cannot be used, the training wall connection method provides a suitable alternative because the water tank connection method is unstable in hydraulics.

4 AIR-ENTRAINING COUNTERMEASURES
(HYDRAULIC MODEL TESTING OF AN AIR EXHAUST SYSTEM CONSISTING OF AIR INTAKE PIPES)

4.1 Background and purpose
The use of storage pipes and long, large inverted siphon pipes that are under pressure during rainfall may be the cause problems such as decreased pipe efficiency, sewage gushing and damage to manholes (scattering of manhole lids, and manhole structures and pavements coming to the surface) associated with water from high head manhole impacting on structure and safety.

It is believed that the problem could be resolved by reducing the volume of air taken from the high head manhole to the pipe.

An example of equipment used for air-entraining in a high head is the air exhaust system developed by JIWET (Patent application, Special opening2003.253739), which includes air intake pipes. The system was verified in a hydraulic model experiment that confirmed the high exhaust performance. Meanwhile, the current air intake pipe design has been verified by hydraulic model experiments at individual facilities. As a result, there is no standard design method corresponding to the size of the facility and air intake pipe.

This experiment uses hydraulic model testing to verify the parameters of the air intake pipe and the impact of collection air efficiency on hydraulics, and generates hydraulics data on the functionality of air intake pipes.
4.2 Air intake pipe

An air exhaust system of air intake pipes, consisting of porous air intake pipes (approximately 5 mm in diameter), an exhaust pipe and the curtain, is installed at the downstream pipe connected to the high head manhole, where it captures entrained air and expels it from the system (see Figure 19).

Figure 19 Exhaust system with air intake pipe

4.3 Experimental methodology

The experimental equipment in connecting pipe is shown in Figure 20. The experimental conditions are outlined in Figure 21 and Table 1.

Table 1 Experimental conditions

<table>
<thead>
<tr>
<th>Hydraulic conditions</th>
<th>Water depth in main pipe</th>
<th>Flow velocity</th>
<th>Air mixing ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100% : pipe full</td>
<td>1.0(0.35), 2.0(0.71), 3.0(1.06)m/s</td>
<td>5.0%, 10.0% of flow discharge</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Collector pipe conditions</th>
<th>Fixed conditions</th>
<th>Comparison conditions</th>
<th>Measured items</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Internal diameter $\phi$ 250mm(Φ31mm) : 1/10 of connecting pipe diameter</td>
<td>Extended (collector pipe length) $\rightarrow$ Type I [6D, D : connecting pipe diameter]</td>
<td>Water level, observation of flow, air mixture quantity, collected air quantity</td>
</tr>
<tr>
<td></td>
<td>Pore diameter $\phi$ 5mm</td>
<td>Type II [10D, D : connecting pipe diameter]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pole distribution open area ratio 2%, pores on 2/3 section of downstream side</td>
<td>Modified (drain) $\rightarrow$ Type A [drain pipe]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Curtain height 500mm : 1/5 of connecting pipe diameter</td>
<td>Type B [external discharge]</td>
<td></td>
</tr>
</tbody>
</table>

※In parentheses, it is a model value.
4.4 Experimental outcomes

4.4.1 Bubble surfacing distance in connecting pipe

The experiment illustrated the bubble surfacing distance in the connecting pipe in each pass flow discharge condition. As Figure 22 shows, there is a linear relationship between flow velocity in the connecting pipe and the bubble surfacing distance in the model.

![Figure 22 Flow velocity in connecting pipe versus bubble surfacing distance (Model value)](image)

**4.4.2 Efficiency of air collection at installed air intake pipe**

Table 1 shows the air content in each pass flow discharge condition of two types for different lengths of air intake pipe.

Figure 23 shows the outcomes from experiment types I and II. In experiments performed with flow velocity of 1.0 m/s (flow velocity 0.35 m/s in the model) and 2.0 m/s (0.71 m/s in the model), all the air taken from the manhole into the connecting pipe surfaces on the upstream side of the curtain and is collected in the top part of the connecting pipe where the air intake pipe is installed. This occurs in a single action because the surfacing distance of the bubble is shorter than the air intake pipe. Therefore, the flow velocity is collection air efficiency in the experiment on 1.0 m/s (0.35 m/s in the model) and 2.0 m/s (0.71 m/s in the model) which is very similar to types I and II.

On the other hand, when flow velocity is 3.0 m/s (1.06 m/s in the model), the bubble surfacing distance is 2.8 m (9.3D) as the model value, and the air collection efficiency of type I (the length of the air intake pipe is 1.91 m as the model value) decreased more than that of type II (pipe length of 3.0 m as model value) because some of the bubbles pass by the curtain and reach the surface.

![Figure 23 Results from air intake experiments](image)

**4.4.3 Examination of remedial measures of collection air efficiency**

As shown in Figure 24, observation of the inner air intake pipe suggested that water was obstructing the exhaust, since the water was collected in the refraction part from the air intake pipe to the exhaust tube while the exhaust was intermittent.

We therefore considered whether air collection efficiency might be improved by using a water extractor pipe to exclude water in the refraction part. Type A set up the water extractor pipe of $\phi$ 20mm in the inside diameter of the model in the pipe bottom in the air intake pipe refraction part. The water extractor pipe exit is oriented in the same direction as the connecting pipe downstream. Type B uses a water extractor pipe in the bottom of the refraction part as does type A, but with the water draining outside the system. Type B was used for verification when the backflow did not influence it because in Type A, there was the potential for water to flow backward from the water extractor pipe (see Figure 25).
The experimental results for type II satisfied the bubble surfacing distance at a flow velocity of 3.0 m/s. Figure 26 shows the outcome of the experiment when remedial measures were applied. The rate has greatly improved to air collection efficiency Q3/Q1 of type II A and II B by 90% or more in the case with large volumes of air taken from the manhole to the connecting pipe. Moreover, air collection efficiency is similar for types II A and II B. This was attributed to the effect of the water extractor pipe and of draining the water outside the system.

![Figure 24 Exhaust obstruction in the intake pipe refraction part](image1)

![Figure 25 Study of modifications to collector pipe (detail of bend in pipe)](image2)

![Figure 26 Comparison of air collection](image3)

### 4.5 Summary

Through this hydraulics model test, we obtained new findings regarding the extension of pipe length based on the bubble surfacing distance and the effect of a water extractor pipe in the refraction part of the system.

However, the results in this study were obtained under a set of given preconditions. We have therefore not established an idealized geometry. Further research is required into material specifications and installation methods.

**LIST OF REFERENCES**

JIWET (Japan Institute of Wastewater Engineering Technology). (1999). *Design material concerning Helicoidal-Ramp Type Drop Shaft.* (In Japanese)