



Research article

Hydraulic feasibility of discharging sludge from a local WWTP to a centralized WWTP through sewage network lines

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ABSTRACT

Over the recent years, due to the increase in the population covered by local wastewater treatment plants (WWTP), upgrading the existing treatment plants needs special attention more than ever. One of the suggested solutions removal the existing sludge treatment units in local WWTP and transfer the sludge to a centralized WWTP. The present study was developed to investigate the hydraulic feasibility of sludge transfer from Shahrak-e-Gharb WWTP as a local treatment plant to South Tehran sewage treatment plant in Tehran. To this end, at first, a map containing descriptive information and hydraulic characteristics related to the sewage transmission network between local and centralized WWTP was collected from the sewage company. This information was used to calculate the maximum capacity, current flow and draw the hydraulic profile of the sewage transmission line. Then, the transmission line profile was drawn using Manning's hydraulic model and SewerCAD v10.01 software. According to the obtained results, areas 1 and 3 with sewage line diameters of 1000 and 1400 mm did not have any special problem in terms of entering the sludge. Hydraulic analyzes showed that some lines in areas 2, 4, 5, and 6 suffered setbacks and crises after the increase of sludge, which require auxiliary lines. The results indicated that more than 85% of the sewage network lines have the ability to transfer the excess sludge of the local treatment plant, however, in 36 lines, mostly located in zones 2 and 6, with a diameter of 1200 and 2000 mm, there is a crisis of sewage filling and backflow. Therefore, in order to reduce hydraulic stresses in these lines, it was suggested to build an auxiliary line (bypassing at the beginning and end of these lines).

1. Introduction

The vast urbanization, as a result of economic and industrial development, and population growth lead to production of a large amount of urban wastewater, causing the pollution in the environment, if not properly collected and treated [1]. Wastewater collection and transmission networks are among the most important urban infrastructures implemented in the urban area and require huge capital cost. In these networks, the urban wastewater produced flows in pipes and then collects together in downstream pipes and directed to sewage treatment plants with the help of gravity or pumping. These networks can prevent the environmental pollution and subsequently threaten the human health [2]. The capacity of wastewater collection and transmission by the implemented sewage

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transmission lines are calculated during hydraulic studies and designs based on the population covered, the design period, peak coefficients, leakages and runoff entering the network, and etc. However, applying any additional load into the network, such as entering sludge into them, can imbalance the load entering the network and its capacity [3]. Currently, there are two types of centralized and decentralized wastewater treatment (WWTPs) systems in the world. In the first type: wastewater is treated in local treatment plants built in different parts of the city. While, in the second type: the sewage of the whole city is transported by the sewage collection network to a large treatment plant that is often built outside the city. The excess sludge from small local treatment plants is transported by sewage lines or trucks. By directing the sludge to the wastewater treatment plant and increasing its input load, there is a need to upgrade the treatment plant system in terms of quantity and quality; it can treat the incoming wastewater up to the existing standards. Sludge discharged into sewer networks may be the result of various processes such as: sludge from sewage treatment, sludge from water treatment, sludge illegally discharged into the network by operators of sewage suction combines, etc.

Backflow of sewage into the street due to the discharge of sludge beyond the capacity into the sewer networks causes widespread social dissatisfaction, many financial losses and environmental pollution. The various effects of these pollution are shown in the form of the spread of infectious and parasitic diseases directly through contact with sewage and indirectly through the growth and proliferation of pathogenic agents and the transmission of diseases by insects and arthropods. On the other hand, removal the blockages caused by sedimentation of discharged sludge into the network and lines will be very costly and accompanied by many health and safety risks for the operating staff and the unblocking team. Municipal sewage sludge produced in wastewater treatment process must be decontaminated and purified before reuse. Condensation, stabilization, purification and dewatering are among the most common sludge treatment processes. These measures usually account for 50% of the total costs of wastewater treatment. At the same time, they demand special and specialized guidance [4–7]. The most common methods of sludge disposal in the world include: direct discharge into the environment, such as discharge into rivers and channels near the drinking water treatment plant, taking into account environmental laws and guidelines, land application such as use as fertilizer in agriculture or restoring the forest and discharge to the sewage collection network which has recently received attention [8,9]. In general, there are two types of treatment plants in terms of sludge management system. In the first type: the remaining excess sludge is treated in the sludge digester located at the same treatment plant. While, in the second type: excess sludge resulting from wastewater treatment processes is collected from several local and smaller treatment plants and transferred to a larger treatment plant that has sludge processing and digestion facilities and is often built outside the city such as: Deer Island sewage treatment plants in Boston, America and Bailonggang located in Shanghai, China [10]. There are two methods for transferring sludge from local treatment plants to a treatment plant that with sludge treatment system located outside the city: 1- Sludge transportation by vehicles carrying sludge and 2- Sludge transportation by pipelines [11]. An important point to keep in mind is that the discharge of sludge into the sewage network means applying an additional load to the network and subsequently affecting its hydraulic parameters; if not managed, it will cause the blockage of lines and eventually the sewage will flow out of the network [12,13]. Economic benefits and lower cost in the centralization of sludge treatment using the transfer of sludge from smaller sewage treatment plants to centralized sludge processing and digestion facilities are feasible as a practical approach [12]. In addition, the financial and time limitations of the implementation and operation of new wastewater treatment plants reveal the necessity for reviewing and revising the process of the treatment plants in view point of operation in order to solve the problems caused by the increase in the input flow rate. It is obvious that the results of these investigations, in addition to preventing calculation and operational errors of ongoing projects, can lead to the improvement of WWTPs in operation in order to achieve a healthier environment and perform cheaper operations and operation through changes in existing facilities, implementation of operation maneuvers and use of new equipment and technologies [14]. Therefore, it seems that conducting studies hydraulic capacity of sludge acceptance by the sewage transmission network and lines, and on the other hand, upgrading the existing sewage treatment plants is a possible way to exploit the advantages of this method without any problems. The present study was developed for the first time in middle east to calculate the hydraulic capacity of entering the excess sludges produced the localized shahrak-e-GharbWWTP by the sewage collection and transmission lines leading to the centralized south Tehran WWTP (STWWTP), taking into account the hydraulic parameters including: diameter and slope of the lines, speed, filling percentage, and etc.

2. Materials and methods

The present study is an applied and modeled study to determine the hydraulic feasibility of transferring the produced sludge from Shahrak-e-Gharb Sewage Treatment Plant to South Tehran Sewage Treatment Plant and also determine the critical points in the sewage transfer lines of these two sewage treatment plants.

2.1. Data collection

The information related to the sewage collection lines of Tehran city was prepared from Tehran Water and Wastewater Company in the form of shape file and GIS. This information included the properties of the manholes, the diameter of the pipes, the slope and the length of pipelines along the transmission route. In the next step, the hydraulic parameters of the wastewater transfer pipelines from Shahrak-e-Gharb wastewater treatment plant to South Tehran wastewater treatment plant were isolated in the ArcGIS software environment. Considering that the line map is based on GIS, by using this software in the Arc map environment, all the lines that should be separated in this research were selected and saved in the form of a new shapefile after data preparation, by extracting data from the information table. Descriptive and calculations are done during the matching process. In this stage, information classification and clustering system and classification, ordering and coloring tools were employed based on line diameters. After the final preparation, the classified toll selection information was entered into the Sewer Cad v10.01 software to draw the longitudinal profile of the lines.

GIS software is coordinated with Sewer cad after installation, and after the adaptation process, the sewer cad program toolbar appears on the GIS graphical interface and is available to the user. An important command that is used in GIS mode is the Trex command. Using this command, height codes are assigned to manholes and other sewage collection networks, and maximum flow calculations and line profile drawing are performed.

2.2. Preparation the data to draw a profile in the program sewer cad

In order to draw a profile in SewerCad software (Version 10.1), the GIS mode and Trex command, the land toll layers and height codes were called from the location reference in the GIS software. Next, the information of manholes, pipelines and other elements of the sewage collection network was directly transferred to the data in the main file of the SewerCad program with a matching process. The longitudinal profile of the sewage transmission network between the Shahrak-e-Gharb WWTP and STWWTPs.

2.3. Critical points selection

After drawing the hydraulic profile and performing calculations, the critical points were determined according to Manning's formula, which depends on various parameters such as: Manning's coefficient, pipe cross-section, slope and hydraulic radius. At this stage, the percentage of filling (D/d) above 80% was defined as critical points, which were identified by applying a filter on the data.

$$Q = \frac{1}{n} AR^{2/3} S^{1/2}$$

Q: Flow rate in m³/s.

A: Channel cross section in m.

R: hydraulic radius in m.

S: Slope of the energy line in m/m (equivalent to the slope of the channel floor in constant uniform flow).

N: Manning's roughness coefficient.

3. Results

In this study, the hydraulic feasibility of discharging the sludge from the sewage treatment plant in Shahrak-e-Gharb to the lines of the sewage collection network in Tehran was studied and investigated. In fact, the main goal of this research was to find the critical points of the mentioned sewage network and to investigate whether it is possible to transfer the sludge from the Shahrak-e-Gharb sewage treatment plant through the sewage transmission lines to the STWWTP for its treatment, without clogging and sewage backflow. According to the diameter of its different sections, the sewage pipeline was divided into 6 zones, zones 1, 2, 3, 4, 5, and 6 with diameters of 1000, 1200, 1400, 1600, 1800 and 2000 mm, respectively. The most critical points found along the route of the transmission line are located in zones 2 and 6.

3.1. Physicochemical characteristics of excess sludge and wastewater

The hydraulic and physico-chemical characteristics of excess sewage mixed with sludge are summarized [Table 1](#).

3.2. Specifications of the pipes for transferring excess sludge and sewage from shahrak-e-gharb sewage treatment plant toSTWWTP

[Table S1](#) shows the hydraulic information of the sewage transmission lines from the Shahrak-e-Gharb WWTP to STWWTP. As can be seen in [Table S1](#), with the increase in the covered population, the amount of sewage flow has increased, and the slope of the sewage transmission lines is gradually decreasing, causing the filling percentage to exceed 80%. And we will have critical points in these lines. Here [Table S1](#): Hydraulic information of wastewater transfer lines from Shahrak-e-Gharb wastewater treatment plant to South Tehran wastewater treatment plant.

3.3. The critical points

After performing calculations, critical points (with d/D greater than 80%) were found in more than 23,351 m of pipelines due to improper slope, improper size, or other factors and hydraulic parameters in the pipeline route. [Table 2](#) shows the critical points of the

Table 1

Physicochemical parameters of surplus wastewater and primary and secondary sludge of the sewage treatment plant in the West city.

Specifications	TS (mg/L)	^a Q (m ³ /d)	TS (mg/L)	TVS (mg/L)	TFS (mg/L)
Excess sewage	1115	500	1115	836	279
Primary and secondary sludge	43600	349	43600	34880	8720

^a The wastewater entering the treatment plant is mixed with sewage sludge and leaves the treatment plant without any treatment process being performed on it.

Table 2
 Characteristics of pipelines at critical points by diameter along with the size of the proposed overflow.

Row	Location	Diameter pipe(mm)	The length of the main pipe(m)	Auxiliary tube length (m)	Q 100% l/s	Current Q L/S	Suggested auxiliary diameter mm	Slope
1	Bolvarbahmanyar	1200	61.6	67.76	2111.81	2280.2	500	2.5
2	Alley rohi	1200	49	53.9	2111.81	2280.5	500	2.5
3	Alley24	1200	40.4	44.44	2351.61	2284	500	2.6
4	Bolvarbahmanyar	1200	50.6	55.66	2153.63	2287.5	500	2.6
5	Bolvarbahmanyar	1200	49.1	54.1	2194.65	2291	500	2.7
6	Bolvarbahmanyar	1200	56.1	61.71	2234.93	2298	500	2.8
7	St. sadi	1200	19.8	21.78	2194.65	2319	500	2.7
8	St hafezsharghi	1200	15.8	17.38	2234.93	2330.4	500	2.8
9	Bolvarbahmanyar	1200	76.6	84.26	2274.49	2344.77	400	3
10	Bolvarbahmanyar	1200	58	63.8	2313.7	2340.5	400	3.1
11	Bolvarbahmanyar	1200	106.7	117.37	2084.9	2356.2	600	2.4
12	St. takhti	1200	98	107.8	2175.49	2358.9	500	2.7
13	Alley aliyari	1200	100.8	111.6	2145.07	2364.2	600	2.6
14	Bolvarbahmanyar	1200	77.4	58.14	2037.17	2364.8	600	2.3
15	Alley danesh 19	1200	61.5	85.14	2234.93	2364.8	500	2.8
16	St. vesal	1200	65.5	67.65	2274.49	2368	400	2.9
17	St. vesal	1200	71.8	72.25	2194.65	2371.7	500	2.7
18	St. vesal	1200	80.4	85.91	2274.49	2378.3	500	2.9
19	St. vesal	1200	66.2	72.82	2313.37	2381.8	400	3
20	Azadgan	1200	58.5	64.3	2342.19	2403	400	3.1

21	St. azimi	1200	60.8	66.88	2360.76	2411.5	400	3.1
22		1200	64.9	71.39	2313.37	2412	500	3
23	Shahidrajayi	1800	77	84.7	226.32	6428.9	500	2.5
24	St. asi	2000	74.6	82.3	6799.96	6862.2	500	1.7
25	Salman farsi	2000	122.2	134.42	6799.96	6927.6	500	1.7
26	Ahahr ray	2000	31.6	34.76	7557.3	7600.1	600	2
27	Shahr ray	2000	98.7	107.58	7558.58	7760.9	500	2.1
28	Alley golafshan	2000	146	160.6	7735.58	7841.9	500	2.2
29	Bolvarsalmanfarsi	2000	177	194.7	7557.73	7913.6	500	2.1
30	Shahr ray	2000	121.1	133.21	8079.55	7959.55	500	2.4
31	Shahr ray	2000	108.5	119.35	7735.73	8060.9	600	2.2
32	Shahr ray	2000	165.3	181.3	7735.73	8101.9	600	2.2
33	Shahr ray	2000	113.4	124.74	8079.55	8190/7	500	2.4
34	Refinery Road	2000	79.3	87.23	8409.47	8220.2	500	2.6
35	Refinery Road	2000	120/7	133.4	8079.55	8280.1	500	2.4
36	Refinery Road	2000	145.9	160.49	8246.16	8309.3	400	2.5

sewage collection route from Shahrk-e-Gharb sewage treatment plant to South Tehran sewage treatment plant. As can be seen in [Table 2](#), out of the 36 critical points identified, most of the critical points were located downstream of the transmission collection route, and the increase in flow rate and decrease in slope are the main reasons for creating critical conditions in these points.

As Shown in [Figs. 1 and 2](#), the highest number of critical points, i.e. 61%, is in the line with a diameter of 1200, which is due to the smaller diameter, high population density, and numerous branches that have been transferred to the main pipeline on the way, as well as the low slope of the route.

4. Discussion

4.1. Choosing the time to load sludge in the sewage network

4.1.1. Based on biological parameters

The amount of total solids (TS) of the surplus sludge of the Shahrak-e-Gharb WWTP is 39 times the value of this parameter in the excess wastewater entering the transmission line and is equal to 43,600 (mg/L), which is compared to the maximum standard amount of total solids of raw urban sewage in developed countries. 1100 (mg/L)) is much more [\[15\]](#). Taibi et al. (2005), reported that the

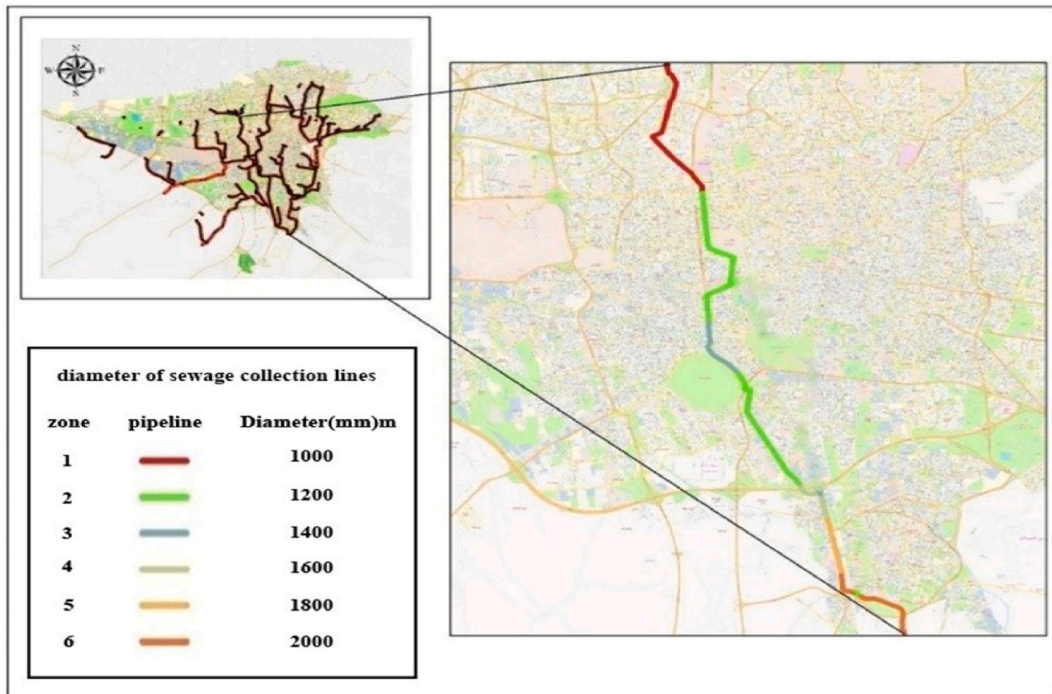


Fig. 1. Map of the sewage transfer line between the west and south treatment plant.

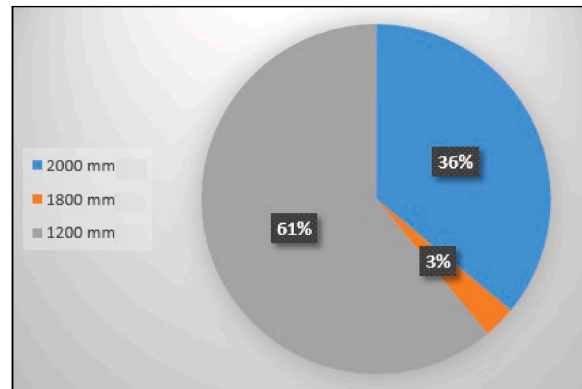


Fig. 2. Shows the percentage distribution of pipe sizes in the mentioned critical points.

amount of suspended solids entering the wastewater treatment plant of Isfahan city between 1377 and 1379 was measured as 302 (mg/L) on average [16]. The total flow rate of primary and secondary sludge produced in the processes of the sewage treatment plant in Shahrak-e-Gharb WWTP was 349 cubic meters per day, which is mixed with the excess wastewater of this treatment plant with a volume of 500 cubic meters per day, and a total of 849 cubic meters per day enters the wastewater transfer pipeline; This flow is only 20% of the maximum nominal capacity of the pipeline at the beginning of the route. However, this value reaches 100% of the nominal capacity of the pipeline at the end of the route.

Due to the high amount of total solids in the excess sludge of Shahrak-e-Gharb WWTP, there is a high possibility of sedimentation in the sewage network. Therefore, in view point of biological aspect, it is better to discharge the excess sludge into the sewage network during peak hours and maximum discharge to avoid the risk of sedimentation inside the network. On the other hand, considering the hydraulic aspect, it is better to drain the excess sludge in flow rate at least into the sewage network; because in this case, the network has a higher hydraulic capacity to accept and transfer sludge. Finally, taking into account all the considerations, it is better to discharge the sludge into the sewage network at the maximum flow rate, considering the biological aspect. The solid deposition do not occur at the bottom of the pipe. It is also possible to install bypass lines for those points where the hydraulic capacity of the network cannot accept the volume of incoming sewage and are called critical points, and the excess sewage is discharged outside the network. Brombach et al. (2005) investigated the data on the quality parameters of raw sewage from different WWTP with a combined sewage

collection and transfer system. The authors reported that the average suspended solids in the sewage network were 174.5 (mg/L) [17].

4.1.2. Based on hydraulic parameters

According to Manning's formula, the parameters of Manning's coefficient, pipe cross section, slope and hydraulic radius are effective on the nominal flow capacity of the pipe. In addition, in Zone No. 1, due to the fact that the pipeline has a smaller diameter (1000 mm), so the cross-sectional area of the pipe is also smaller, which has affected the volumetric capacity of the pipe and has caused a decrease in its value. Instead, the slope of the line in this area is mostly more than that at the end of the route. The slope parameter at the end of the pipeline route (zone no. 6) has gradually decreased and the decrease of this parameter is the most important factor in the occurrence of critical points in the end of the pipeline.

In a study conducted by Arjamand et al. (2017), the hydraulic radius parameter after the roughness coefficient and the cross-sectional area was the most important among the different parameter Manning's formula determination the flow rate.

In the critical points found in this study, the filling of the pipeline and the lack of empty capacity, and subsequently, the increase in the retention time of the sewage and the state of siphoning (especially during peak discharge hours and the addition of new load such as during rains) were observed. The most possible reasons were reducing the speed of sewage passage due to the change in the slope of the line, the change in the diameter of the pipe, the sudden change in the route of the transmission line and the sectional increase in flow rate due to the high population density in the region are among the most important of them. To solve this problem at critical points, overflows were considered to transfer excess volume of sewage through these overflows. After adding the overflows, the equivalent diameter was calculated. Then, it was loaded again in the software, which shows that the ratio of D/d has decreased below 80% in these points. The diameter of these overflows is between 300 and 600 mm. Also, the length of the overflows has been considered 10% more to be sure.

In a similar study conducted by Nishant Sourabh in 2018 with computer modeling in a 4.79 km long pipeline at the Sardar Vallabhbhai National Institute of Technology in India, 11 points were identified as critical points and it was stated that there is a need to increase the diameter of the pipes. In order to solve the excess hydraulic load, it has a network so that the sewage transmission line can respond to the hydraulic load created following the discharge of sludge in the current and future years, as well as the new hydraulic load that will be created due to the increase in population in the coming years [18].

After performing the calculations and modeling the transmission line, 36 lines were identified on the route, and the mentioned lines were named as "critical lines"; the non-standardity of some hydraulic parameters in these points caused the speed of the passing sewage to decrease and the sewage to remain in these areas and rise. The level of sewage inside the facilities (pipelines and manholes) has increased.

If we intend to transfer sludge in this route, these points should be given special attention and their defects should be fixed so that the process of transferring sewage mixed with the sludge of the West Settlement Treatment Plant can be carried out without any defects. Therefore, taking into account the mentioned capacities as well as paying special attention and correcting the critical points, it is possible to proceed with the controlled discharge of sludge into the transmission line. It should be noted that in order to prevent sludge deposition in the line, it is suggested that the said sludge be diluted first and then discharged into the line according to a schedule according to the calculated capacities.

5. Conclusion

According to the plan to improve the capacity of the house of Shahrak-e-Gharb, the main goal of this plan waste determine the critical points and also to determine the best time to discharge the sludge to the transmission line. According to the results obtained in this research, more than 85% of the sewage network lines are passable. There is excess sludge and sewage in the West settlement treatment plant, however, in 36 lines, which are mostly located in zones 2 and 6, with a diameter of 1200 and 2000 mm, there is a crisis of overflowing and backflow of sewage. In order to reduce the hydraulic stresses in these lines, it was suggested to build an auxiliary line (the rim next to the crossing at the beginning and end of these lines). Furthermore, the best time to discharge the sludge to the transmission line is the maximum flow rate to prevent sedimentation. The model used in this study can be used for other local treatment plants that plan to transfer their sludge to centralized treatment plants. In addition, some limitation of present study were: Lack of data on different zones and decentralized WWTP located in different districts of Tehran city to centralized WWTP and accurate determination of Manning's roughness coefficient and its measurement in critical sections of the minimum and maximum slopes and checking the sedimentation situation in the different sections.

Author contribution statement

Sohila Ghorbanpour; Mahdi Farzadkia: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data.

Majid Kermani: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Roshanak Rezaei Kalantary: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Hasan Pasalari: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Data availability statement

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.heliyon.2023.e15574>.

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