# Pipe Network Rehabilitation to Minimize Head Losses in Trunk/Limb Mains in Makassar, Indonesia

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**ABSTRACT**

Rehabilitation and reinforcement of the existing distribution pipe network to restore and upgrade its flow capacity and to reduce non-revenue water (NRW) are growing concerns of all waterworks across the globe. Kota Makassar is not an exception. There are a number of old and deteriorated Cast Iron Pipes (CIP) installed in 1920s in city center and a length of over 2,700 km Polyvinyl Chloride Pipes (PVC) installed in 1980-2010 in newly developed residential and commercial areas, both of which are not necessarily functioning properly. PDAM Makassar (waterworks) pays utmost attention to urgent rehabilitation of the pipelines. This study aims to propose a design concept of the pipeline network that emphasizes minimization of head losses particularly at trunk/limb mains (Trunk/limb Main Reinforced - TMR). Additional trunk/limb mains to be installed are considered most cost-effective and practical solution for rehabilitation of the exisiting pipe network, and are able to cope with an unexpected increase in zonal water demand in future. Our preliminary study also suggests that this TMR pipe system benefits to the PDAM, in terms of 1) direct, social and environmental costs, 2) O&M aspects of the pipe network, and 3) flexibility in future expansion of the network.

Keywords: hydraulic gradient, minimization of head losses, pipe rehabilitation, trunk/limb mains, TMR pipe system

## BACKGROUND

Kota Makassar, a capital of South Sulawesi Province, has been developing rapidly as center of administration, industry, commerce and education in east Indonesia. Its population in 2010 was 1,339,374 people, increasing rapidly with an annual growth rate, 2.2% (2004-2010), much higher than a national average growth rate, 1.6% of Indonesia (2000-2010, BPS-Statistic Indonesia).

Infrastructural development, inclusive of water and sanitation, could hardly catch up with this rapid pace in the area. Many people, particularly in north and east parts of the city, are suffering from chronic water shortage and low water pressure.

The current crucial situation may be caused from a high rate of non-revenue water (NRW) as well as a limited production capacity resulting from the delayed system development. Water losses, despite financial investment in the past several decades to decrease the level of pipe leakage, are still at a high level of 45% in 2010 (PDAM, 2010).

NRW based on causes can be classified into physical and non-physical losses (Thronton, 2002). In case of Kota Makassar, according to previous studies, physical water losses may account for 20-25%, nearly a half of the NRW. They are mainly those of leakage particularly from old deteriorated CIP pipes and fittings installed in 1920s and from PVC service mains, branching saddles and connections installed in1980-2010. PVC pipes are vulnerable to heavy loads and damage.

This study aims to propose new design concept of distribution pipe network by minimizing head losses of trunk/limb mains and verify that this pipe system is most cost-effective and practical solution for rehabilitation or reinforcement of old pipe network and is able to cope with unexpected increase in future water demand and easy to controll water losses.

## EXISTING WATER SUPPLY SYSTEM

PDAM Makassar (city-owned waterworks) is one of twelve drinking water companies classified into a large group in Indonesia, which has over 100,000 customers.

The PDAM currently operates five (5) water treatment plants (WTP). Panaikang WTP with a production capacity of 1,100 L/s and Somba Opu WTP with 1,000 L/s are major two, supplying water to north and south parts of the city respectively. The remaining three are relatively small in water production; they are Ratulangi (50 L/s) located at city center, Antang (85 L/s) in east residential area and Maccini Sombala in south commercial and residential area (150 L/s). Actual water production at these 5 WTPs has reached to 2,340 L/s in 2010.

Population serviced by the PDAM has been gradually increasing, approximately 72% of total population as of January 2011 (PDAM, 2011). To cope with the city development, the PDAM has been expanding its service area. Service area is currently divided into 46 supply zones for administrative purpose as shown on **Figure 1**.

Existing distribution mains cover almost all administrative area of Kota Makassar as seen on **Figure 2**. The whole service area is distributed by pumping from each WTP, except for a low lying area of north-western part where supplied by gravity.

**Figure 3** shows that service mains (250 mm or less in diameter) are 2,892 km in length, accounting for 95% of the total pipe length, 3,043 km, while trunk/limb mains (300 mm or more) are 151 km, or 5%. Pipe materials typically installed in Makassar, as indicated in **Table 1**, are mostly of PVC, accounting for over 90% out of the total. DCIP (3%) and GIP (2%) then follow. In the city center, old and deteriorated cast iron pipes (CIP) laid in 1920s have been left without repair. These pipes extend to a length of 58 km or 0.2% of the total. Furthermore, hazardous asbestos cement pipes (ACP) with a length of 28 km laid in 1980s are still in service despite frequent bursts. **Figure 4** "Comparison of distribution mains by diameter" indicates that Kota Makassar has a longer length of 50 mm service mains than those of waterworks in Japan, almost double in percentage.

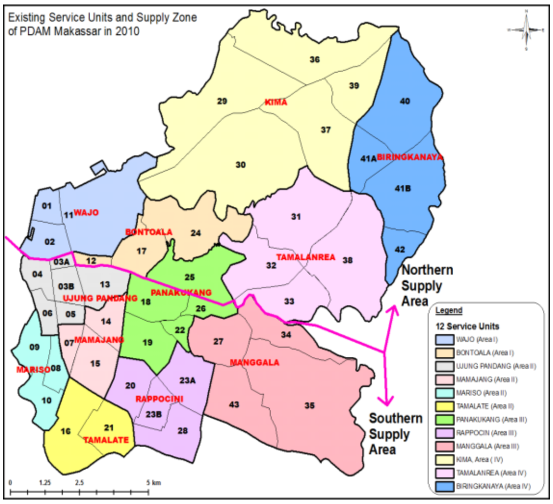


**Figure 1** Existing Service Units and Supply Zones


**Figure 2** Existing Distribution Mains

(PDAM, 2011)

**Table 1** Pipe Length in Kota Makassar (Unit: m)

| SP | DCIP | CIP | PVC | GIP | ACP | Total |
|---|---|---|---|---|---|---|
| 19,631 | 87,779 | 58,334 | 2,774,389 | 75,695 | 27,570 | 3,043,398 |
| 1% | 3% | 2% | 91% | 2% | 1% | 100% |

(PDAM, 2011)

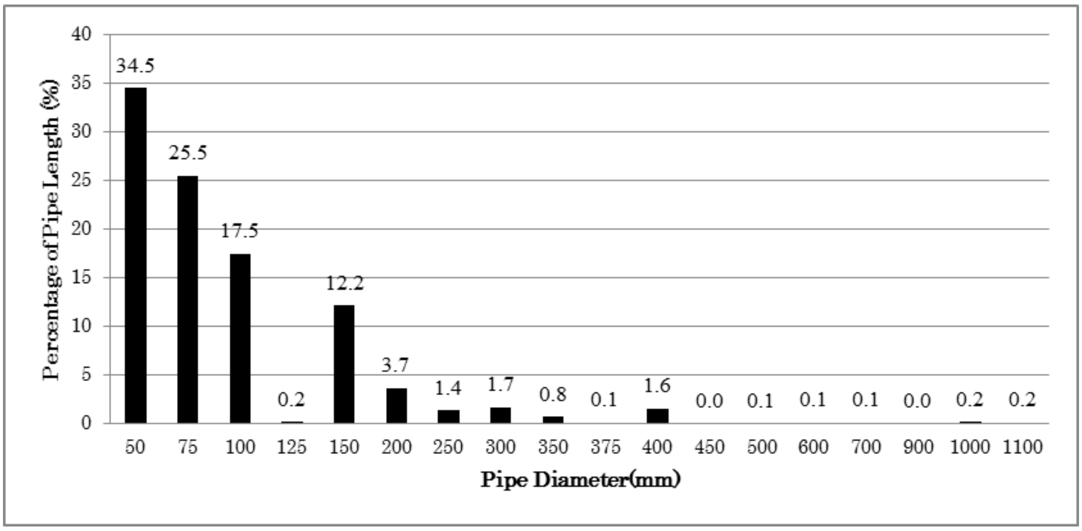


**Figure 3** Distribution Mains by Diameter in Makassar

(PDAM, 2011)

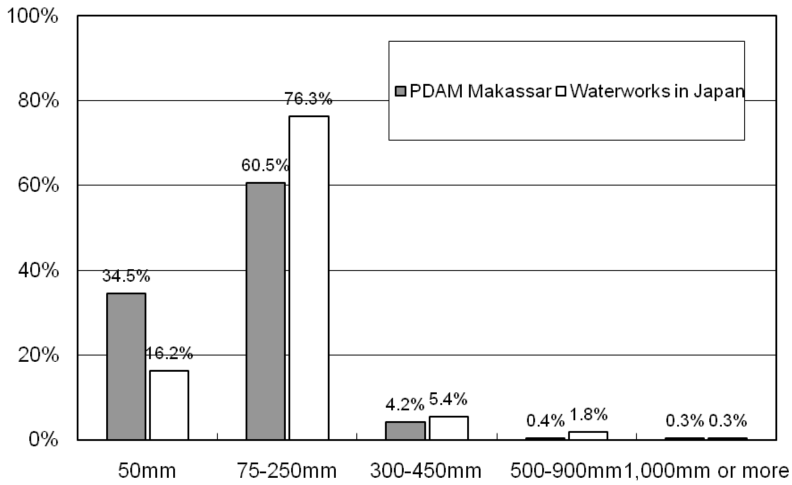


**Figure 4** Distribution Mains in Makassar and Japan

With regard to valves, wash-outs, hydrants, meters and flow controllers installed to control water flow, they are rarely found in the pipe network. Most of such devices and accessories, even if they exist, are not working any more due to heavy corrosion and a lack of maintenance.

## CURRENT PROBLEMS

The PDAM recognizes urgent needs of rehabilitation and reinforcement of the existing distribution pipe network to improve water supply condition in the area. Implementation of these works in Makassar may render a financial burden of approximately US$20-25 million in total. Major problems the PDAM currently encounters are enumerated below;

1) High rate of NRW

Despite financial investment to reduce pipe leaks, the PDAM has been suffering the high rate of NRW, namely, 45% in 2010. Full-fledged NRW reduction to a national target of 20% by 2015 may contribute to a significant increase of water sales.

2) Old CIP mains

One of the major causes for the high rate of NRW may be attributed to the deteriorated CIP installed more than 90 years ago. Several rows of the CIP mains, currently, run northward and southward along main roads in the city center. The 1989 survey report suggests that their outer pipe walls are heavily corroded by aggressive soils. Furthermore, cross-sectional area of the pipes has reduced almost half due to encrustation thickly developed inside. Many leaks are found at pipe joints, flanges, bends and fittings.

3) Low water pressure

Water pressure particularly in the north and central parts of the city is in a low level, 0-0.5 $kg/cm^2$, due mainly to the NRW and the inadequate alignment of distribution pipelines. Majority of customers (including large factories and commercial centers) tends to have suction pumps on their premises to supplement the pressure. This makes situation worse. Unsanitary sewage and wastes discharged into city drains may be possibly entering into water mains installed in the ditch. This may further cause contamination of the piped water, raising risk of endangering public health.

4) Restricted activities for fire fighting

It is said that around 400 fire hydrants were installed at every 200 m of the main roads in 1920s. Due to an absence of adequate maintenance, most of these hydrants are missing and no longer usable. Once fire occurs, fire engines rush to and fro between Ratulangi WTP and fire site. The lack of fire hydrants and the burdensome fire fighting has been a long pending issue of Kota Makassar since 1970s, posing threats to human life and social security.

5) Road expansion

Main road expansion in the city center that connects its adjacent cities and an airport had been implemented in 1990s. Along with this expansion, many water mains buried underground, however, had not been shifted to proper place. Pipes installed under pavement of the main roads, accordingly, had become hardly accessible. Thus NRW control and reduction is getting more difficult task than ever before.

6) Newly installed PVC pipes

In the newly developing area, the PDAM has been used to install mainly PVC pipes. They have been laid in a shallow depth (50-80 cm) under sidewalks as service mains. It is considered adequate to install PVC pipes, so far as they are installed under unpaved sidewalks, generally free from heavy load. As the pipelines recently installed are relatively small, i.e., 50-100 mm of PVC pipes, customers at the fringe area may be restricted from continuous water supply.

7) Weak financial capability

Due to a financially weak standing with long-term debts, the PDAM is not capable to allocate sufficient amount of funds for the pipe rehabilitation and NRW reduction.

## BASIC CONCEPT OF TMR PIPE SYSTEM

To overcome all problems stated above, replacement or reinforcement of the existing distribution pipe network with minimum cost is inevitable with an aim to establish a base for financially sound PDAM at the earliest date possible. If the NRW reduced to zero, the PDAM could double its annual income to nearly Rp 190 billion (US$17 million).

### *Major Issues Considered*

The pipe replacement or rehabilitation shall be well-planned in view of current situation of the overall distribution network and future expansion of the service area. To seek optimal and cost-effective solution for the pipe rehabilitation (Arai, 2007), special attention was paid to the following:

1) <u>Insufficient Capacity of Pipe Network</u>: Commerical, industrial and residential areas are

expanding rapidly. Many modernized hotels, commercial centers, and large scale factories are constructed or under contruction throuout the city. The exisiting pipe network is not sufficient in flow capacity to meet the increasing water demand in the area.

2) Low Pressure: Extremely low supply pressure shall be improved as early as possible. This may cause adverse effects on human health and local economy.
3) PVC Pipes: PVC pipes are dominantly used as service/limb mains, which are laid in shallow depth under sidewalks. They shall continue to be in service after some adjustment or reinforcement.
4) Easy Operation: Pipe network shall be simple and functional for ease of routine O&M and NRW reduction.

The pipe rehabilitation may be a good opportunity for the PDAM to establish flexible and durable distribution pipe network in the area. To attain this goal, we propose TMR (Trunk/limb Mains Reinforced) pipe system which will be further explained in succeeding paragraphs.

***TMR Pipe System and Old CIP Network***

**Figure 5** shows conceptual pipeline alignment of the existing and TMR pipe system. In the city center, many existing trunk/limb mains run in parallel, usually located deep under thick pavement (1.8 m to 2.3 m below the ground surface). They are all deteriorated after years of use. Under such circumstances, installation of an integrated pipeline is more cost-effective and hydraulically preferable than replacement of all mains for rehabilitation. For example, from the Hazen-Williams equation, 400 mm diameter pipeline is hydraulically 6 times more effective than 200 mm pipeline in terms of pressure loss, although its cross-sectional area is 4 times larger than the 200 mm. Consequently, renewal costs may drop to one-half or one third of the replacement of all pipelines. In addition, the TMR system does not require any temporary or bypass pipes during civil works. Furthermore, service main arrangement or installation as planned stepwise can be implemented according to a priority or urgency of the supply area.

As regards to “hydraulically equivalent pipes”, we prepared logarithmic charts that exhibit number of pipes vs. hydraulically equivalent diameter as shown on **Figures 6 and 7**. Pipe design engineers can easily refer to and find adequate diameter of the larger main based on these charts. In the newly developed residential and commercial area where water pressure is extremely low due to small diameter PVC pipes, it is clear that new trunk/limb mains shall be additionally installed. This may drastically improve water supply conditions in the area.

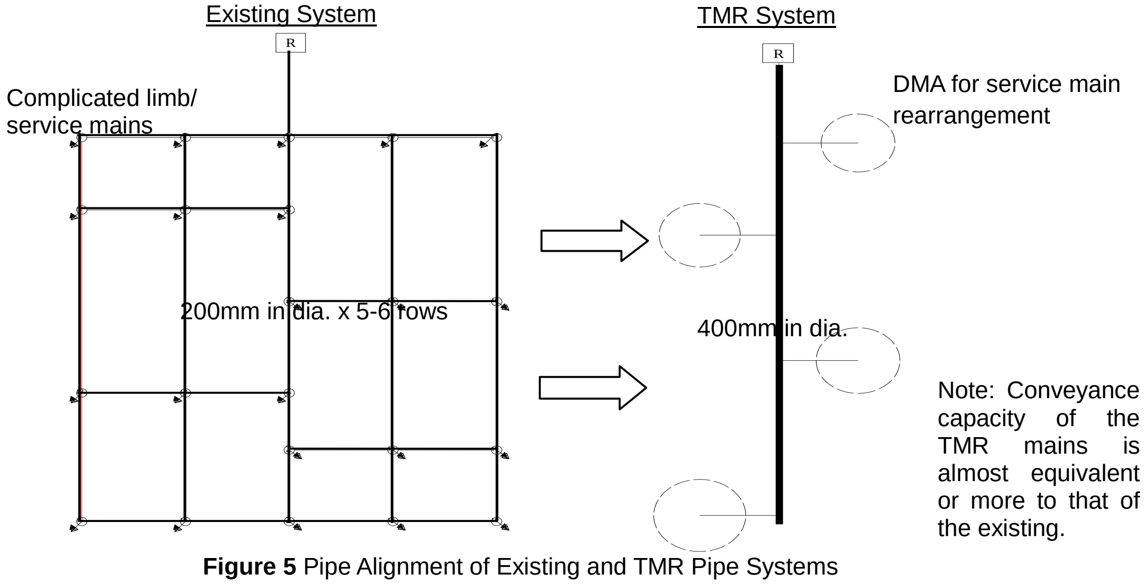


**Figure 5** Pipe Alignment of Existing and TMR Pipe Systems

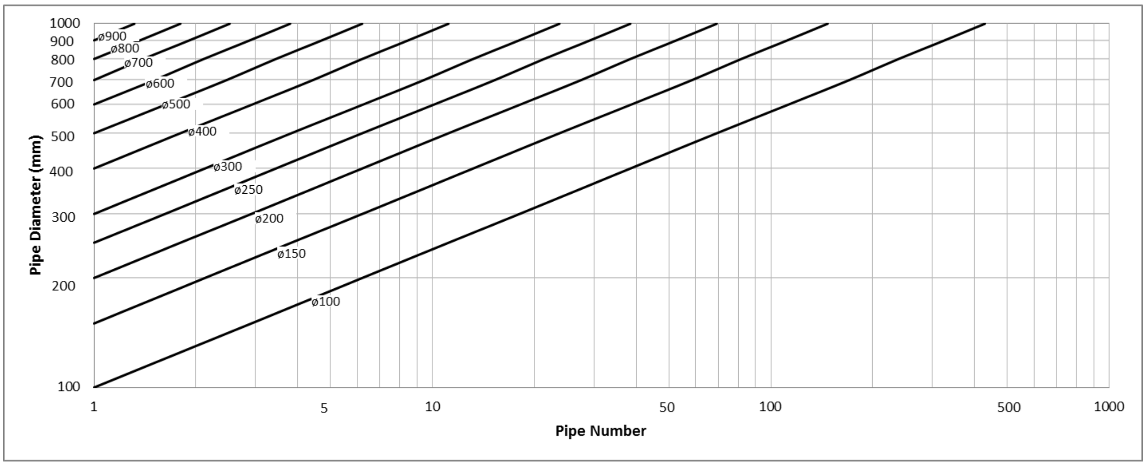


**Figure 6** Number of Pipes-Trunk/Limb Main Hydraulically Equivalent

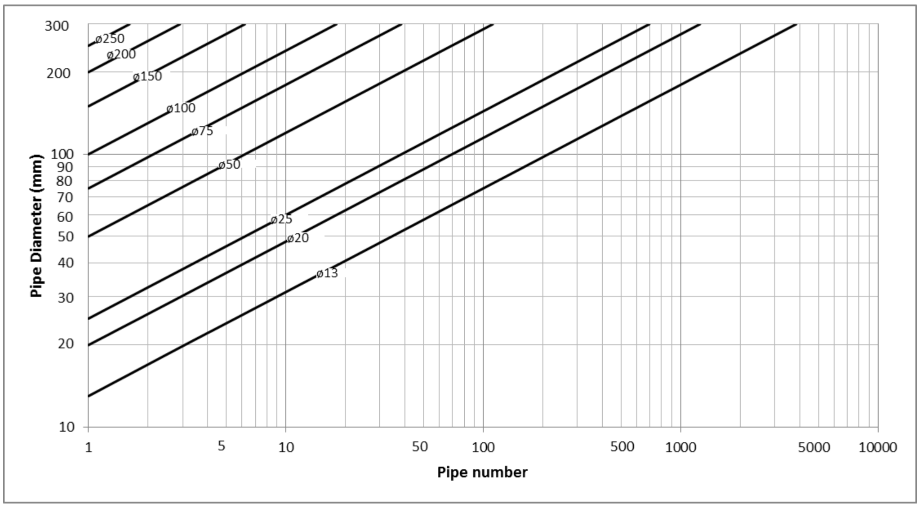


**Figure 7** Number of Pipes - Service Main Hydraulically Equivalent

***Pipe Alignment***

The TMR pipe system consists of simple pipeline alignment. Depending on needs, it is easy to expand the area. Service main rearrangement or District Metering Area`s (DMA) establishment in the distribution pipe network will enable the PDAM to conduct effective control and management of the NRW as a part of routine maintenance.

***Design matrix***

To clarify further a whole picture of the TMR pipe system, we prepared “design matrix” (JICA, 2007) which focuses on scope and effectiveness of the TMR as given in **Table 2**.

The trunk/limb mains installed probably under pavement of main/sub-main roads shall have sufficient strength, durable against long term use. Optimal route for new pipelines shall be carefully selected so that pipe laying works may not cause any serious impacts or disturbance on social life and traffic.

Service mains, instead, can be laid at a shallow depth under sidewalks as currently practiced by the PDAM. Eventually, the pipe network forms “double-layer”: trunk/limb main in 1.2-1.5 m and service mains in 0.5-0.8 m depth underground. This may be appropriate for the PDAM to carry out routine maintenance of the pipe network effectively. PDAM staff can easily access to the installed service mains when urgent repair and maintenance are required. Application of the TMR pipe system to the pipe rehabilitation may have advantages as follows;

**Table 2** Design Matrix of TMR in Makassar

| Components | Scope | Renewal Cost* | Effectiveness | Current situation |
|---|---|---|---|---|
| Civil Work | | | | |
| Trunk main | Additional trunk mains are small in quantity | Similar | -Moderate | -Trunk mains, 700-1,000mm in dia. installed |
| Limb main | Integrated pipelines are installed | 1/2-1/3 of simple replacement | -Highly effective<br>- New pipe installation may render less impacts on traffic/human life | -CIP limb mains deteriorated due to encrustation |
| Limb main (PVC) | New limb mains are installed | Reasonable, as installation of temporary pipes are not required | -Highly effective<br>-Water pressure will be drastically improved | -Small diameter PVC mains are not functioning as limb mains |
| Service main (old GIP) | New main installation | Reasonable, as installation of temporary pipes are not required | -Highly effective<br>-Water pressure will be drastically improved | -Service mains deteriorated due to encrustation<br>-Low pressure at end users |
| Service main (PVC) | Existing mains to be rearranged | Reasonable, as installation of temporary pipes are not required | -Fairly effective | -Small PVC pipes extend to newly developing area, from which a number of service pipelines branch entangled |
| Multi-function chamber | Newly constructed on inlets to service mains | Not costly | -Highly effective | -Flow controllers not exist |
| Operation & Maintenance Aspects | | | | |
| Flow/pressure control | Flow controllers installed in MfC* | Additional costs required for flow control equipment | -Highly effective<br>-Flow control becomes easier | -O&M is not considered.<br>-Flow control is hardly possible |
| Fire fighting | Fire hydrants installed | Increased costs for installation of fire hydrants | -Highly effective | -Due to low water pressure, fire engines rush between plant and fire site |
| NRW control | DMA established | Similar | -Highly effective<br>-DMA will be established for NRW control | -Leakage control is hardly possible |
| Water quality control | Public campaign | Additional chlorine dosage equipment may be installed. | -Highly effective<br>-House pumps are abandoned because of increased pressure<br>-Frequent wash-out may be required<br>-Residual chlorine may reduce in the pipes | -Residual chlorine is not detected at end users.<br>–Many customers tend to install house pumps on their premises, resulting in possible contamination |
| Asset management | GIS | Not costly as the PDAM uses GIS software | -Highly effective | -As the priority of the existing pipelines is uncertain, it is hard to propose a strategic asset management. |
| Flexibility for Future Expansion | | | | |
| Pipeline installation | Additional limb /service main installation for new DMA | New DMA not costly | -Highly effective | -Small diameter of the existing limb mains shall be reinforced to expand service area |

Note:

* "Renewal Cost" and "Effectiveness" above are a result of comparison with normal pipeline replacement.

** MfC implies "a multi-function chamber" in which various devices for flow control, flow measurement, air release, wash-out, etc. are encased all together.

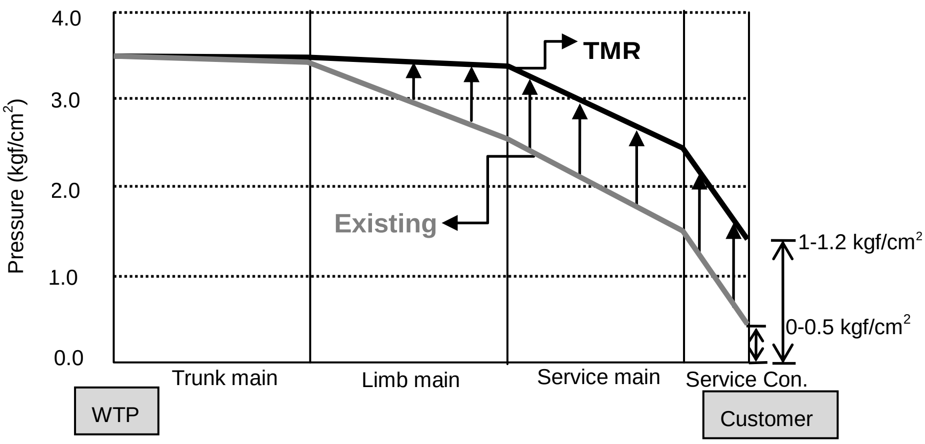


**Figure 8** Hydraulic Profile of TMR Pipe System

***Head losses***

Water flow loses its energy due to its internal friction with pipe wall. A number of branches, bends, reducers, and valves are also additional causes for head losses. Under a certain flow rate and pipeline alignment, hydraulic gradient becomes steeper at small diameter mains than that of large ones. **Figure 8** illustrates hydraulic profile of distribution mains. The TMR pipe system, by reinforcing size and alignment of trunk/limb mains, minimizes head losses. High water pressure kept in the limb mains will be desirable for stable and continuous supply. Although hydraulic gradient (=head loss/distance) of water flow in the service mains is similar to those of the existing, all customers even in the fringe area can enjoy continuous 24 hour supply.

***Sufficient water pressure***

As head losses of distribution mains are smaller than that of the existing, customers enjoy sufficient water continuously on 24 hour basis. Although peak hour demand may cause pressure drop, the TMR pipe system keeps water pressure sufficiently high even at peak hour. Large diameter and low flow velocity in the extended limb mains will decrease head losses. Customers are no more required to have suction pumps to supplement the pressure. They may abandon their use. In addition, strengthened and durable trunk/limb mains are also effective in preventing pipe leaks.

***Cost –effectiveness***

Renewal cost of limb/service mains is moderate, nearly 1/2 – 1/3 of that of “all-pipe replacement”. Short (in total length) but extended length of limb mains and simplified network contribute to substantial reduction of labor, procurement and O&M costs.

***Flexible and durable pipe alignment***

Rapid population growth and economy may trigger robust and unexpected increase in water demand in future. Strengthened trunk/limb mains have sufficient capacity to cope with this situation. Water can be supplied through service mains with minimum effects on water flow in the limb mains. Depending on the situation, the PDAM can install new service mains at shallow depth under sidewalks which are not costly.

***Easy operation and maintenance***

Multi-function chamber that will function as flow measurement, flow control, air release, and wash-out is beneficial to the PDAM, resulting in easy operation and maintenance.

Surrounding fence may protect from human access and tampering of equipment installed in the chamber. Costs required for operation and maintenance of the simplified network may decrease significantly.

***Effective control of water losses***

Detection and reduction of leaks or water losses become easier by introducing the TMR pipe system. Any water leak can be easily detected in well-designed DMA network (Morrison, 2007).

## CONCLUSIONS

The TMR pipe system we propose is considered more effective than the method commonly applied in the world (all-pipe replacement). Basic concept of the TMR is to keep head loss at minimum, by replacing the existing distribution mains with larger diameter trunk/limb mains.

Minimized pipes length, number, accessories and volume of civil works will benefit to a decrease in project costs. Increased conveyance capacity of the mains and interconnected limb mains are flexible for growing water demand. Because of its simplicity, NRW control and management will become easier than ever before.

To verify further effectiveness of the TMR pipe system, it is necessary to look into details of the pipe system by conducting case-study and research on the following;

1) Water demand projection in the area
2) Model development for computerized distribution pipe network
3) Comparative study through life cycle cost planning

## ACKNOWLEDGMENTS

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