Journal of Engineering Science and Technology
Vol. 15, No. 1 (2020) 355 - 363

ANALYSIS OF SEDIMENTATION IN TRUNK SEWER WITH LABORATORY INVESTIGATION OF SEWAGE SEDIMENT CHARACTERISTICS IN BAGHDAD CITY

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Abstract

Sediment accumulated in sewers is a major concern source as it induces numerous operational and environmental problems. For instance, during wet weather flow, the re-suspension of this sediment accompanied by the combined sewer overflow may cause huge pollutant load to the receiving water body. The characteristics of the sewer sediment are important as it shapes its behaviour and determines the extent of the pollution load. In this paper, an investigation of sewer sediment and its characterization is done for a case study in Baghdad city. Sediment depth covers more than 50% of the sewer cross-sectional area; several operational causes are comprised to cause this huge depths of sediment depositions. The testing and analysis of the sediment showed that the median particle size of the sediment is 0.3 mm, which infer a poorly graded sandy sediment in accordance with the unified classification system, particle's specific gravity to be 2.63; with a water content of 41%. The organic content is tested and found to be 32.45 g per kg of sediment (equivalent to 3.24%).

Keywords: Baghdad trunk sewer, Organic content, Particle size distribution, Sewer sediments, Specific gravity, Water content.

1. Introduction

Recently, sediment deposition in the sewers is becoming a major scientific research subject; as it contributes to some hydraulic problems [1]; for instance, blockage and the hydraulic deficiency of the sewers, which may raise the frequency of flooding events [2]. Some environmental problems are induced by the erosion and re-suspension of the deposited solids during wet weather flow (WWF) [3]; Hannouche et al. [4] assert that the contribution of the sewer sediment re-suspension to the total suspended solids of the wastewater is in order of 20-80%.

Because it exists a variety of sources for sediment that arrives at a sewer system, sediments deposits in the sewer are highly nonhomogeneous [5] and enclose a wide range of particles with various size, forms, chemical composition, and exhibiting various physical and biological properties.

Ashley et al. [6] detailed the following sources for sewer sediments: atmosphere, contributing with the finest fraction of sediment (dust and aerosols); impervious surfaces in the catchment, where solids are accumulated during dry-weather conditions, these solids are mainly inorganic in nature [7]; domestic wastewaters, contributing with the highest proportion of organic solids; commercial and industrial effluent; areas under construction; other sources, like infiltration from surrounded soils or degradation of the pipe material itself.

The physical characteristics of the sediments are highly variable; depending on the nature of the catchment, population practices, type of the sewer system (combined or separate), and local characteristics [8]. When studying the transportation, re-suspension, and deposition of cohesive sediment; the most significant properties affecting these processes are particle size and distribution, density, moisture content [5].

In this paper, the study of sediment accumulation in Al-Thawra trunk in Baghdad city is presented, afterwards, in order to understand the nature of sediment that accumulates in the sewers, the study of their properties is performed using a laboratory study.

2. Case Study Description

Al-Thawra trunk (TH-trunk) sewer in the Rusafa district is selected as a study area as shown in Fig. 1. The TH-trunk is constructed in 1983 as combined type; receiving the residential sewage from densely populated area (approximately 1.43 million inhabitants) and rainwater; flowing by gravity with a total length of 10.5 km starting with 1800 mm at Al-Shaab district then expand to 2400 mm, and enters Al-Saddar district with a 3,000 mm diameter and ends in AL-Habeebiya pumping station [9].

Al-Habeebiya sewage pumping station is selected as a sampling site because taking samples from manholes (which is preferred) is very dangerous and complicated to perform. Sampling procedure standard code followed in this study is the British code of practice for site investigations (BS 5930) [10].

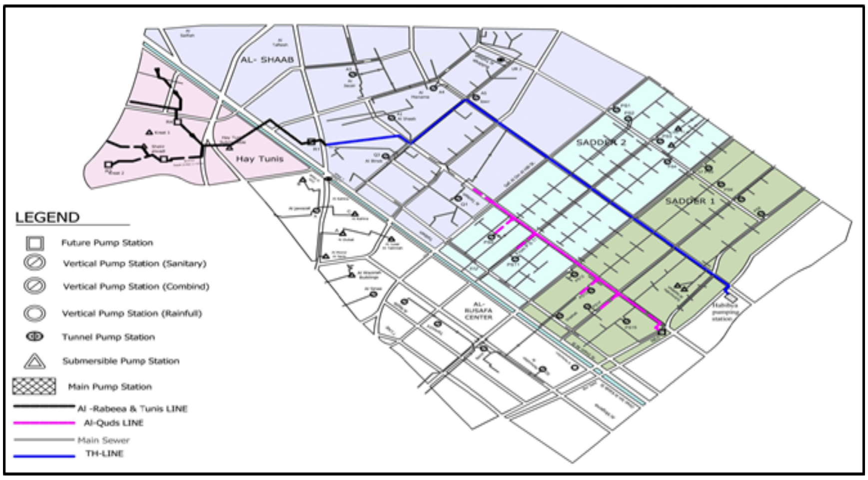

Fig. 1. Layout for TH-trunk sewer.

3. Data Collection and Methods

In July of 2014, Baghdad Mayoralty conducted an inspection survey for the TH-trunk. A multisensory inspection-boat is employed; this boat comprises three measuring devices: a closed-circuit television (CCTV) to capture the above-water-level condition of the sewer: a laser profiler, to quantify the corrosion in the above-water-level part of the pipes; and finally, a sonar mounted in the bottom of the boat to measure the sediment that deposited in the sewers. The data derived from this inspection is obtained and implemented throughout this research.

Three grab sediment samples (1 litre each) have been taken in three consecutive days from Al-Habeebiya pumping station; the samples are of the disturbed type taken using a shovel and collected in a sealed container; taken at the time of minimum flow-DWF. Efforts have been spent in order to be representative of the whole depth of sediment at the selected location. The sample is shown in Fig. 2(a) and it is clearly dark in colour; with an unpleasant odour; contains different materials such as hair and worms. Another three disturbed samples are taken for the moisture content test using sealed plastic bags as shown in Fig. 2(b); this special consideration is to ensure that all the moisture present in the samples are kept until the time of the testing.

(a) General disturbed sample. **(b) Sample for moisture content.**

Fig. 2. Sediment samples preparation from Al-Habeebiya pumping station.

The samples preparation is done by spreading them in a flat clean plastic sheet and left in the laboratory conditions for two weeks at a temperature ranging from 24-45 ºC to ensure that all water is evaporated. Although the standard code states that drying is to be in the oven at 105 ºC; drying in a lower temperature for such samples is preferred to ensure that minimum organic content is evaporated [11]. After drying, the colour of the sediment turned to dark yellowish-green colour as shown in Fig. 3. Dry sediment Specimens are taken from these samples for each test (particle size distribution, organic content and specific gravity).

(a) Before air-drying.

(b) After air-drying.

Fig. 3. Sample preparation before and after air drying.

4. Sediment Characteristics Concepts

In the sediment transport equations, the size of sediment particles is usually considered through a mean particle size (d_{avg}); however, it is convenient to describe the structure of a sediment deposit, considering the particle size distribution (PSD) by ranges, which can be found through a sieve analysis; PSD can be represented in a distribution curve and then, the standard parameters d_{10}, d_{50}, and d_{90} can be obtained [11]. The methodology used to determine the particle size distribution and the median particle size d_{50} is consistent with the British Standards (1377-2: 1999 Clause: 9). PSD is the most tedious test performed, high organic content can result in clogging the sieves; therefore, the wet sieve analysis is avoided; the dry sieving is performed to determine the coarser portions of the sediment particle sizes (including gravel and sand). The smaller portion that passes the sieve No. 200 (63 microns) should be tested (if significant) using the hydrometer test adopting the sedimentation principles; hereby, enabling a continuous PSD curve, which can include gravel, sand, silt, and clay [12].

The particle size is a commonly used parameter, involved in the assessment of deposition and transport. There is a common link between the particle size and the settling velocity, and with minimum velocity needed to keep the solids in suspension [13]. Wide variability in the size distribution is observed from catchment to catchment [14]; spatial and temporal variability also found in the same catchment. Generally, sewers found at the upstream part of the network is showing coarser material in the bed deposits and become finer towards the outlet of the system [15]. Physical processes such as transportation- sedimentation of particles are affected by the particle's specific gravity (*Gs*); theoretically, it is particle's density divided by water density at the same temperature [16]. While moisture content (w%) is a gravimetric determination of the percentage of the mass of pore water contained in a given mass of sediment to the mass of the dry sediment solids; moisture content shapes the mechanical properties of the sediment; it is shown to have a direct relationship with organic content and an inverse relationship with the mean grain size [5]. Organic content (OC) is an important indicator to assess the attitude of the deposits in showing possible cohesive behaviour [17]. Besides, OC is shown to be the most important characteristic of sediment erodibility [18]. The most employed parameter to assess sediment and soil organic content is the volatile solid determination; based on mass loss on ignition (LOI), which is the percent of the weight that volatile at high temperature [11].

Specific gravity refers to the mass of solid matter of a given soil sample as compared to an equal volume of water. The specific gravity of the individual particle is determined in accordance with the British Standards (1377-2: 1999 Clause:8); the test used is called small pyknometer method. To determine the specific gravity GS, Eq. (1) is used [19]:

$$GS = \frac{m_{pyk+s} - m_{pyk}}{(m_{pyk+w} - m_{pyk}) - (m_{pyk+s+w} - m_{pyk+s})} \quad (1)$$

where m_{pyk} refers to the mass of pyknometer; while m_{pyk+s} refers to the mass of pyknometer and dried soil; $m_{pyk+s+w}$ is the mass of pyknometer, soil soaked into water; m_{pyk+w}; describes the mass of pyknometer filled with water.

Gravimetric moisture content test is performed according to the British standards (1377-2:1999 Clause:3). Five samples each more than 100 g are taken for this test; these disturbed samples are saved in a sealed plastic bag and tested for moisture content in the sampling day to assure minimum loss of the moisture. The wet and dry weighed is needed to calculate the water content w% of the soil [19]:

$$w\% = \frac{m_1 - m_2}{m_2 - m_{container}} * 100\% \quad (2)$$

where: m_1 refers to the initial weight of the sample; m_2 is the final weight for the soil after being dried in the oven at 105 ºC for 24 hours; while $m_{container}$ is the container weight. Modification regarding the drying temperature stated above, which does not consider the organic matter volatilization, which can indicate a much higher moisture content. Therefore, the drying temperature used here is less than 50 ºC and a drying period of seven days until a constant weight is attained [15]. The loss on ignition (LOI) test is considered representative of the total organic content present in the sediment sample [15]. The test is performed according to the British Standards Institution [19] and the ignition temperature is set to be 500 ºC; the calculation of the loss on ignition is given as:

$$LOI(organic\ content) = \frac{m_1 - m_2}{m_1 - m_c} \quad (3)$$

where m_1 is pre-ignition mass of specimen and crucible; m_2 is the post-ignition mass of specimen and crucible; m_c is the mass of the crucible.

5. Result and Discussion

5.1. Sediment depth survey

In 2014, inspection survey for the TH-trunk using multi-sensor inspection boat has been conducted by Baghdad mayoralty. The results of this survey are summarized in Table 1 and Fig. 4, while the x-axis represents the distance from the first manhole (TH-60), the y-axis represents the average sediment depth between two successive manholes, the solid line represents the sewer diameter along TH line.

It appears that the sediment depth; in some areas, reaches very high levels and cover more than 50% of the sewer cross-sectional area. Many operational reasons are included causing this huge depths of sediment depositions: shutdowns of lift stations during wars originating stagnation, accumulation, consolidation of sediment; moreover, inadequate maintenance of the sewerage system; likewise, human-behavioural reasons subsidise to this problem (for instance, scattering of solid waste in the roads). it may be noted that the when there is a change the diameter, a momentous escalation in the sediment level (ds); this can be justified by the continuity equation; when the pipe diameter change without increasing the flow, the flowing velocity will be decreased increasing the probability of the solid sedimentation [20].

Table 1. Depth of sediment in TH-trunk.

Reach	D (cm)	Length(m)	Depth of sediment (cm)			$\frac{ds_{avg}}{D}$
			Min	Average	Max	
1	180	3192.4	8.3	38.79	86.1	21.55%
2	240	2053.6	80	122.02	140.65	50.84%
3	300	5195.6	23.57	105.18	170.23	35.06%

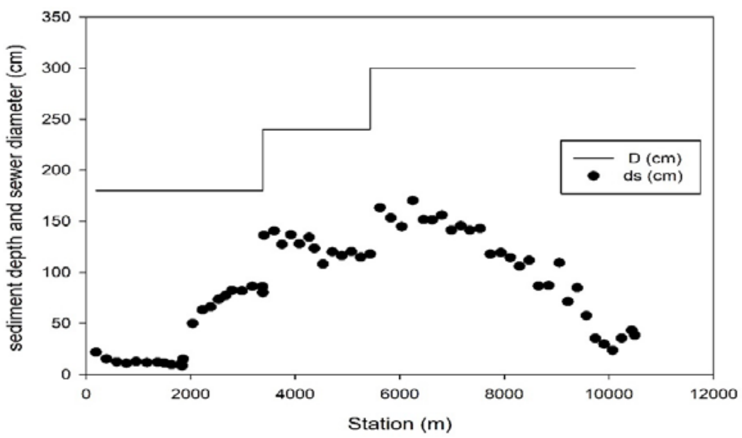

Fig. 4. TH-trunk sediment profile.

5.2. Sediment characteristics tests

Three successive sieve analysis tests are performed for the three samples (mass of each sample is more than 1000 g, which is selected according to the British standards); in this test, six different sieves are used (ranging from 4.75 mm to 75 microns). The average values are presented in Table 2. The characteristic size of the sediment (d_{50}) can be calculated from the particle size distribution curve in Fig. 5 by projecting the percent passing of 50% on the curve and determine the size of the particle on the x-axis. Here the sediment showed a median particle size d_{50} of 0.3 mm, similar to values found by Seco [15] and Schellart et al. [21]. In order to classify this sediment, the unified soil classification system is used. The curve is showing coarse-grained soil (less than 50% is passing from sieve#200). Sand (≥ 50% of coarse fraction passing No. 4 sieve).

The d_{60}, d_{30}, and d_{10} is projected and found to be 0.352 mm, 0.2117 mm, and 0.157 mm, respectively. This means that the coefficient of uniformity ($C_u = d_{60}/d_{10}$) and coefficient of gradation ($C_c = (d^{30})^2 /(d_{10})\ (d_{60})$) are 2.24 and 0.809, respectively; not meeting the two criteria for well-graded sand (for well-graded sand; C_u should be more than 6 and C_c should be between 1 and 3) and, which means that the sediment can be considered poorly graded sandy soil (symbolled as SP) with a few amounts of fines [12]. To determine the specific gravity of the particles, the small pyknometer test is performed for three specimens. The result showed that the average specific gravity of the sediment is in order of 2.6307 ± standard deviations of 0.004. While the result showed that the average water content of three sediment samples is 40.36% with a standard deviation of ±1.94%.

For organic content, the loss on ignition is considered representative of the organic content of the sediment. Three sediment specimens are taken, dried, and then pulverized to pass the 425-micron sieve. Then ignited at 500 ºC for four hours. The difference in the weight is taken and the loss on ignition found to be 3.245% ± 0.218%, which means 32.45 g per kg of sediment. Also, these sediments are considered class A (coarse, and granular in nature) [6].

Table 2. Summary of calculation for sieve analysis.

Sieve no.	Diameter (mm)	Mass of soil retained (g)	Passing (g)	Percent passing (%)
4	4.75	11	1000.5	98.9
8	2.38	21.5	979	96.8
10	2	12.5	966.5	95.6
40	0.425	288.5	678	67.0
100	0.15	561.5	116.5	11.5
200	0.075	102.5	14	1.4
Pan	0	14	0	0.0

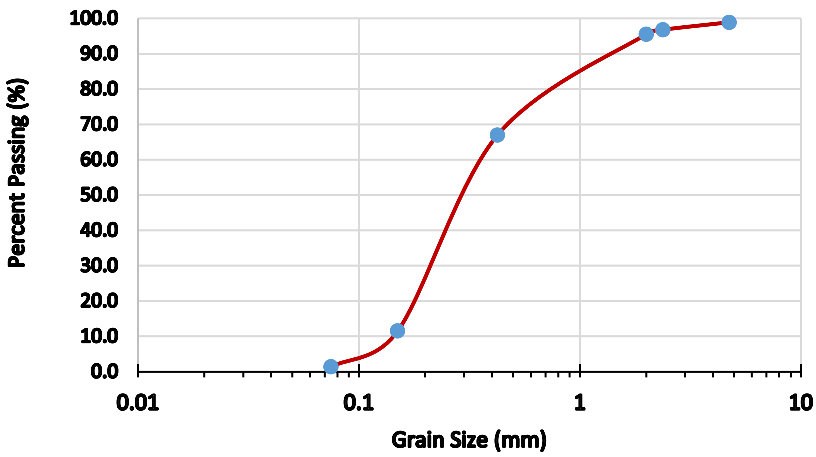

Fig. 5. Particle size distribution curve.

6. Conclusions

The following conclusion has been drawn from this study:

- Baghdad Mayoralty carried out a multi-sensor inspection survey for TH-Trunk; sediment depths are found to be extremely high, which may be attributed to several operational mismanagements.
- The clogging and sedimentation may be due to damage or collapse of sewer lines.
- The depth of sediment can be affected by operational and hydraulic factors. for the case study of TH-trunk, the lack of adequate slope and flowing velocity found to be one of the crucial reasons for these sediment.
- Depending on laboratory sediment study and the derived C_u and C_c, the deposited sediment can be classified as poorly graded sand with d_{50} of 0.3 mm and a specific gravity of 2.63, which agreed with the classification.

Nomenclatures

C_c	Coefficient of curvature
C_u	Coefficient of uniformity
d_{10}	10% of the particles are finer than this size
d_{30}	30% of the particles are finer than this size
d_{50}	50% of the particles are finer than this size
d_{60}	60% of the particles are finer than this size
d_{90}	90% of the particles are finer than this size
d_{avg}	Mean particle size
ds	Sediment level
Gs	Specific gravity

Abbreviations

CCTV	Closed-Circuit Television
LOI	Loss on Ignition
OC	Organic Content
PSD	Particle Size Distribution
TH-trunk	Al-Thawra trunk
WWF	Wet Weather Flow

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