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EFFECT OF NODAL ELEVATION REVISION IN WATER DISTRIBUTION SYSTEM: A CASE STUDY OF METROPOLITAN WATERWORKS AUTHORITY, THAILAND

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ABSTRACT: Bangkok, Nonthaburi and Samut Prakan are the three most densely populated provinces in Thailand. They have a large drinking water consumption supplied by the Metropolitan Waterworks Authority (MWA). MWA's service area is over 2.42 km^2 with 2.33 million customers (1 customer is 1 household) and it had to supply 5.843 million m^3 of drinking water per day in the year 2017. Because the main pipe network is very complex and extremely large. For this reason, it is very difficult to manage the water supply. In order to decide a suitable supply, EPANET is one of the tools for managing a water supply in the main water piping network but it can lead to an error of nodal elevation in the pipe network. In this research, we have revised the nodal elevation on the pipe network by reference from Bangkok roads elevation map, it was found that the new pipe network has better accuracy of up to 87.63%, an improvement on the existing model of 3.95%.

Keywords: EPANET, WDS software, Water distribution network, Hydraulic engineering, Pipe nodal elevation

1. INTRODUCTION

Nowadays, computers have become much more developed and influence our everyday life. In water supply engineering, the computer is used as a water supply managing tool. Many algorithms have been developed for solving a complex water distribution network [1]. All algorithms use two initial equations, a continuity equation "Eq. (1)" for water balance and head loss equation "Eq. (3)" for water head calculation. They are different from the matrix definition and numerical methods technics. One of the most popular algorithms is "Gradient Method", as defined by Todini and Pilati. This algorithm is a simple solution for water distribution network by assigning node and link, do not create a loop like a complicated circuit calculation. Gradient Method uses Newton's iteration method to calculate a series of continuity equations and head loss. The Todini and Pilati algorithms were developed into water distribution software called EPANET by Lewis A. Rossman [2] of United States Environmental Protection Agency (EPA). EPANET can simulate the hydraulic behavior and chemical concentration in water supply systems. EPANET is widely used because it is freeware and often used in research because its open source code can be developed to a higher ability. It can convert many computer languages such as C++, Java, Python etc.

1.1 Flow Continuity Equation

$$Q = V_i A_i = V_j A_j \tag{1}$$

where Q = water flow rate (volume/time), V = mean water velocity (length/time), A = pipe inner cross-section area (square length)

Flow continuity around all nodes:

$$Q_{ij} - D_i = 0 \text{ for } i = 1, \ldots, N \tag{2}$$

where D_i is the flow demand at node i.

1.2 Head Loss Equation

$$\frac{p_i}{\gamma} + \frac{V_i^2}{2g} + z_i = \frac{p_j}{\gamma} + \frac{V_j^2}{2g} + z_j + h_f \tag{3}$$

where $V^2/2g$ = velocity head (length) , z = elevation head or potential energy (length), h_f = friction head loss (length), p = pressure (force/area), γ = specific weight (weight/unit volume), g = gravitational acceleration (length/time^2), i, j = index number (1...n). In a pipe of constant diameter, both flow rate Q and velocity V are also constant Q_i=Q_j, V_i=V_j [3]. So, Eq. (3) is.

$$\frac{p_i}{\gamma} + z_i = \frac{p_j}{\gamma} + z_j + h_f \tag{4}$$

Form p / γ = Static Head or Pressure Head [4, 5].
Form (p / γ) + z = Head Grade Line.

$$H_i - H_j = h_f = r_k Q_k^n \tag{5}$$

where H is the nodal head (length), r is resistance coefficient, n is flow exponent [6]. For a set of known heads at the fixed grade node, we seek a solution for all heads H_i and Q_{ij} flow that satisfy equations (2) and (5).

1.3 Gradient Method

The gradient solution technique starts with an initial approximation of flows in each pipe that may not essentially satisfy flow continuity [7]. By systematically calculating the matrices, new nodal heads are found in each iteration.

$$\mathbf{A}_{11}\mathbf{Q} + \mathbf{A}_{12}\mathbf{H} = \mathbf{A}_{10}\mathbf{H}_0 \quad (6)$$

$$\mathbf{A}_{12}\mathbf{Q} = \mathbf{q} \quad (7)$$

So, we get a system matrix form:

$$\begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} \\ \mathbf{A}_{21} & 0 \end{bmatrix} \begin{bmatrix} \mathbf{Q} \\ \mathbf{H} \end{bmatrix} = \begin{bmatrix} \mathbf{A}_{10}\mathbf{H}_0 \\ \mathbf{q} \end{bmatrix} \quad (8)$$

where $\mathbf{A}_{12} = \mathbf{A}_{21}^T$ (np, nn) unknown head nodes incidence matrix

$\mathbf{A}_{10} = \mathbf{A}_{01}^T$ (np, no) fixed head nodes incidence matrix

$\mathbf{Q}^T = [Q_1, Q_2, \dots, Q_{np}]$ (1, np) flow rates in each pipe

$\mathbf{q}^T = [q_1, q_2, \dots, q_{nn}]$ (1, nn) nodal demands

$\mathbf{H}^T = [H_1, H_2, \dots, H_{nn}]$ (1, nn) unknown nodal heads

$\mathbf{H}_0{}^T = [H0_1, H0_2, \dots, H0_{nn}]$ (1, no) fixed nodal heads

$$\mathbf{A}_{11} = \begin{bmatrix} r_1\left|Q_1\right|^{n-1} & & & \\ & r_2\left|Q_2\right|^{n-1} & & \\ & & \ddots & \\ & & & r_{np}\left|Q_{np}\right|^{n-1} \end{bmatrix} \quad (9)$$

Equation (9) is an (np, np) diagonal matrix with:
nn = number of nodes with unknown head
no = number of nodes with fixed head
np = number of pipes with unknown flow

$$\mathbf{A}_{12}(i,j) = \begin{cases} 1 & \text{if flow of pipe } i \text{ enters node } j \\ 0 & \text{if pipe } i \text{ and node } j \text{ are not connected} \\ -1 & \text{if flow of pipe } i \text{ leaves node } j \end{cases}$$

$$\begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} \\ \mathbf{A}_{21} & 0 \end{bmatrix} \begin{bmatrix} \mathbf{Q} \\ \mathbf{H} \end{bmatrix} - \begin{bmatrix} \mathbf{A}_{10}\mathbf{H}_0 \\ \mathbf{q} \end{bmatrix} = [\mathbf{F}] \quad (10)$$

Where **F** is an (N×1) vector of left-hand side terms. Apply the Newton-Raphson iteration technique to solve this series of equations.

2. MATERIALS AND METHODS

2.1 MWA water distribution network

Bangkok is the capital city, economic center, transport hub, and the highest population density in Thailand. As a result, Bangkok has a huge drinking water consumption. The agency responsible for supply drinking water for Bangkok is Metropolitan Waterworks Authority (MWA), which is a government agency. The MWA also has two service areas covering Nonthaburi and Samut Prakan. These two provinces have the second and third highest population densities in Thailand. Not only are both provinces close to Bangkok but also Nonthaburi is a growing area and Samut Prakan is an industrial and air transportation region. MWA service area covers the three most densely populated provinces in Thailand. This area has single houses, high buildings offices, government buildings, especially in economic zones, so there is a lot of water demand. In 2017 MWA supplied 5.843 m^3 of drinking water per day to 2.418 km^2 of the service area with 2.328 million customers (1 customer is 1 household). MWA pipeline is a large system consisting of underground water tunnels, main pipes and service pipes with 34,675,903 km of total length, 4 water treatment plants with total water production capacity of 6.72 million m^3 per day. Drinking water is pumped into elevated tanks and delivered through an underground water tunnel to the 18 pumping stations distributed in the service area. The water is discharged into the main pipeline by pumps at each pumping station, then the water flows from the main pipeline to service pipelines and then to customers. The service area of MWA is currently divided into 18 branches and subdivided into 669 District Metered Areas (DMAs). Managing a large water distribution system to meet water demand with the desired water pressure level in all service areas at different times is challenging. The water distribution software is one choice to help water supply planning. MWA has adopted EPANET for use in both water supply and water quality. The authors have studied only the hydraulic characteristics of the water supply in the main pipe system. In the first phase, the use of EPANET has many errors compared to actual pressure and flow data of 134 field measurement points as shown in Fig. 1, even though MWA have frequently updated the WDS model for better simulation results.

Fig. 1 MWA main pipeline network.

2.2 Pipeline nodes revision

The main pipe network consists of 500 – 1,800 mm diameter pipes connected to a large water piping network. There are 13,738 pipes and 13,416 nodes, each node on the pipeline must have the elevation assigned when the pipe levels are not the same since the elevation of each node is used for calculation in Equation (4). But the current model has not the altitude of the node assigned because of no elevation data. Moreover, MWA service areas are not too much changing in their altitude the elevations vary around 0 - 2 m above mean sea level, so MWA has not seen the importance of the elevations of pipe nodes. In fact, only 1 or 2 m elevation error of the node affects the result of the pipeline network model. Because the pressure in the main pipe of MWA is lower than in other countries, the pressure at some points is less than 10 m. Therefore, an elevation of a node of only 1 or 2 m gives an error as high 20% or more. For example, at measuring points number U121 U145 U203 and U220, it was found that the measured pressure and simulation pressure curves had the same trend and same distance apart all the time; these errors are the elevation errors of the nodes. The current models, U121, U145, U203 and U220, had errors of 34.56%, 27.41%, 23.43% and 17.85%, respectively (see Fig. 2). If the elevations of nodes are revised, the errors can be reduced by up to 20%. The elevation used in the hydraulics is usually based on the mean sea level (MSL). The elevation of the node can be obtained from a topographic map. According to the AWWA Manual M32, a topographic map resolution of 2 ft (0.6 m) or less is desirable [8]. The elevation of the MWA service area can be approximated using the Bangkok Metropolitan Region elevation map of the Royal Thai Survey Department (see Fig. 3). The map resolution is 0.5 m, which is acceptable within the AWWA Manual M32 recommendation. Bangkok area elevations can be approximated by using the mean elevation map along the roads in Bangkok, 2006-2007 of Land Survey and Map Division, Public Works Department, Bangkok Metropolitan Administration (see Fig. 4). This map is better with 0.2 m of elevation resolution. Normally, the main pipe is placed along the road, the elevation of the node can be established by reference from the road elevation. The elevations of the roads in Bangkok are 0 - 2 m, based on the mean sea level.

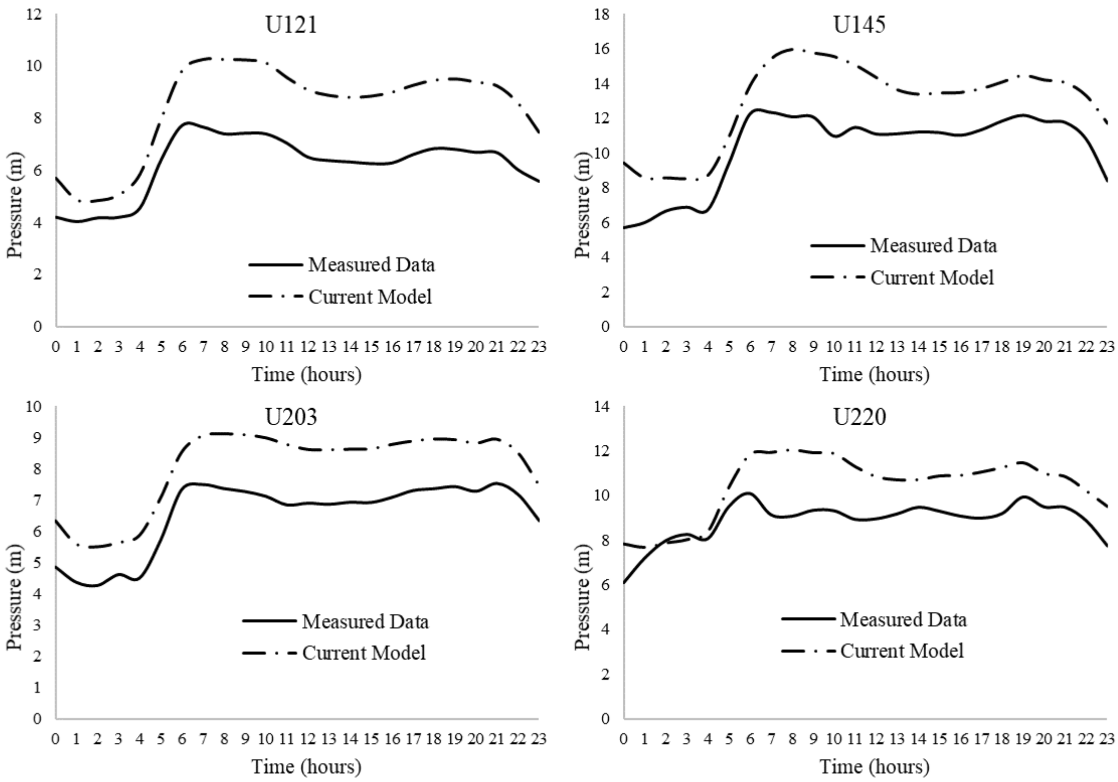

Fig. 2 Comparison of the current model simulation results and measured values of pressure at nodes U121, U145, U203, and U220.

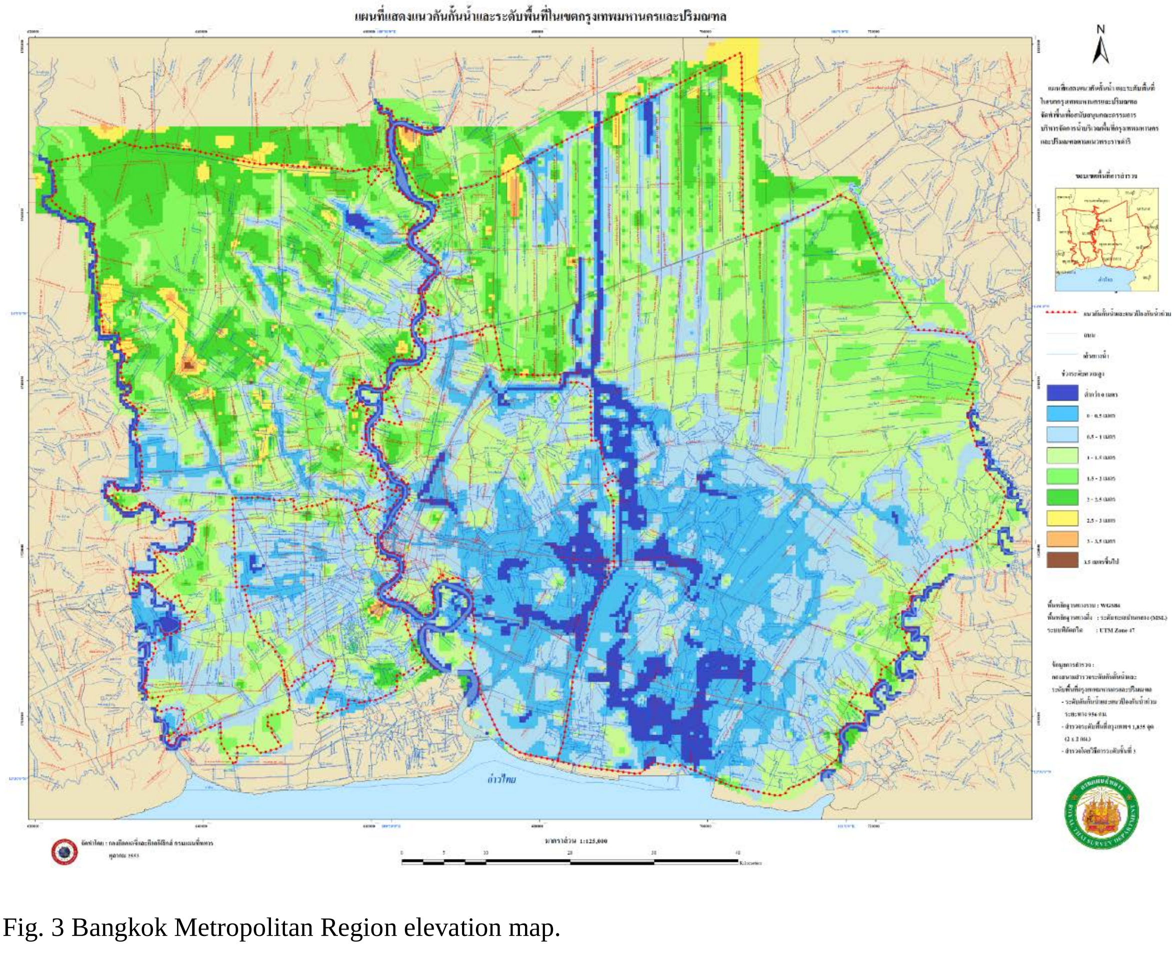

Fig. 3 Bangkok Metropolitan Region elevation map.

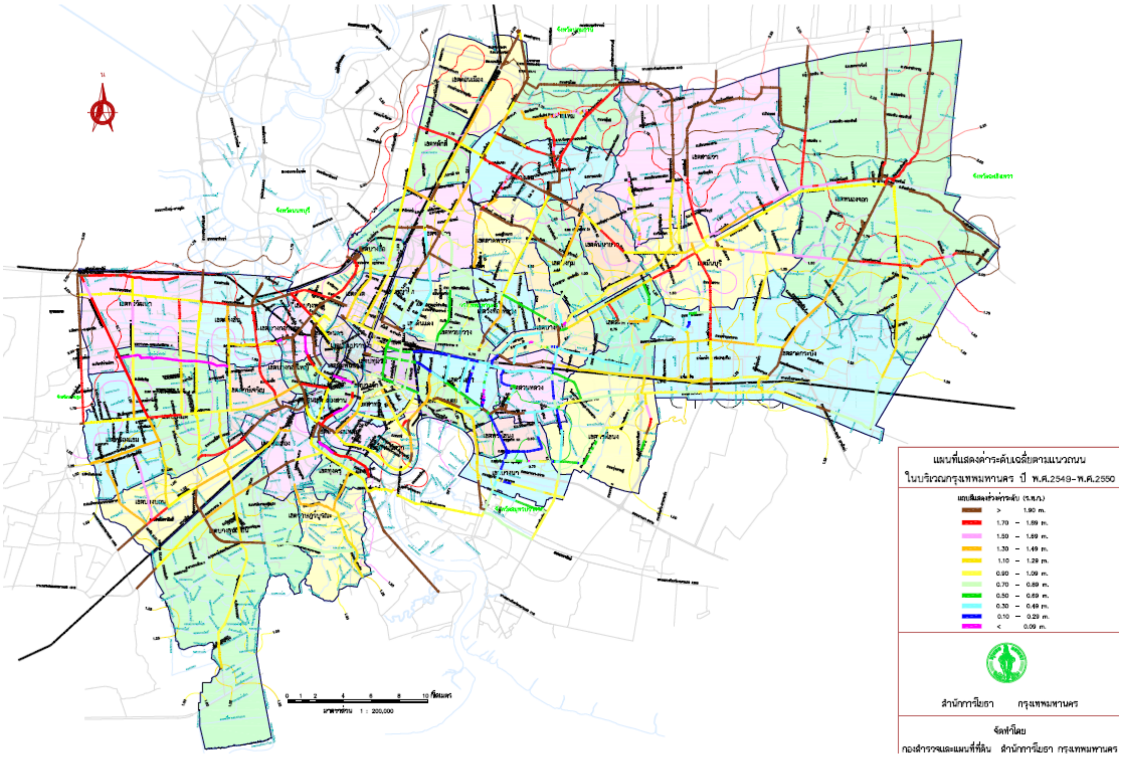

Fig. 4 Bangkok roads elevation map

3. RESULTS AND DISCUSSION

When the simulation results of the new elevation correction model were compared to the field measured pressure points, it could be seen that the improved model offers a better solution. Comparison of the existing model, the accuracy of the mean was highly improved with the introduction of the new elevation; for example, at measurement points U121, U145, U203 and U220, (see Fig. 5). The errors of these 4 measurement points were reduced by 19.49%, 19.12%, 17.22% and 10.15% respectively. We have compared simulation results with all 134 field measured pressure points, the new model has increased the accuracy to 87.63% from 83.68% for the existing model; accuracy up 3.95%. Although the new models are more accurate, there are also some errors for other reasons. In Fig. 5, it is observed that 0 - 5 a.m. is a high error period with lower pressure than during other periods. This period had lower water consumption, so the MWA reduces the pressure at the pump station to reduce leakage from the pipe. During this time, there is a relatively low flow rate in the pipelines. It could be suspected that this error may be happened by a selection of Hazen-William head losses model. The Hazen–Williams formula is frequently used for the design of large-diameter pipes, without regard for its limited range of applicability; the application of the formula is accurate only if the operation of the pipe is located within the transition or smooth, turbulent-flow regimes. Most working ranges for water-supply pipes usually fall outside such conditions [9]. The authors strongly recommend using the Darcy-Weisbach formula, which includes all flow regimes and better accuracy.

4. CONCLUSIONS

Revision of the elevations of the nodes makes the calculation of EPANET more accurate. Although the elevations of the service area of the MWA are not very different, the water pressure in the pipe is relatively low. Therefore, only 1 - 2 m of elevation error give a high error in simulation results. So, it is necessary to assign the elevation to every node in the pipe system. Although the accuracy of this model is significantly improved, errors could be found at night because of the low flow rate of water supply. Even though it is very complicated to use a Darcy-Weisbach model, the recommendation is to choose this option which is applicable to all of the flow ranges instead of the Hazen-Williams formula [10].

5. ACKNOWLEDGMENTS

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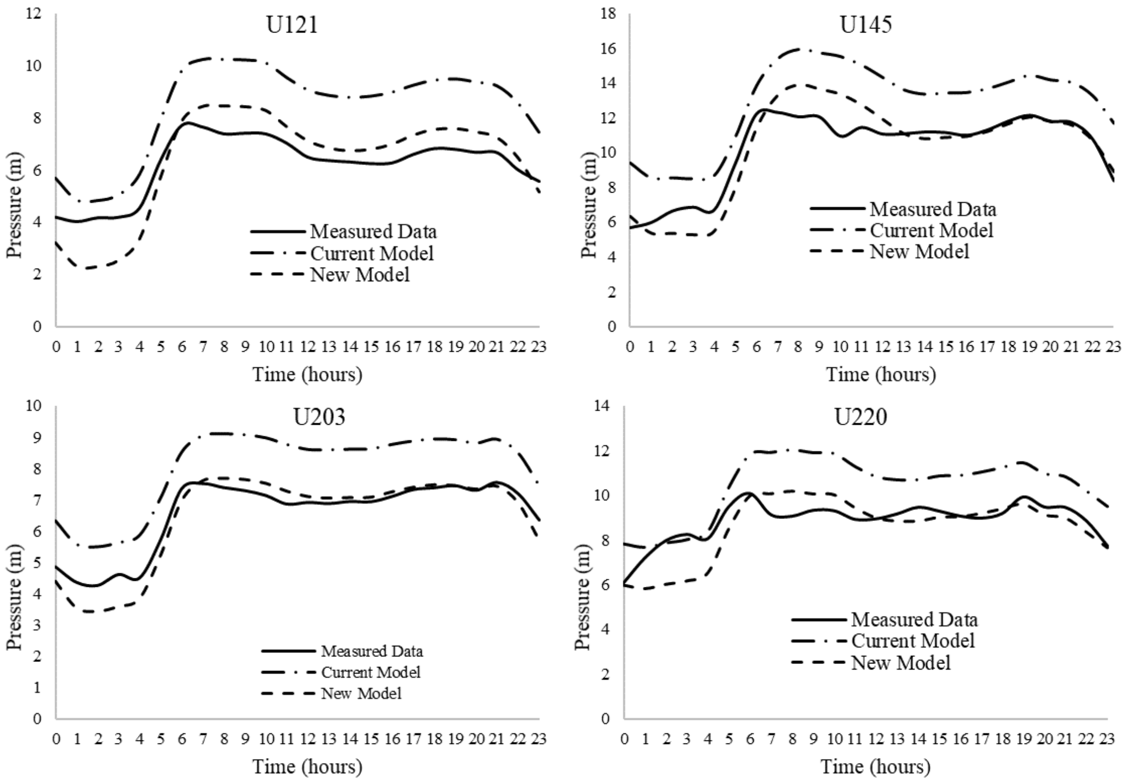

Fig. 5 Computed results of the current model and measured values for pressure at node U121, U145, U203 and U220.

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